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Using Solar-Powered Groundwater Recirculation to Enhance Reductive Dechlorination at Kennedy Space Center

Robert Kline, P.E. (Robert.A.Kline@NASA.gov)
(NASA, Kennedy Space Center, Florida)
Jim Langenbach, P.E., Emily Lawson, and Tom Peel, Ph.D.
(Geosyntec Consultants, Florida)

ABSTRACT: Geosyntec Consultants (Geosyntec) designed and implemented a groundwater Interim Measure (IM) using a solar powered recirculation system to facilitate enhanced reductive dechlorination (ERD) at a site located at the Kennedy Space Center (KSC) in east-central Florida on behalf of the National Aeronautics and Space Administration (NASA). The ERD system included biostimulation, bioaugmentation, and groundwater recirculation to treat elevated concentrations of trichloroethene (TCE), *cis*-1,2-dichloroethene (cDCE), and vinyl chloride that exceeded Florida Department of Environmental Protection (FDEP) Groundwater Cleanup Target Levels (GCTLs).

INTRODUCTION

Geosyntec completed a Resource Conservation and Recovery Act (RCRA) Facility investigation (RFI) at the General Services Administration (GSA) Seized Property Yard (GSSP), located at KSC in east-central Florida. The GSSP was formerly used to store and auction government owned vehicles, trucks, and boats. During the RFI, elevated concentrations of tetrachloroethene (PCE), TCE, cDCE, and vinyl chloride were identified in the groundwater at levels that exceeded GCTLs.

A limited PCE source area with groundwater PCE impacts ranging up to 32,000 micrograms per liter (µg/L) and PCE saturated zone soil impacts ranging up to 130,000 micrograms per kilogram (µg/kg), was identified in the central portion of the site. The PCE source area was wet-excavated in November/December 2008, prior to the ERD IM, to a total depth of 12.5 feet (ft) (9 ft below the water table). During the IM, approximately 450 tons of source material was removed; however, several acres of chlorinated solvent impacted groundwater remained.

The ERD IM treatment zone is the approximately 3,000 square foot (ft^2) area located immediately downgradient of the former PCE source area, including groundwater with concentrations exceeding the FDEP Natural Attenuation Default Criteria (NADC) of 300 µg/L for TCE, 700 µg/L for cDCE, and 100 µg/L for vinyl chloride (Figure 1). The treatment zone extends from approximately 10 to 21 ft below land surface (bls) and is within an interval of fine to medium sand with shell fragments.

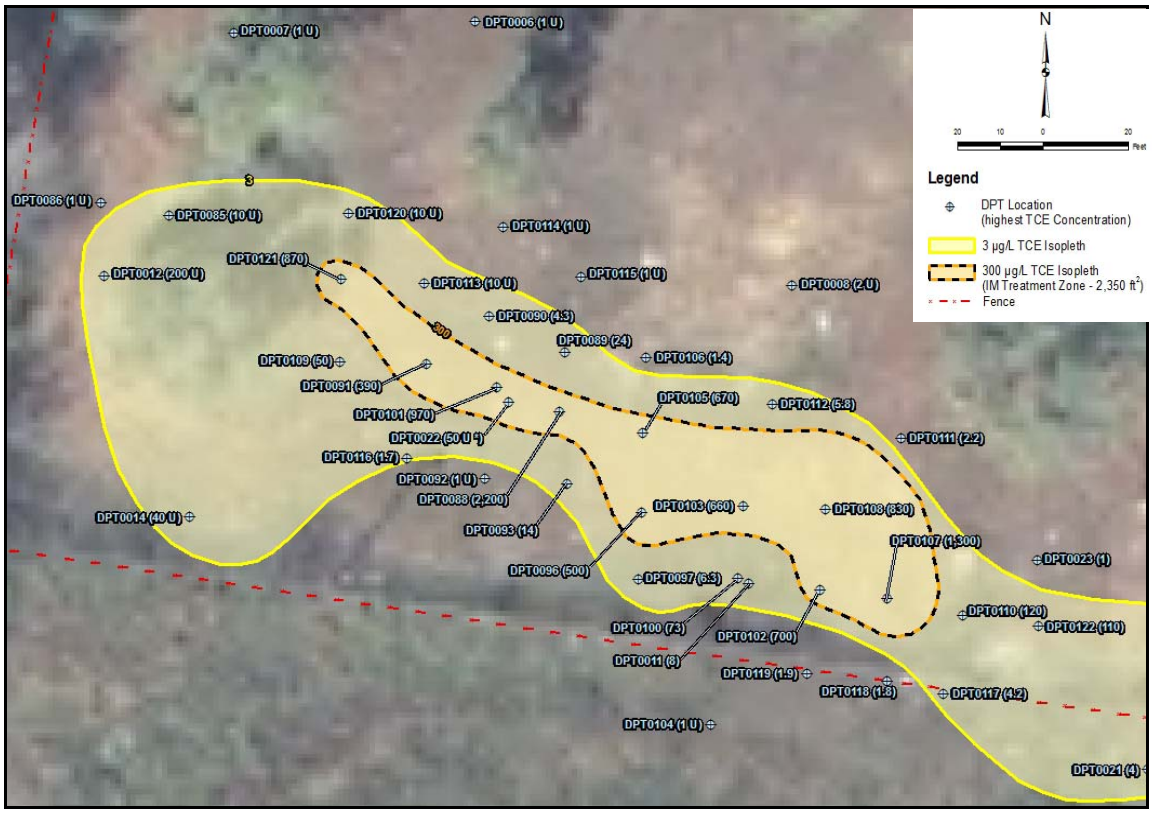


FIGURE 1. ERD IM treatment area.

A variety of remedial technologies for the treatment of volatile organic compounds (VOCs) in the dissolved plume were screened against both RCRA corrective measure criteria and USEPA's Green Remediation Best Management Practices. Although several strategies were judged to meet the corrective measure goals, the bioremediation remedy also aligned well with USEPA's core elements of Green Remediation. The remedial strategy selected was an enhanced reductive dechlorination (ERD) system which included biostimulation, bioaugmentation, and groundwater recirculation. Groundwater recirculation is accomplished using a solar powered extraction system, with an objective of enhancing mixing and the distribution of injected electron donor and microbial culture within the treatment zone.

MATERIALS AND METHODS

The ERD remedy was implemented as an IM in August 2010 to address elevated VOC concentrations in the treatment zone, an approximately 3,000 ft^2 area within the overall dissolved plume. The objective of the IM is to reduce groundwater concentrations within the treatment zone (which represents the primary core of the overall dissolved plume) to less than FDEP NADCs to facilitate natural attenuation of the overall plume within a reasonable timeframe.

ERD was implemented through the delivery of emulsified oil, microbial culture and anaerobic chase water to a network of 46 direct-push technology (DPT) permanent injection points with 5-ft screen intervals installed throughout the treatment zone. Electron donor and microbial culture in situ mixing and distribution is aided by a solar-powered groundwater recirculation system. This system includes two extraction wells, each fitted

with a solar-powered submersible pump. Extracted groundwater is re-injected into nine injection wells oriented in three transects up-gradient and down-gradient of the extraction wells to maximize contact and distribution within the targeted treatment zone (Figure 2).

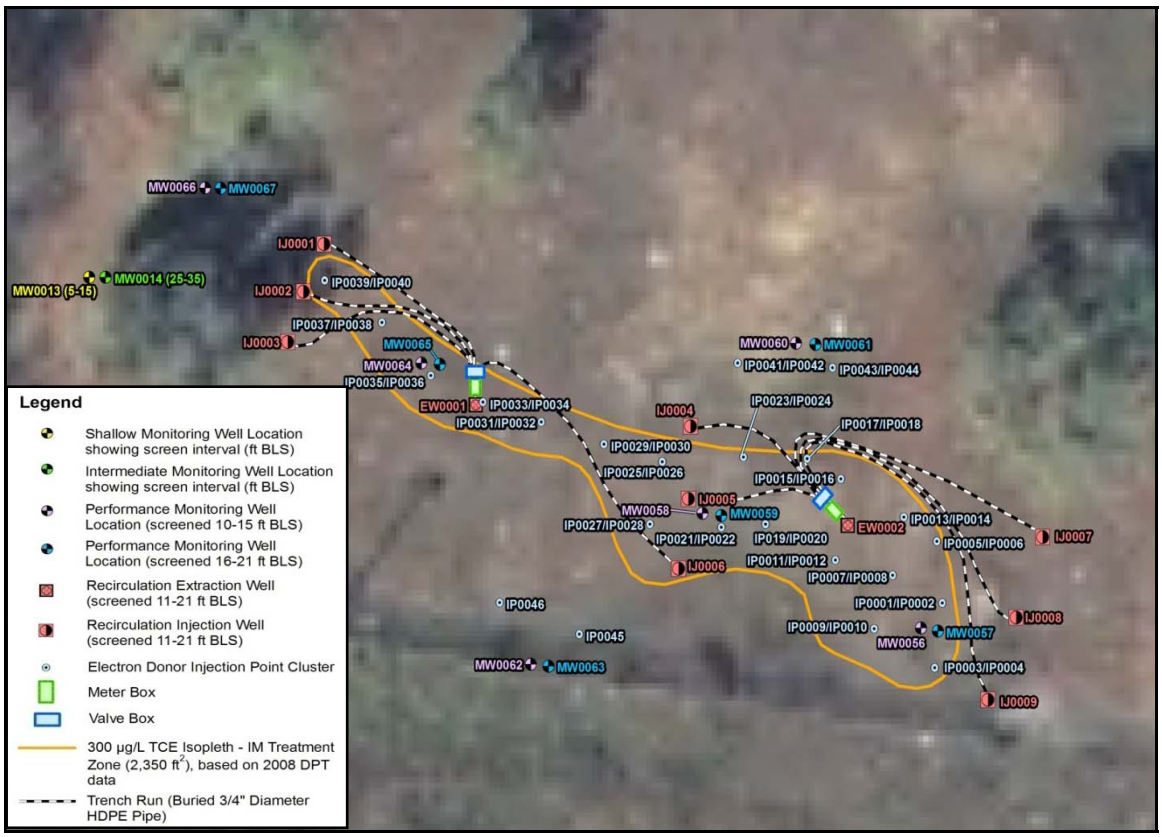


FIGURE 2. ERD IM overall well layout.

