

## Combined Remedies: Take Advantages of the Universe of Possibilities

November 2017



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Boston Operations



## Fill Your Tool Box



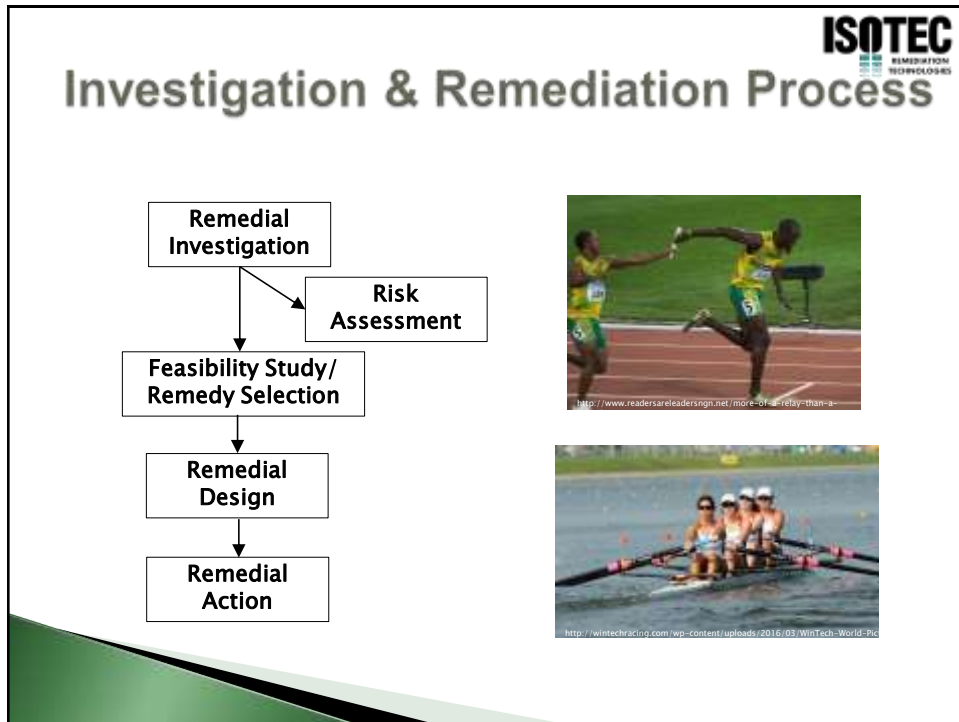
### Sciences

- Geology
- Organic chemistry
- RedOx Chemistry
- Microbiology
- NAPL Transport
- Advection/Dispersion
- Matrix Diffusion
- Vapor Transport



### Technologies

### Clichés



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TECHNOLOGIES

## There is No Silver Bullet

Sites to Consider Combined Remedies

- Large sites with multiple areas of concern
- Multiple sources
- Mixed plumes/multiple contaminant types
- Plumes with wide concentration ranges
- Low remediation criteria (MCLs)
- Inaccessible contamination (roadway, building)
- Heterogeneous geology
- Accelerated schedule
- Cost savings

## It's Dark Down There

- ▶ Discrete Data
- ▶ Heterogeneities
  - Vertically
  - Horizontally
  - Geologically
  - Contaminant Phase
- ▶ Macroscale design for microscale processes
  - Gallons, cubic yards, pounds
  - Chemical reactions + microbial activity



Dehalocyclohexene in camp? Strain 145

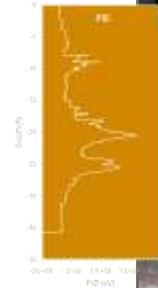
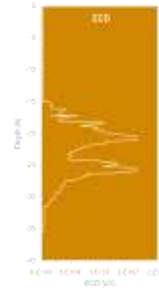
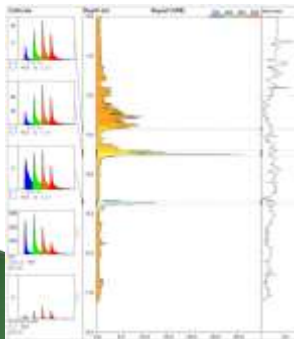


Sand Grains

<http://www.nasa.gov/images/content/243>

## More Data is Better ...Maybe

- ▶ High Resolution Site Characterization
  - Membrane Interface Probe
  - Laser Induced Fluorescence
  - Hydraulic Profiling Tool
- ▶ Field Laboratory



