



Lowry Operable Unit 5

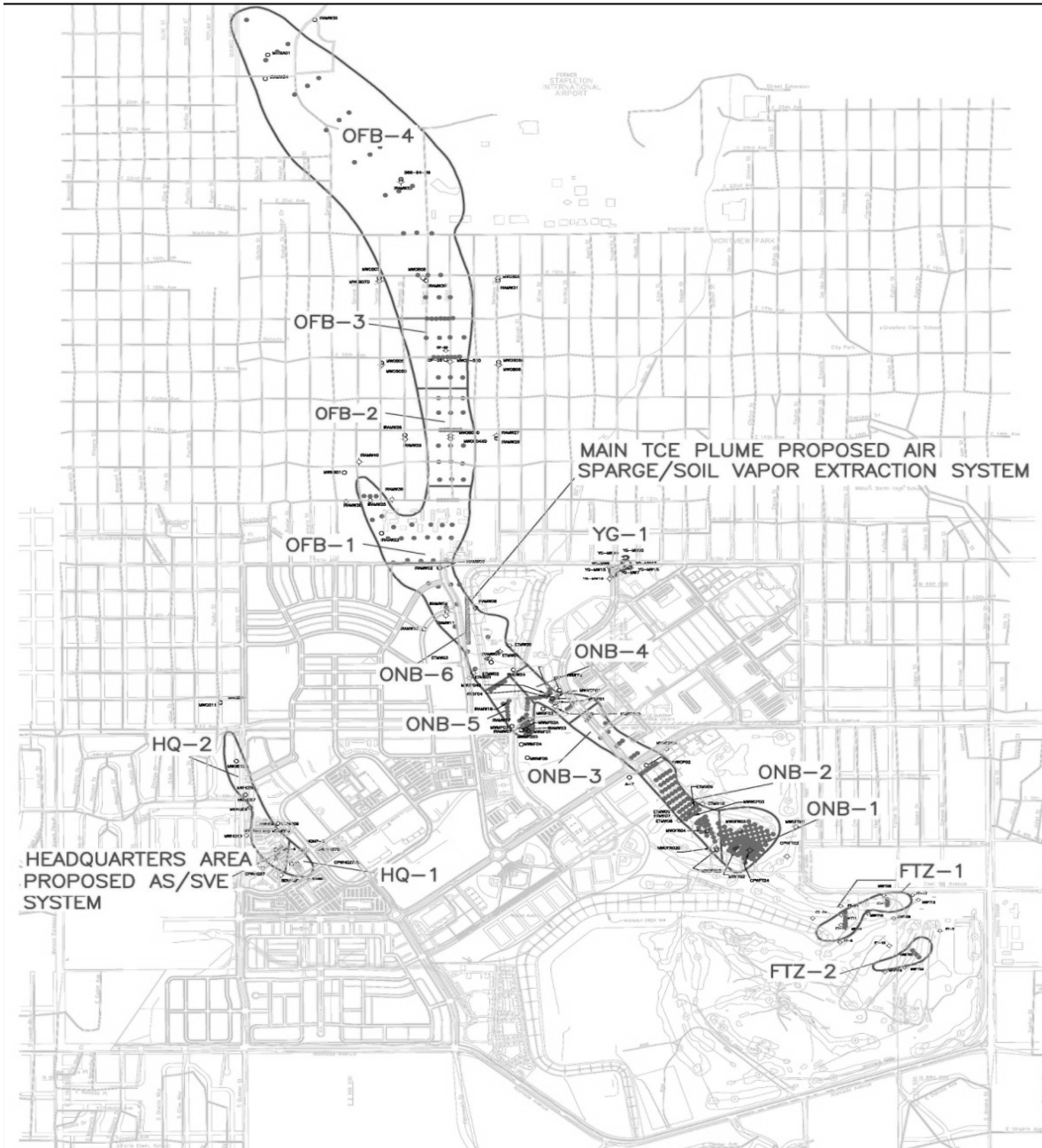
Remedial Progress Assessment

October 2010



Introduction

- Remedial Progress Assessment 2010
 - Focused on Main TCE Plume
- Detailed Assessment
 - Remedial Efforts
 - Historical Concentration
 - Plume Area Reduction
 - Mass Reduction
- Projected Outcome
- 2010 Scope of Work



Remediation Areas



Treatment Summary

- **Interim Remedial Actions 1996-2002**
 - BAHCS, SARS, PRB
 - Heritage Estates, 1235 Uinta St. Soil Gas Mitigations
 - Building 404 OWS Removal - HQ Source Area
 - Building1432 Tank Removal
- **Phase 1 CAP (Remedial Options Evaluation)**
 - **Technologies to Support Other Remedial Options**
 - No Action (baseline comparison) including continued OM&M of the BAHCS, ICs, monitored natural attenuation, and process monitoring
 - Institutional Controls (in conjunction with other technologies)
 - Monitored Natural Attenuation
 - Process Monitoring (in conjunction with other technologies)
 - Fracture Enhancement (augment other delivery technologies)



Treatment Summary, con't.

Phase 1 CAP Remedial Options Evaluation (Con't)

- **In-Situ Treatment**

- In-Situ Biological processes (aerobic co-metabolic, enhanced reductive dechlorination, nitrate enhancement, and phytoremediation)
- In-Situ Chemical Processes (Chemical Oxidation using Lasagna™, Fenton's Reagent, Potassium Permanganate, Sodium Persulfate, Ozone sparging, and Zero-valent Iron)
- In-Situ Physical Processes (Air Sparging, Steam Flushing, Steam Flushing/SVE, Air Sparging/SVE, in well vapor stripping, fracture enhancement)

- **Containment Technologies** (Vertical barrier, PRBs, BAHCS)

- **Nine Remedial Alternatives Retained (Phase II CAP)**

- NA, ICs, PM, FE, CO (Fenton's Reagent, KMnO_4 , Ozone sparging)



Treatment Summary, cont.

- Phase II CAP
 - Treatability Studies
 - Off-base
 - KMnO_4 (OFR and HQ Source Areas)
 - AS/SVE (USIB) used for KMnO_4 Injection
 - On-base
 - KMnO_4 (OFB-1 and OFB-2 Areas)
 - Ozone Sparge (ONB-2 and ONB-6)
 - Selected KMnO_4 Chemical Injection As Primary Treatment Technology
 - Density
 - Persistence
 - Distribution
 - Chemical Injection has been Performed Throughout the Main Plume
 - Direct Push Injections
 - Pressurized delivery of KMnO_4 Solution
 - Primary Emphasis on Source Areas



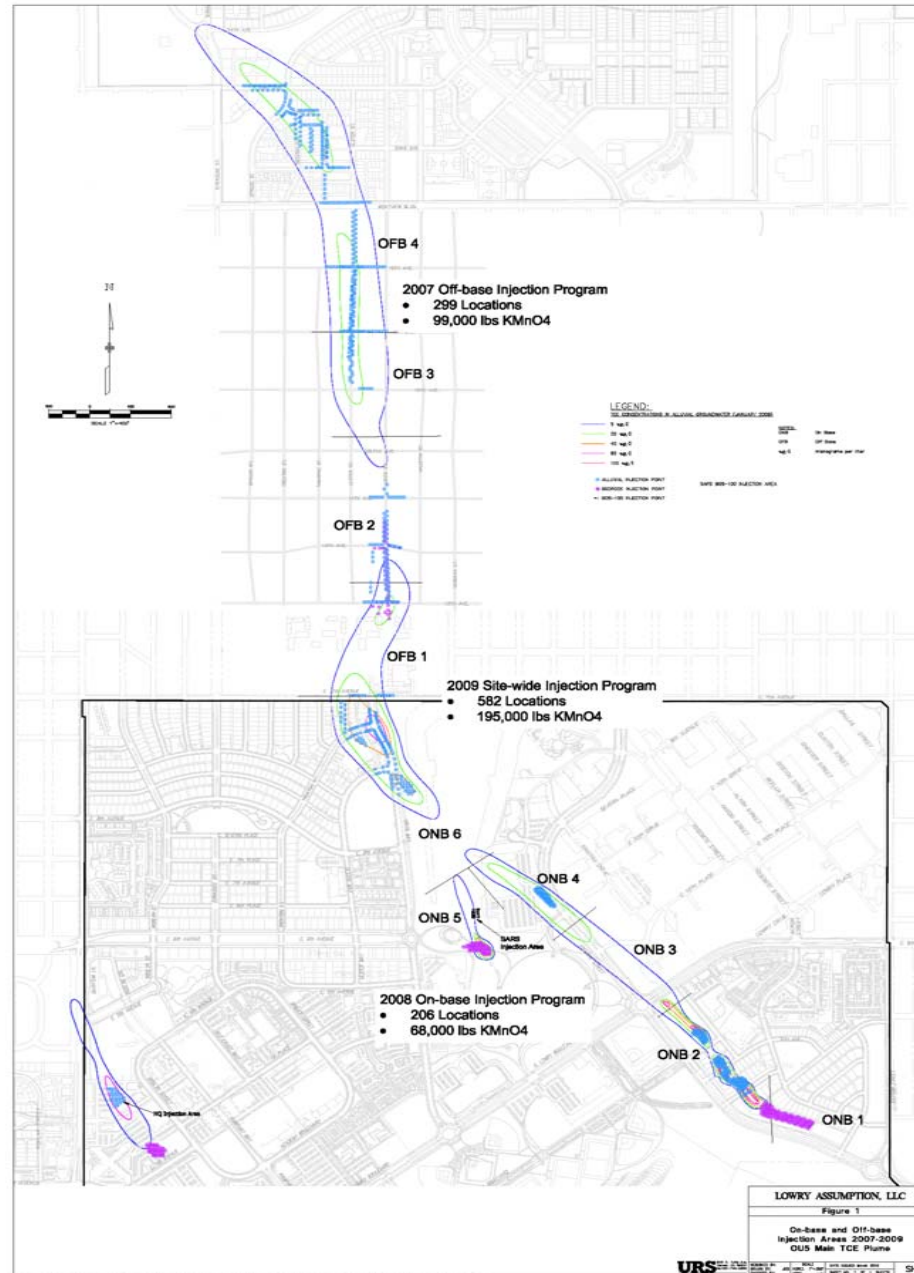
Treatment Summary, cont.

- Active Plume-Wide KMnO_4 Treatment 2004-2007
 - Phase I and Phase II KMnO_4 Injections (LAC and MACTEC)
 - October 2004, Site-wide, 404 Locations, 76,769 lbs KMnO_4
 - » Main Plume (On/Off-base), HQ Plume, FTZ Plumes, and SARS (see next figure)
 - August 2006, On-base, 366 Locations, 44,000 lbs KMnO_4
 - » Main Plume, HQ Plume, FTZ Plumes, and SARS
- Active Plume-Wide KMnO_4 Treatment 2007-2009
 - LAC KMnO_4 Injection Program 2007-2009
 - November 2007 Main Plume Off-base
 - 299 Location 99,000 lbs KMnO_4 (OFB-1, 2, 3, & 4)



Treatment Summary cont.

- April 2008 Main Plume On-base
 - » 200 Locations, 68,000 lbs KMnO_4 (ONB-2 and ONB-4)
- May-October 2009 Site-wide
 - » 582 Locations, 195,000 lbs KMnO_4 (Bedrock and Alluvium)
 - » Main Plume (ONB-1,5,& 6 and OFB-1,2,3 & 4)
 - » HQ Plume (HQ1 & HQ2)
- Phase II CAP Addendum (BOS-100)
 - CCl_4 Bench Scale Treatability Study SARS/CT (2007)
 - Evaluated BOS-100 In-situ Trap and Treat Technology for treatment of CT and TCE
 - CCl_4 Source Area Remediation In-situ BOS-100[®] (2008)
 - In-situ BOS-100[®] SARS (2009) treatment of TCE utilizing BOS-100[®]





Plume Evaluation

- Approximately 70-80 Wells sampled Semi-annually
- Large amount of Data (now in usable database)
- Trend Analysis
 - TCE Concentration Reductions
 - Plume Area Reduction
 - TCE Mass Reductions
- Remedial Success in most areas
 - Reduction in TCE concentrations up to 100% in some areas
- Distribution of KMnO₄ is limited by geologic constraints
 - Alluvial Silt/Clay and Bedrock
 - Access Limitations



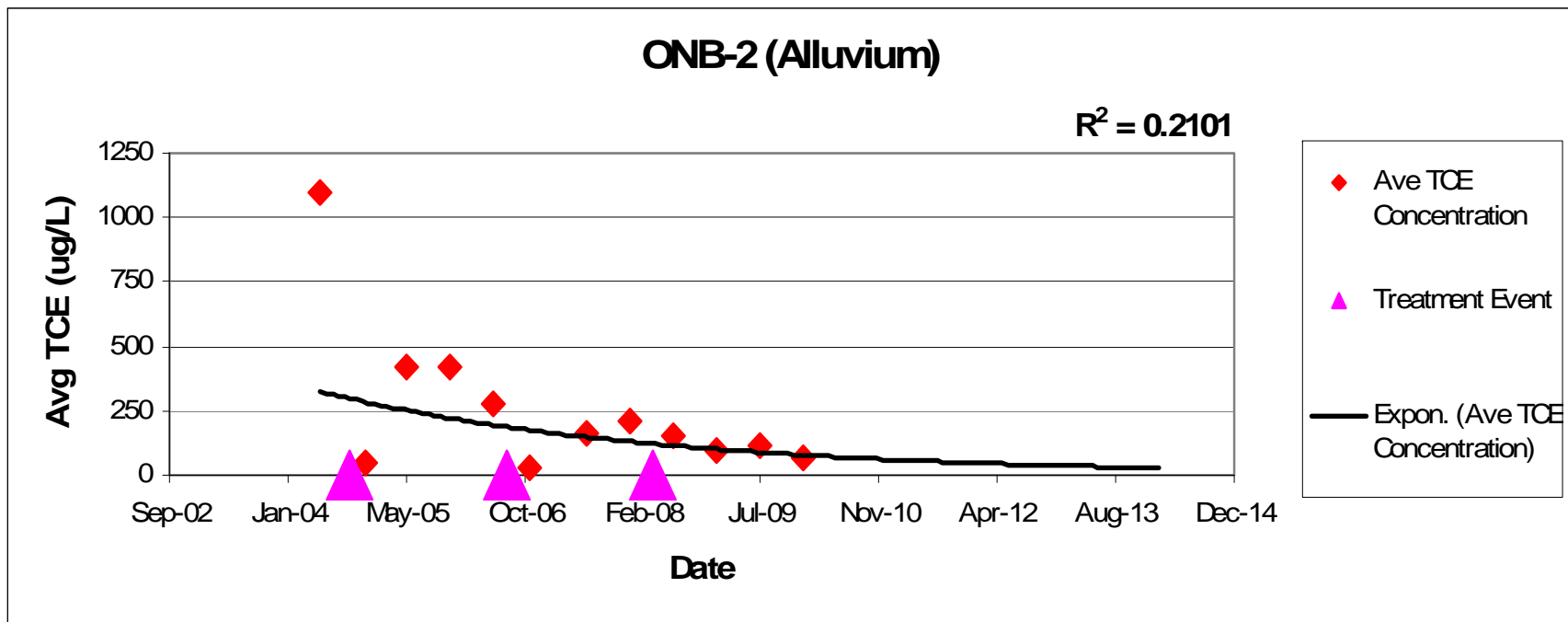
Plume Evaluation: Reduction in TCE Concentrations