A performance monitoring well network, the network of injection points, and groundwater recirculation system (extraction wells, injection wells and piping system) were installed in August and September 2010. The performance monitoring well network was installed to assess ERD progress within the treatment zone over time. The performance monitoring network includes six well clusters with shallow wells screened from 10 to 15 ft bls and deeper wells screened from 16 to 21 ft bls. Three performance monitoring well clusters were located within the treatment zone (at worst-case distances between injection points to avoid data bias). Three additional monitoring well clusters provide general down-gradient and side-gradient monitoring to document that the IM is not having a negative impact on surrounding groundwater conditions (plume spreading).

The network of DPT injection point clusters was installed to facilitate injection activities associated with the ERD IM (Photograph 1). Permanent injection points will allow additional injection activities in the future, if warranted. The network of points includes 22 clusters (shallow injection points screened from 10 to 15 ft bls and deeper points screened from 16 to 21 ft bls) and two shallow points (screened from 10 to 15 ft bls).

Two groundwater extraction wells and nine groundwater injection wells were installed as part of the groundwater recirculation system associated with the ERD IM. The

extraction and injection wells were installed using hollow stem auger drilling techniques. The extraction wells are located within the centerline of the IM treatment zone. The injection and extraction wells are screened from 11 to 21 ft bls. The injection wells are oriented in three transects located upgradient, downgradient, and between the extraction wells in order to create groundwater circulation cells enhancing the mixing and distribution of the electron donor and microbial culture.

PHOTOGRAPH 1. DPT injection point installation.

Baseline groundwater sampling was performed in August 2010. Groundwater samples collected from the performance monitoring wells and the two extraction wells were laboratory analyzed for VOCs by Environmental Protection Agency (EPA) Method 8260B, Total Organic Carbon (TOC) by EPA Method 415.1 and dissolved gases (methane, ethane and ethene [MEE]) by EPA RSK SOP 147. Samples from monitoring well clusters within the IM treatment zone were also laboratory analyzed for *Dehalococcoides (Dhc)* and the vinyl chloride reductase gene (*vcrA).* All groundwater sampling activities include the collection of field parameters: pH, temperature, conductivity, dissolved oxygen (DO), and oxidation-reduction potential (ORP).

EOS®, an emulsified oil consisting of 59.8% soybean oil, 4% lactic acid, 10.1% emulsifiers and preservatives, and a balance of water, was selected as the electron donor for GSSP. KB-1® was selected as the microbial culture for injection within the treatment zone. KB-1® is a naturally occurring, non-pathogenic microbial culture that contains *Dhc* with the *vcrA* gene. A microbial culture was deemed necessary at GSSP based upon: (1) a series of laboratory treatability studies which documented dechlorination stall at vinyl chloride unless a microbial culture was added, (2) the detection of low *Dhc* and absence of *vcrA* in collected groundwater samples from the treatment zone (suggesting naturally occurring microorganisms capable of dechlorinating vinyl chloride were absent or present at very low levels), and (3) the dissolved plume characteristics (downgradient plume is largely comprised of vinyl chloride).

Electron donor and anaerobic water solution, microbial culture, and anaerobic chase water were injected into the injection points using an injection trailer. A total of six drums of EOS® were injected within the treatment zone. The six drums of EOS® were diluted 1:10 (by volume) with anaerobic water and evenly injected into each of the 46 injection points. Each injection point received approximately 70 gallons of diluted EOS® solution (3,200 total gallons of solution to the 46 injection points). Prior to injection of KB-1®, field parameters (pH, DO, and ORP) were collected from each injection point to verify that the aquifer was anaerobic and reducing. A total of 21.5 liters of KB-1® was added to the treatment zone, 0.5 liter into 40 of the 46 injection points, and 0.25 liters into six shallow injection points (Photograph 2). In order to obtain the desired initial radius of

influence (ROI) of 5 ft, approximately 665 gallons of anaerobic chase water was injected into each injection point following the addition of the KB-1®. Anaerobic chase water was obtained from the two extraction wells. Each injection point received approximately 735 total gallons of fluids (total treatment zone injection volume of 33,800 gallons). During all injection activities, the injection pressure was maintained at less than 20 pounds per square inch (psi) to minimize the potential for short-circuiting and/or daylighting of injected fluids. No daylighting of any fluids was observed during the performance of injection activities.

After baseline sampling and injection activities, the groundwater recirculation system was piped from the extraction wells to the injection wells. The groundwater recirculation system consists of nine injection wells and two extraction wells completed with solar powered submersible pumps. The groundwater recirculation system pumps groundwater from two extraction wells into three injection well transects consisting of three injection wells each. Groundwater is pumped from the extraction wells using solar powered pump kits (Photograph 3). The kits include 27 inch by 42 inch solar panel(s) and submersible Robison BL40Q quad pumps. To evaluate panel performance, one kit was purchased with one solar panel and one kit includes a two panel assembly. Each solar panel provides an estimated 75 Watts of solar power during peak sunlight hours. The pumps are designed to provide a groundwater flow of approximately 5 gallons per minute (gpm) during peak sunlight hours. Since the system was designed to enhance groundwater movement and contact, continuous operation is not required; accordingly, the system only operates during sunlight hours.

The ERD recirculation system was officially started on 30 September 2010, following the completion of all injection activities. Routine operation and maintenance visits are conducted to confirm operation, record flow totalizer readings, and measure water levels within the treatment zone.

PHOTOGRAPH 2.
KB-1® injection.

PHOTOGRAPH 3.
Solar panel system.

RESULTS AND DISCUSSION

To date, performance monitoring has been conducted at one month, two months, four months, and six months post EOS® and KB-1® injection. Groundwater samples collected from the performance monitoring wells and extraction wells were laboratory analyzed for VOCs by EPA Method 8260. Groundwater samples collected from the three performance monitoring well clusters within the IM treatment zone and from the two extraction wells

were also analyzed for TOC and MEE. Samples collected from the central performance monitoring well cluster within the IM treatment zone were also analyzed for *Dhc* and *vcrA*.

Performance monitoring and aquifer suitability for ongoing reductive dechlorination were evaluated using the following data: (1) field parameters; (2) presence and distribution of VOCs; and (3) geochemical and microbial parameters. The following summarizes the findings.

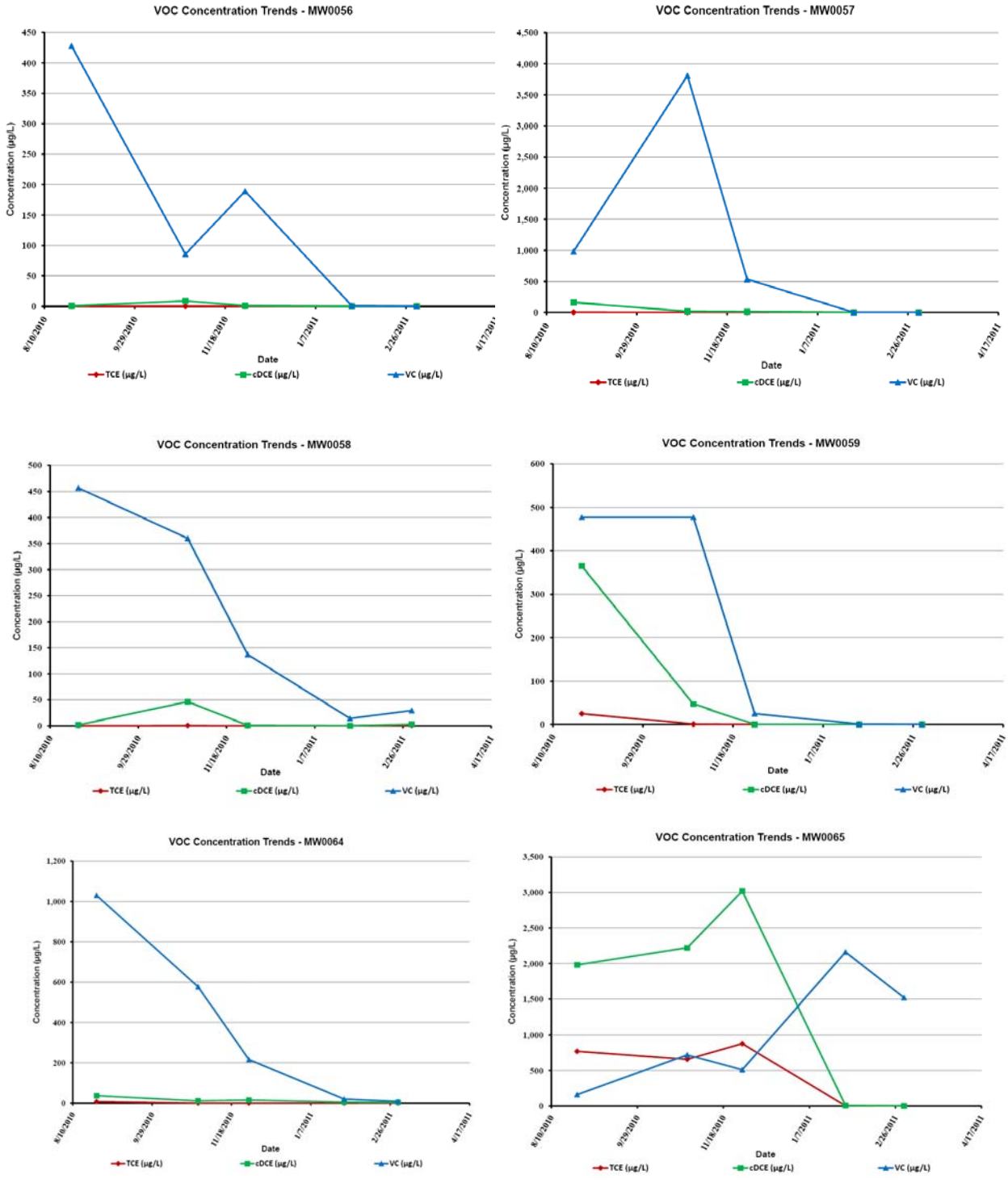
Field parameters were collected to evaluate the ongoing suitability of the aquifer for reductive dechlorination. Optimal conditions include a neutral pH (near 7 standard units), negative ORP and low DO (generally accepted as less than 0.5 mg/L). The month six average pH of 7.1 standard units, average DO of 0.31 mg/L and negative ORP (-94 milliVolts) all indicate a favorable environment for bioremediation to occur.

