Environmental Molecular Diagnostics Demonstrate Chem-Bio Treatment Train Effectiveness for Benzene

John Black, **Steve Kretschman**, & Matt Burns
WSP USA Corp.
11190 Sunrise Valley Drive
Suite 300
Reston, VA
703-709-6500
Steve.kretschman@wspgroup.com

providing management and consultancy services to the built and natural environment

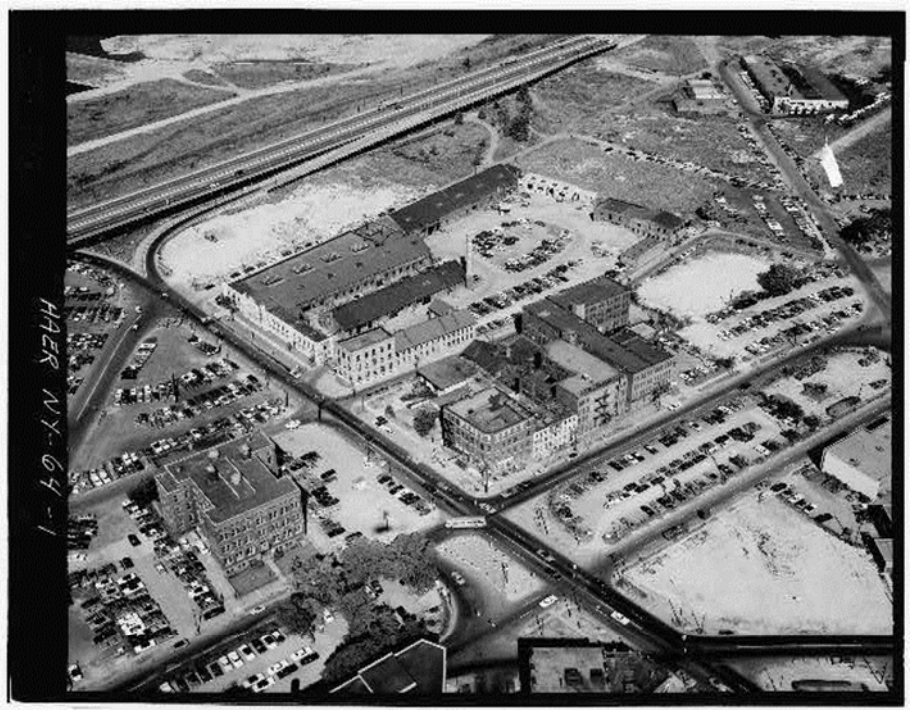
15,000 people
300 offices
35 countries

Setting

- Massive remediation project of a former Manufactured Gas Plant in downtown Buffalo, New York
- The project was stalled for nearly a decade
- Looking for a single remedy to address complex soil, waste and groundwater problems
- State and City wanted a remedy that allowed the site to be put back into productive use.
- Real answer was moving to correct regulatory program, implementing multiple complementary remedial actions and a business solution

MGP Site History

- Manufactured Gas Plant – Operated from the mid-1800's and closed circa 1948
- Serviced by the Erie Canal – Wilkeson Slip
- Storage and Distribution from 1948 to 2004
- Idle from 2004 to 2005

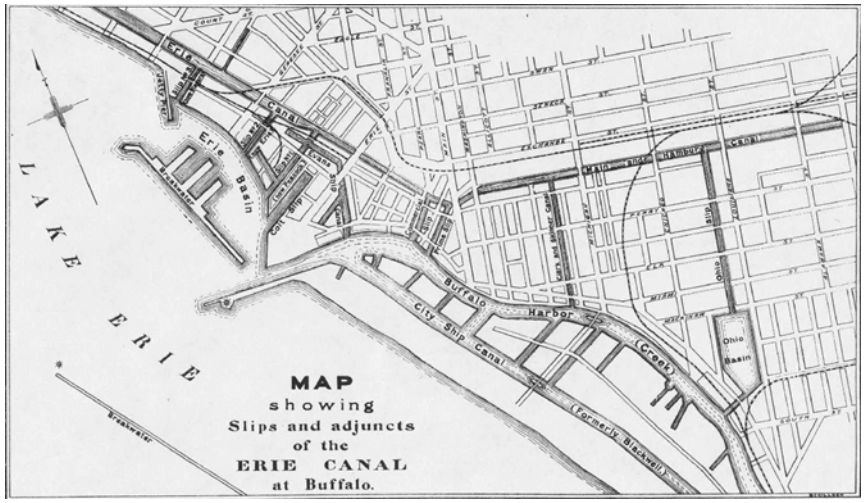


Site Conditions

- MGP Buildings removed in 2000
- Former Wilkeson Slip backfilled in 1940s/1950s
- Waterfront School built over portion of site and slip in 1970s
- Site Investigation Identified the presence of NAPL at depth
- Affected soil and groundwater conditions representative of decades of MGP production byproducts
- Primary Compounds
  - BTEX
  - PAHs
  - Cyanide