- January 2010 GMP Sampling (79 wells)
 - On base: **Bedrock** - 21 wells monitored, 14 decreased
3 wells stayed neutral, and 4 wells increased
Alluvial - 32 wells monitored, 18 decreased,
11 wells increased, and 3 wells stayed neutral
 - Off base: **Bedrock** - 5 wells monitored, 4 decreased
1 well stayed neutral
Alluvial - 21 wells monitored, 9 decreased,
7 wells increased, and 5 wells stayed neutral
 - Plume wide 72 % of the wells sampled stayed the same or decreased in concentration while 28% of the wells increased in concentration
- Significant reduction in average alluvial TCE concentration for all remedial areas over time



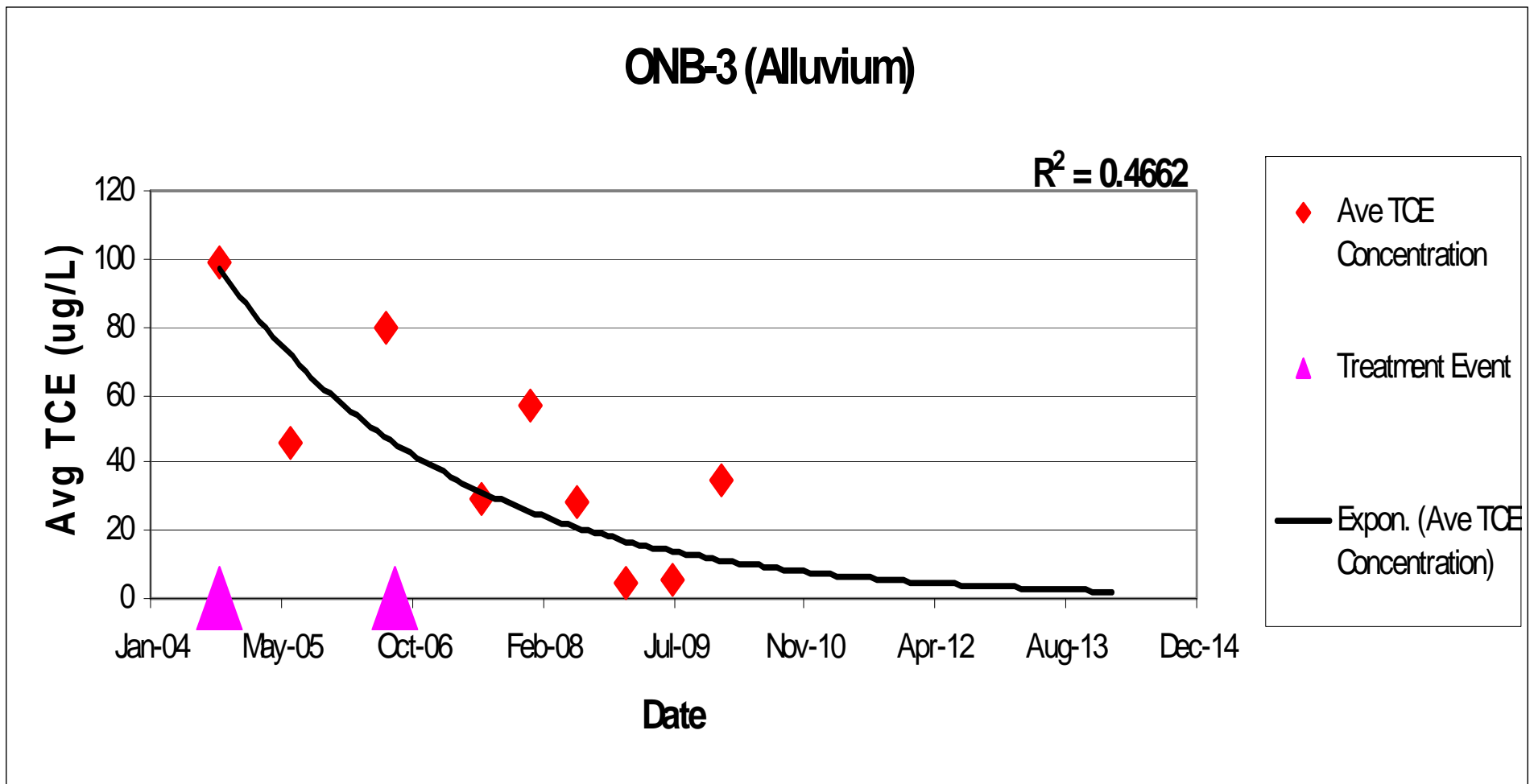
Average TCE Concentration Decline ONB-2

Note: Scale larger than other plots



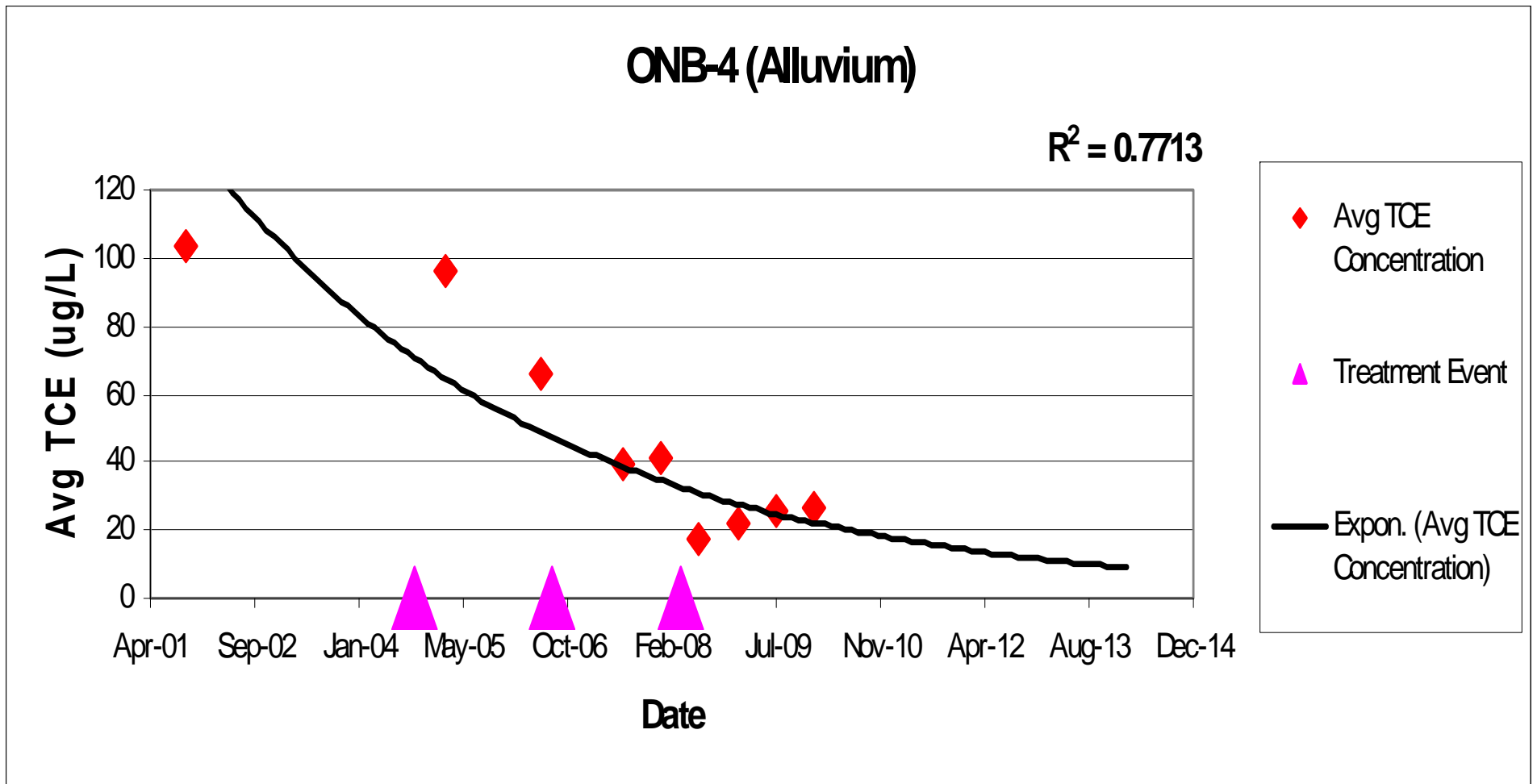


Average TCE Concentration Decline ONB-3





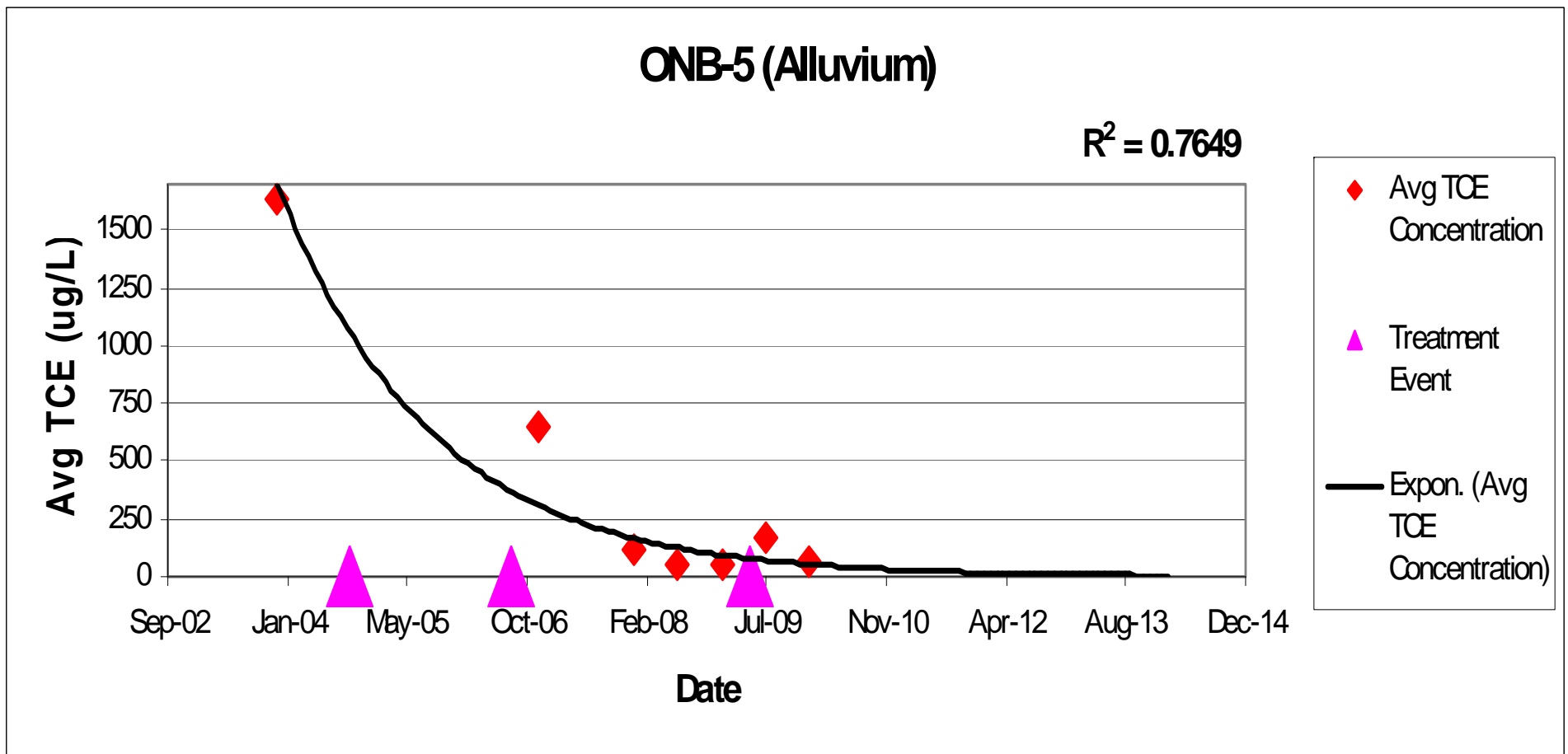
