

Go With The Flow

Enhanced Anaerobic Biodegradation of a Refinery Benzene Groundwater Plume

Robert (Rory) S. Johnston, PE
Michael Eberle

SAWEA CONFERENCE
DECEMBER 2007

Presentation Outline

Go With The Flow

- Go With the Flow
 - Anaerobic Process Naturally Occurring
 - Compounds Degraded by Sulfate Reducing Bacteria (SRB)
 - Effective When Coupled with Mass Reduction
- Case Study-Enhanced Anaerobic Degradation by SRB
 - Large Refinery Site
 - Additional Applications for MTBE
 - Potential Applications - Remediating Dissolved Metal Plumes

SRB - Friends or Foes

Enhances the Attenuation of Hydrocarbon & Oxygenate Plumes

Inhibits the Attenuation of Halogenated Plumes

Refinery History

- 1913 – Refinery constructed
- 1987 – Original Owner sells refinery
- 1988 – New Owner files for bankruptcy, refining ceases
- 1989 – In the interim, another Operator leases facility, starts jet fuel production
- 1991 – New Owner buys refinery out of Bankruptcy Court, crude refining restarts
- 1993 – Owner stops refining, lays off most workforce
- 1996 – Owner uses facility for bulk storage and distribution
- 1997 – Interim remediation started using Dual Phase Extraction (DPE)
- 1997 – Regulatory Agency issues Owner an AOC under Section 7003 of RCRA
- 2004 – Regulator requests Owner to address impacts at offsite pipeline
- 2004 – New Consultant Retained-Develop Exit Strategy and Expedited Program
- 2005 – Interim Dual Phase Extraction (DPE) started at offsite pipeline
- 2005 – Design of Expedited Program
- 2006 – Bioventing (SVEB) and Sulfate Pilot testing started on Refinery
- 2007 – Full Scale SVEB initiated at refinery-second Pilot test on sulfate conducted

Site



Major AOCs and Contaminants

- Central Plant Area (AOC -2) – BTEX, LNAPL, MTBE & As
- Bluff Area – 2 landfills reported to contain listed waste
- Offsite Area – Benzene & MTBE
- Pipeline Area – LNAPL and BTEX

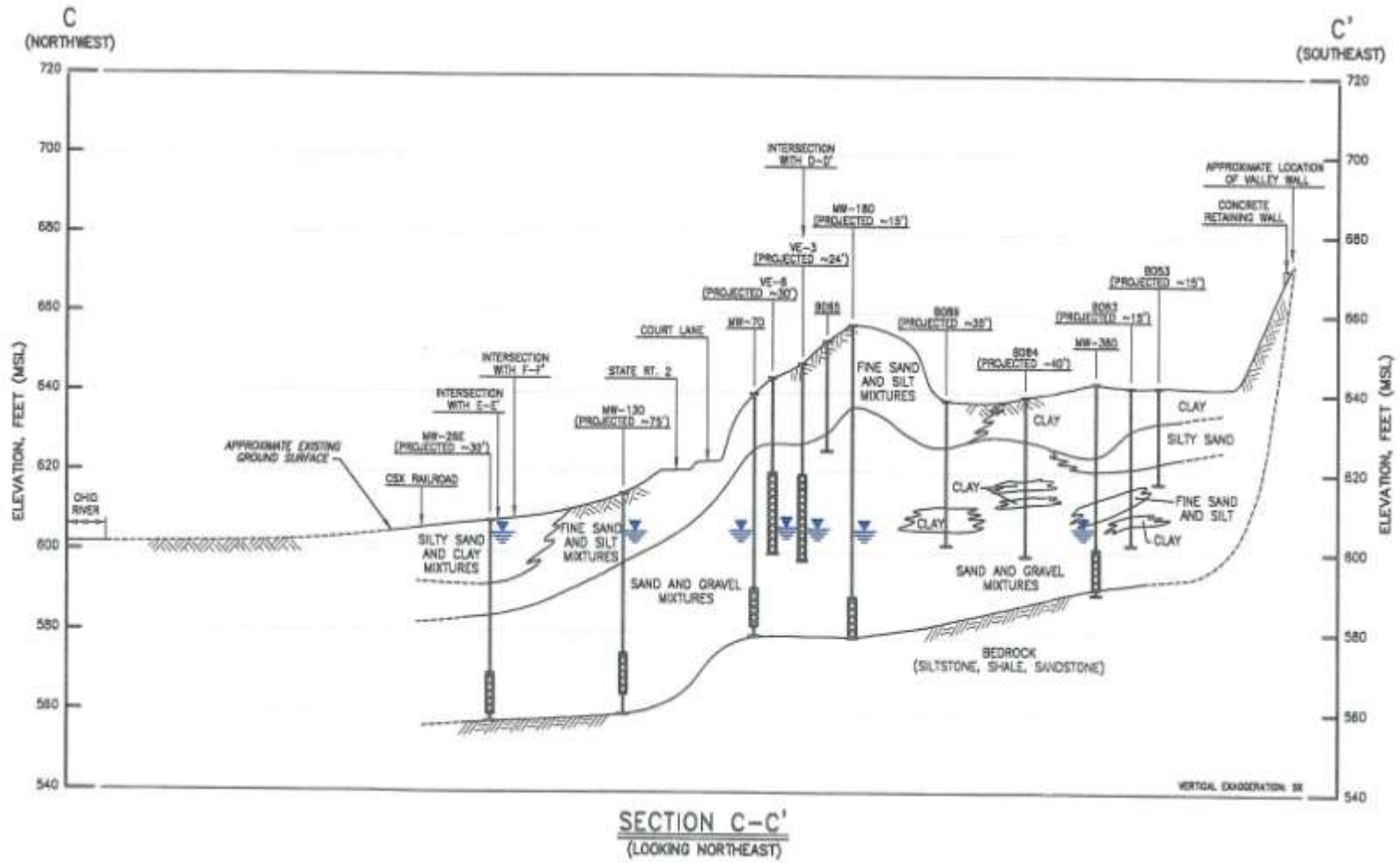
Refinery Operations Impacts

- **Source of impacts:** refinery processes including sewers, piping, storage tanks, and process units
- **Impacted soils:** confined within the central refinery and pipeline areas
- **Groundwater flow:** impacted groundwater extends approximately 300 feet to the west and is confined within a narrow region due to the natural groundwater gradient and natural attenuation processes
- However past groundwater flow influenced by town water wells to the north

General Site Conditions

- GW flow direction is towards Ohio River
- Three layers of groundwater flow – shallow (low permeability), intermediate and deep (most permeable)-Delineation issues near Ohio River
- Offsite groundwater impacts in deeper layers
- Onsite groundwater impacts in all three layers
- Onsite soil impacts – shallow and deep
- Pipeline and Barge area – groundwater and shallow soil impacts associated with pipeline releases

Cross Section C-C'