VOC results from baseline to month six show significant reduction of VOCs. A summary with respect to IM objectives follows:

- TCE was reduced from a maximum of 769 µg/L to less than the GCTL of 3 µ/L in all performance monitoring wells and has exceeded the IM objective;
- cDCE was reduced from a maximum of 1,980 µg/L to a maximum of 194 µ/L, and has exceeded the IM objectives; and
- Overall vinyl chloride has decreased with concentrations exceeding the IM NADC objective in only one performance monitoring well; concentration increases with a follow-up decrease has been observed at select locations suggests ERD is ongoing.

Reductive dechlorinating bacteria thrive in similar environmental conditions to methanogens; therefore, methane production is a good indicator that favorable conditions exist for reductive dechlorination. Methane concentrations have increased from an average of 1,304 µg/L during baseline sampling to 5,618 µg/L in month six. The presence of ethene at a maximum of 182 µg/L (generally less than 5 µg/L prior to implementation) indicates that complete dechlorination is occurring within the IM treatment zone. The average concentration of TOC more than doubled to an average of 71 mg/L in month one, and has slowly decreased to 49 mg/L in month six (approximately 50 percent above background), indicating that the electron donor is being effectively distributed throughout the treatment zone and is currently being utilized by the microbial population.

Within the treatment zone, *Dhc* concentrations increased one order of magnitude in monitoring well MW0058 (from 10^6 to 10^7 gene copies/L) and two orders of magnitude in MW0059 (from 10^5 to 10^7 gene copies/L) from baseline to Month 6. *vcrA* was not detected in any of the six baseline samples above the detection limit of 10^3 gene copies/L. Month six performance monitoring samples revealed *vcrA* concentrations of 10^7 gene copies/L in the two monitoring wells sampled, MW0058 and MW0059. The increasing trends in *Dhc* and significant increase/detections of *vcrA* suggest that reductive dechlorination is occurring and that a microbial population capable of reducing vinyl chloride to ethene has been established within the treatment zone.



GRAPHS. VOC concentrations through month 6 in six monitoring wells located within the treatment zone.

The operating solar-powered groundwater recirculation system recirculated 660,000 gallons of groundwater during the first six months of operation representing more than 10 treatment zone pore volumes. During sunlight hours, individual extraction well groundwater pumping rates have ranged from 1.9 to 7.0 gallons per minute. Collected groundwater level measurements have documented that the operating groundwater recirculation system is achieving an objective of creating zones of enhanced contact and groundwater mixing, with groundwater elevation contours similar to flow model predicted contours.

CONCLUSIONS

The effectiveness of the ongoing ERD IM was evaluated via the sampling of performance monitoring wells located in and around the IM treatment zone and laboratory analysis for VOCs, geochemical parameters, and biological indicators. All indications point toward effective in situ treatment of CVOC impacted groundwater within the treatment zone. After only six months of operation TCE and DCE concentrations are below corrective action objectives and vinyl chloride concentrations are rapidly approaching objectives.

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Using Solar Powered Groundwater Recirculation to Enhance Reductive Dechlorination at Kennedy Space Center

Presented to:

Battelle Bioremediation and Sustainable Environmental Technologies Symposium

By:

Robert Kline, P.E. NASA, Kennedy Space Center, Florida

June 28, 2011

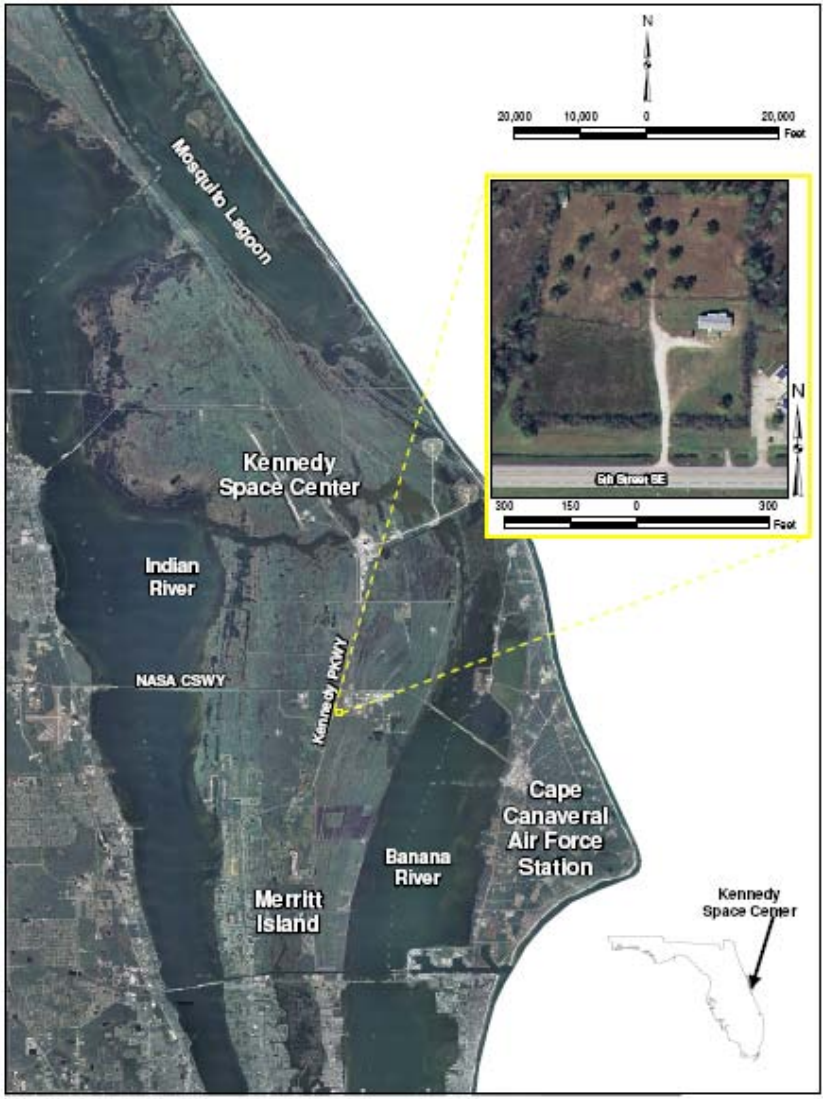
Reno, Nevada

Presentation Outline

- Site History and Background
- Assessment and Supporting Actions Overview
- Comparison to Core Elements of Green Remediation
- Enhanced Reductive Dechlorination (ERD) Interim Measure (IM) Remedy
- ERD IM Results
- Conclusions