Average TCE Concentration Decline ONB-4





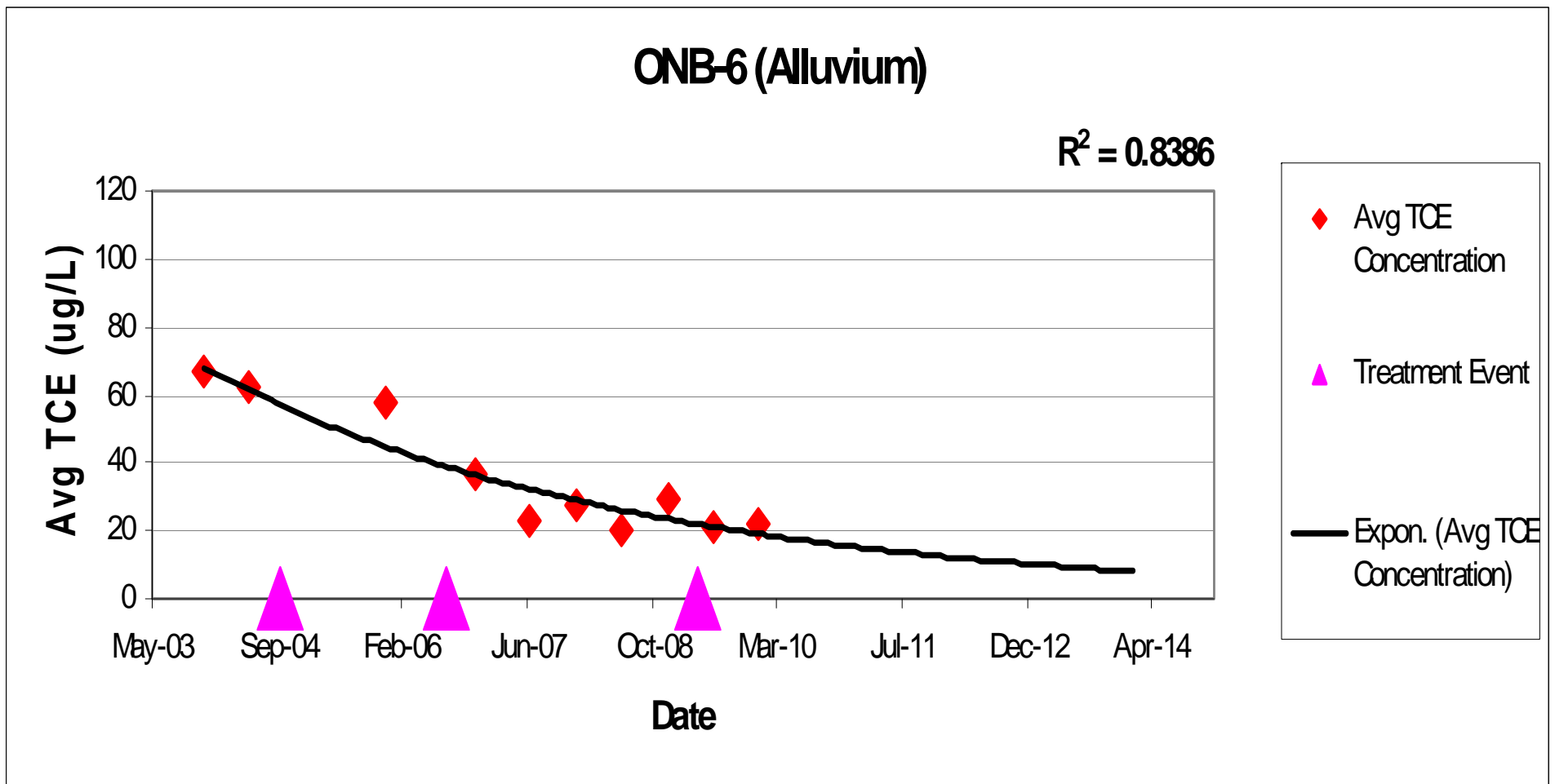
Average TCE Concentration Decline ONB-5

Note : scale larger than other plots



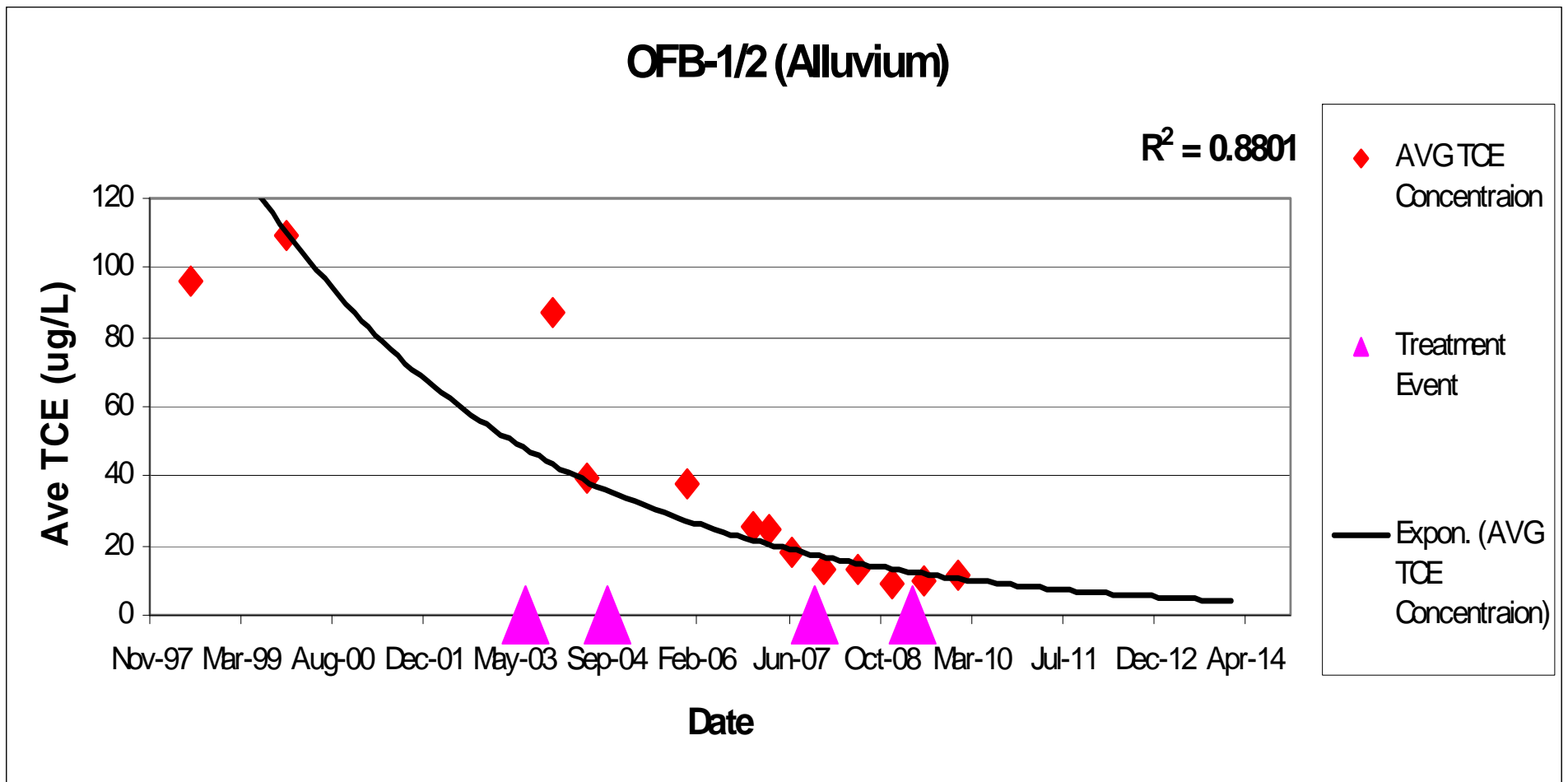


Average TCE Concentration Decline ONB-6





Average TCE Concentration Decline OFB-1/OFB-2

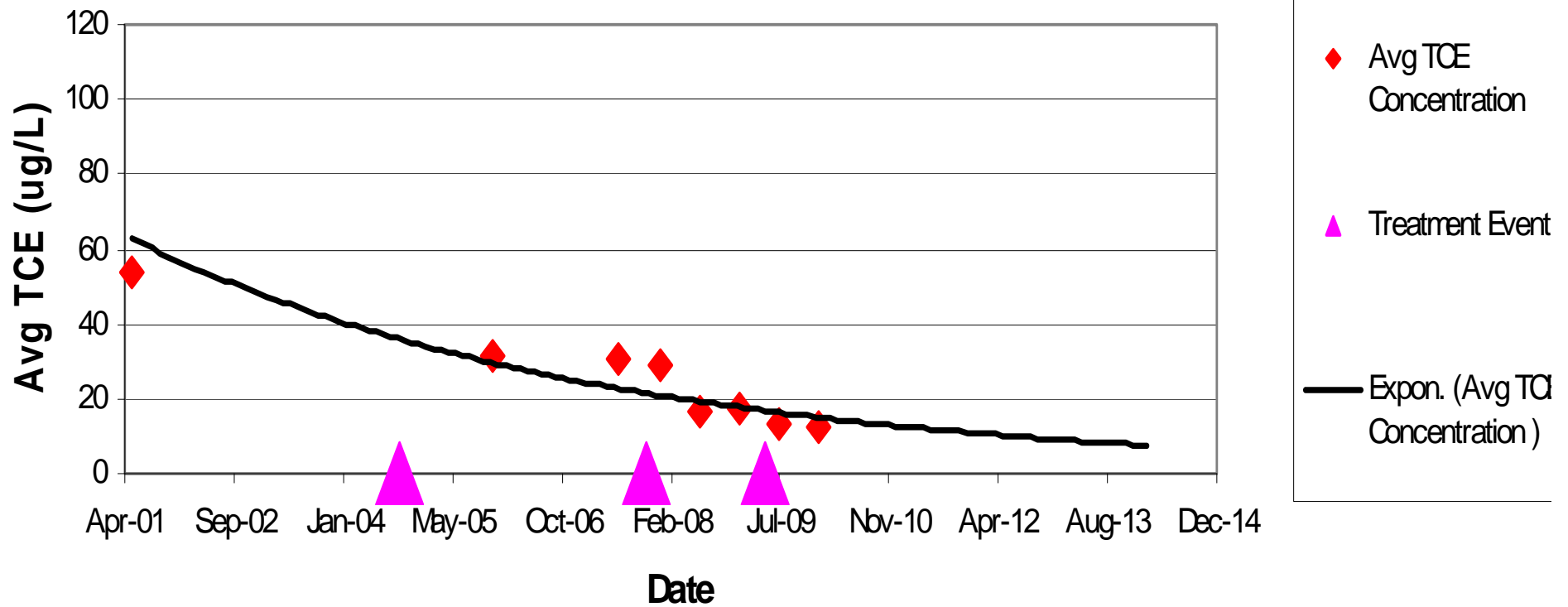




Average TCE Concentration Decline OFB-3/4

OFB-3/4 (Alluvium)

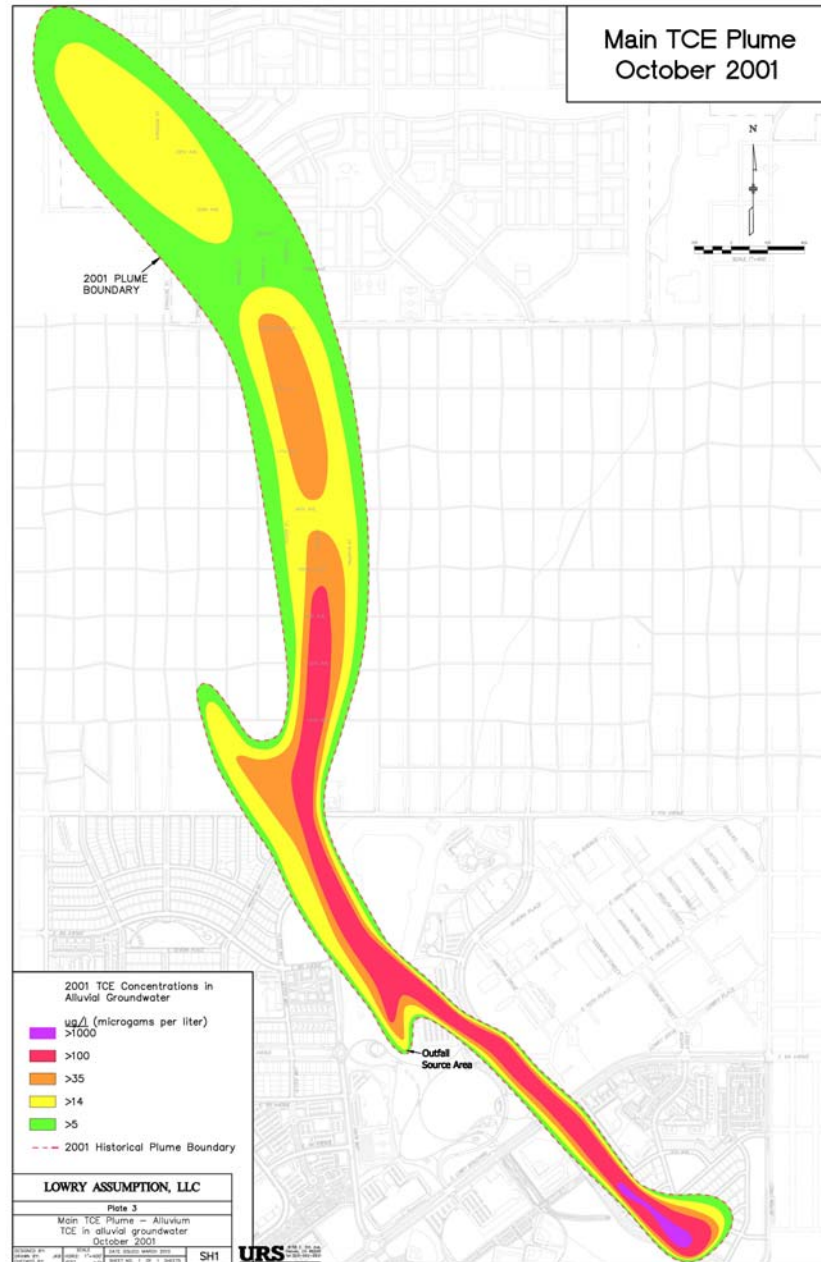
$R^2 = 0.8196$





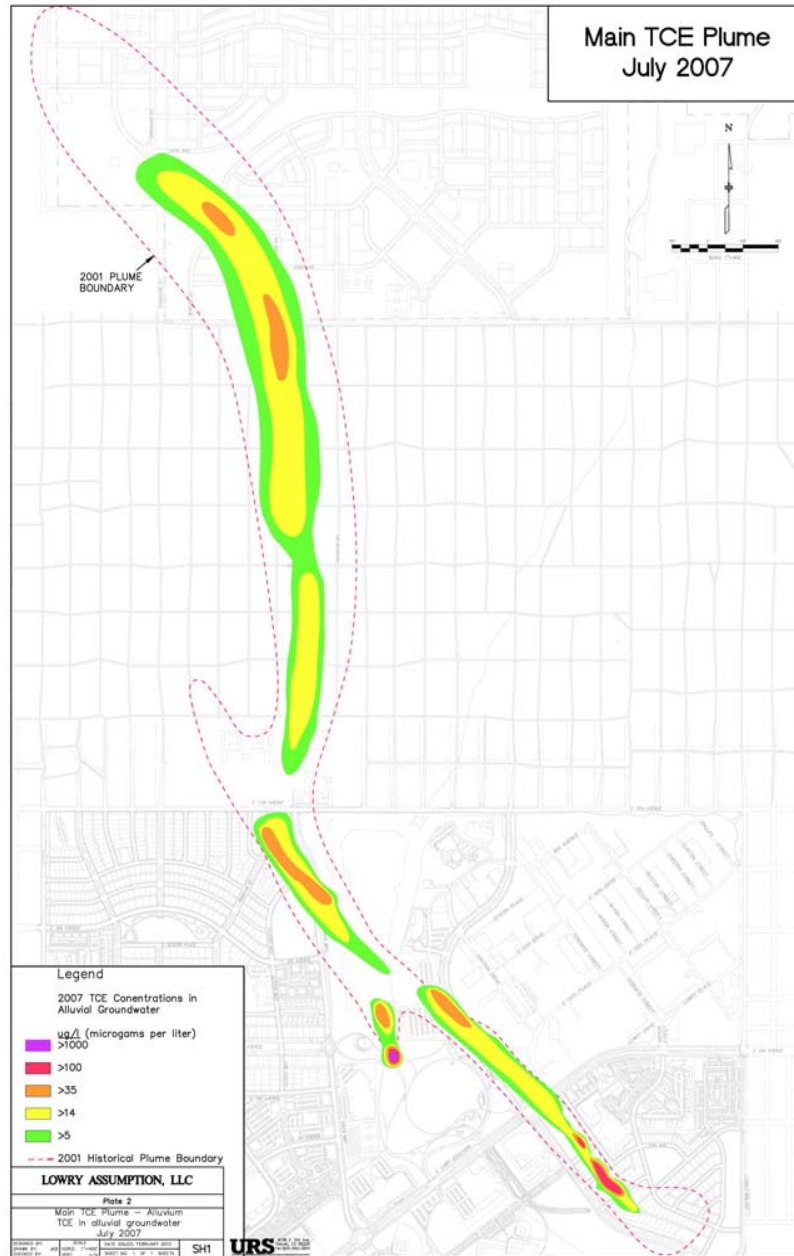
Plume Evaluation: Reduction in TCE Concentrations

- Trends – significant average concentration declines across remediation areas
 - Since 2001 Average Alluvial Concentration Decline Plume-wide = 83% to 95%
 - Percentages are based on using the initial versus the latest measured concentrations (as of January 2010) and the minimum versus maximum concentrations detected in the wells, respectively.