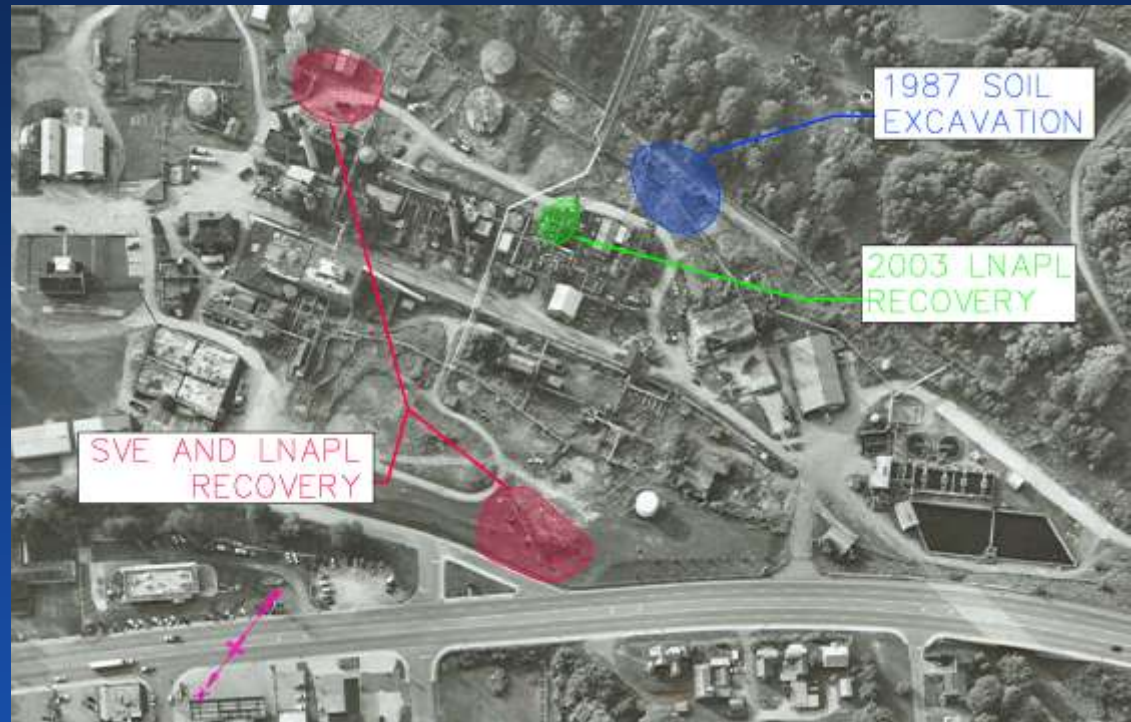
Initial Remedial Actions 1987-2004

- **Impacted Soils Removed**

- 1987 Almost 1 million pounds (470 tons) of petroleum impacted soils removed

- **Known Light Non-Aqueous Phase Liquid (LNAPL) Removed**

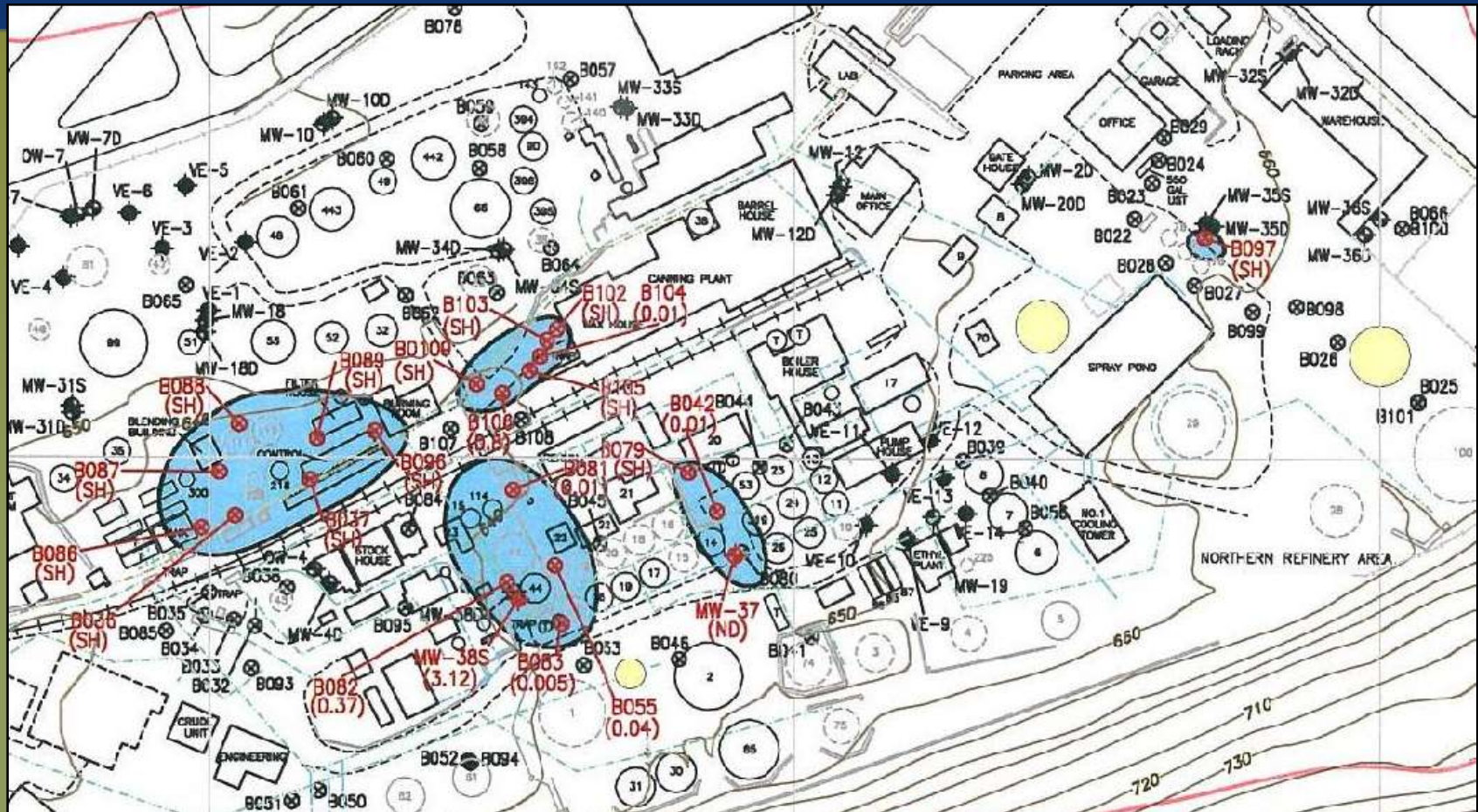
- 1993 - 1994: Approximately 36,000 gallons of total fluids recovered
- 1995 - 2003: More than 1,800 gallons of oil recovered
- **Satisfied Agency remediation requirements**



- **Localized Soil Vapor Extraction (SVE) operations**

- 1996 - 2004: Approximately 480,000 pounds of hydrocarbons removed from soil
- Approximately 2 times as much (960,000 lbs.) estimated to have been degraded by naturally occurring microorganisms at the site
- **Benzene Groundwater Concentration Reduced by 99% in these zones**
- **Satisfied Agency remediation requirements**