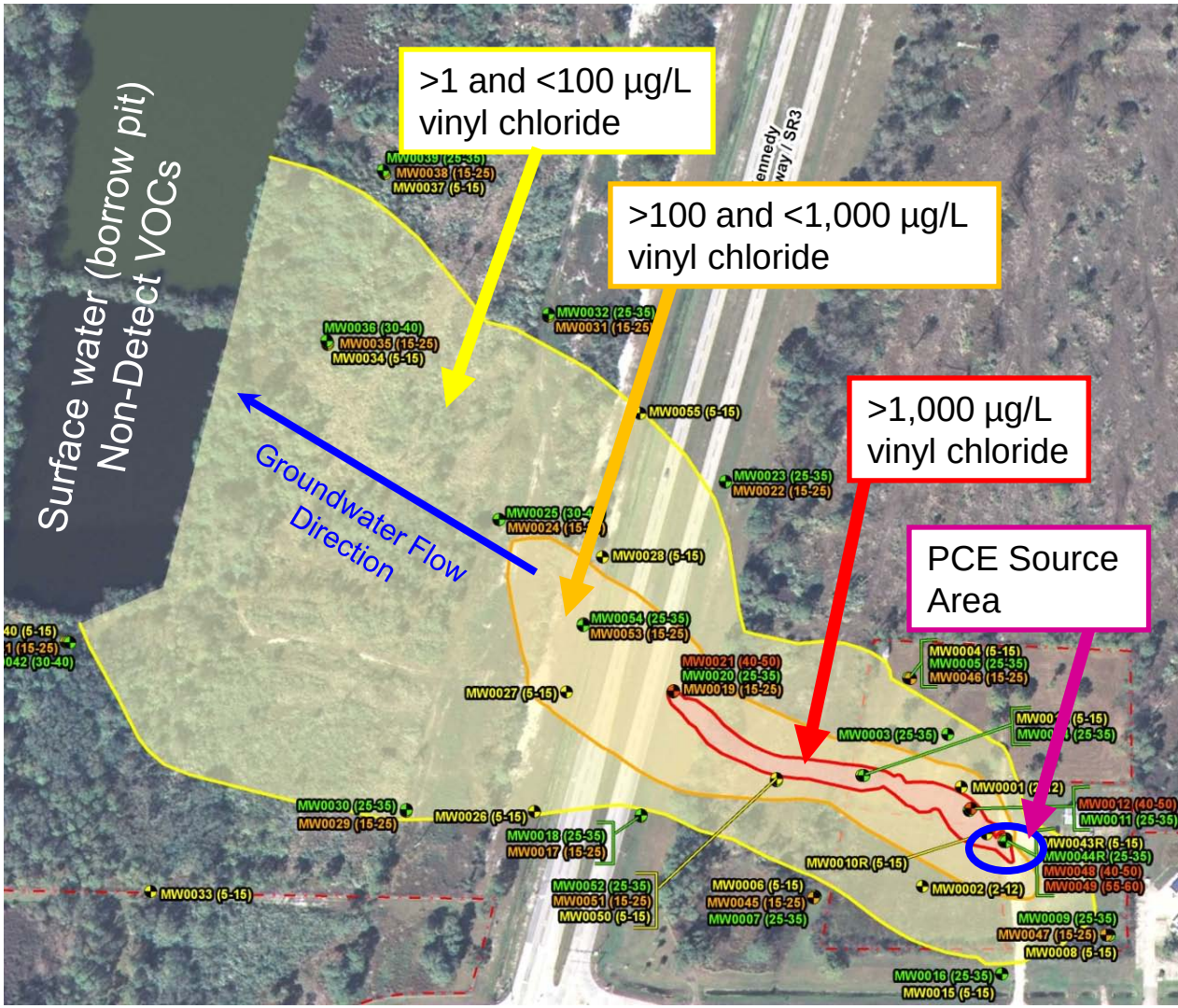
Site History

- GSA Seized Property Yard (site) is a ~6 acre property within the Industrial Area of Kennedy Space Center, Florida
- Formerly used to store and auction seized vehicles
- Six to seven administrative trailers have been used/stored on site in the past



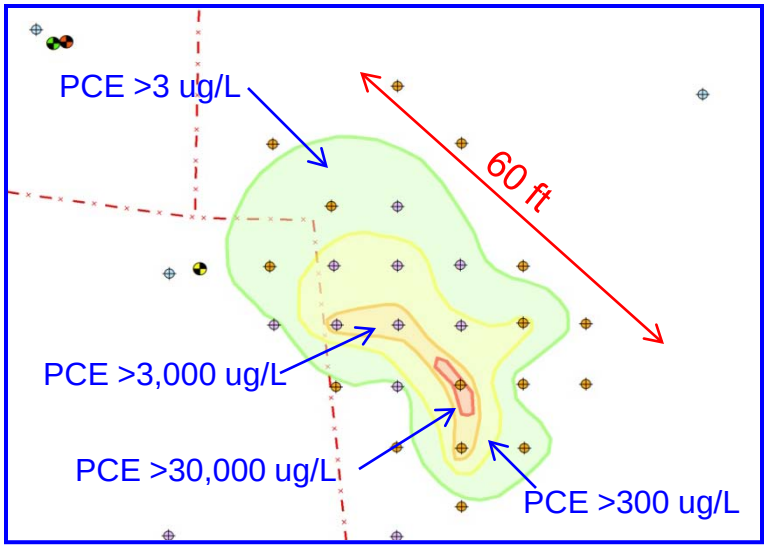
Assessment

- RFI completed in 2008
- Detailed DPT assessment (over 100 locations) and follow-up micro-wells revealed:
  - 1,650 ft dissolved plume (primarily vinyl chloride)
  - PCE source area (<1,000 ft^2)
  - Plume transport primarily in 10 to 21 ft bls interval
  - Dechlorination to vinyl chloride
  - *Dhc* detected; however, vinyl chloride reductase absent (explains vinyl chloride plume)



Source Area Assessment/Interim Measure (IM)

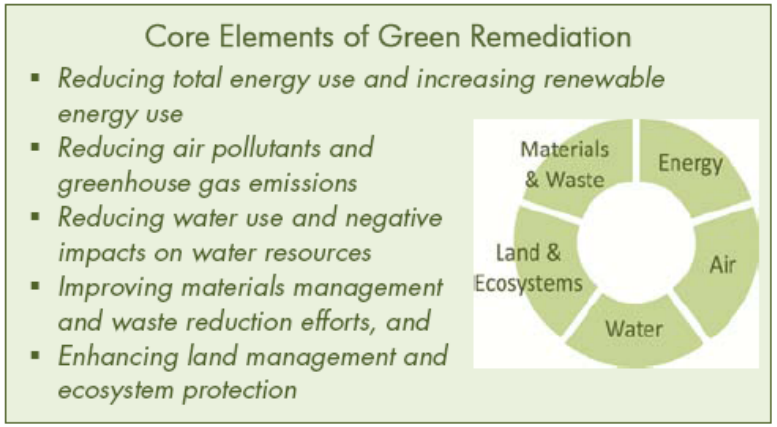
- PCE source area identified from 8 to 12 ft below grade (water table at 4 ft):
  - PCE groundwater concentrations up to 32,000 µg/L
  - Saturated soil PCE up to 130,000 µg/kg
  - Limited PCE footprint laterally and vertically based upon DPT investigation
- Wet excavation IM to 13 ft below grade in December 2008:
  - 442 tons of PCE impacted soils removed
  - electron donor addition to open hole
- Source area addressed: Max PCE <3 µg/L in former source area wells as of October 2010



ERD Groundwater IM

- Purpose: Remediate groundwater downgradient of the former source area with elevated VOC concentrations:
  - Approximately 3,000 ft^2 area
  - VOCs focused in 10-21 ft below land surface (bls) depth interval
  - Screening considered USEPA Green remediation BMPs
  - Bench-scale treatability testing performed
  - ERD with biostimulation, bioaugmentation and integration of solar-powered groundwater recirculation selected
- Corrective Action Objective (CAO): Reduce VOC concentrations in the IM treatment zone to less than 300 µg/L TCE, 700 µg/L cDCE, and 100 µg/L vinyl chloride

ERD IM Compared to Green Remediation Core Elements



- Energy:
  - Limited construction energy use
  - Solar system for groundwater recirculation
  - Minimal O&M
- Air Emissions:
  - *In Situ* treatment technology
  - Lower CO_2 operational emissions than air sparge and P&T alternatives considered
- Materials Management/Waste Reduction:
  - No ongoing water use
  - Reusable solar pumps/panels
  - Majority of drilling work via DPT (limited IDW generation)
  - Minimal waste stream associated with cleanup efforts
  - Approval to place sampling water in closed-loop recirculation system (no IDW)
  - Limited impacts to land and ecosystem associated with system/construction

IM Activities
Well Installations

- Field activities conducted August 2010
- Performance Monitoring Wells (DPT Installed)
  - Six well clusters (pre-packed screen 10-15 ft bls and 16-21 ft bls)
  - Three clusters down centerline of Treatment Zone, two side-gradient, and one down-gradient
- Injection Points (DPT Installed)
  - 22 clusters (screened 10-15 ft bls and 16-21 ft bls)
  - 2 individual 16-21 ft bls points
- Two, 5-inch diameter extraction wells (screened from 11-21 ft bls)
- Nine, 4-inch diameter injection wells (screened from 11-21 ft bls)

IM Layout

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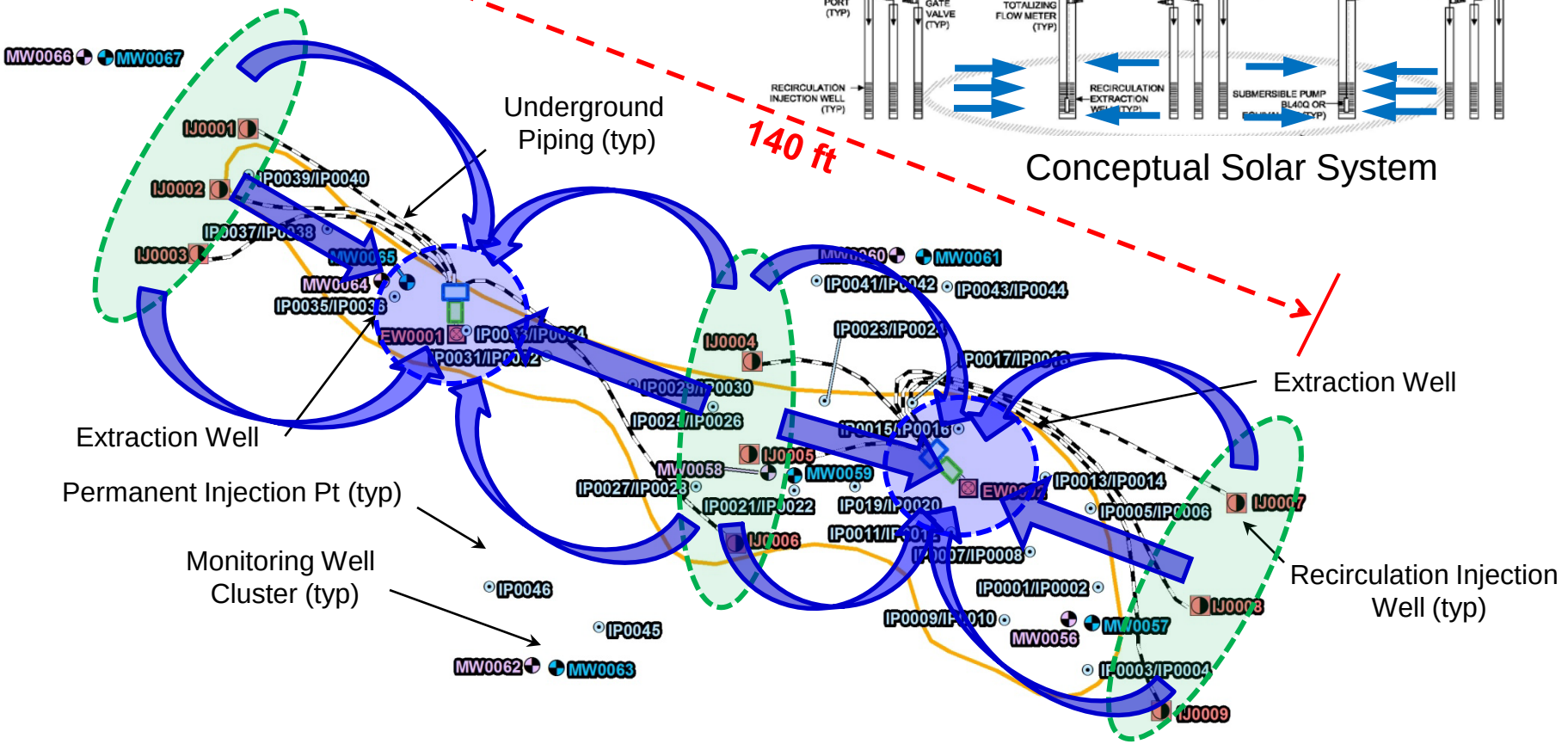
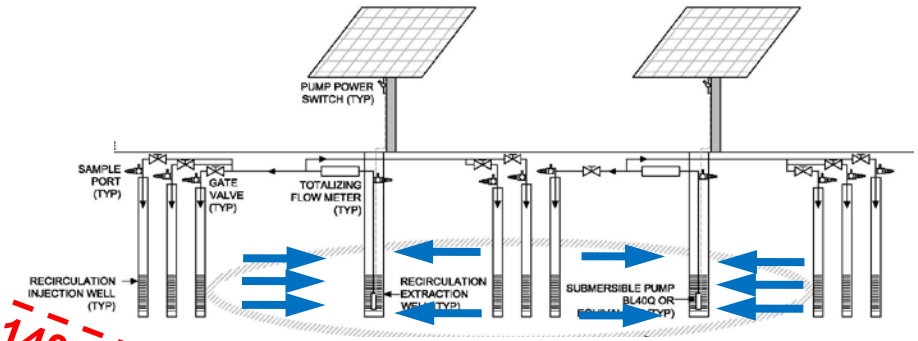
Groundwater Recirculation System Layout