LOWRY ASSUMPTION, LLC







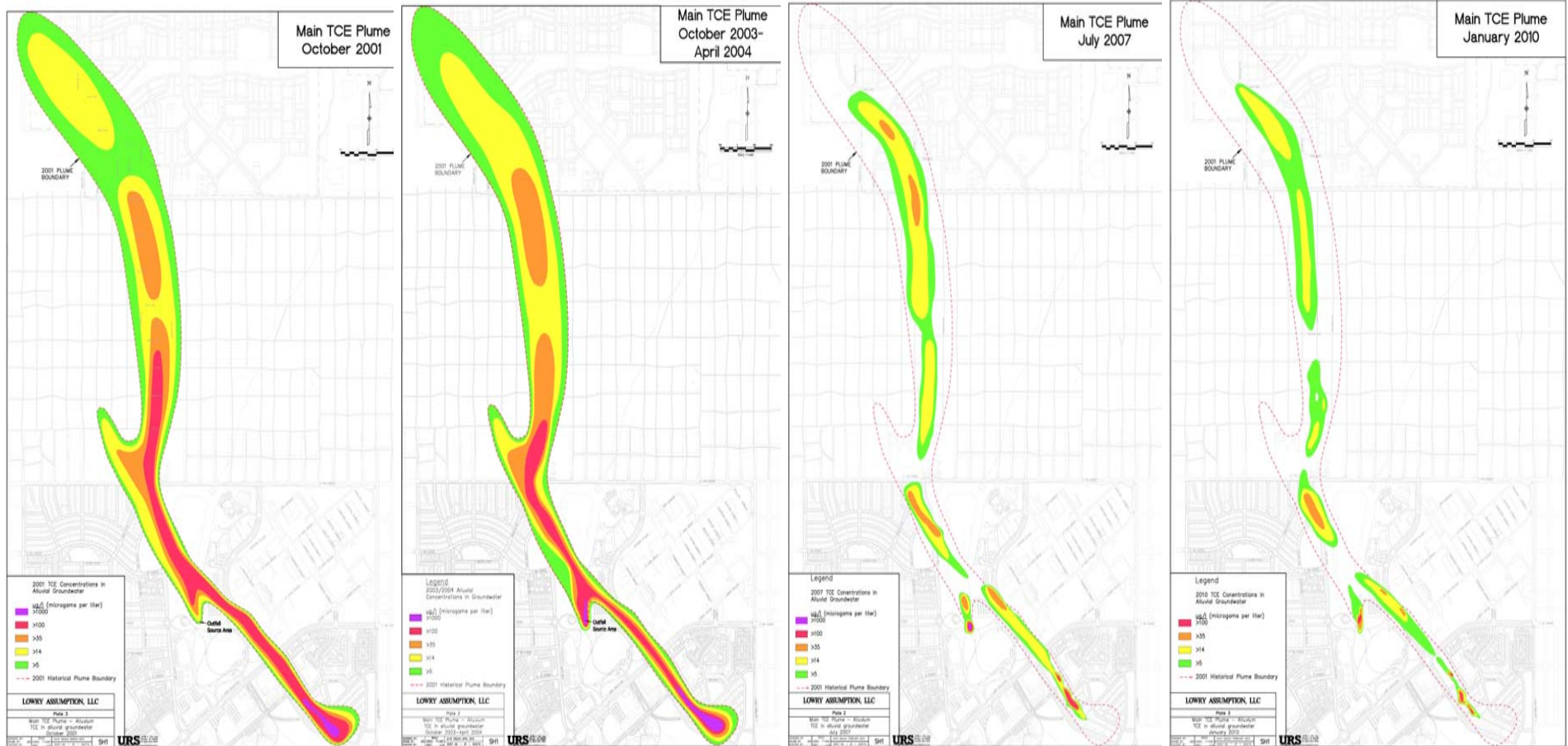


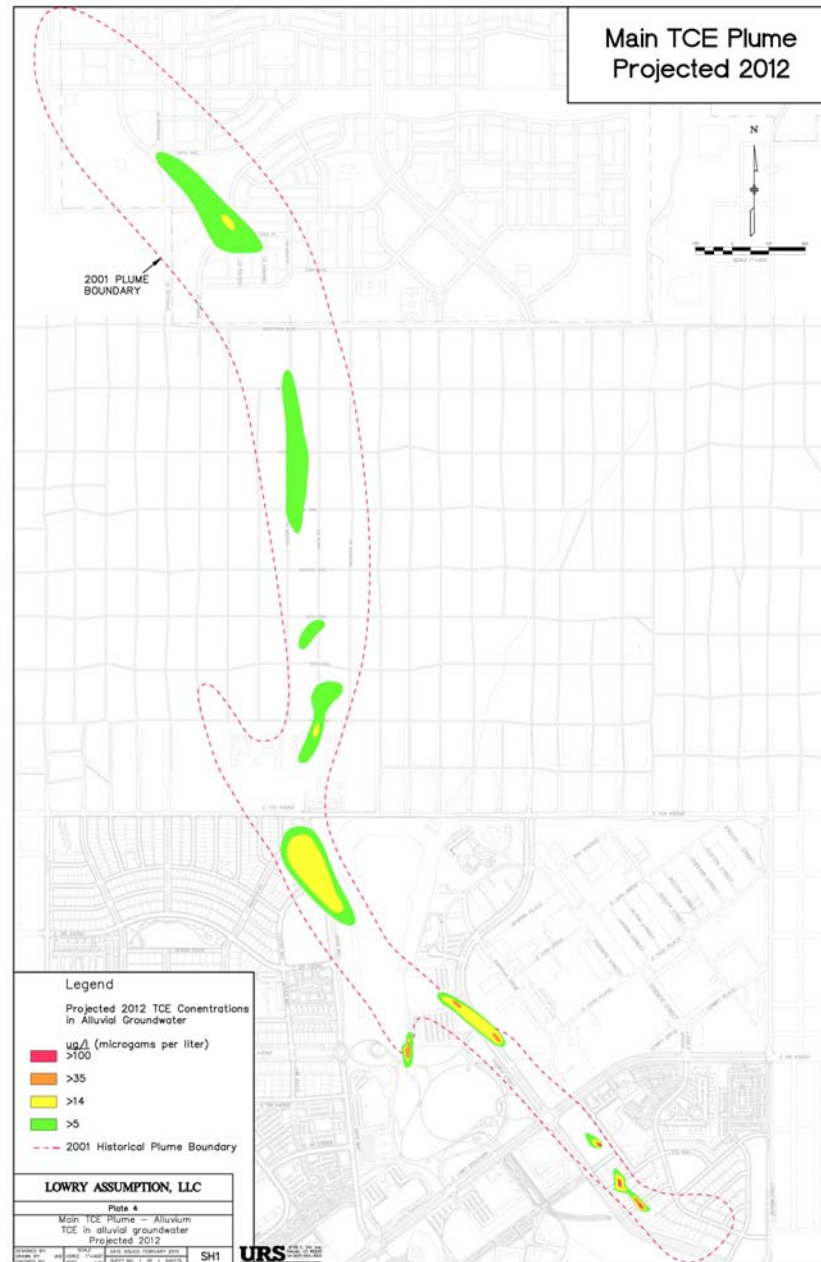
Risk Mitigation: Plume Area Reduction

- Plume Area has been Reduced:
 - Overall Plume Area = 65% Reduction
 - Based on Original RI Plume Area vs. the Plume as Currently Mapped (Jan 2010)
- Reduced areal extent as well as TCE concentration reductions in the plume can be correlated to risk reduction
 - Population and Magnitude



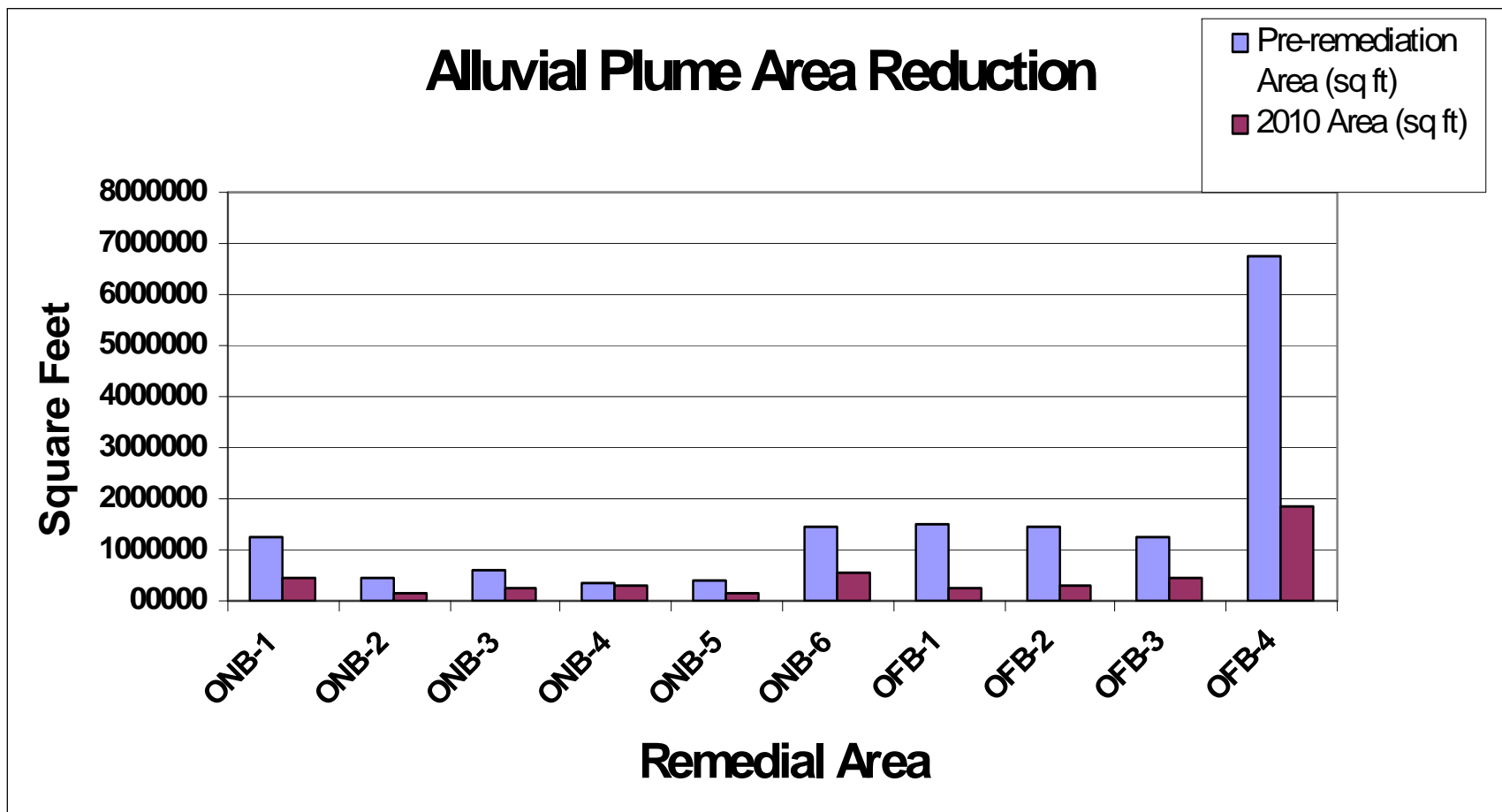
Operable Unit 5 - Project Status Main TCE Plume (Alluvium) Concentration Reduction 2001 through 2010







Alluvial Plume Area Reduction Pre-remediation – Jan 2010





Risk Mitigation: Reduction in TCE Mass

- Method for Measurement
 - Conceptual Model Mass
 - Sorbed TCE in sand
 - Sorbed TCE in silt
 - TCE in bedrock
 - TCE in groundwater
 - Mass Calculated for Several Monitoring Events



Mass Calculation Example

- Formulas for Calculating Sorbed/Total Mass:
 - $MassTCEsorbed = CTCEgwtr \times Kd \times Vaqfr \times Bulk\ Density\ (g/cc)$
 - $MTCEsorbedBedrock = CTCEbedrockgwtr \times KdBedrock \times Vaqfr \times Bulk\ Density\ (g/cc)/1000000000$
 - $MTCEsorbedsand = CTCEalluvialgwtr \times (1-\%S\&C) \times KdAlluvium \times Vaqfr \times Bulk\ Density\ (g/cc)/1000000000$
 - $MTCEsorbedsilt = 5 \times CTCEalluvialgwtr \times \%S\&C \times KdAlluvium \times Vaqfr \times Bulk\ Density\ (g/cc)/1000000000$
 - $MassTCEgwtr = (CTCEalluvialgwtr \times Valluvialaqfr/1000000000) + (CTCEbedrockgwtr \times Vbedrockaqfr/1000000000)$
 - $MassTotal = MTCEgwtr + MTCEsorbedbedrock + MTCEsorbedsand + MTCEsorbedsilt$

For silt, calculated sorbed mass multiplied by factor of 5 to account for increased surface area

K_d (alluvium) = 0.1221 ml/g (OU 5 RI Report, Versar, 2001)

K_d (bedrock) = 0.00898 ml/g (OU 5 RI Report, Versar, 2001)

Bulk Density = 1.86 g/cc

Weight of Water = 8.345 lbs/gallon

M = mass (ug)

C = concentration (ug/L)

K_d = ml/g (distribution coefficient)