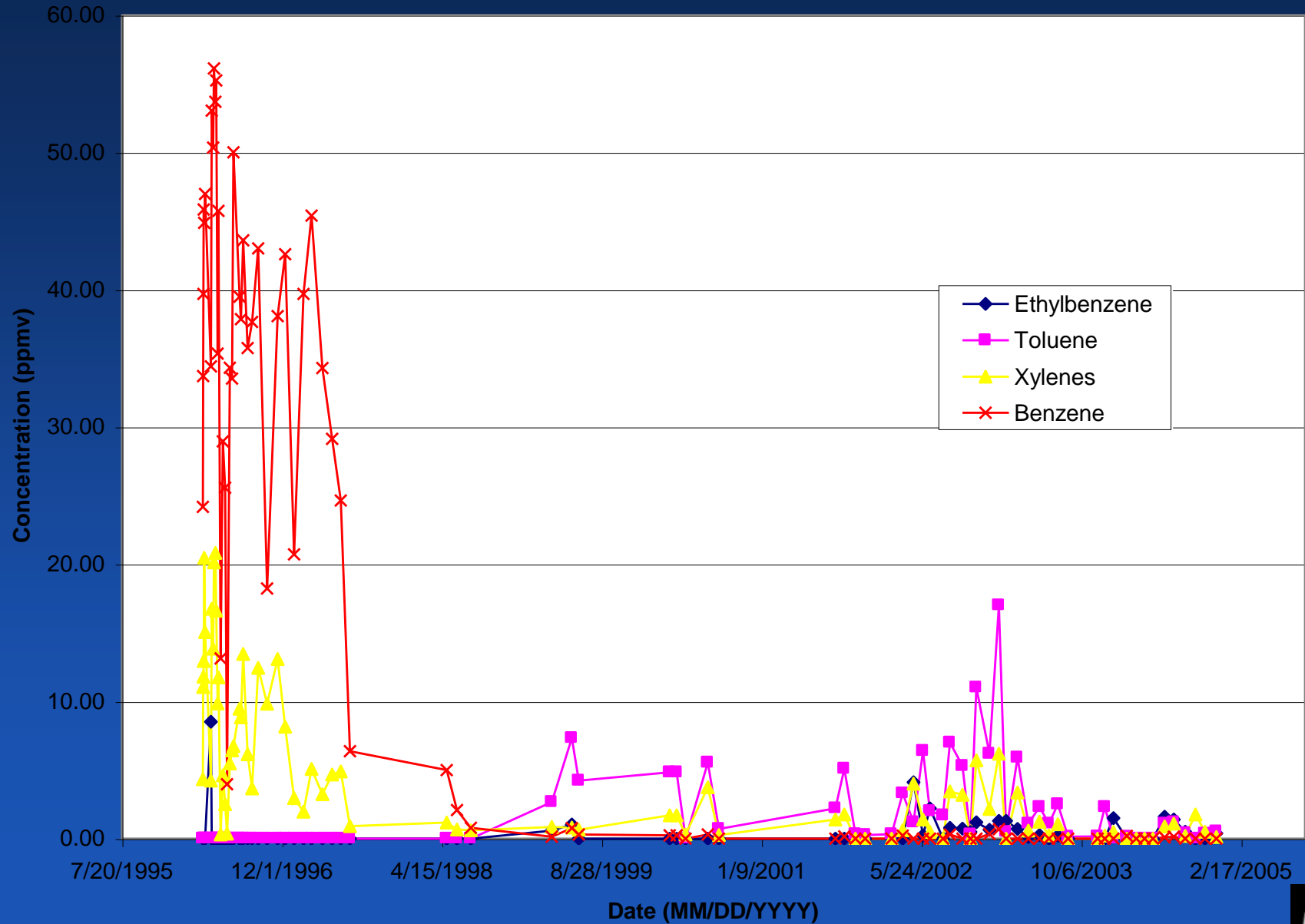
AOC 2 Residual Source Areas



Observations of SVE System

- Operating for 6-8 years
- No Optimization
- Influent Streams flat
- Need new approach for Residual Hydrocarbon Removal
- Must also deal with Offsite Plume

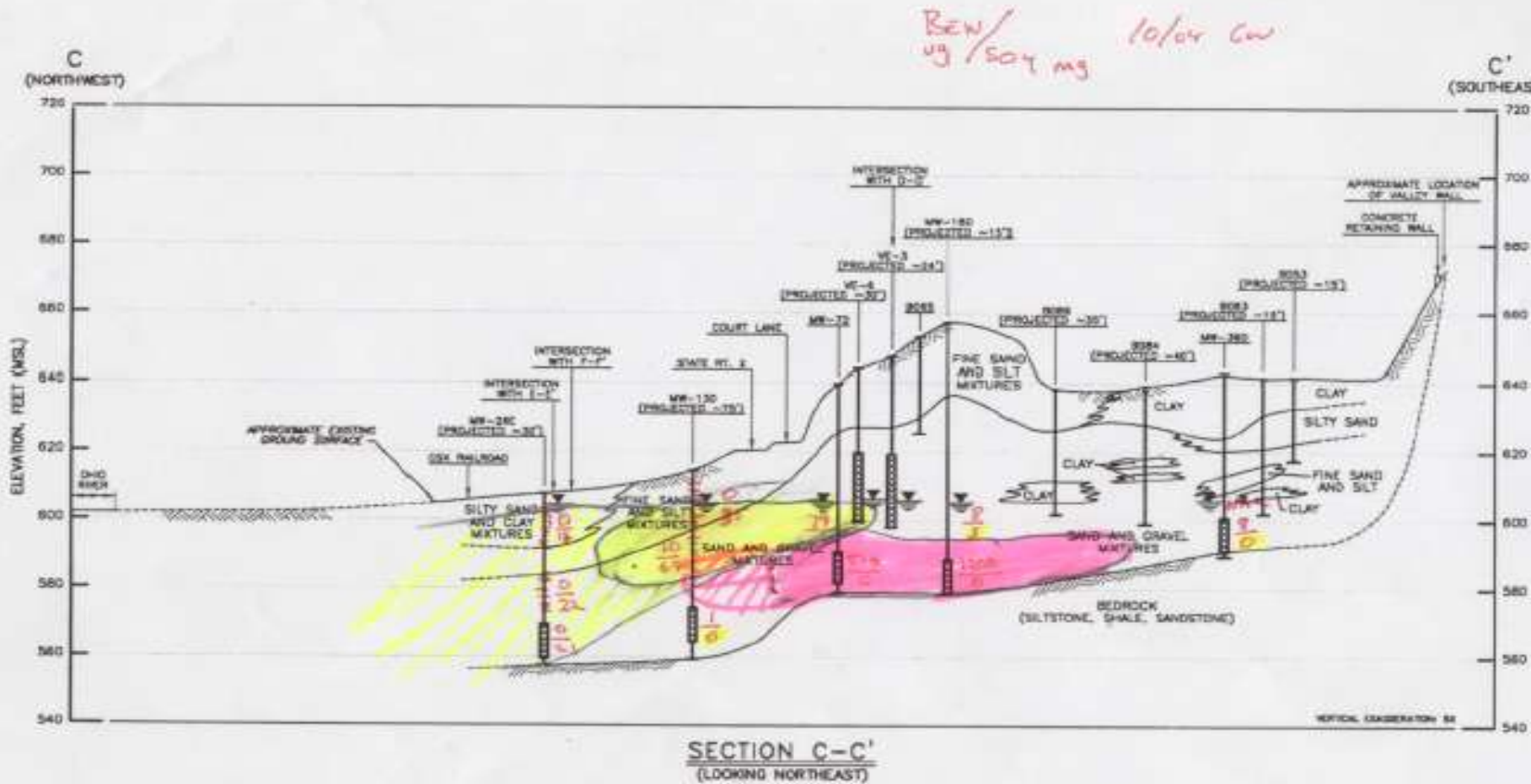
OW-7/MW-18 Area, BETX Concentrations vs. Time



Initial Evaluation

- Turn Off SVE System
- Evaluate Groundwater
- Evaluate Large Scale (Full Refinery) Bioventing
- Understand Complex Geology through Gamma Logging of Extractions Wells


Section C-C'