## Actionable Data is Better

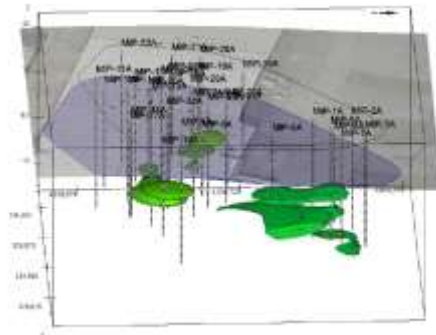
Data  
Collection  
with a  
Purpose



<https://d3nevzfk7ii3be.cloudfront.net/igi/oqFZEOVCLGIMYGs>

## Multiple Lines of Evidence... Connecting the Dots

- ▶ Data Management
- ▶ 3-D Visualizations – screening/qualitative
- ▶ Geology/lithology
- ▶ GW Concentrations
- ▶ Soil Concentrations
- ▶ Geochemistry



## Multiple Lines of Evidence... Connecting the Dots

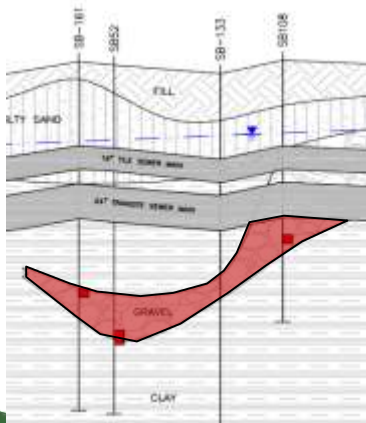
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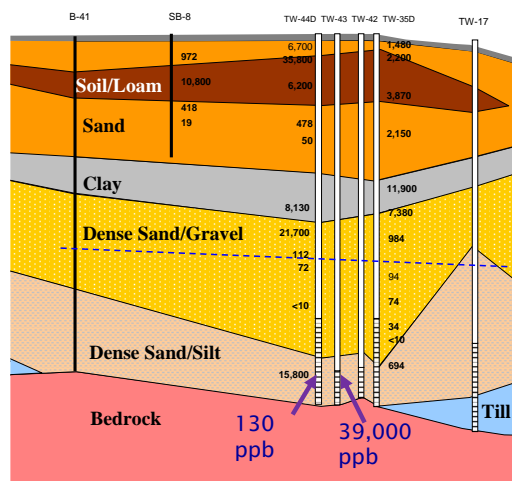
**Do Not Perform Remedial  
Design Based on Blobs Alone**

## Geology Matters

- Contamination located primarily in more permeable interval



- Contamination located primarily in less permeable interval



## Geologic Bread Crumbs

- ▶ Where is contamination?
- ▶ Where is it traveling? & How did it get there?
- ▶ What amendment is being delivered?
- ▶ Can air or fluid move through site subsurface?
  
- ▶ How does site geology impact the answers to these questions?



## Remediation is a Contact Sport

- ▶ Cliché is True
- ▶ Amendments not effective without contact with contaminants
- ▶ Focus design on delivery of amendment(s) to the contaminant mass
  - Geology
  - Contaminant distribution
  - Contaminant density vs. reagent density



## Keep the Bacteria Happy



- ▶ Bacteria are like people
- ▶ Bacteria have highest activity in different conditions
- ▶ Will remediation affect subsurface conditions that could impact microbial activity?
  - Change pH and/or RedOx state?
  - Inhibitory effects
- ▶ “How can I give the bacteria what they need?”



## Rebound is NOT a Dirty Word

- ▶ Concentration rebound can occur after remediation
- ▶ 62% of sites experienced rebound in one or more monitoring wells following ISCO (Krembs & Clayton, 2010)