Surrounding Properties

- US Postal Service
- Television Studio
- Parking
- Subsidized Housing



The Project - 2004

- MGP property owned by utility (environmental liability through acquisition of MGP operator)
- Former Order on Consent
- Site Investigations had been ongoing for years
- WSP enters the project at Remedy Selection Stage
- No remedial actions other that structure demolition
- Historic Façade designated a local landmark

The Business Solution

- Developer and major tenant identified
- Site location was perfect, but needed shovel ready site in less than 12 months
- The liability cost shared by utility and buyer
- Developer willing to share in liability cost as a function of purchase
- Liability transferred to a sole purpose entity
- Insured program Pollution Legal Liability Insurance

The Regulatory Solution

- Met with the State, City and parties to define time line
- Consent Order entered for adjacent school/Wilkeson Slip component
- BCP applications accepted for other areas sold to developer by the City of Buffalo
- Agreed to revised submittals:
  - Work Plan/FFS
  - Aggressive Schedule with full time onsite presence for state
  - Aerial monitoring of daily progress

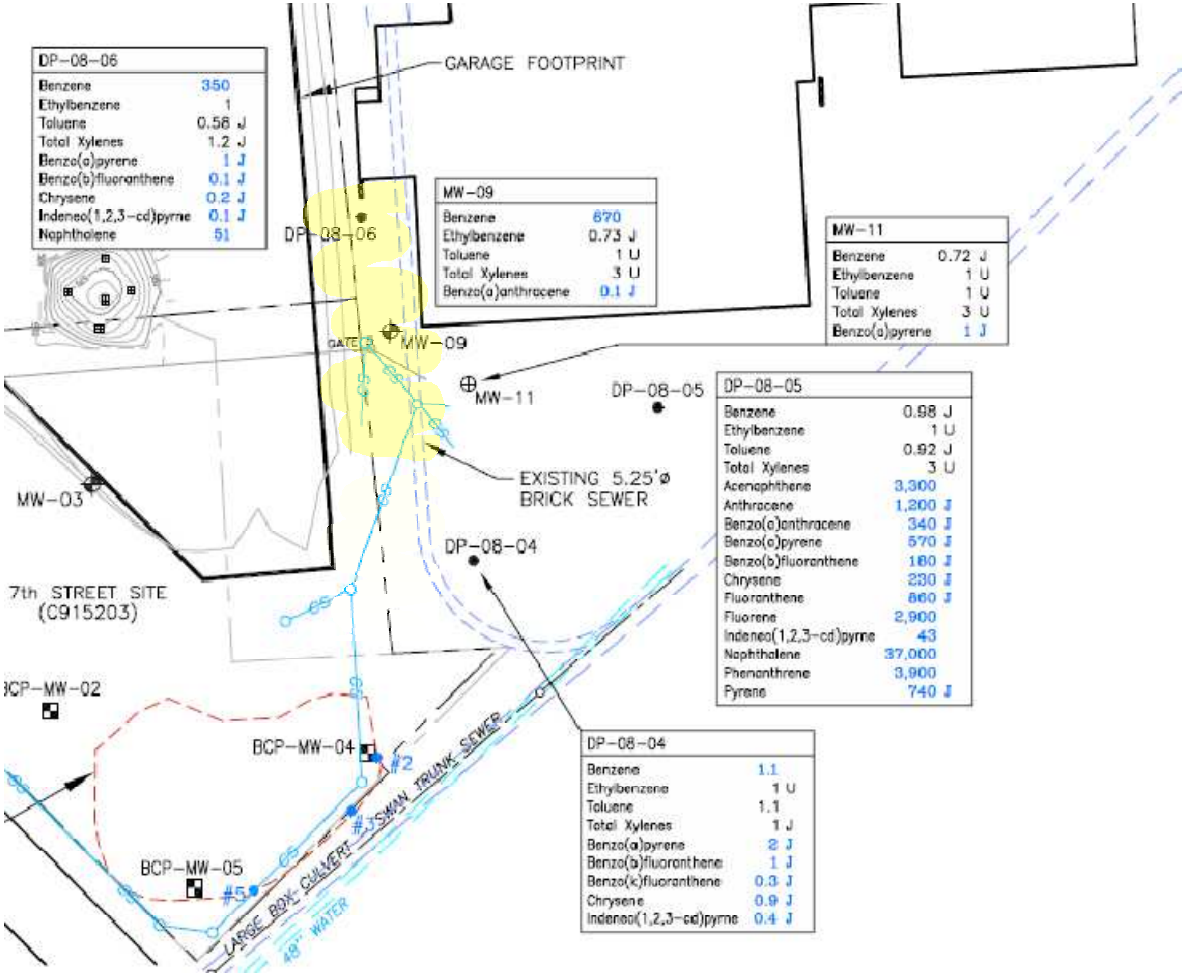
School Property/Wilkeson Slip

- Protect the school structure
- Remove impacted fill and saturated soil
- Soil cleanup level of 1mg/kg
- Install sub-slab vapor mitigation system
- Coordinated remediation and new construction to meet the schedule for development

One Hundred Sixty Thousand Tons

On Time Completion Allowed Redevelopment

Elevated Benzene in Groundwater



Supplemental In Situ Remedy

- Complete delivery testing
- Assess the genetic capacity of native microbes to attenuate petroleum compounds

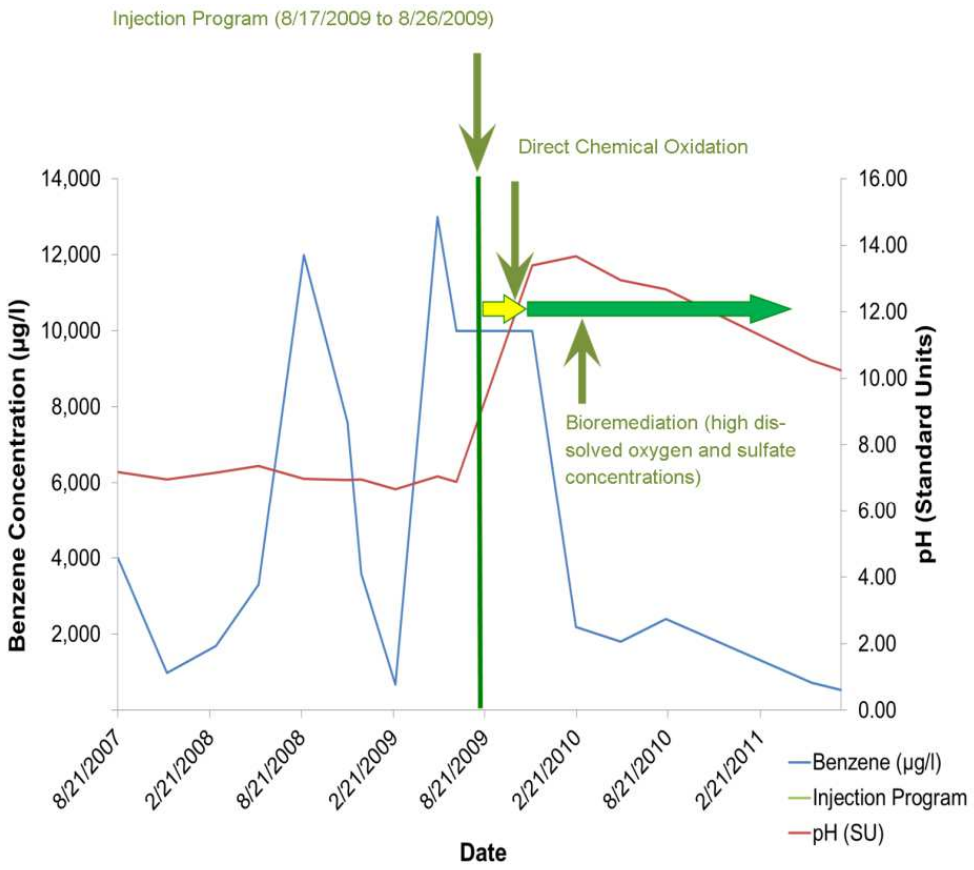
	Baseline 6/26/2009 (DNA)
CENSUS (qPCR)	
Functional Genes (cells/bead)	
Benzyl Succinate Synthase (bssA)	<1.00E+00
Naphthalene Dioxygenase (NAH)	1.37E+08
Phenol Hydroxylase (PHE)	4.06E+04
Toluene Monooxygenase (RMO)	<1.00E+00
Toluene Dioxygenase (TOD)	1.01E+06
Biphenyl Dioxygenase (PPH4)	2.34E+04
Xylene Monooxygenase (TOL)	2.00E-01 J