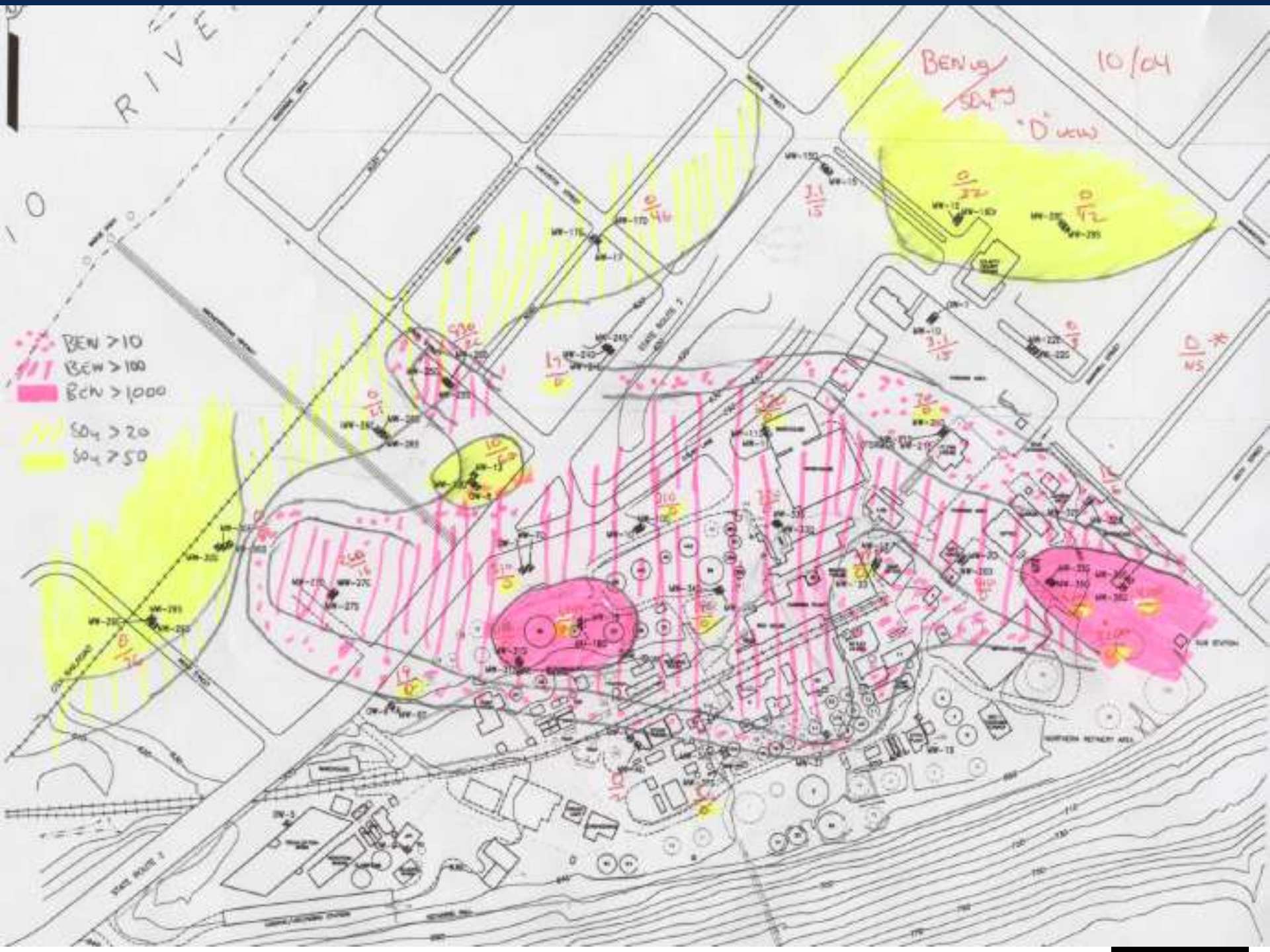


- BGV > 100 ug/l
 - SO₄ > 25 mg/l
 - SO₄ > 10 mg/l
- 1111 BGV > 10

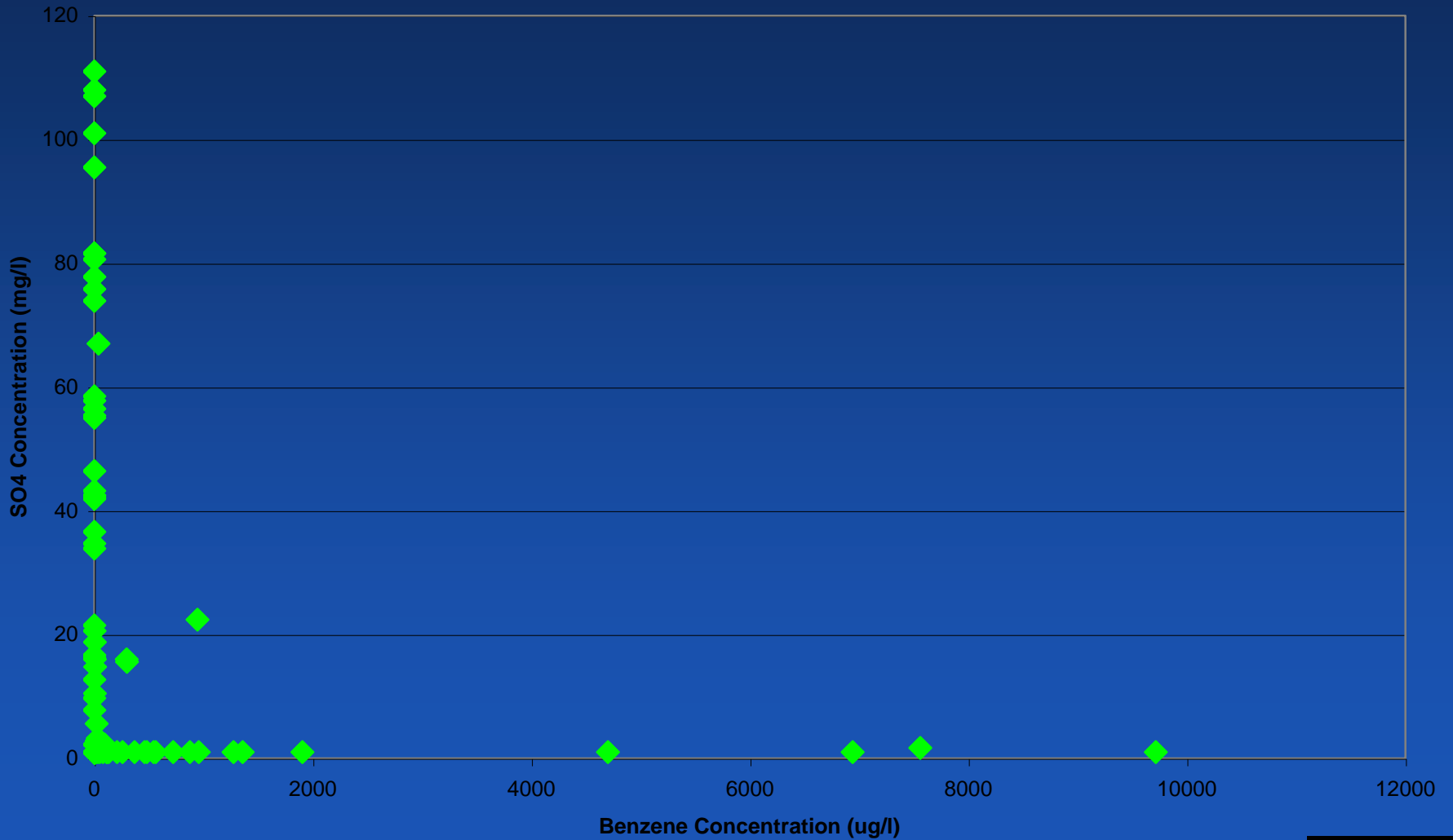
RIVER

BENUG
SATS
10/04
D'ucw

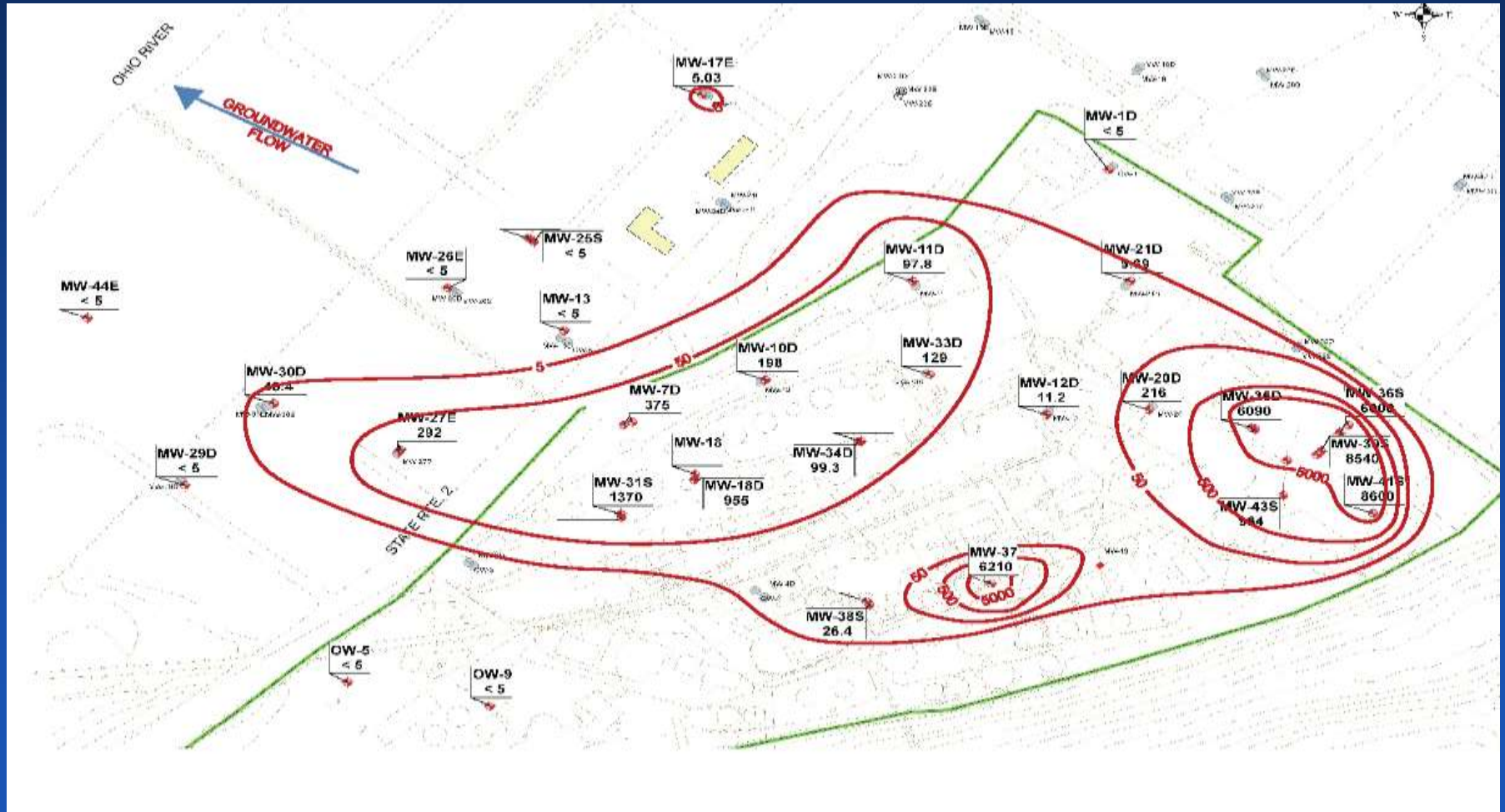
-  BEN > 10
-  BEN > 100
-  BEN > 1000
-  SO₄ > 20
-  SO₄ > 50