V = volume (liters)

ug = micrograms

L = liters

ml = milliliters

g = grams

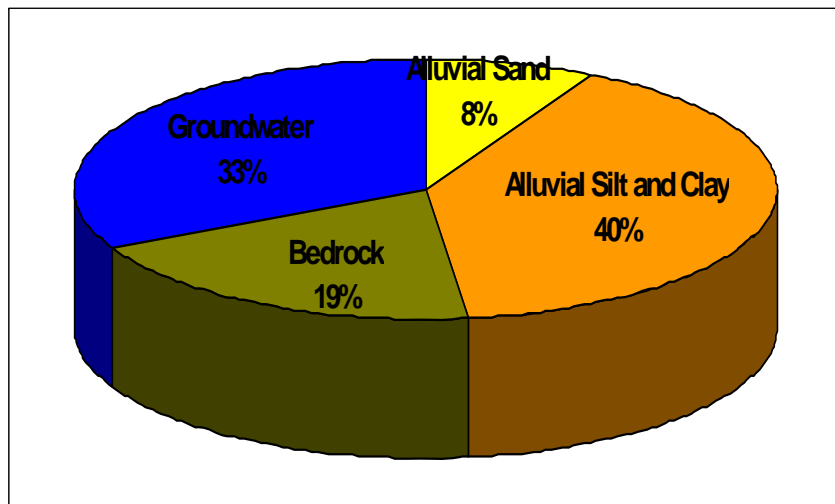
cc = cubic centimeter



Distribution of TOTAL TCE Mass by Medium in the Main Plume (Total Mass Estimate)

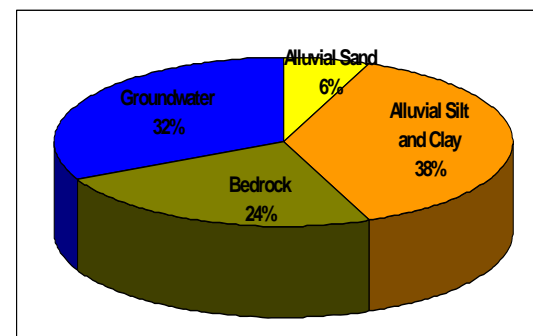
2004 Mass Distribution

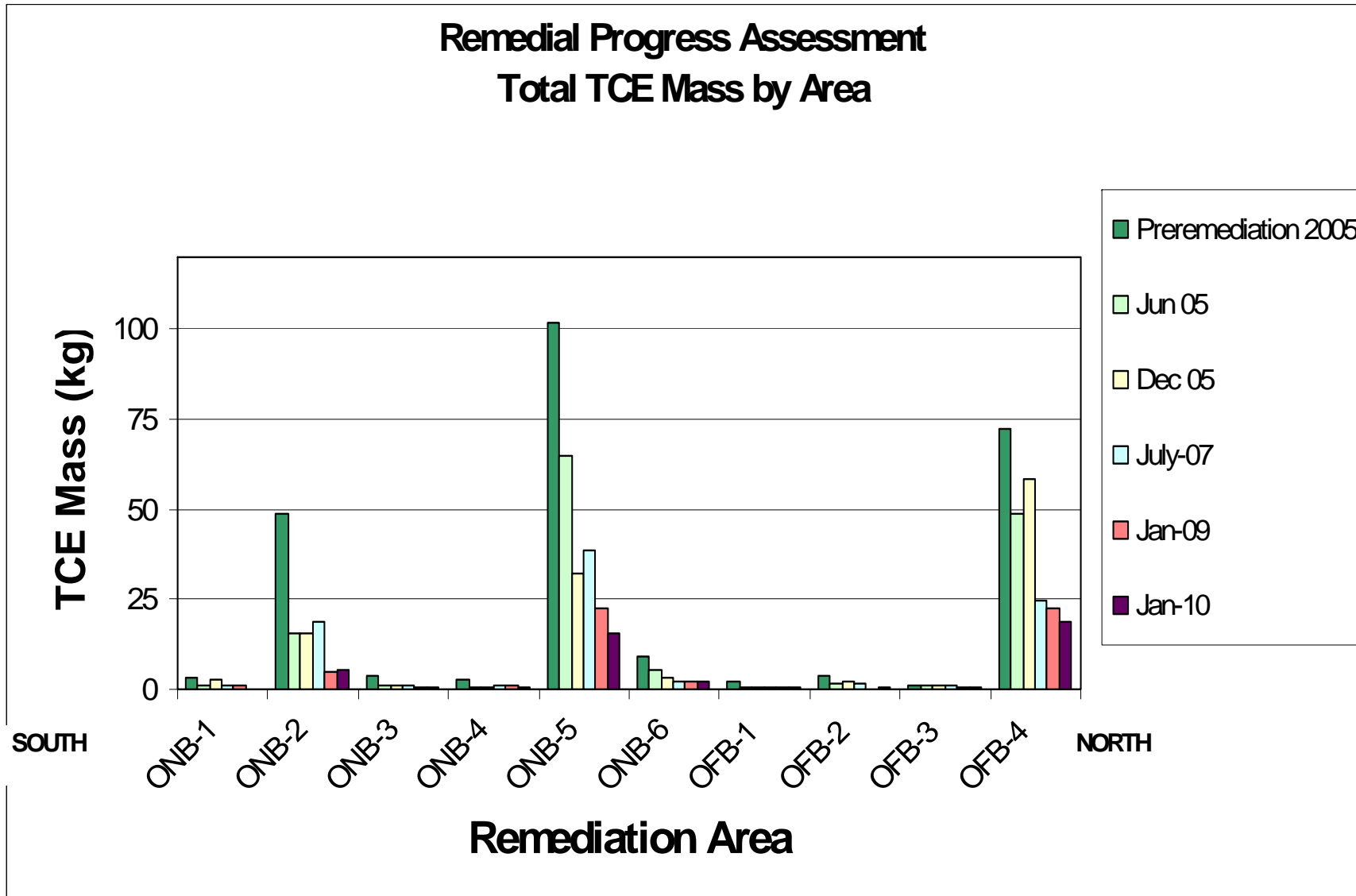
249 kg



2010 Mass distribution

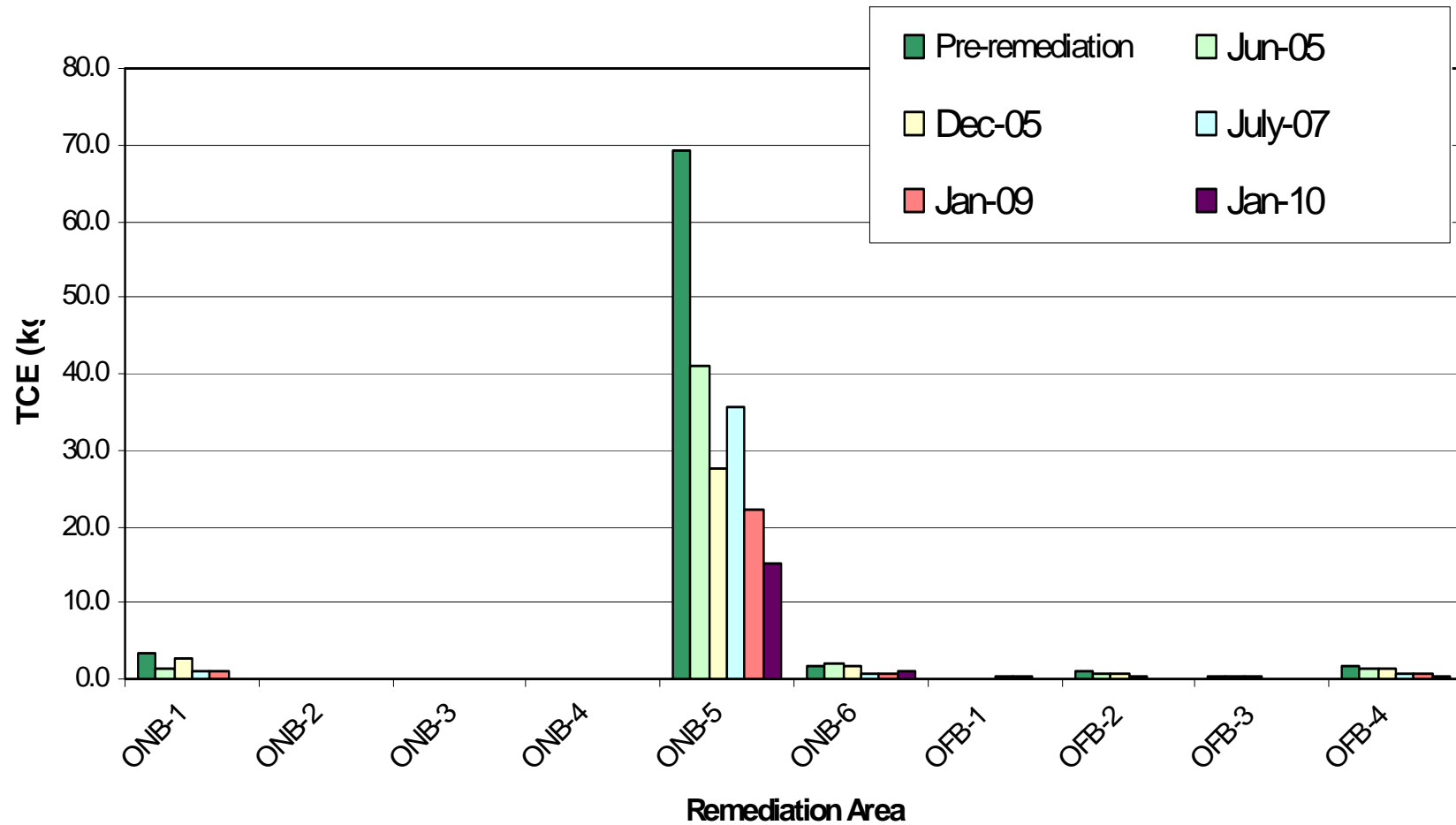
43 kg





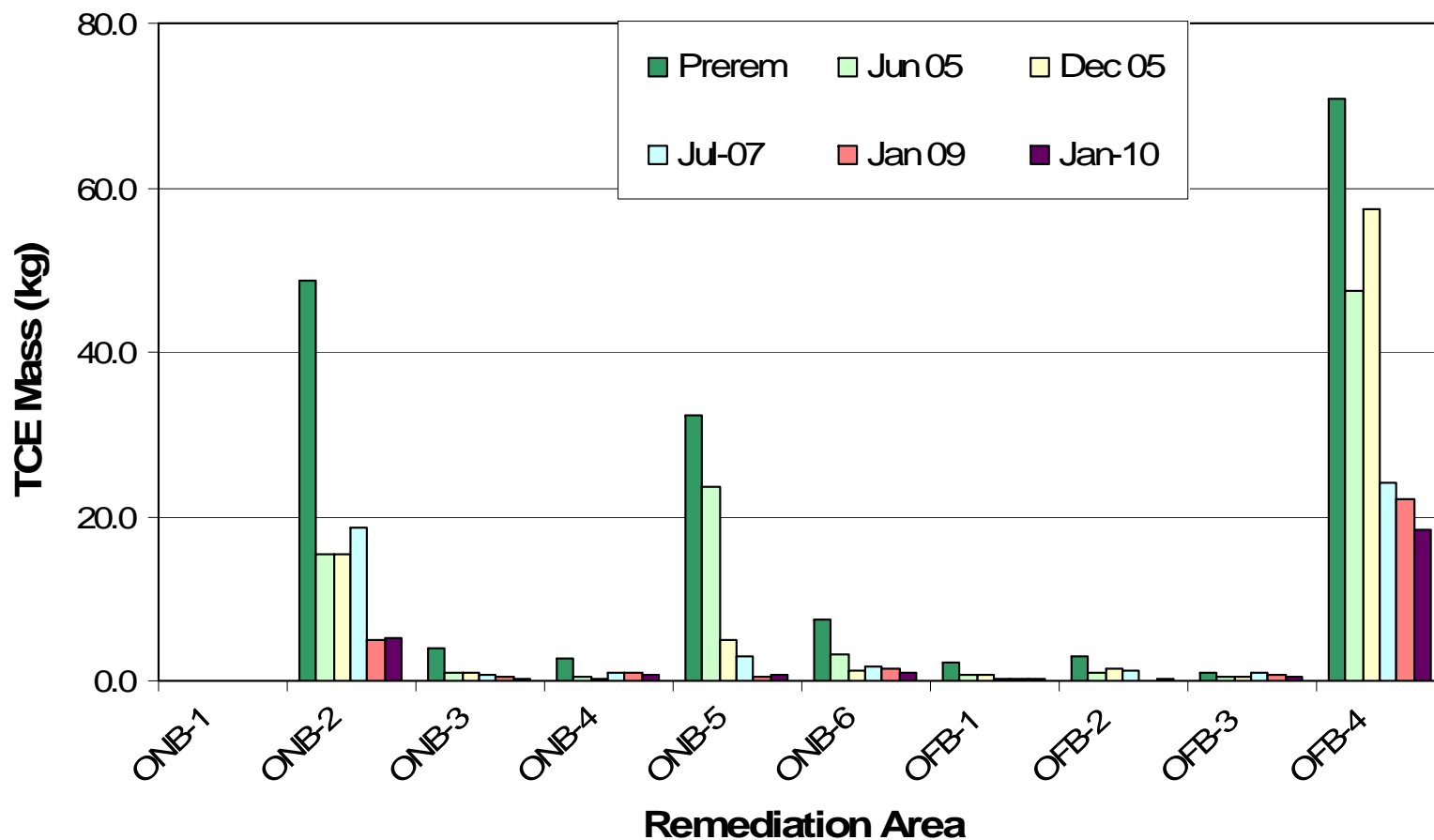


Remedial Progress Assessment Bedrock TCE Mass by Area vs Time





Remedial Progress Assessment Alluvial TCE Mass by Area vs Time





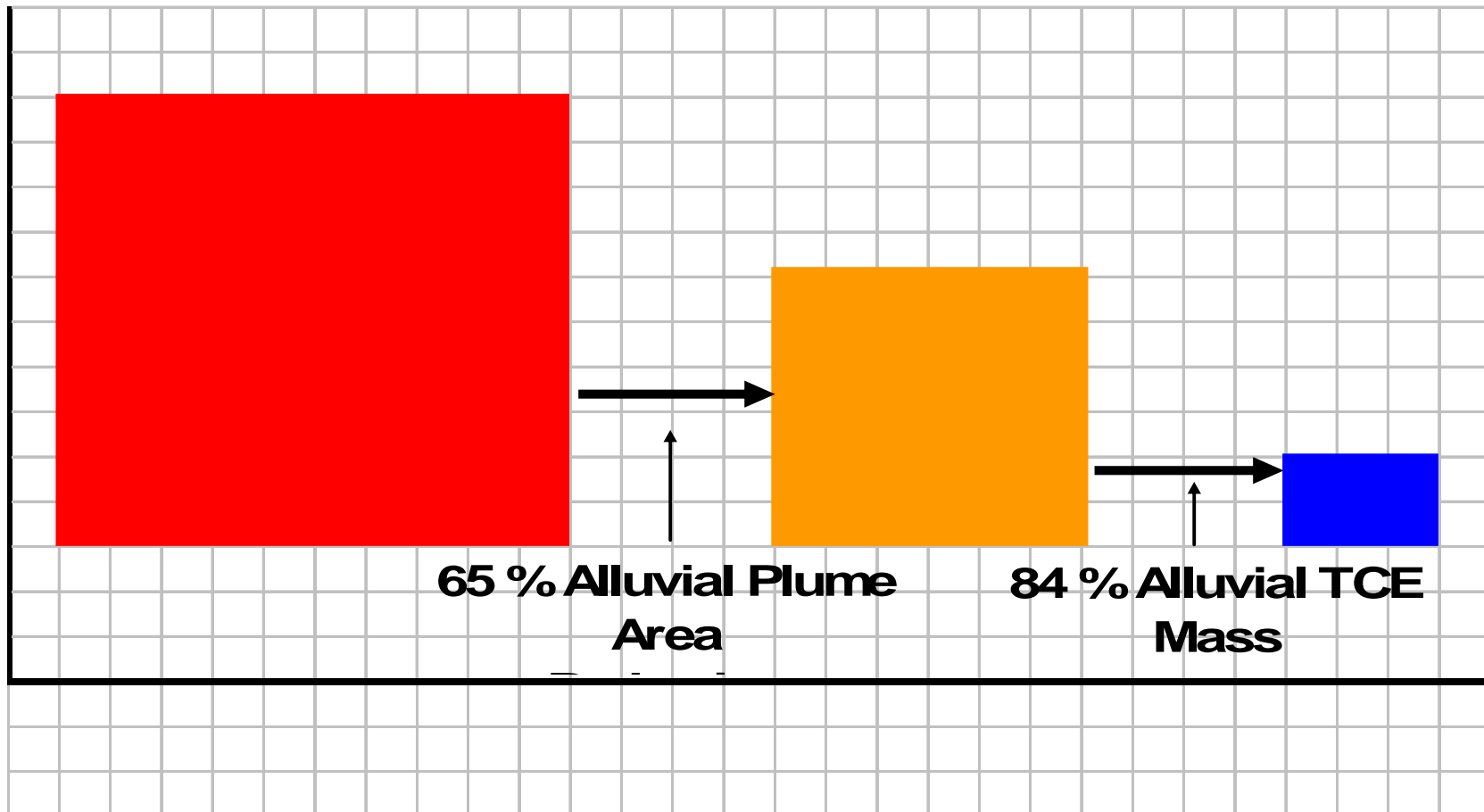
TCE Reduction in Plume Area and Alluvial Mass