**Rebound  $\neq$  Failure**

- ▶ Sources begin to show themselves with treatment

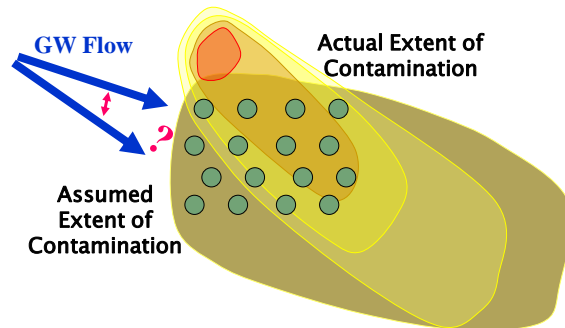




## Causes of Rebound (1)



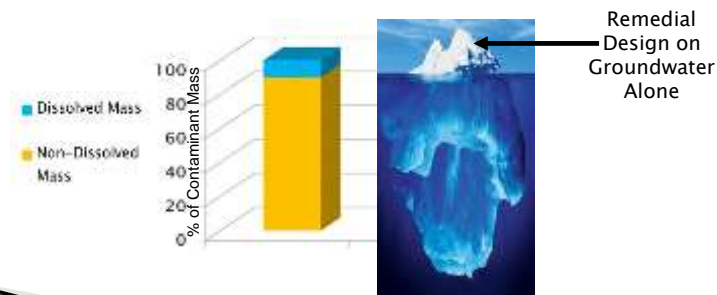
- ▶ Advective Flow
  - Incomplete treatment
  - Groundwater/contaminant transport from untreated areas



## Causes of Rebound (2)



- ▶ Desorption & NAPL Dissolution
  - Significant contaminant mass is not in aqueous phase
  - Dissolution/desorption are slow processes
  - Residual mass re-equilibrates over time

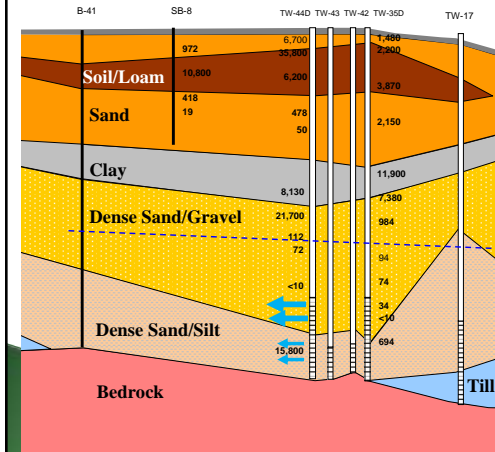




## Causes of Rebound (3)



- ▶ Matrix Diffusion
  - Contaminants in low permeability zones
  - Preferential remediation to more permeable areas/intervals



- Matrix diffusion is a speed bump



<http://www.funnywebsite.com/funny-website/index.php/2013/01/14/fear-of-speed-bumps/>

## More is better (Volume)



- ▶ Increasing injection volumes improves contaminant destruction and reduces potential for rebound
- ▶ Krembs and Clayton (2010)

	<20% Pore Volume	>20% Pore Volume
Rebound at Sites	80%	50%
MWs with Rebound	51%	26%

- Average injection volume of oxidant was only 0.10 PV
- ▶ Siegrist, et. al, (2011)
  - >90% reduction of contaminant for sites that injected >0.5 PV



## Setting Up For Your Next Shot

- ▶ Combining Remedies
- ▶ Proactive
  - Different technologies assumed
  - Harness advantages of all technologies
  - Sequencing
  - Cost/cash flow



k22305408 fotosearch.com ©

## Setting Up For Your Next Shot

- Combined Remedies
- Reactive
  - Now what?
  - First approach didn't fully meet goals
  - Change in conditions
  - Still closer to the hole than when the project started
  - Know when to change approach (club)



# Stall?

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TECHNOLOGIES



- Get back on the road to the destination



or



or



## Oxidants – 1,2-punch

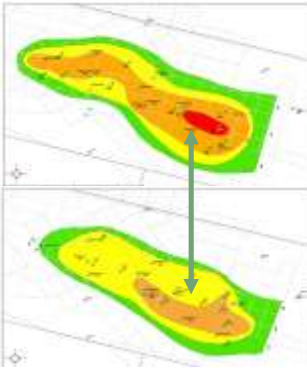
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TECHNOLOGIES

- ▶ Hydrogen Peroxide (MFR)
  - Desorption
  - Oxidation of Contaminants
  - Enhance aerobic biodegradation (DO)
  - Activation of Sodium Persulfate
- ▶ Activated Persulfate
  - Oxidation of Contaminants
  - Enhance anaerobic biodegradation (sulfate)
  - Enhance abiotic dechlorination (FeS)
- ▶ Both oxidants = **SUPER PUNCH!**