Site-Wide Groundwater Results BETX vs. SO4 October 2004

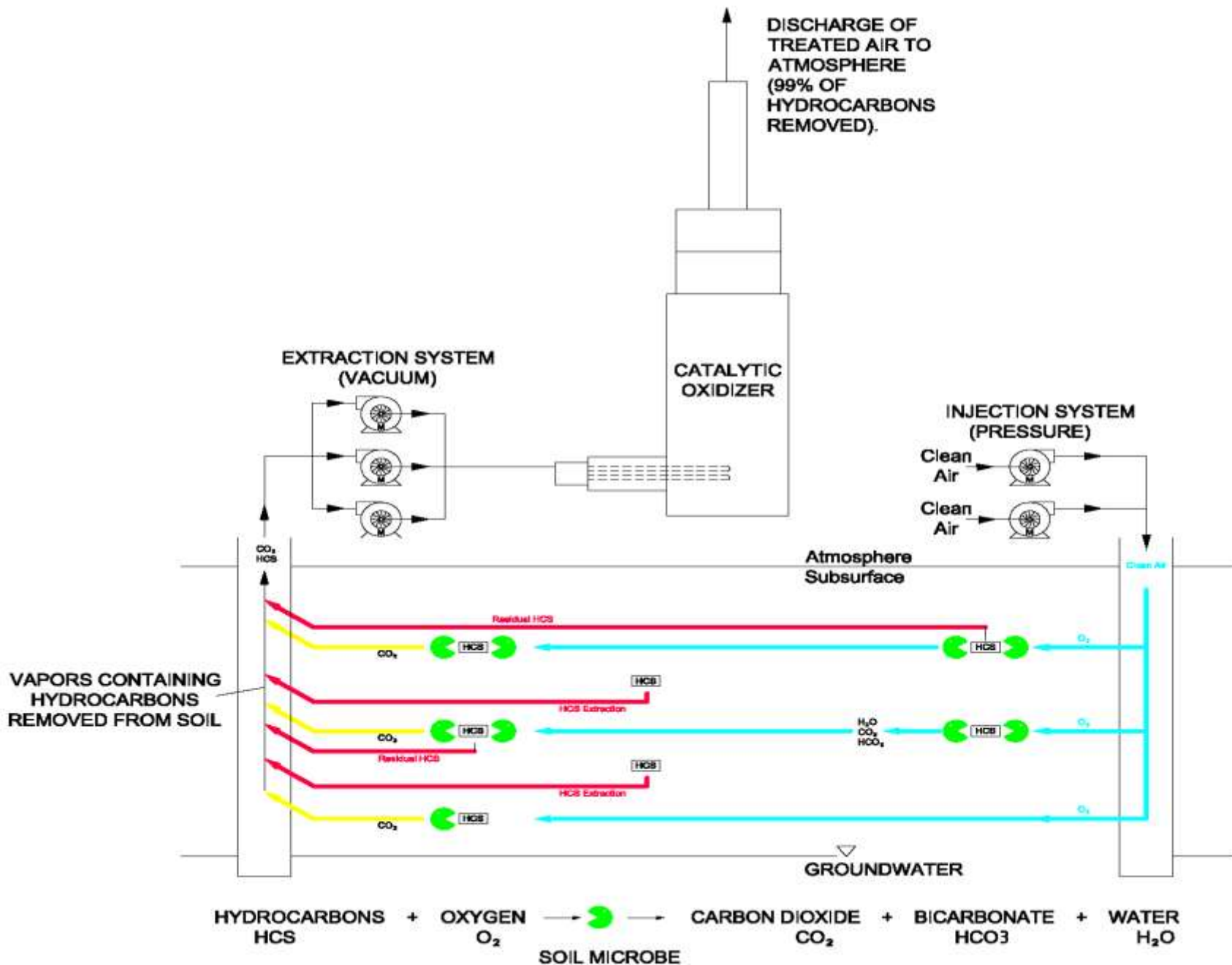


Benzene Plume Map

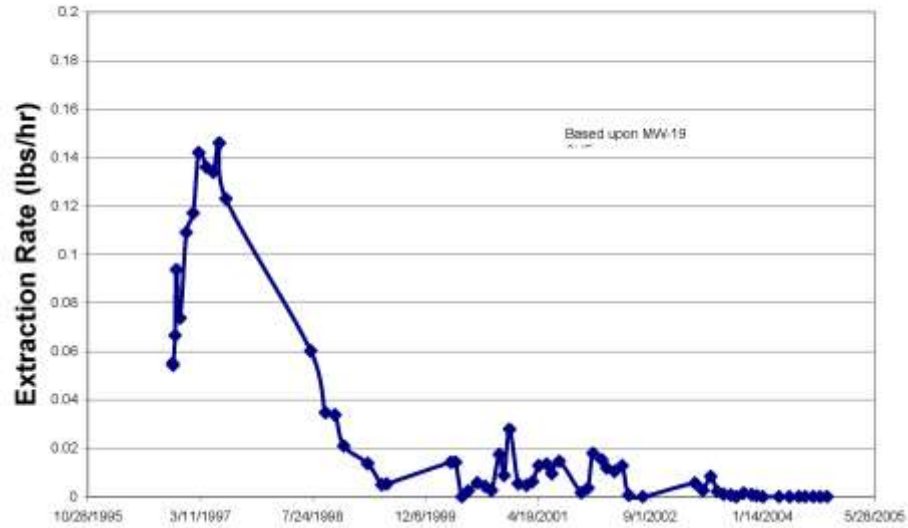


Refinery Remediation Strategy

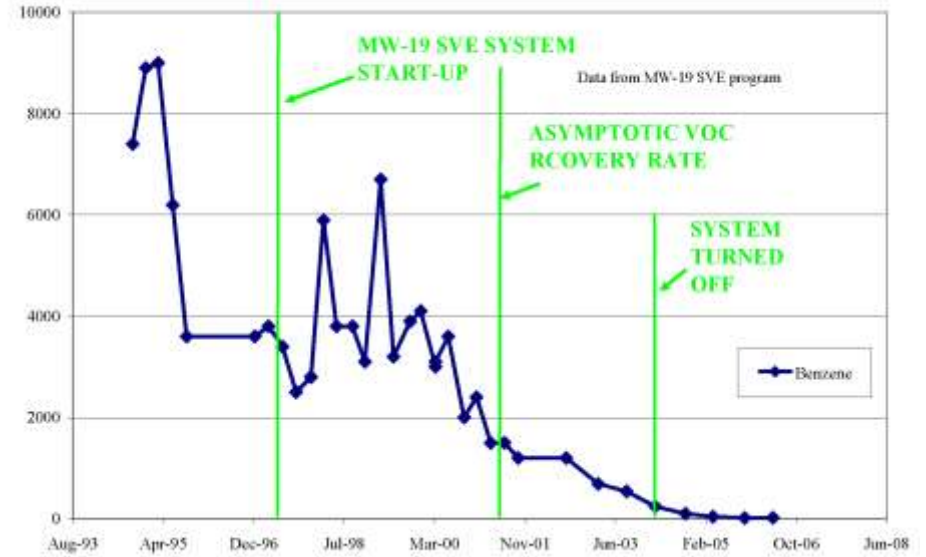
- Remove hydrocarbons from soil
- Remediate residual LNAPL pockets (Dual Phase/SVE)
- Biodegrade hydrocarbons dissolved in groundwater
- Selected Technologies:
 - **Soil Vapor Extraction /Bio-venting (SVEB)**
 - **Sulfate Addition**
- Satisfy environmental obligations