Remediation Area	Percent Reduction in Plume Area Pre-remediation to Jan 2010	January 2010 TCE Mass in Alluvium (kg)	Percent Reduction Mass Pre-remediation to Jan 2010	Percent Reduction Since Last RPASS (2007)
ONB-1	-	-	-	-
ONB-2	75%	5.25	89%	28%
ONB-3	56%	0.31	92%	12%
ONB-4	28%	0.67	75%	10%
ONB-5	65%	0.64	98%	7%
ONB-6	65%	1.05	86%	8%
OFB-1	81%	0.19	92%	1%
OFB-2	80%	0.23	92%	35%
OFB-3	63%	0.46	56%	57%
OFB-4	72%	18.29	74%	8%
Total	65%	27.10	84%	19%



Estimated Total Risk Reduction (Site-wide 2010)

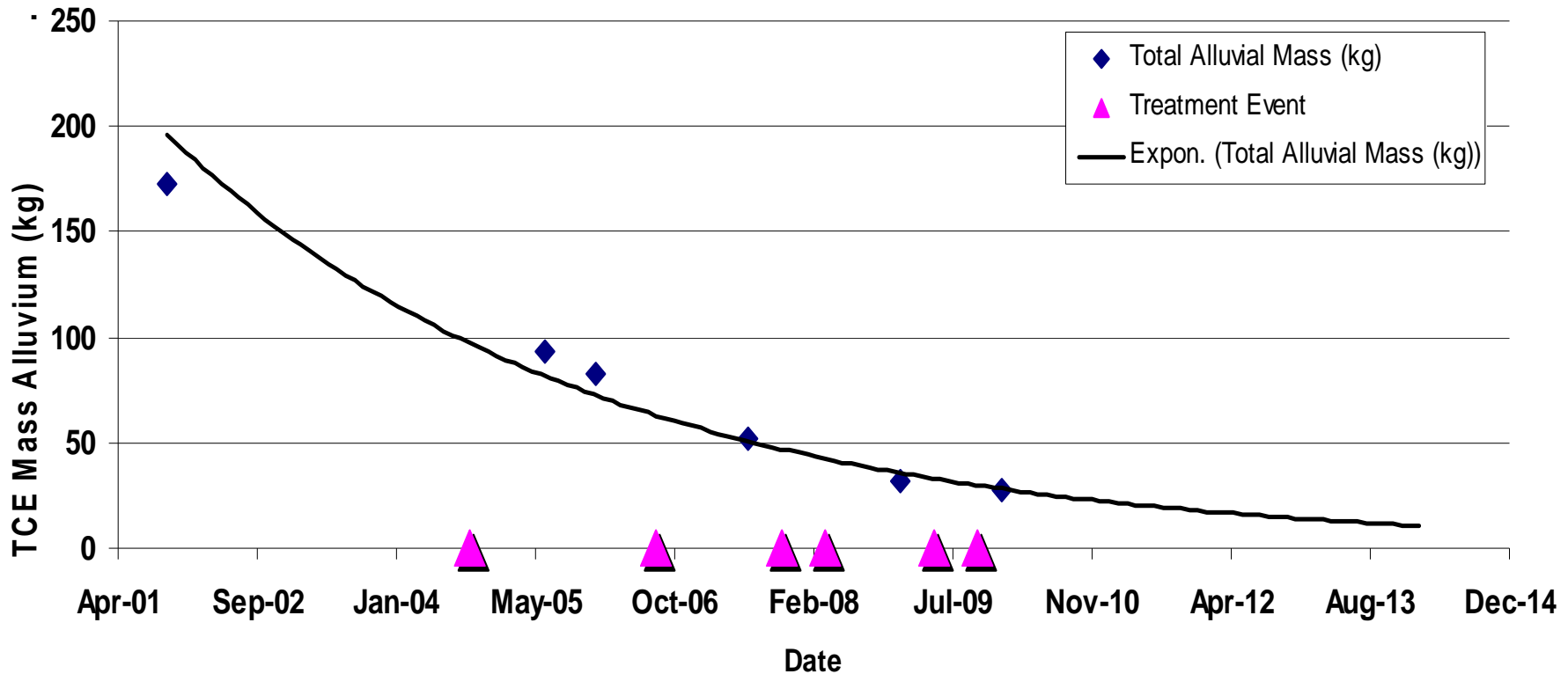
- Estimate **94%** Risk Reduction





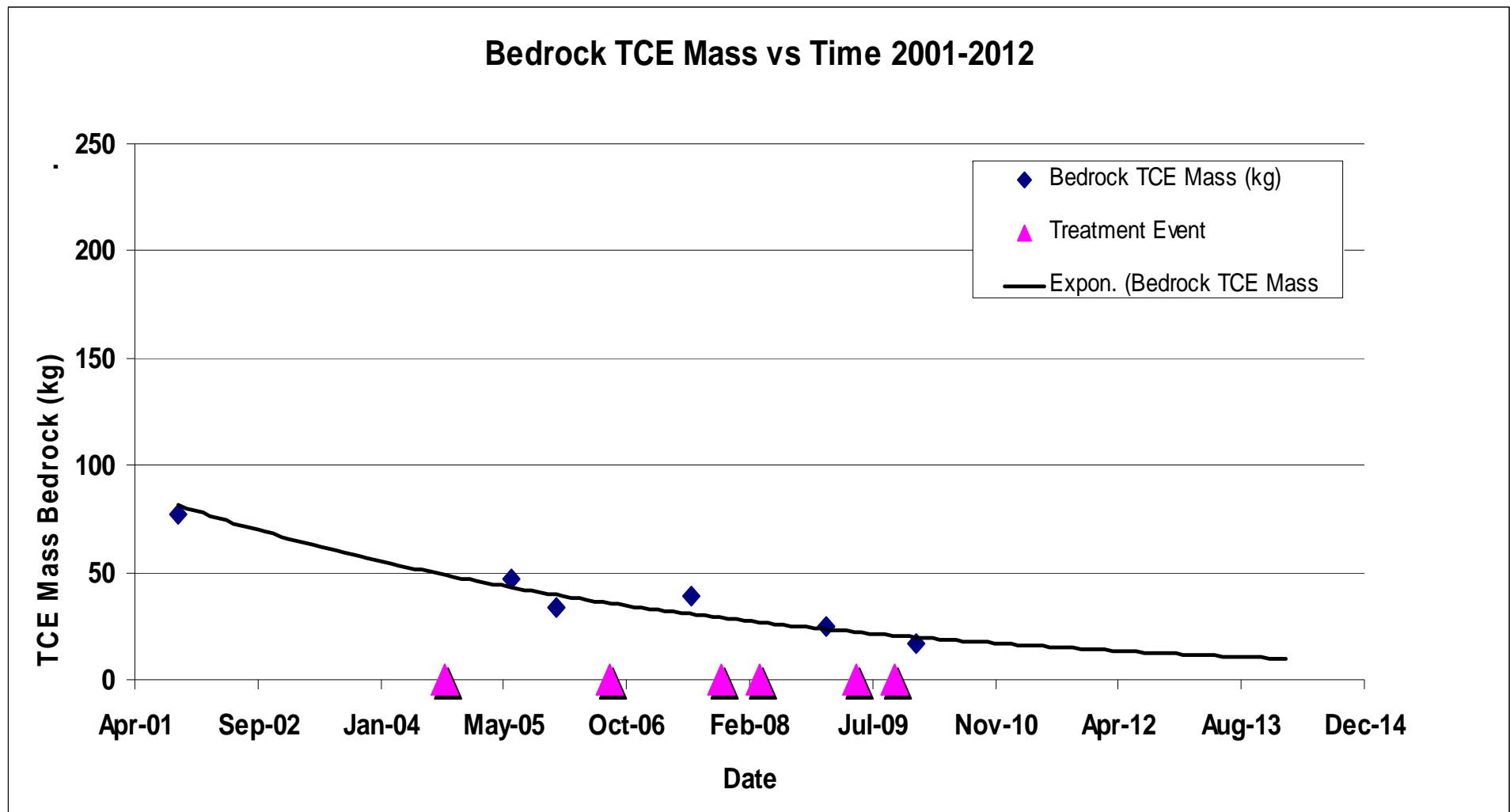
TCE Mass Reduction - (Main Plume Alluvium)

Alluvial TCE Mass vs Time 2001-2012



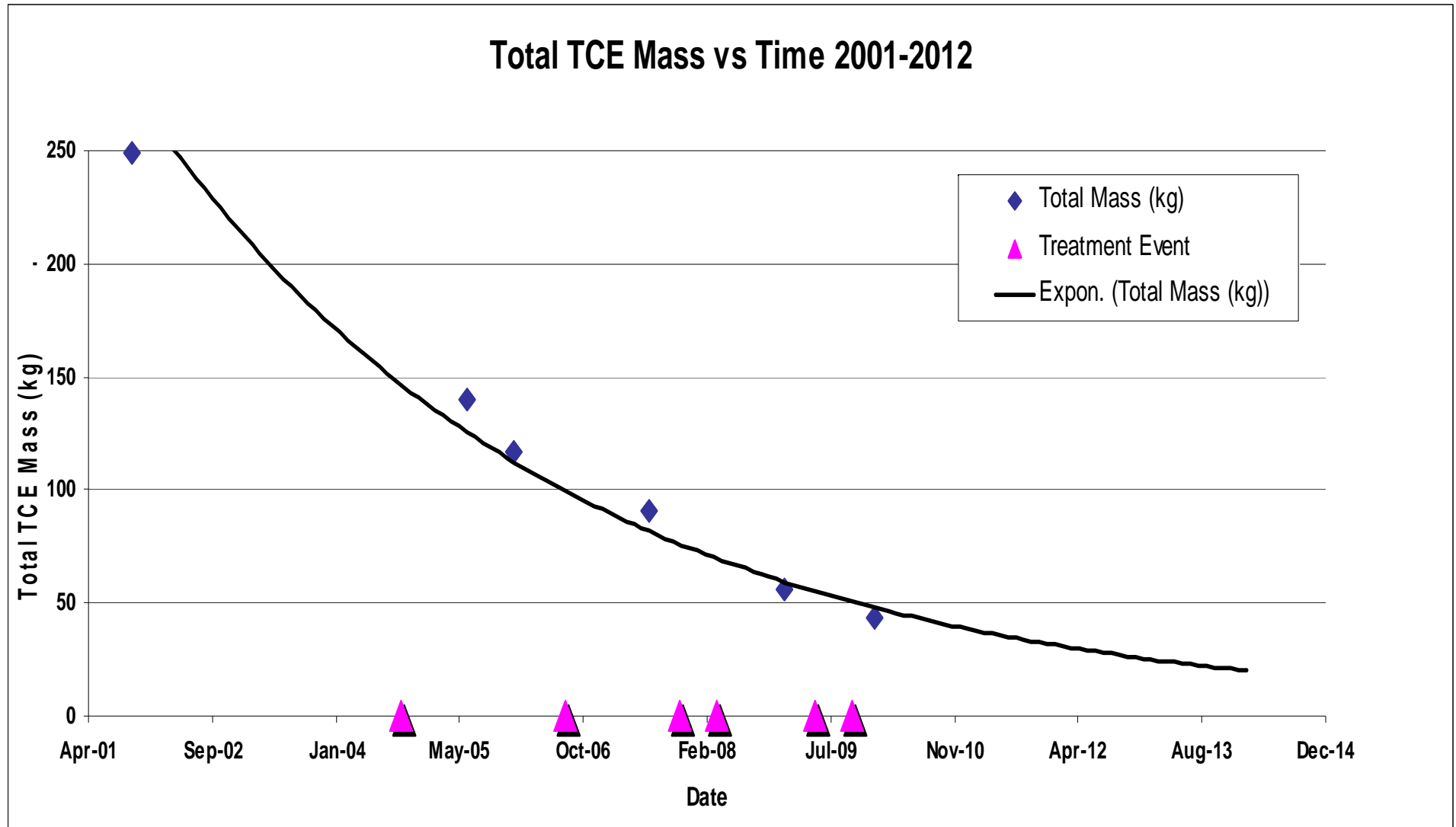


TCE Mass Reduction - (Main Plume Bedrock)