## Peroxide + Persulfate

- ▶ Hydrogen peroxide injected following persulfate



### ▶ Persulfate Sandwich

- Hydrogen Peroxide (native iron as catalyst)
- Base-Activated Sodium Persulfate (ASP)
- Catalyzed Hydrogen Peroxide (CHP)
  - Modified Fenton's Reagent

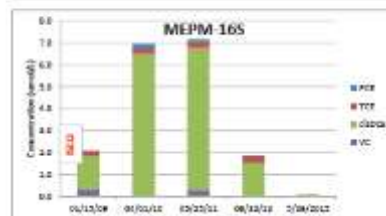
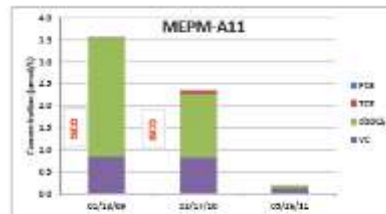


### ▶ Gas stations, CVOC/BTEX, MGP sites

- Different sequences of these 2 oxidants
  - CHP, ASP, CHP
  - CHP, ASP
  - ASP, CHP, ASP

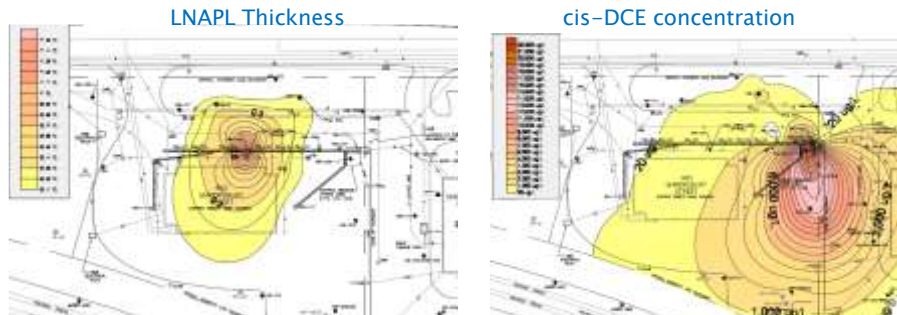
## Polish Treatment after ISCO

- Biodegradation After ISCO
  - Iron- and Sulfate-Reducing Bacteria
  - DHC/VC Reductase
- Abiotic Dechlorination
  - Injection of sulfur (persulfate)
  - High native iron
  - Return to reducing conditions
  - pH > 8 in most wells
  - reduction in CVOC without vinyl chloride



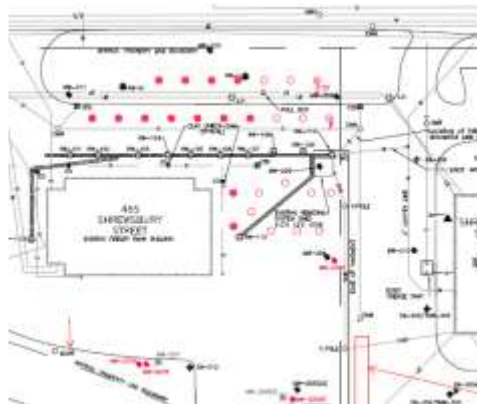
## Surfactant Enhanced Bioremediation

- ▶ Chlorinated VOCs + LNAPL (cutting oil contains TCE)
- ▶ Currently bank and fast food restaurant
- ▶ Evidence of reductive dechlorination occurring



## Surfactant Enhanced Bioremediation

- ▶ Accelerate biodegradation, breakup NAPL, dissolve TCE
  - Use NAPL as food source
- ▶ LNAPL Area
  - customized sodium lactate
    - Surfactant
    - Ammonium chloride
    - Disodium phosphate
  - Sodium bicarbonate
- ▶ Outside LNAPL Area
  - Emulsified vegetable oil
  - Sodium bicarbonate



## Maximize Treatment Processes



- ▶ Low PCE/TCE concentrations
  - PCE = 2–40  $\mu\text{g/L}$
  - TCE = 2 to 110  $\mu\text{g/L}$
- ▶ Multi-acre, low pH plume
- ▶ Really low criteria (1  $\mu\text{g/L}$ )
  - 2 year treatment time
- ▶ Multiple Treatment Processes