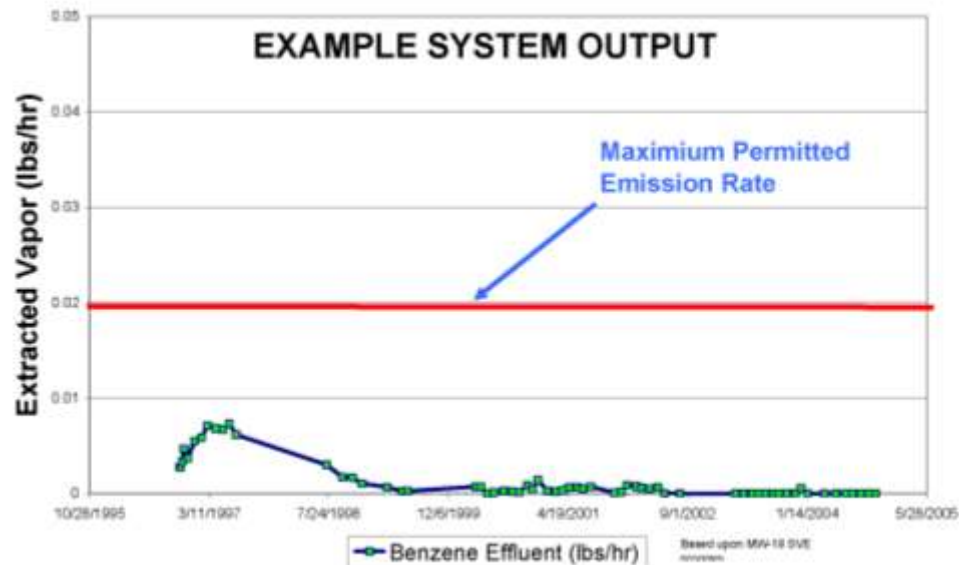
Example Extraction Rate



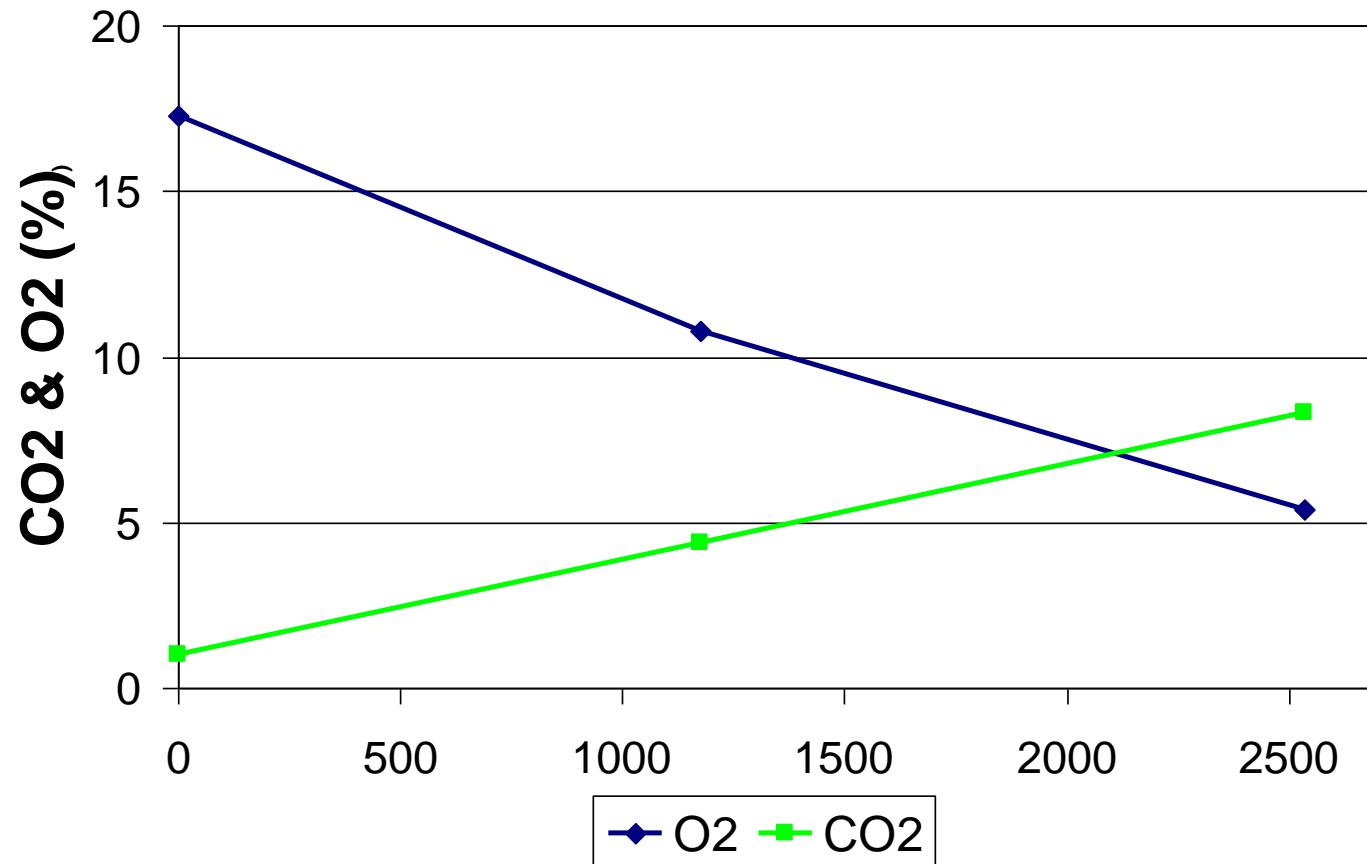
EXAMPLE GROUNDWATER RESPONSE



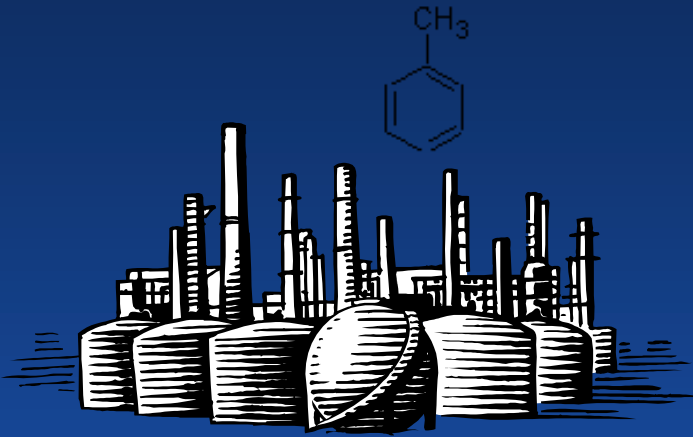
EXAMPLE SYSTEM OUTPUT



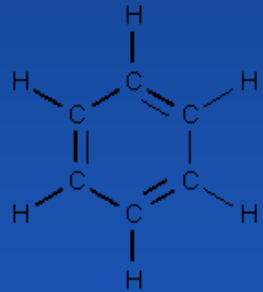
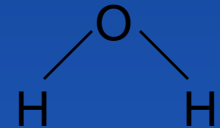
Microbial Respiration /Activity



Reaction Inside Catalytic Oxidizer



Catalytic Oxidizer



Preparation for Next Phase of Refinery Remediation

- Installed 71 Monitoring Wells, and 106 Geo-probes
- Collected and analyzed approximately 1,500 groundwater and more than 500 soil samples
- Successful bio-venting pilot test
- Conducted feasibility studies of piping routing
- Evaluated feasibility of Sulfate Injections

SVEB Construction

- Well Installation Completed
 - 110 Extraction Wells Installed
- Injection/extraction lines
 - Completed December 2006
 - 2 Miles of Piping Installed
- Equipment Installation
 - Completed December 2006
- System Startup
 - Completed February/March 2007
- Full Operations
 - March 2007