Conceptual Solar System

Recirculation System Installation

Geosyntec consultants

Installation of the Solar Powered Groundwater Recirculation System

IM Activities
Emulsified Oil Injection

Geosyntec consultants

- Injection of 1:10 diluted emulsified oil solution
  - *Six drums of electron donor injected September 2010*
  - *Diluted e-donor (60 percent solution) 1:10 with site groundwater and injected 45 to 120 (average of 72) gallons per injection point*

IM Injection Activities
KB-1 Injection

- Confirmed anaerobic, reducing conditions
- Injection of KB-1 Microbial Culture
  - 20 L of culture
  - 500 mL into 40 of the 46 injection points
  - Six shallow injection points received 250 mL of culture
- 665 to 805 gallons of chase water per injection point

Groundwater ERD Results

- Geochemistry
  - Baseline average methane 1,304 µg/L, month 6 average methane 5,618 µg/L
  - Ethene increase from <1 µg/L to month 6 average of 39 µg/L
  - Average TOC of 50 mg/L (month 6)
- Microbial Data
  - *Dhc* increase from 10^6 to 10^7 (MW0058) and 10^5 to 10^7 (MW0059) gene copies per liter from baseline to month 6
  - Vinyl chloride reductase (vcrA) increase from <10^3 (ND) baseline to 10^7 in month 6
  - Data supports findings from the microcosm study that addition of microbial culture was warranted
- Field Measurements
  - Average DO of 0.31 mg/L
  - Average ORP of -227 mV
  - Average pH of 7.1 (neutral)

Groundwater ERD Results

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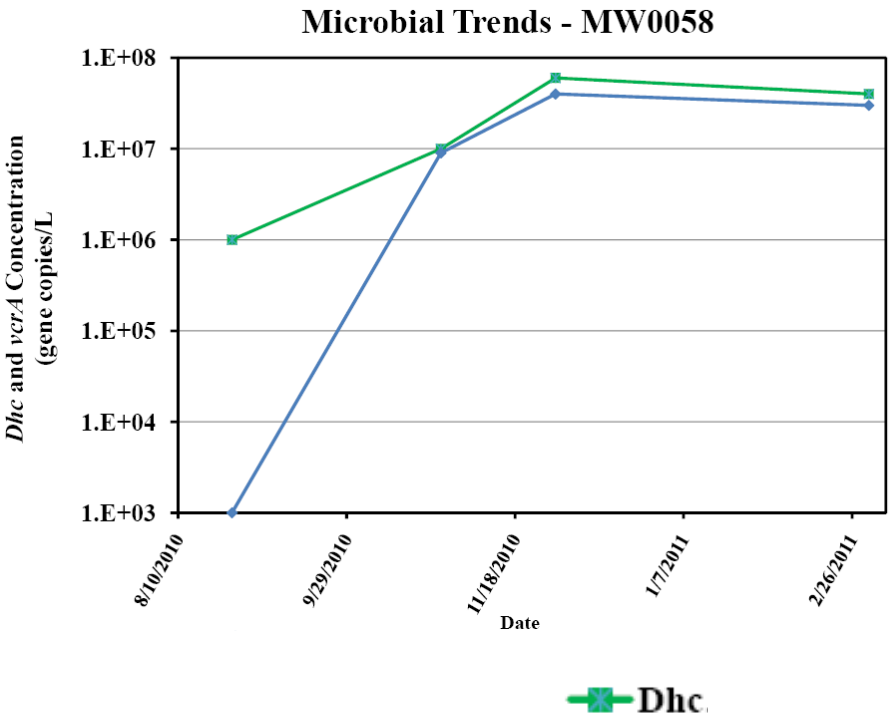

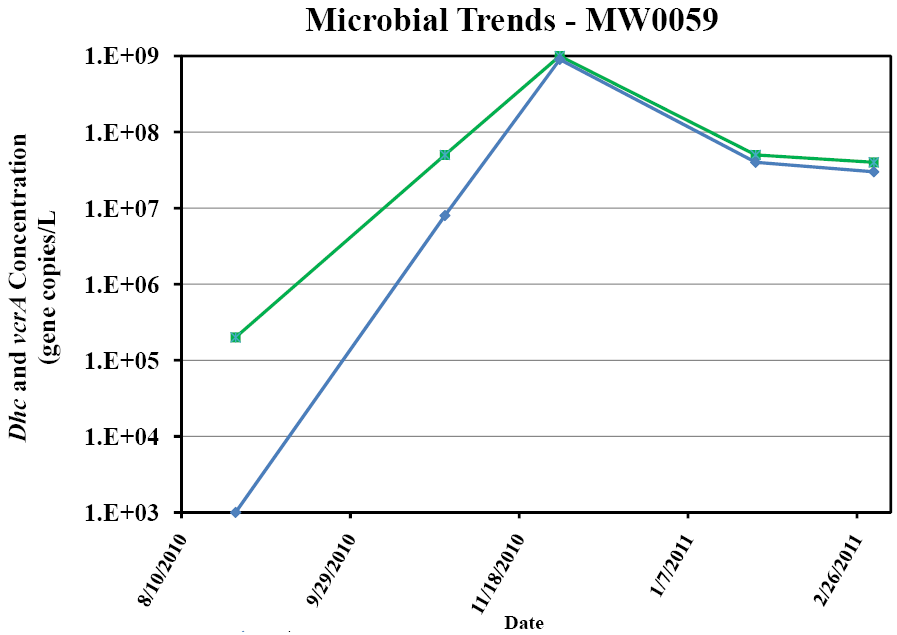

Dhc and vcrA Concentration Trends

Groundwater ERD Results

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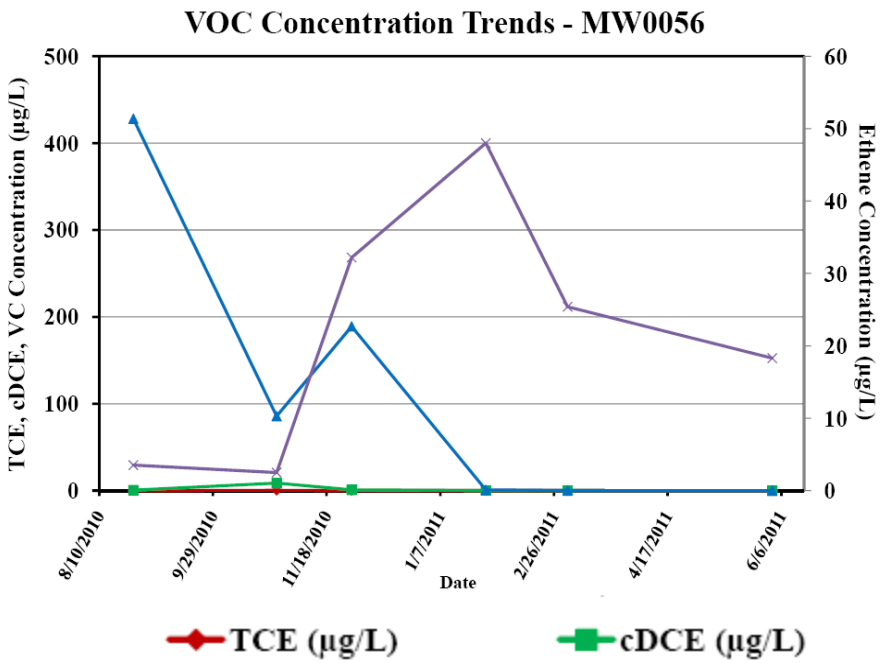