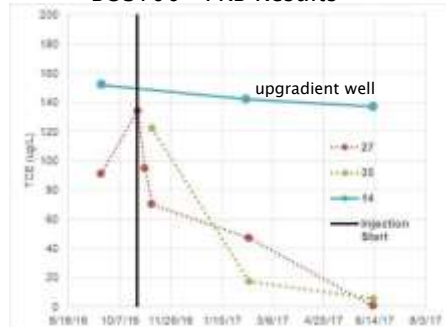
[http://www.worldrecordacademy.com/society/lowest\\_limbo\\_by\\_a\\_woman\\_world\\_record\\_set\\_by\\_Shemika\\_Charles\\_101874.html](http://www.worldrecordacademy.com/society/lowest_limbo_by_a_woman_world_record_set_by_Shemika_Charles_101874.html)

## Trap & Treat & Treat



- CAT 100™
- BOS 100®
  - Injectable Activated Carbon Sorption
  - Reactive Iron
  - Abiotic dechlorination
- ERD components
  - Electron donor (starch)
  - Nutrients
  - Bacterial consortiums (anaerobic and facultative bacteria)
- ISOTEC initiated CAT100™ injections Nov. 2

BOS100® PRB Results

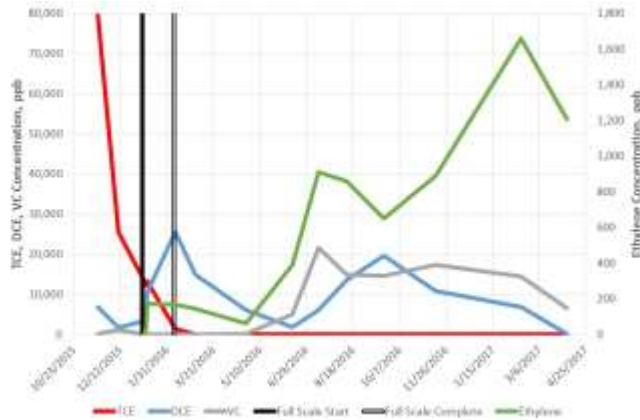




# Trap & Treat & Treat

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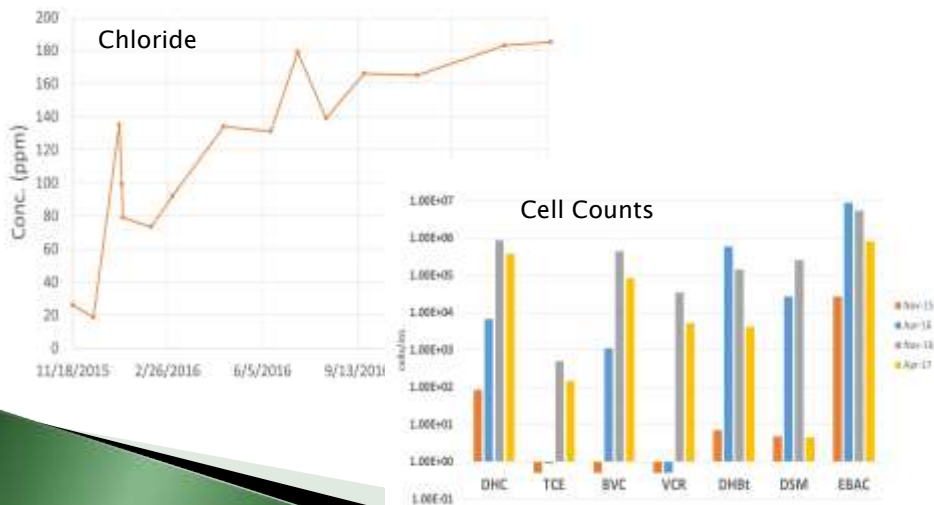
- CAT 100™ also successfully applied on DNAPL Sites



# Trap & Treat & Treat

**ISOTEC**  
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TECHNOLOGIES

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## Horizontal Wells

- ▶ ISCO
  - Catalyzed Hydrogen Peroxide
- ▶ Biosparging
  - Post ISCO



## One Event...ISCO, ZVI, & ERD

- ▶ Historic Mill Redevelopment
  - 18 month remediation period
  - Massachusetts GW-2
  - Low CVOCs in all samples except focused area
- ▶ Catalyzed Hydrogen Peroxide – 1<sup>st</sup> Day
  - Desorption + Oxidation
- ▶ ERD – Inject Outside In
  - Sodium Lactate
  - Small micron ZVI
  - Bioaugmentation
- ▶ Injections early 2018