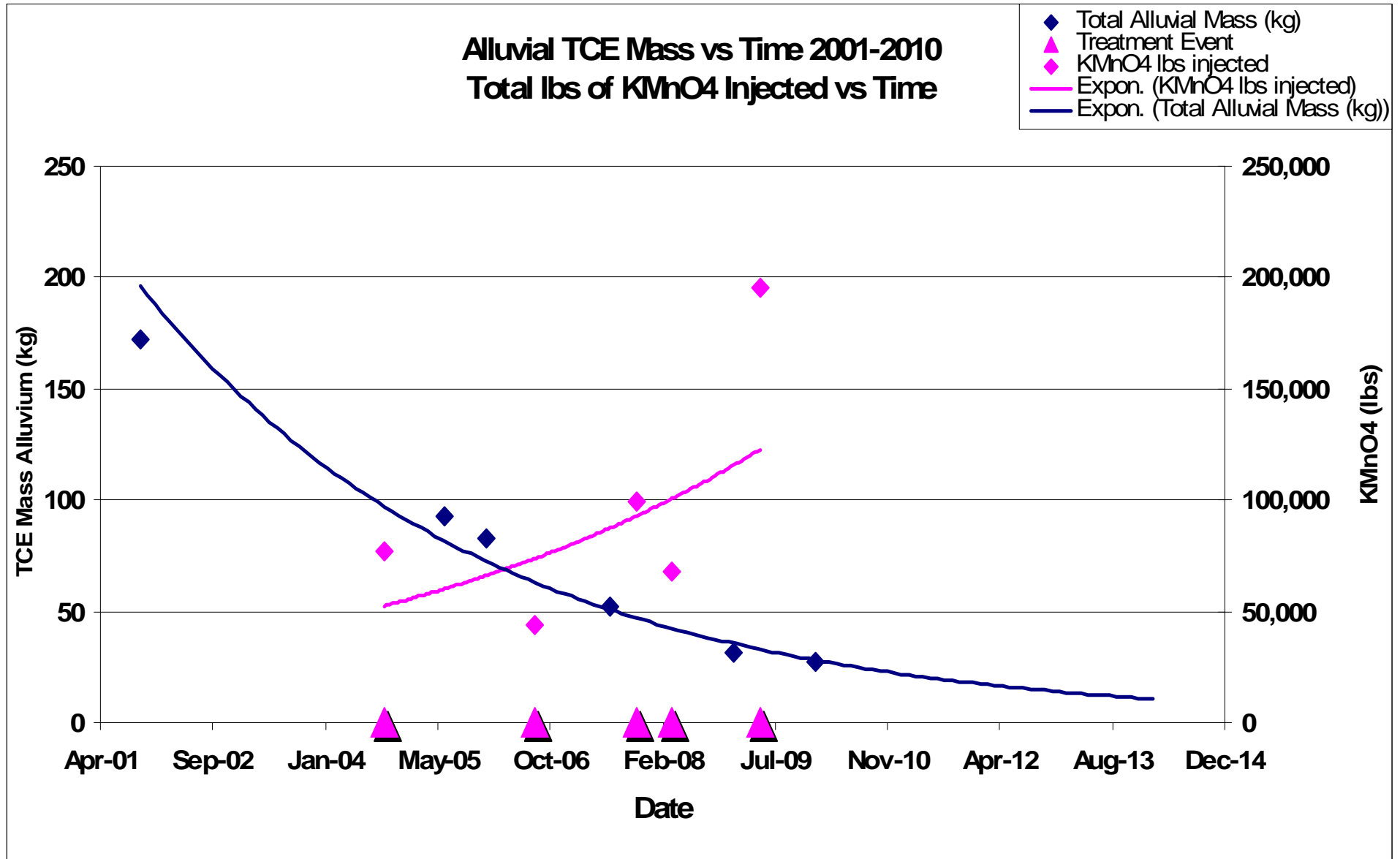
TCE Mass Reduction (Total Mass)





Risk Mitigation: Reduction in TCE Mass

- Mass Calculations Indicate a Total Alluvial Mass Removal of Approximately 84% since Remediation was Initiated in Late 2004
 - Remediation period about 6 years
 - Mass removal from 2007 to 2010 = 19%
- Remedial success is more apparent when mass was at its highest
 - Accounting for the increase in KMnO_4 solution strength and total lbs injected over time
 - 120,408 lbs KMnO_4 injected at a 3% solution between 2004-2006
 - 362,000 lbs KMnO_4 injected at a 4% solution between 2007-2009





Projections Going Forward

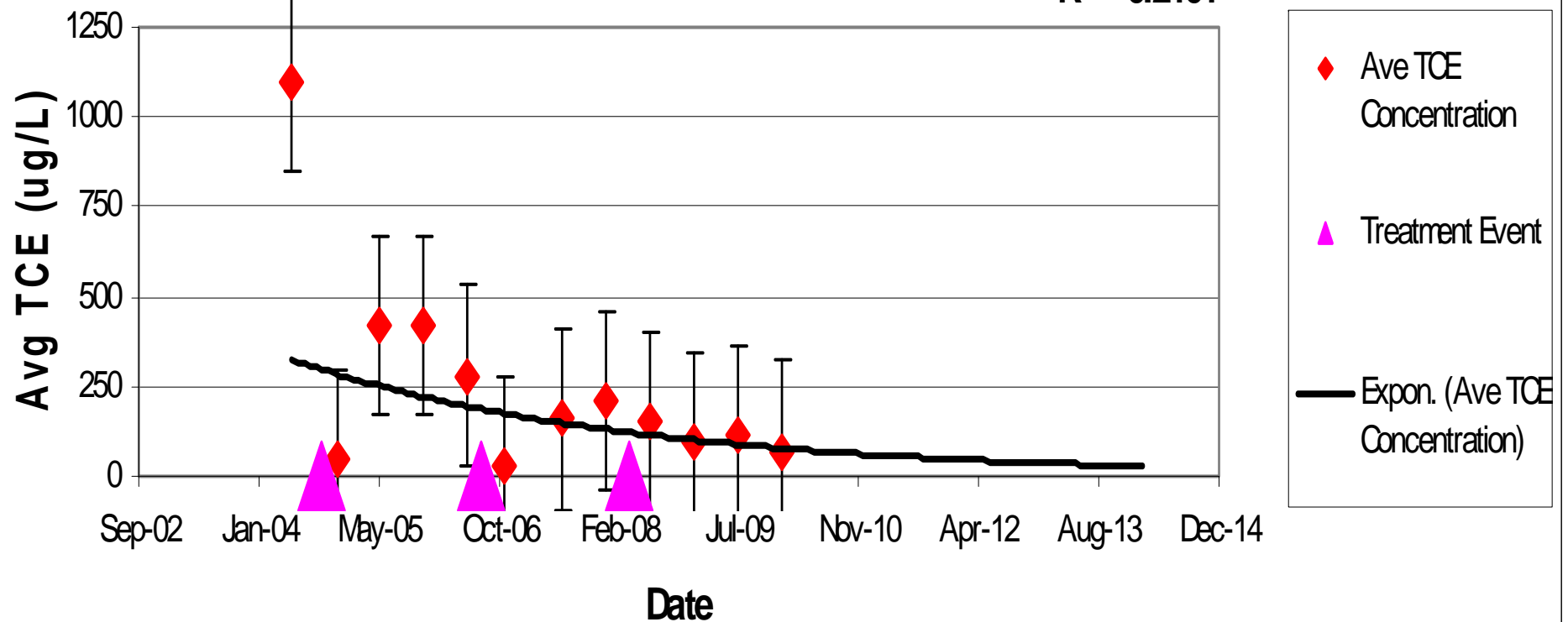
- Projections based on current trend analysis of the Average TCE concentrations for each remedial area over time
- Using the best fit decline curve to predict when the decline curve will intersect 5 (ug/L) the Colorado Basic Groundwater Standard for TCE
- Example ONB-2
 - Trend Analysis
 - Projection



ONB-2 Average Concentration Decline Trend

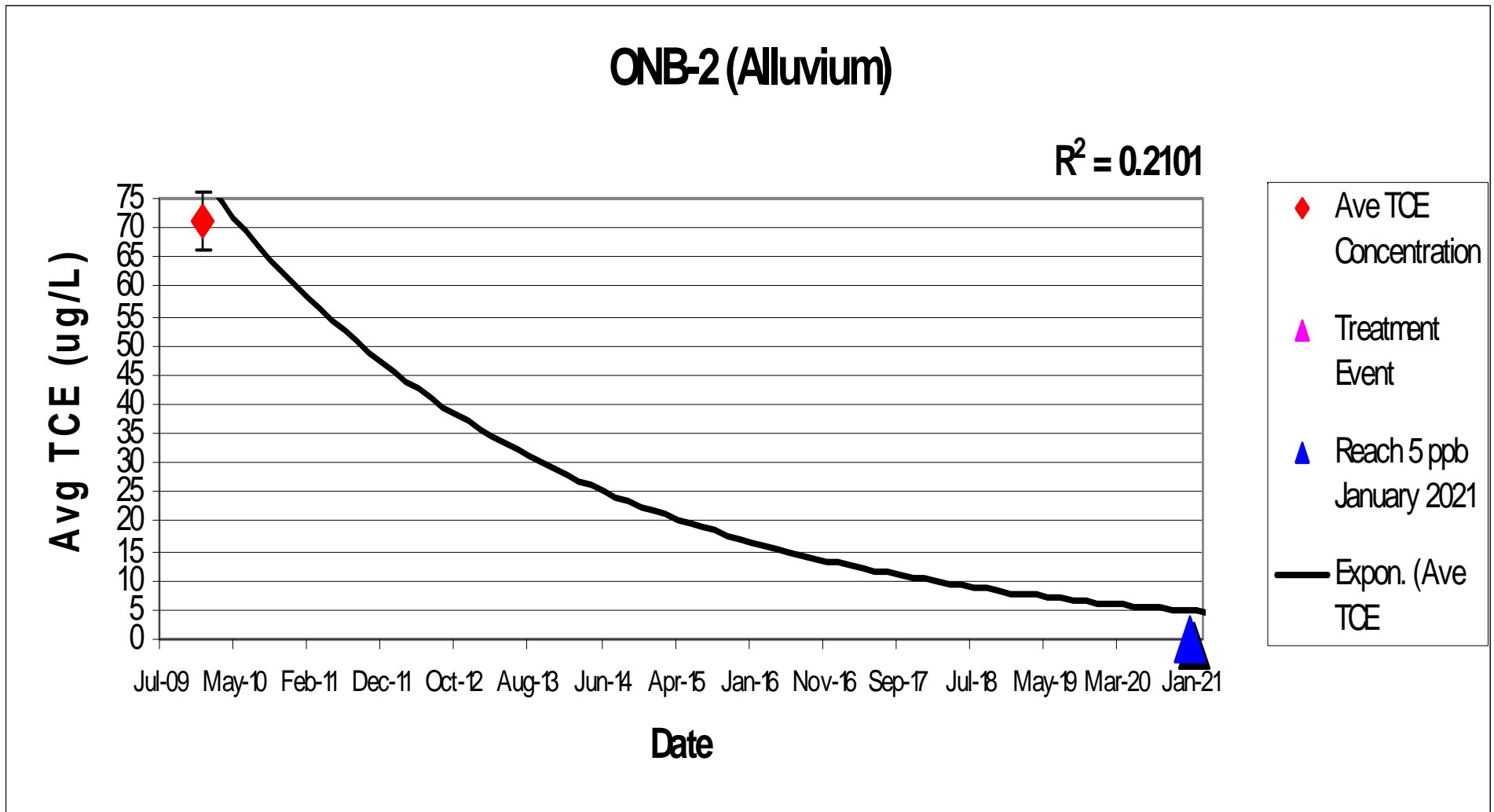
ONB-2 (Alluvium)

$R^2 = 0.2101$





ONB-2 Average Concentration Projection

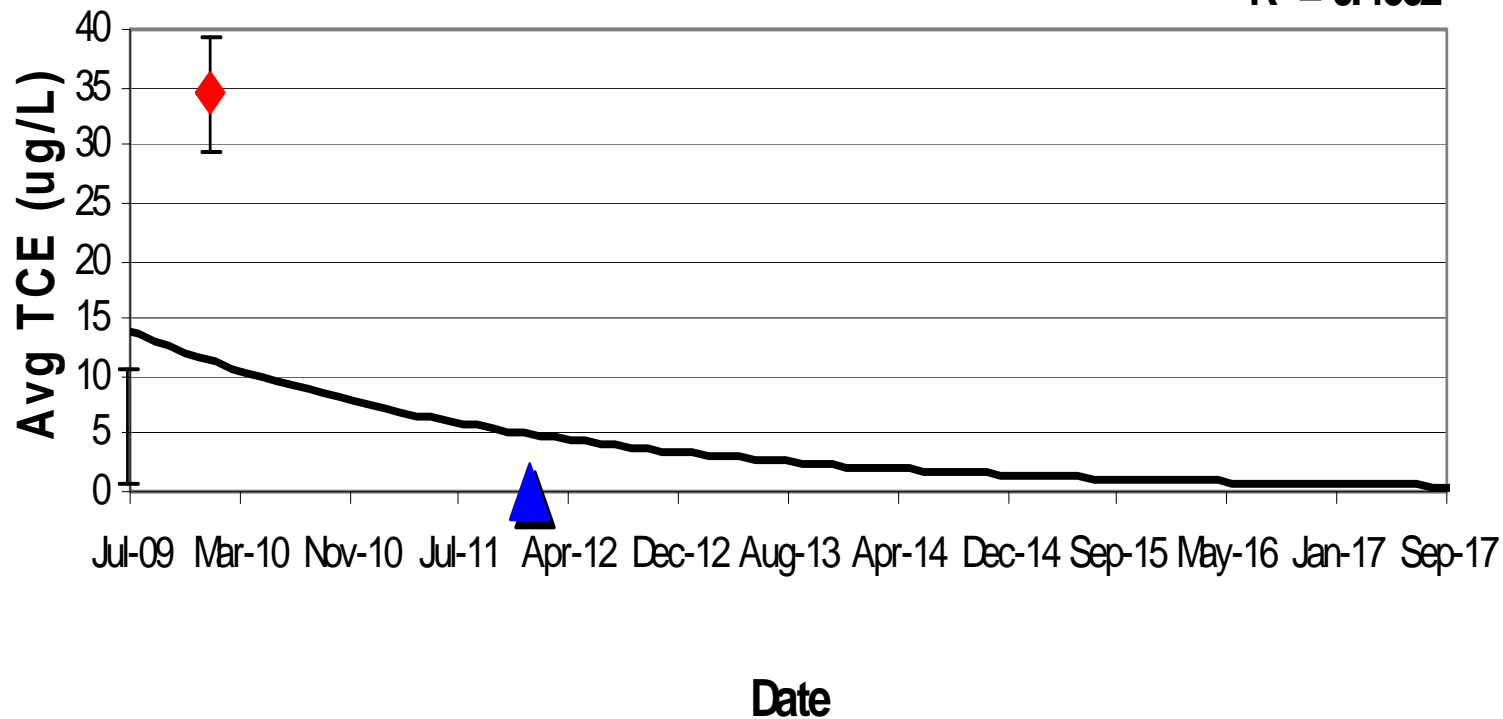




ONB-3 Average Concentration Projection

ONB-3 (Alluvium)