- Applied of 24,030 lbs. of Klozur® CR using direct push slurry injection methods

Klozur CR

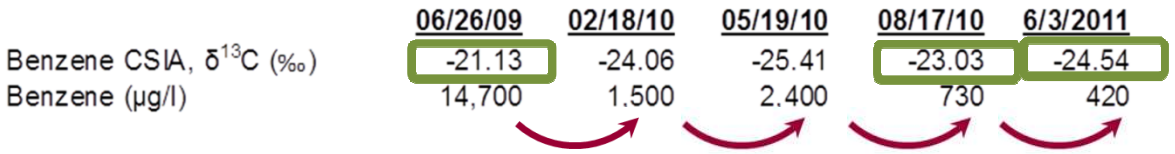
- Consists of sodium persulfate and calcium peroxide
- Three different but coupled chemistries to attenuate petroleum-affected groundwater in a single application.
  - strong chemical oxidant (base activated persulfate)
  - aerobic biostimulant (calcium peroxide is an oxygen releasing comound)
  - anaerobic biostimulant properties (persulfate decomposes to the electron acceptor sulfate)
- Groundwater monitoring limited to one well but included monitoring included EMDs

Concentration Data



- Decrease in benzene concentration following Klozur® CR injections
- pH elevated throughout due to calcium peroxide accumulation in well screen pack
  (in the winter of 2011 the well was replaced by MW-9R located directly adjacent to MW-9. pH in MW-9R was neutral)

Compound Specific Isotope Analysis Confirms Contaminant Destruction



Baseline data rejected because another compound co-eluted with benzene in the sample.

Fractionation value beyond the published, non-degraded benzene range (-23.5 to -31.5) indicates that degradation has occurred.

isotopic depletion shows influx of lesser treated benzene

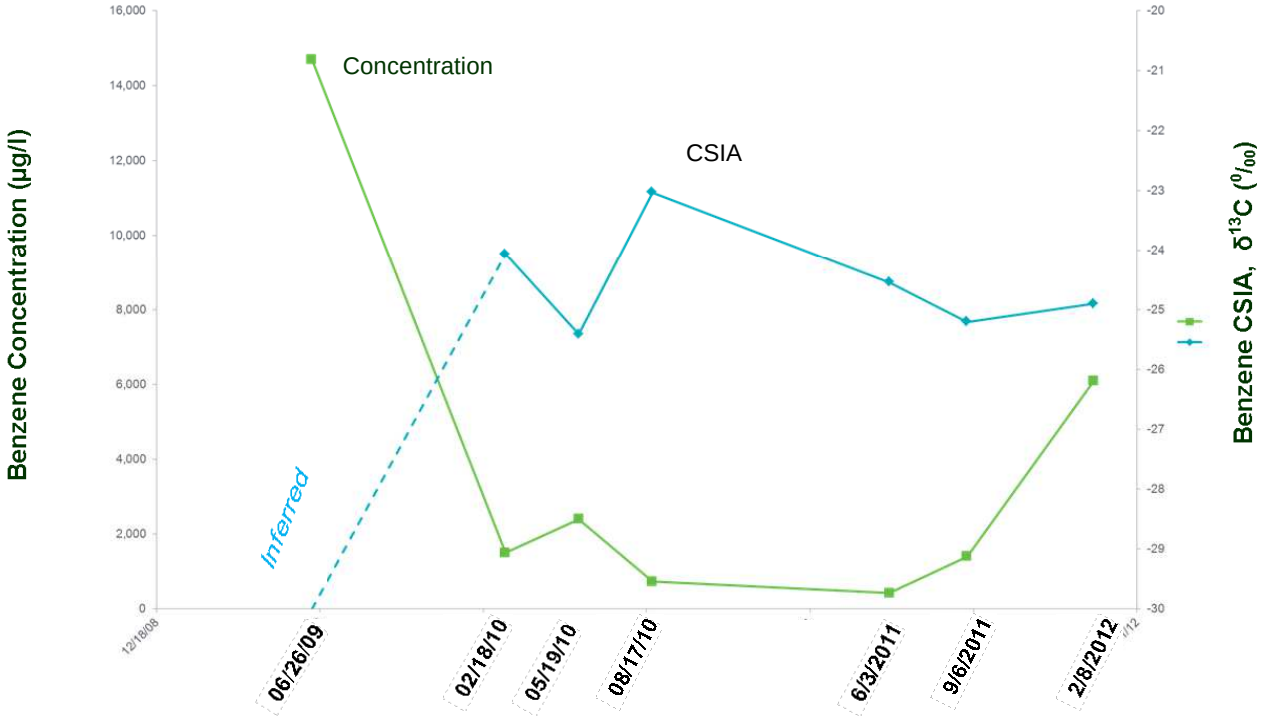
Molecular/Biological Data Identifies the Biological Mechanism of Destruction