## The Kitchen Sink

- ▶ 2 discrete areas inside a building – 25 feet apart
- ▶ Toluene & TPH
  1. Excavation
  2. Oxygen Release Compound + Horizontal Wells in hole
  3. Sodium Persulfate Injections
- ▶ CVOC (1,1-DCE)
  1. ZVI/carbon + Sodium Lactate
  2. Bioaugmentation
  3. Chase water/buffer injection
  4. 2<sup>nd</sup> Bioaugmentation
  5. 3 Permanganate Injections



**Achieved Site Criteria in  
Both Areas**

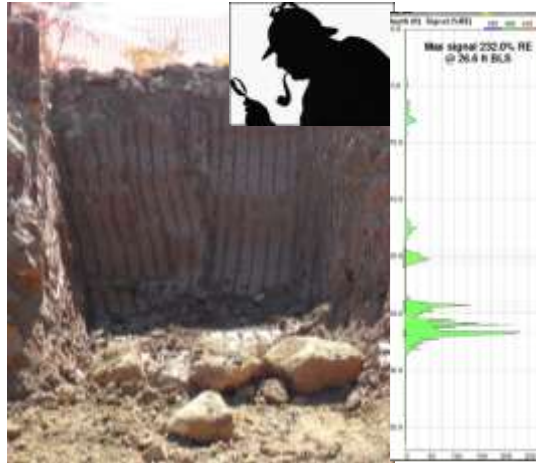
## Take Away

- ▶ Tag Team multiple processes
- ▶ Remediation team
- ▶ Choreograph Sequencing



## Take Away

- ▶ Conceptual Site Model
- ▶ Geology Matters!
- ▶ Be Attentive
- ▶ Focused Remediation



## Take Away Messages

- ▶ Use all your tools
- ▶ Flexibility
  - Technology selection, design, & implementation



## Universe of Possibilities

- ▶ Remediation goal: meet site objectives
- ▶ Process: the path to successfully achieving site objectives



Your Mission

**TO BOLDLY GO WHERE NO**



**REMEDICATION HAS GONE  
BEFORE**

memegenerator.net



Chemical Oxidation  
& Reduction



Bioremediation



Activated Carbon Injectates  
(BOS100® & BOS200®)



Soil Mixing  
(Chemical Reagents  
& Stabilization)



REMEDICATION  
TECHNOLOGIES



U.S. Small Business Administration  
**SBA**  
Your Small Business Resource



Gas Thermal  
Conductive Heating




Treatability  
Laboratory



**Zero OSHA Reportable Incidents in more  
than 20 years of Operations**

# Thank You

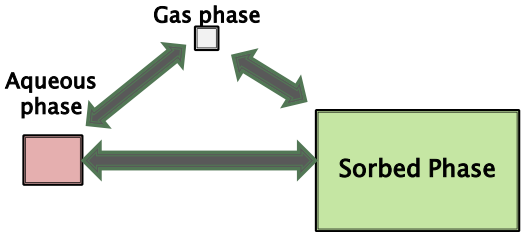
Paul M. Dombrowski, P.E. (MA, CT)  
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O: 617-902-9383 M: 917-971-2956



REMEDICATION  
TECHNOLOGIES

## Cut the Head off the Snake

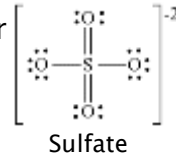
- Many technologies primarily act on a aqueous phase
- Achieving criteria requires mass reduction



Reality!

## Active Combined Remedy Planning

- ▶ Sequence technology implementation
  - Avoid adverse impact for potential following technologies
- ▶ Remedial byproducts: enhancement or inhibitor
- ▶ Contaminant Mobilization
- ▶ Be willing to apply non-traditional sequencing
- ▶ Know when to turn the adjust the knob



## Maximize Treatment Processes



- ▶ One tool cannot be used in all situations
- ▶ Utilize multiple processes to treat/remove
  - Identify synergies