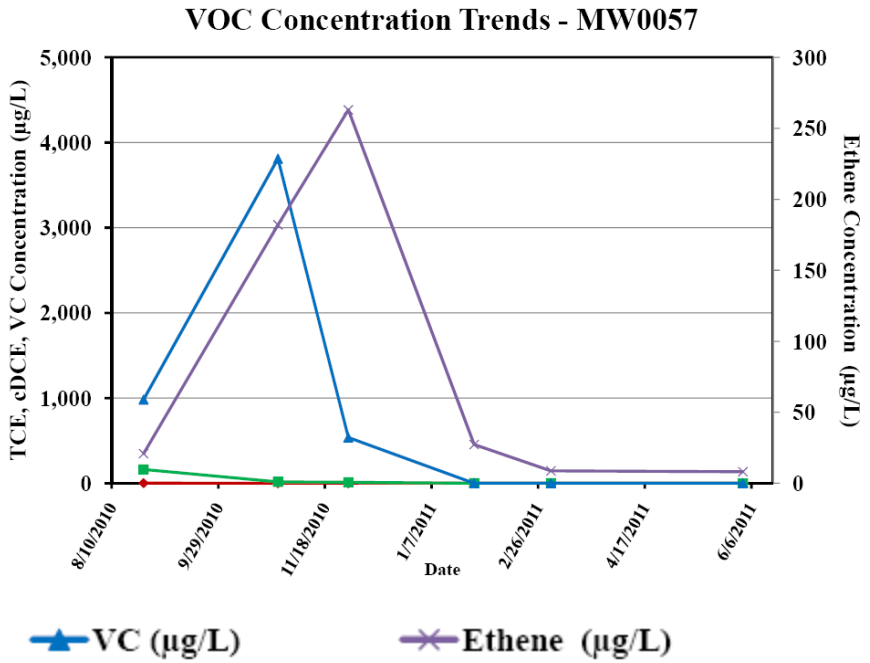

VOC Results – Trend Graphs
(centerline upgradient cluster MW0056/MW0057)

Groundwater ERD Results

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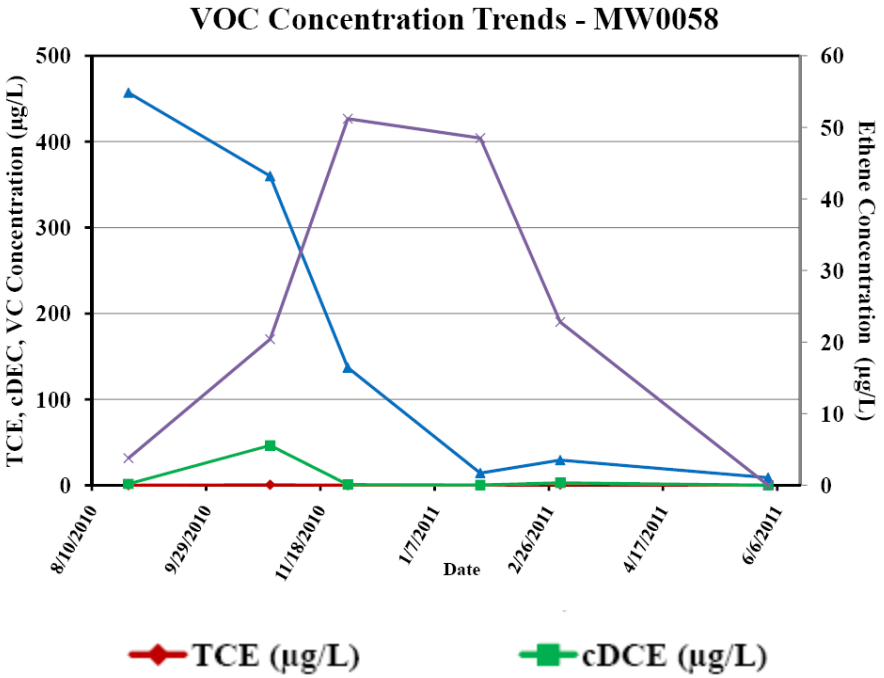

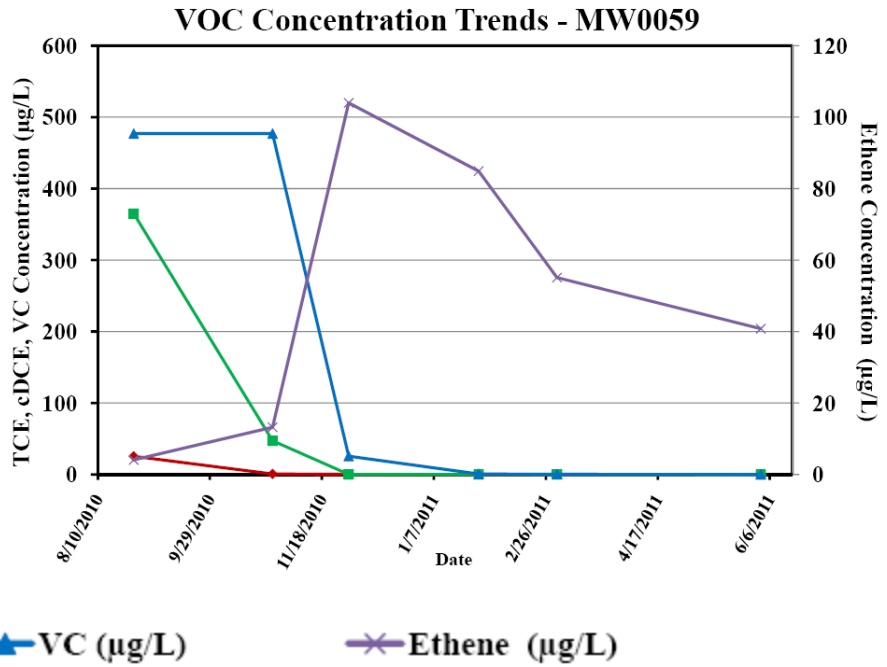

VOC Results – Trend Graphs
(centerline central cluster MW0058/MW0059)