	MW-9				
	Baseline	Performance Monitoring			
	6/26/2009 (DNA)	2/18/2010 (mRNA)	5/19/2010 (mRNA)	8/17/2010 (mRNA)	6/6/2011 (mRNA)
CENSUS (qPCR)					
Functional Genes (cells/bead)					
Benzyl Succinate Synthase (bssA)	<1.00E+00	<5.00E+01	<5.00E+01	<5.00E+01	<5.00E+01
Naphthalene Dioxygenase (NAH)	1.37E+08	<5.00E+01	<5.00E+01	1.73E+10	<5.00E+01
Phenol Hydroxylase (PHE)	4.06E+04	4.47E+01 J	<5.00E+01	<5.00E+01	<5.00E+01
Toluene Monooxygenase (RMO)	<1.00E+00	-	<5.00E+01	<5.00E+01	1.78E+03
Toluene Dioxygenase (TOD)	1.01E+06	3.50E+01 J	<5.00E+01	<5.00E+01	<5.00E+01
Biphenyl Dioxygenase (PPH4)	2.34E+04	<5.00E+01	<5.00E+01	<5.00E+01	<5.00E+01
Xylene Monooxygenase (TOL)	2.00E-01 J	3.14E+01 J	<5.00E+01	<5.00E+01	<5.00E+01

Oxygenase genes which produce the enzymes required degrade petroleum constituents are common.

BioTrap® qPCR data quantifies the expression of genes for protein synthesis and identifies two classes of microbes able to adapt to elevated pH levels.

Additional Round of Concentration and Isotopic Data Definitively Shows Benzene Mass Influx



Explanation:
Upgradient Saturated Soil Cleanup Criteria 1 mg/kg

Equilibrium Partitioning Calculation with 1 mg/kg Benzene in Soil Below the Water Table

$$Ct = Cw[KocFoc + (\theta w + \theta aH')/\rho b]$$

Symbol	Parameter	Typical Value	Low Value (a)	High Value (a)	RSL Calc	Units
C_t	Total concentration in soil	1	1	1	0.0026	mg/kg
K_{oc}	Organic carbon partition coefficient	59	59	59	59	l/kg
H'	Henry's Law constant	0.23	0.23	0.23	0.23	dimensionless
F_{oc}	Fraction organic carbon	0.002	0.01	0.001	0.002	dimensionless
ρ_b	Dry bulk density	1.5	1.3	1.8	1.5	g/cm^3
θ_w	Water-filled porosity	0.43	0.43	0.15	0.3	dimensionless
θ_a	Air-filled porosity	0	0	0.28	0.13	dimensionless
C_w	Concentration in groundwater	2.5	1.1	5.6	0.008	mg/l

a/ "Low" and "High" parameter values refer to values that result in a lower or higher calculated C_w.

With 1 mg/kg total benzene in soil, would expect 1.1 mg/l to 5.6 mg/l in groundwater (best estimate 2.5 mg/l).

Note for comparison: EPA Regional Screening Level for benzene in soil to protect groundwater to the MCL (0.005 mg/l) is 0.0026 mg/kg.

Groundwater Treatment Results/Lessons Learned

- Advanced Site Diagnostics was able to definitively attribute decreased post-application concentrations to destructive degradation.
  - the CSIA data showed fractionation (Delta13C value of -23.03 ‰) outside the typical non-degraded benzene range (-23.5 ‰ to -31.5 ‰) thereby definitively proving destructive degradation.
  - the expression of oxygenase enzyme activity as measured by RNA gene copies identifies the degradation mechanism for at least some of the benzene

- CSIA data also attributed the benzene concentration rebound to influx from an upgradient source.

- Achieved goals to lower benzene concentrations but influx of upgradient benzene limited complete attenuation.

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