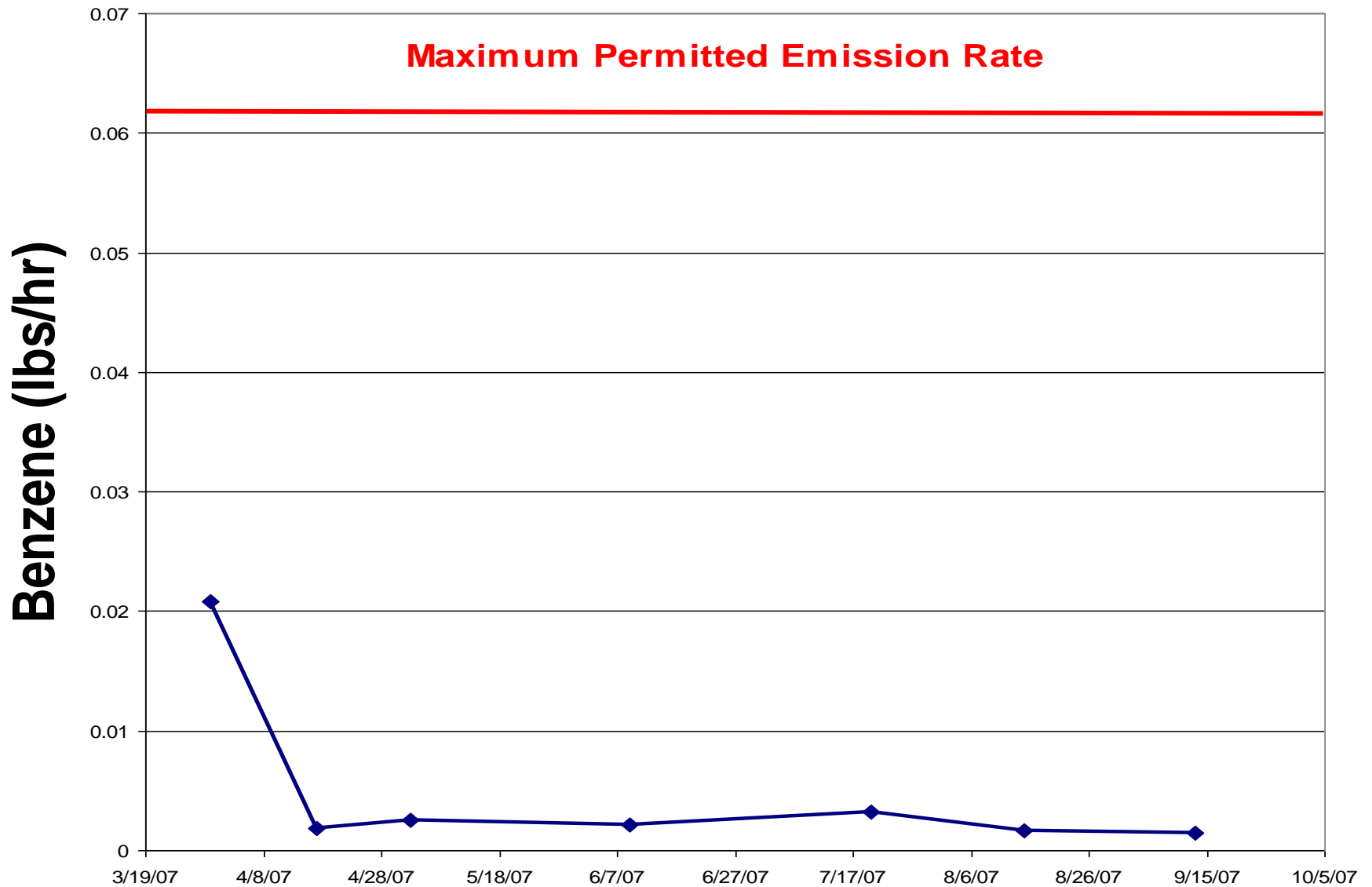


Overview of SVEB Piping Layout





SVEB System Output



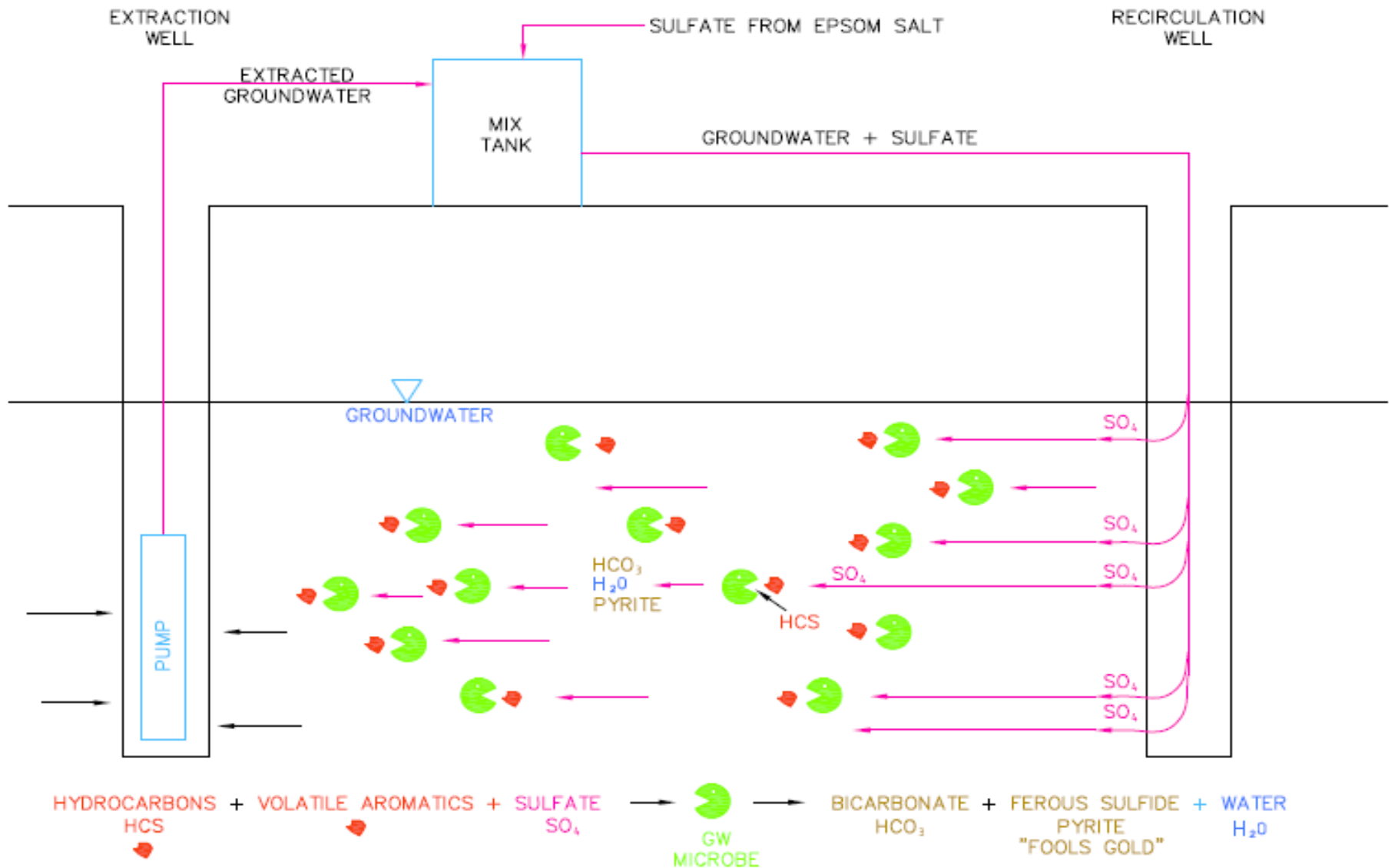
Radius of Influence from SVEB



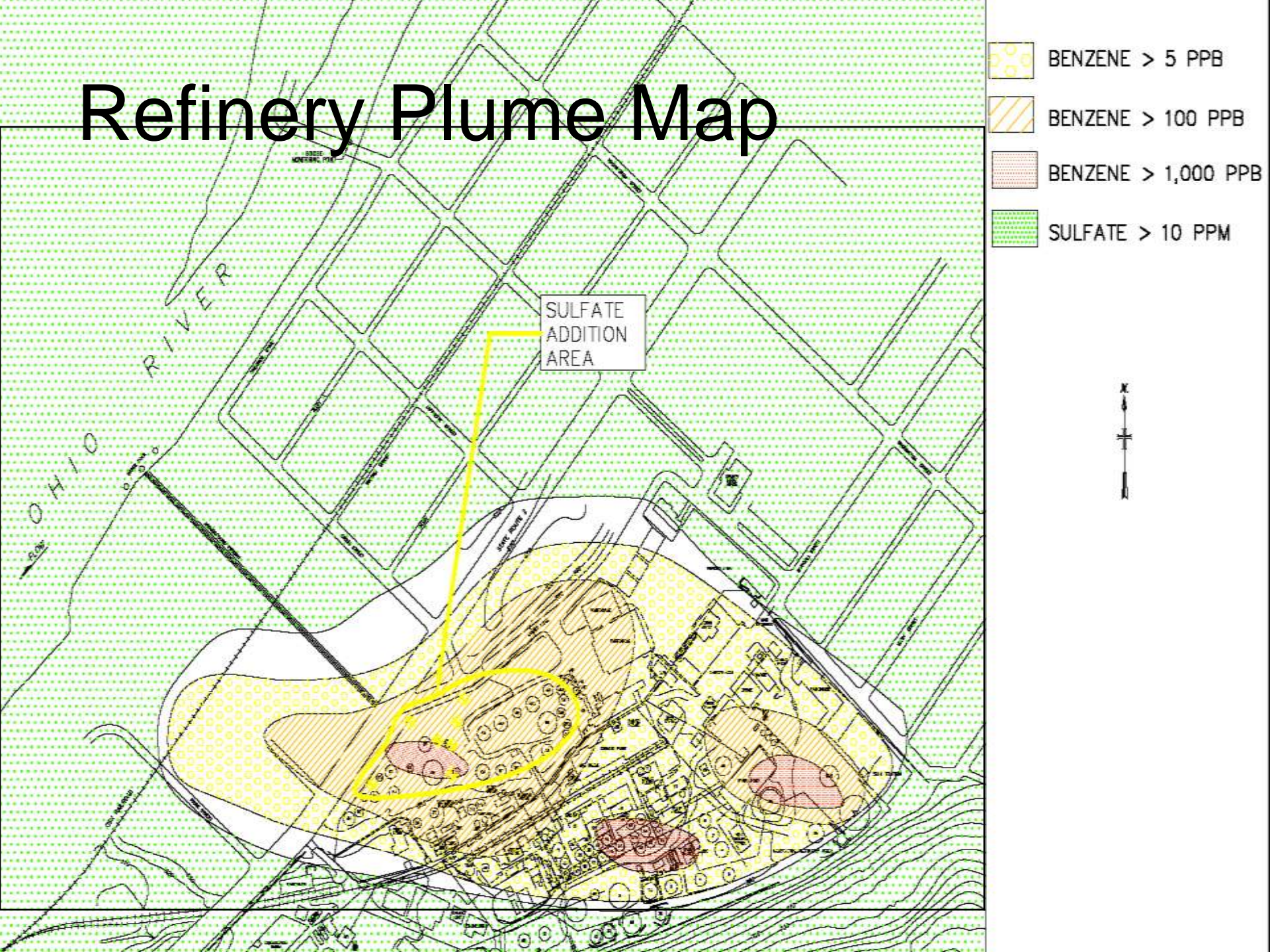
SVEB Remedial Progress





- Residual Source is approximately 50% Remediated
- Greater than 95% operational time
- Actual Area Influenced 3x Further and Projected Vacuum is 10x Higher than Design Estimate
- Identified and Recovered Natural Gas from a Gas Leak discovered near Washington and 6th Streets
- Estimated Completion Date Summer 2008
- System will be Converted to a Barometric Pumping Bioventing System

SULFATE ADDITION



Refinery Plume Map



-  BENZENE > 5 PPB
-  BENZENE > 100 PPB
-  BENZENE > 1,000 PPB
-  SULFATE > 10 PPM

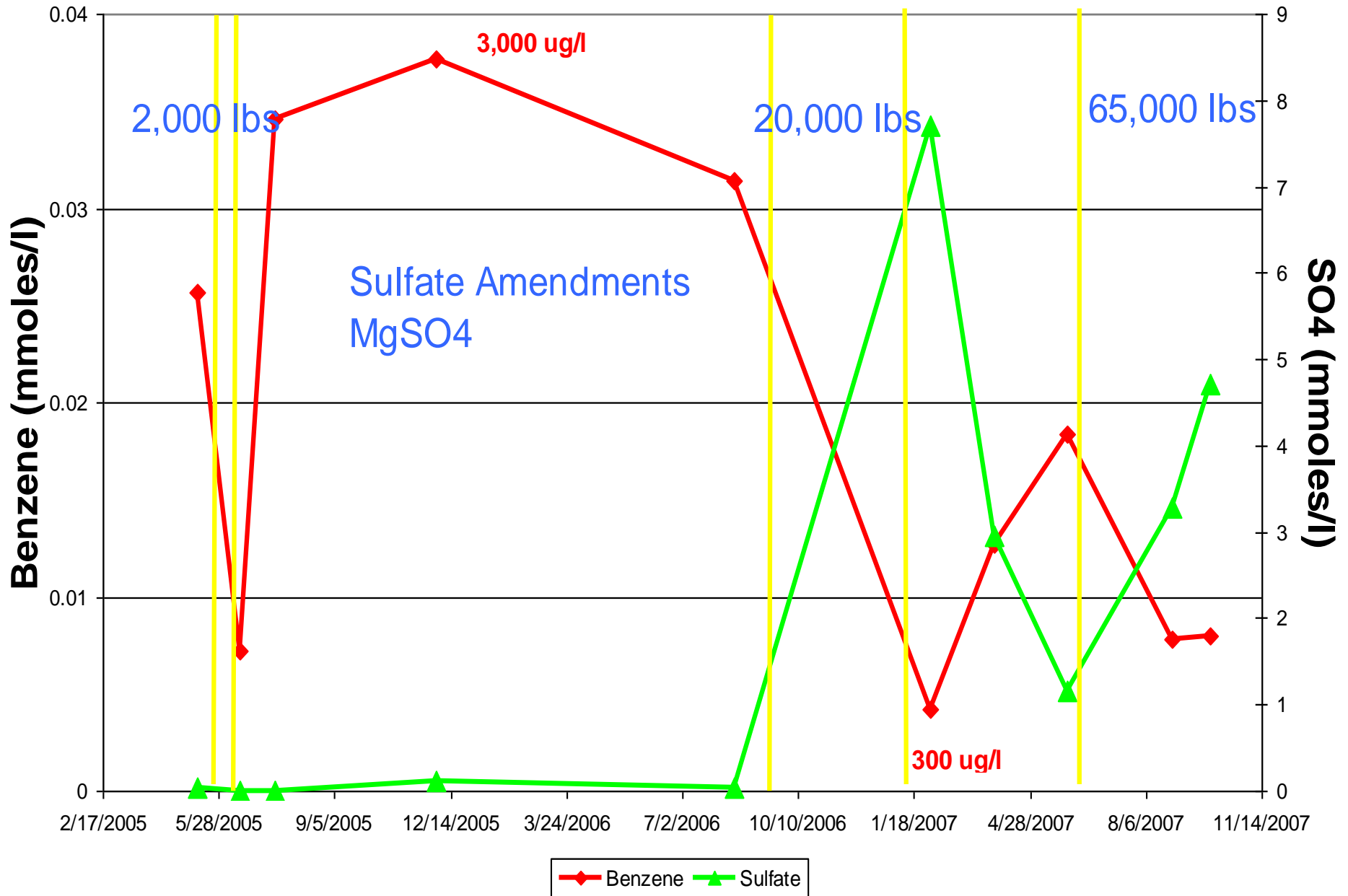
SULFATE
ADDITION
AREA



Phase II Preliminary Results

- 4 Million Gallons of Water Recirculated
- 65,000 lbs of MgSO₄
- Approximately 70% of the SO₄ was Utilized
- 75% of the Plume Width is being Remediated
- 70% Reduction in Benzene Conc.

EAB Pilot I and II - Progress Monitoring



Sulfate Amendment Schedule

- Phase I permits received - May 2005
- Phase I pilot test completed - September 2005
- Additional system components installed/permits received - September 2006
- Phase II testing initiated - October 2006
 - System Expanded May 2007
 - Phase II testing will be completed December 2007
- Full-Scale Installation and Operation
 - Spring 2008

Summary of Combined Remedial Approaches with Sulfate Injections 2004 – October 2007

- Completed Phase I and Initiated Phase II of Sulfate Addition Pilot Tests
- Designed and Installed Full-Scale SVE/Bioventing System
- Operated Full-Scale SVE/Bioventing System for 8 months
- Completed Remediation of POTW Source Area

SRB- Friends or Foes?

- Enhances the Attenuation of Hydrocarbon & Oxygenate Plumes
 - Reliable Technology if Naturally Occurring Conditions are Appropriate
 - Maybe Limited by Nutrient and Co-substrate Availability
- Inhibits the Attenuation of Halogenated Plumes
 - SRB Out-Compete Dehalogenators for Limited Nutrients
 - Sulfate is an Electron Acceptor and Must Be Reduced Prior to Reducing Halogenated Compounds