Groundwater ERD Results

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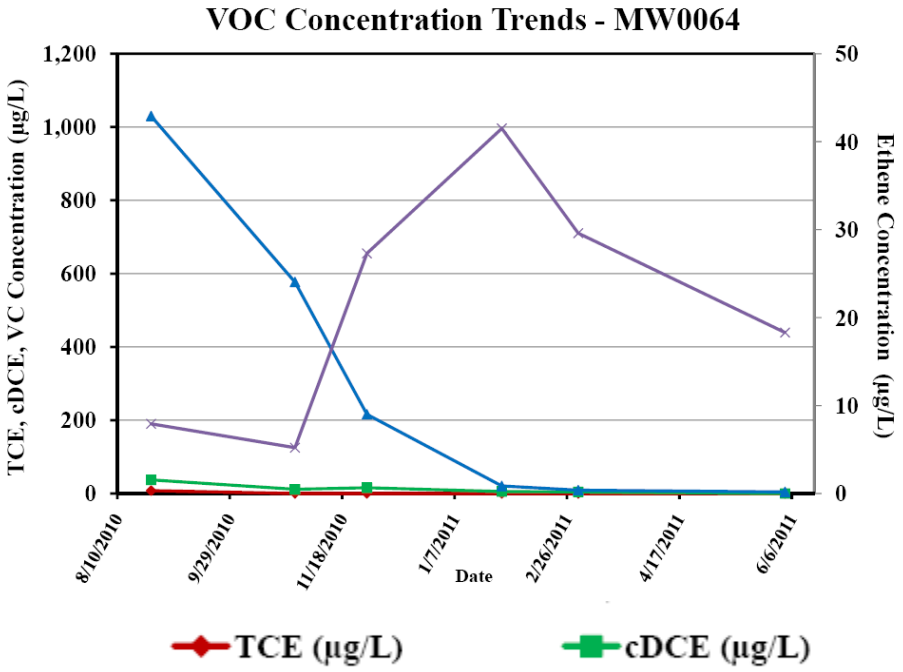
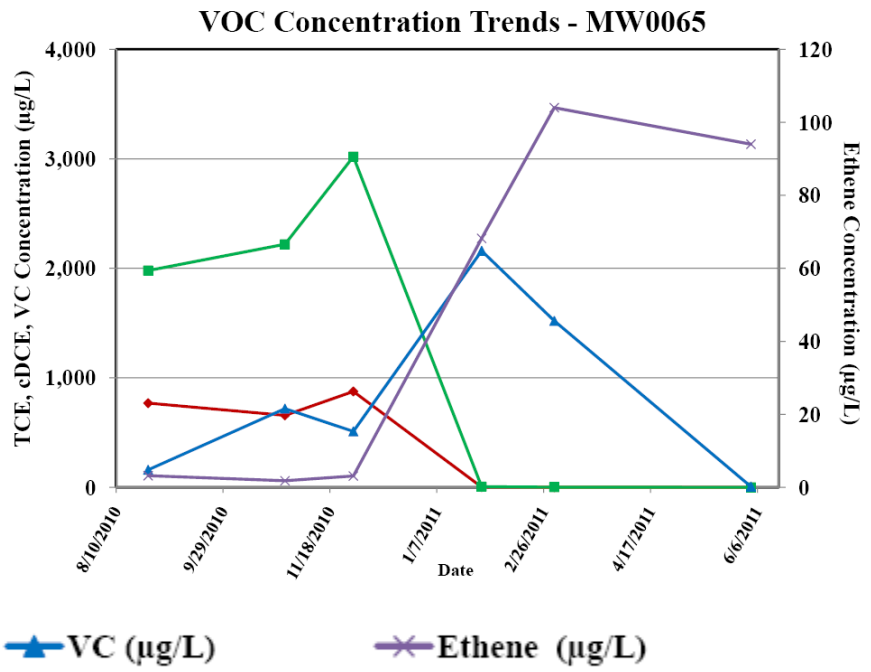
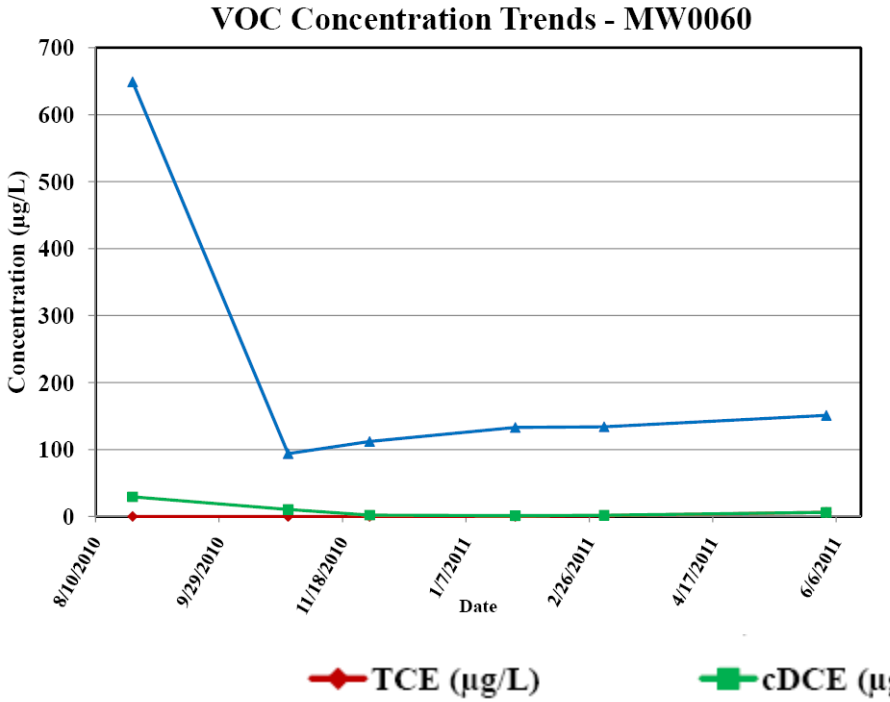
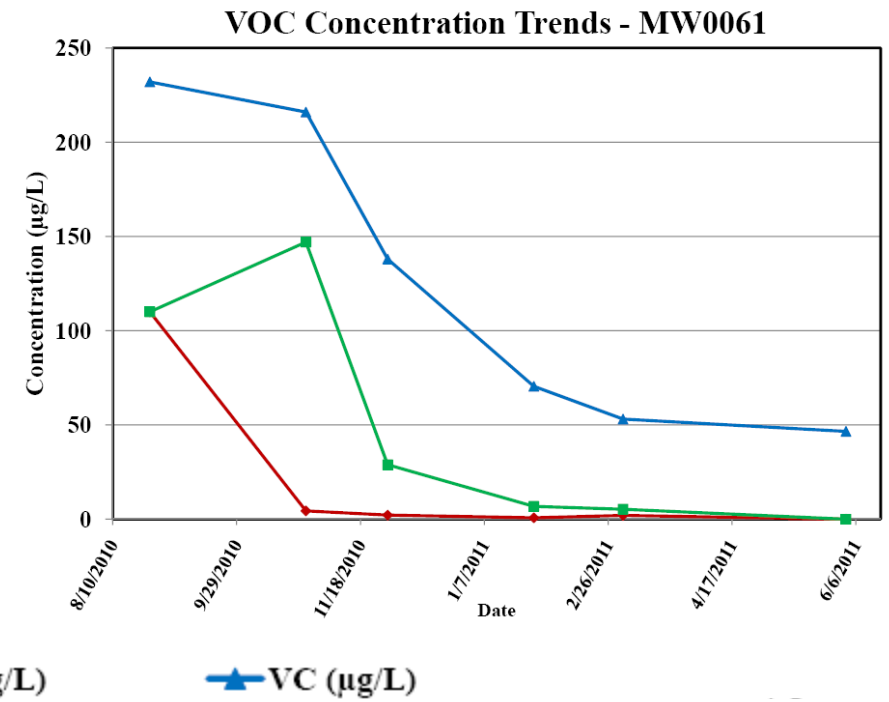




VOC Results – Trend Graphs
(centerline downgradient cluster MW0064/MW0065)

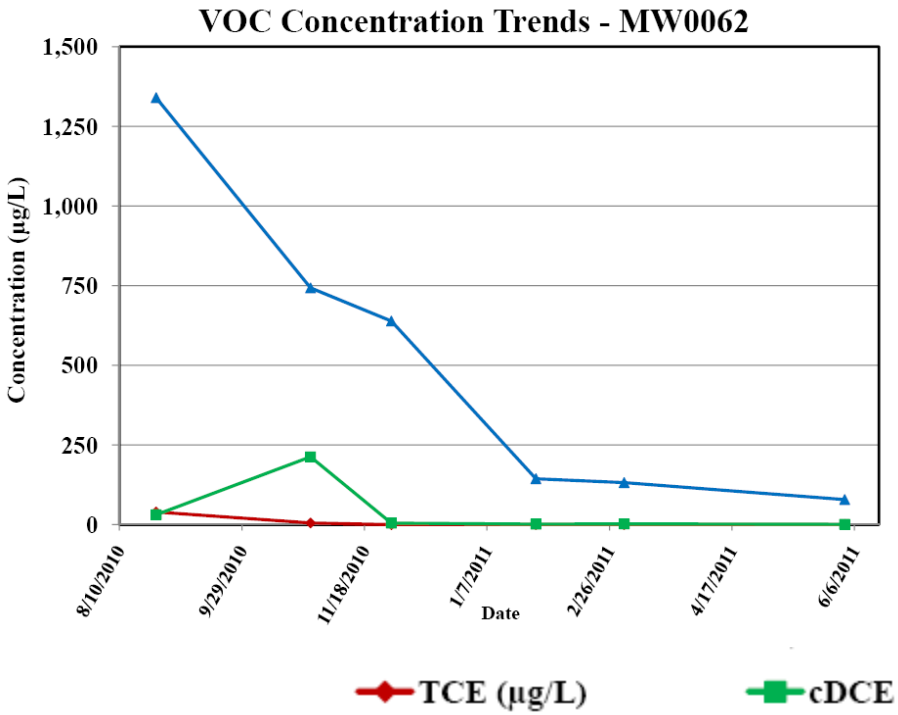
Groundwater ERD Results

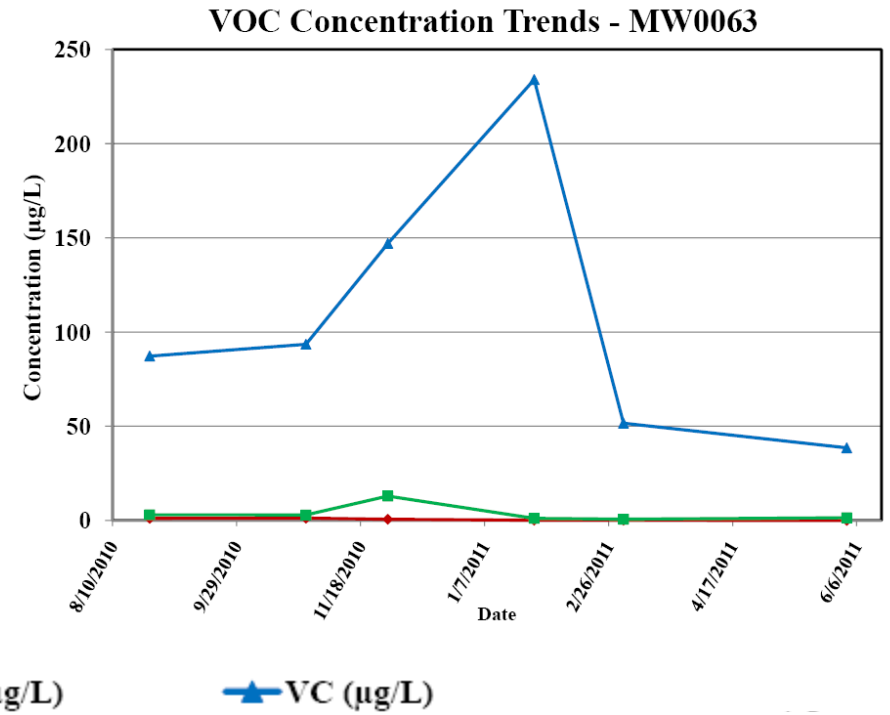




VOC Results – Trend Graphs
(sidegradient cluster MW0060/MW0061)

Groundwater ERD Results





VOC Results – Trend Graphs
(sidegradient cluster MW0062/MW0063)

Groundwater ERD Results

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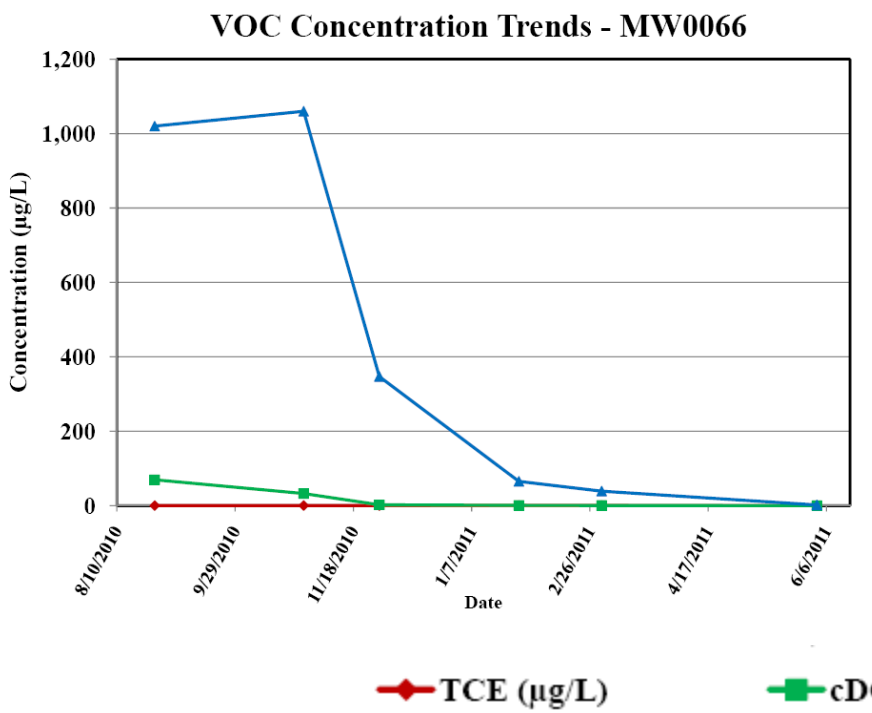
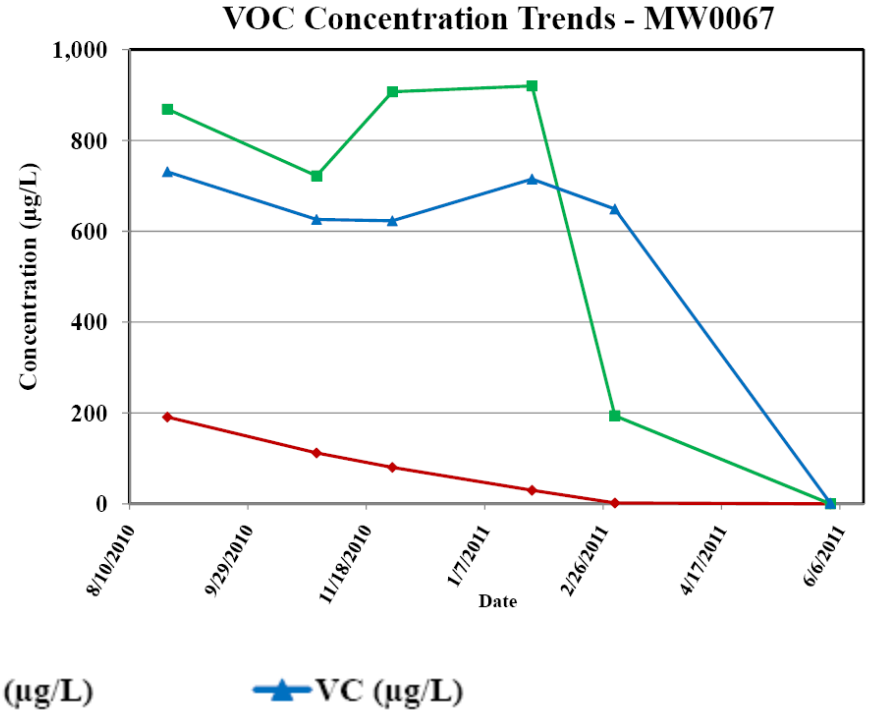
Center Operations Directorate

Medical & Environmental Management Division



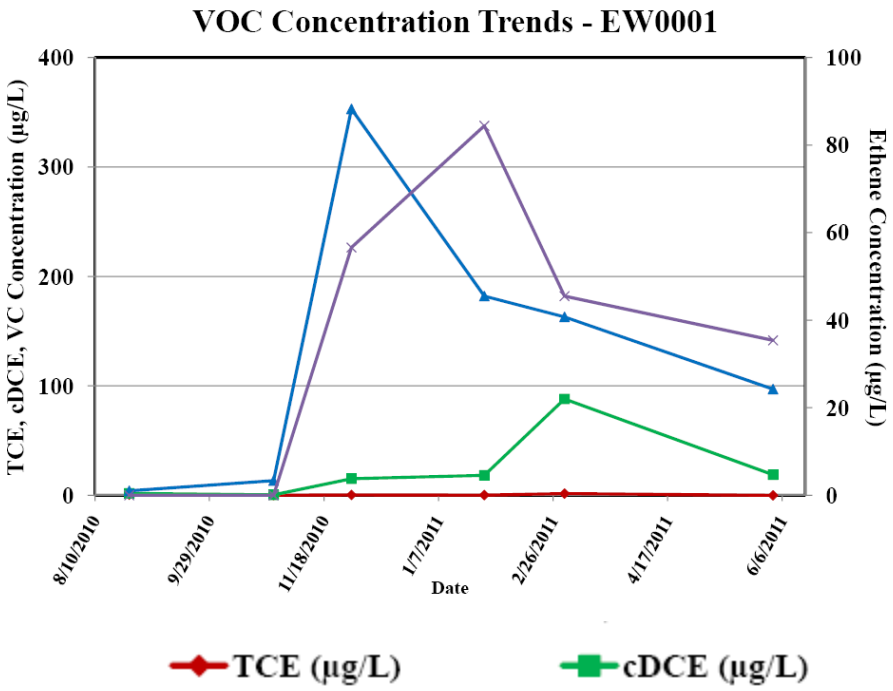


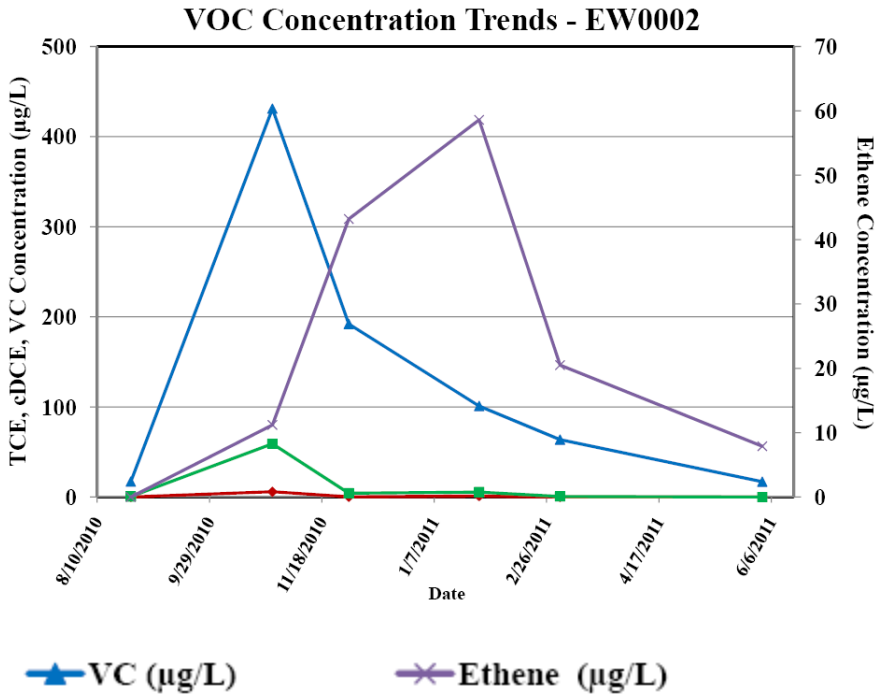
VOC Results – Trend Graphs
(downgradient cluster MW0066/MW0067)

Groundwater ERD Results

Kennedy Space Center
Center Operations Directorate

Medical & Environmental Management Division

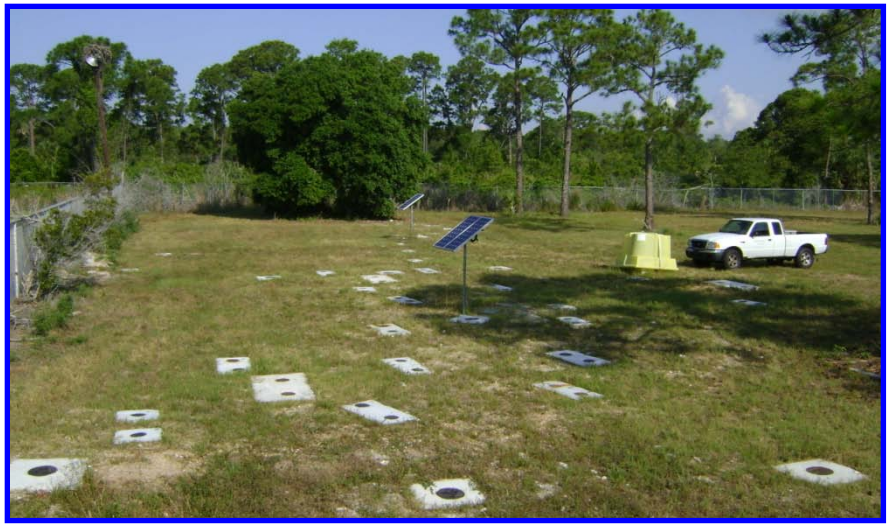




VOC Results – Trend Graphs
(centerline extraction wells EW0001/EW0002)

Solar System Recirculation Summary

- Pumping rates from 1.9 to 7.0 gpm per extraction well
- 936,000 gallons recirculated during 9 months of operation (over 15 treatment zone pore volumes)
- Groundwater elevation monitoring documented effective drawdown, mounding and recirculation



Conclusions

- Corrective Action Objectives (CAOs) achieved within 9 months within treatment zone
- Target treatment area of 3,000 ft^2, actual area treated exceeds 5,000 ft^2
- Integrated solar recirculation system:
  - Provides adequate power at a cost less than dedicated electrical service ($4k for panel/pump/hardware per location)
  - Quick installation/mobilization and demobilization
  - Reusable system/components (reuse plans in the works)
- Total project costs of $300K (capital costs, monitoring, reporting for 9 months)
- Flexible approach which can be expanded downgradient or deployed at other nearby sites

Thank You!

Acknowledgements:

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- Emily Lawson, Geosyntec Consultants

Questions?