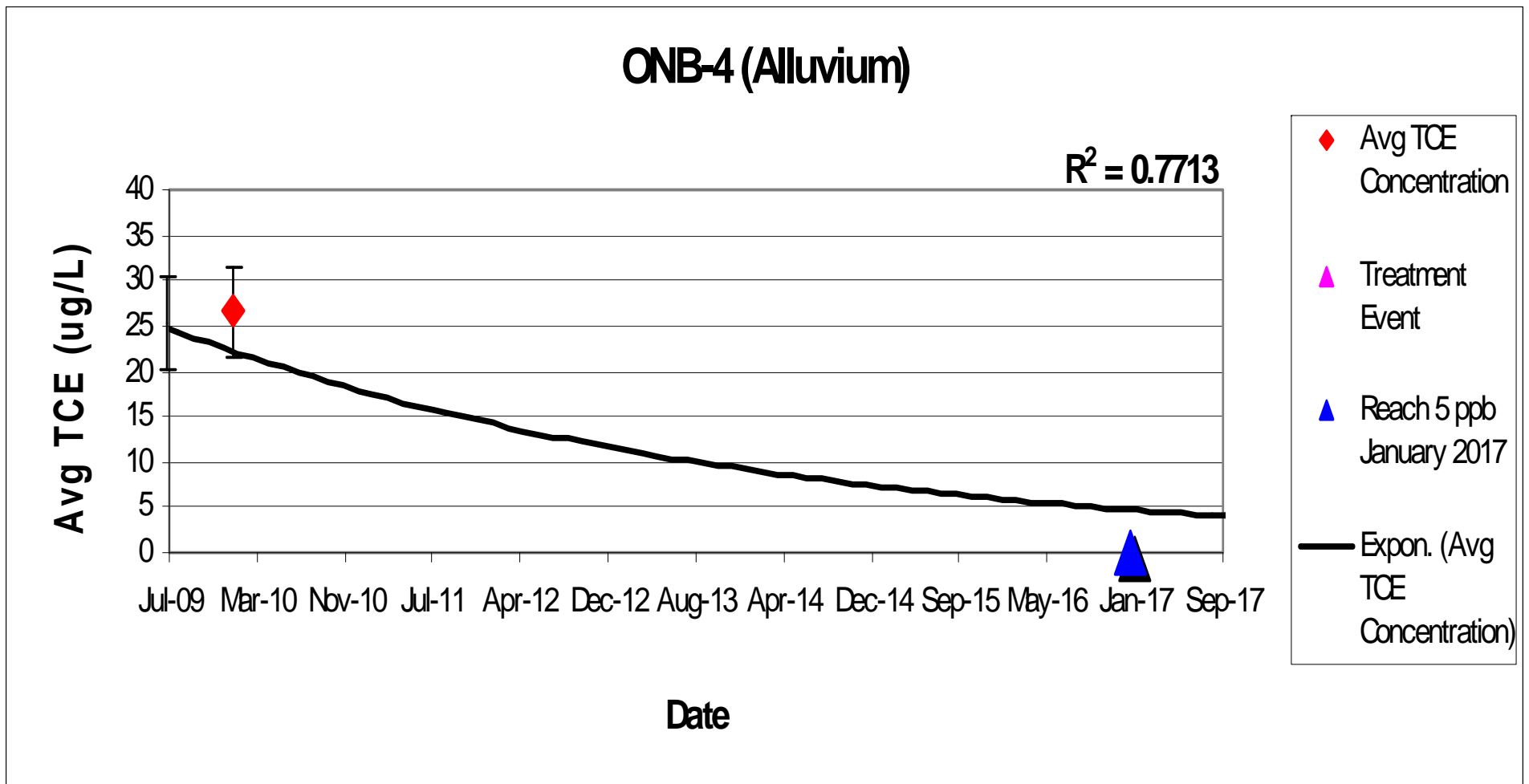
$R^2 = 0.4662$



- ◆ Ave TCE Concentration
- ▲ Treatment Event
- ▲ Reach 5 ppb Jan 2012
- Expon. (Ave TCE Concentration)



ONB-4 Average Concentration Projection

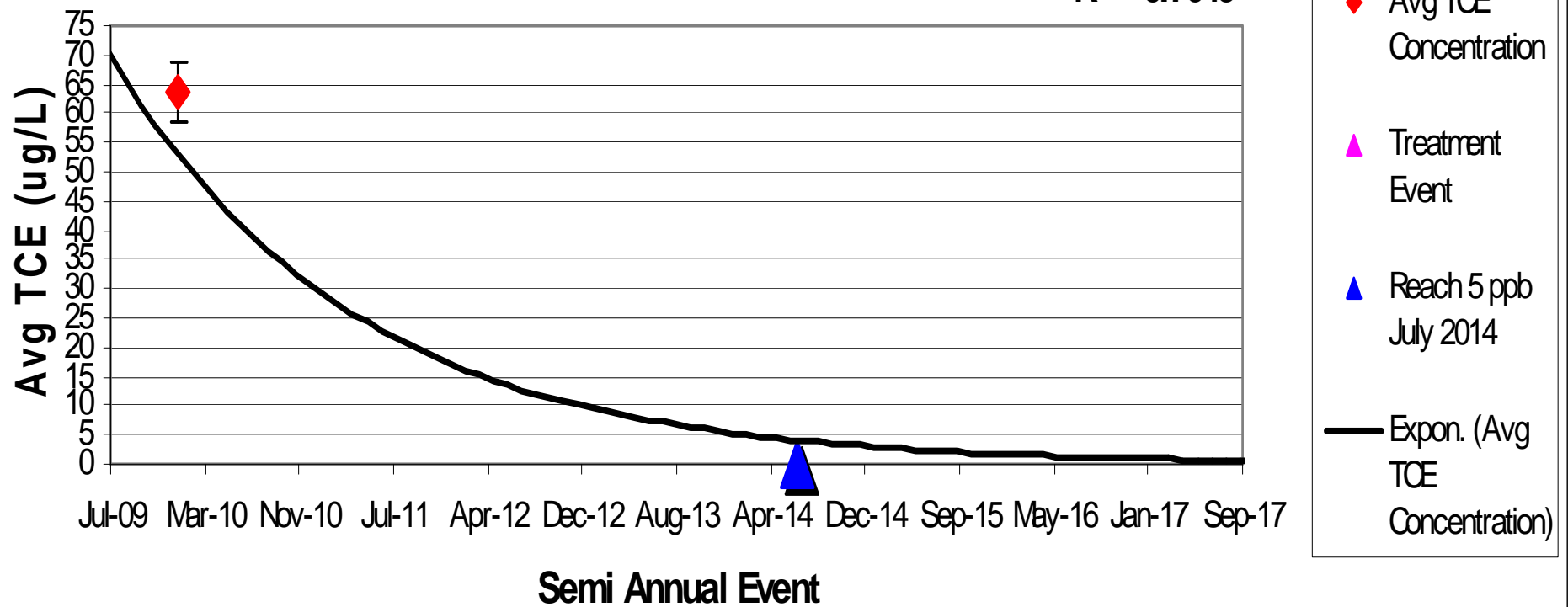




ONB-5 Average Concentration Projection

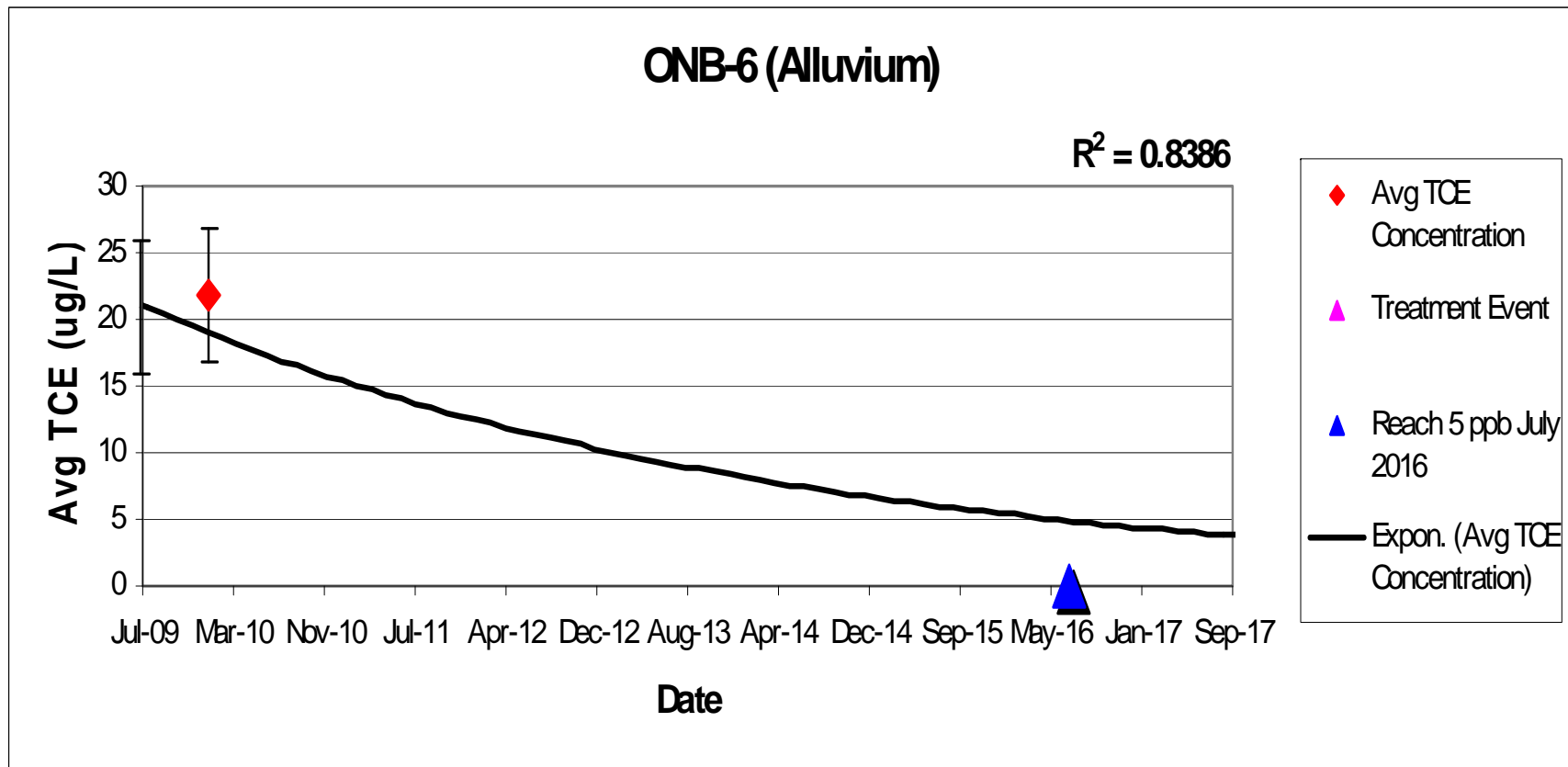
ONB-5 (Alluvium)

$R^2 = 0.7649$



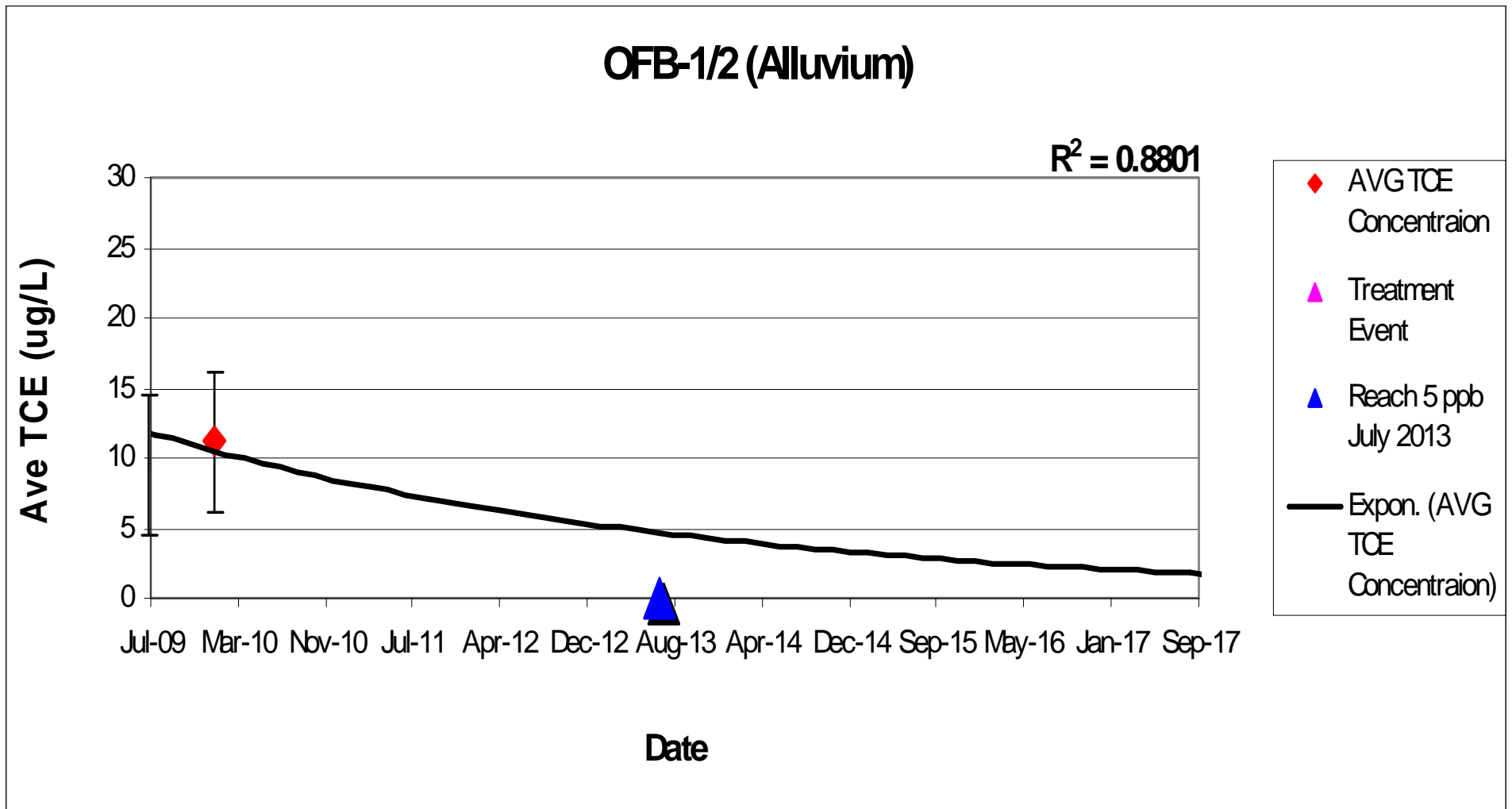


ONB-6 Average Concentration Projection



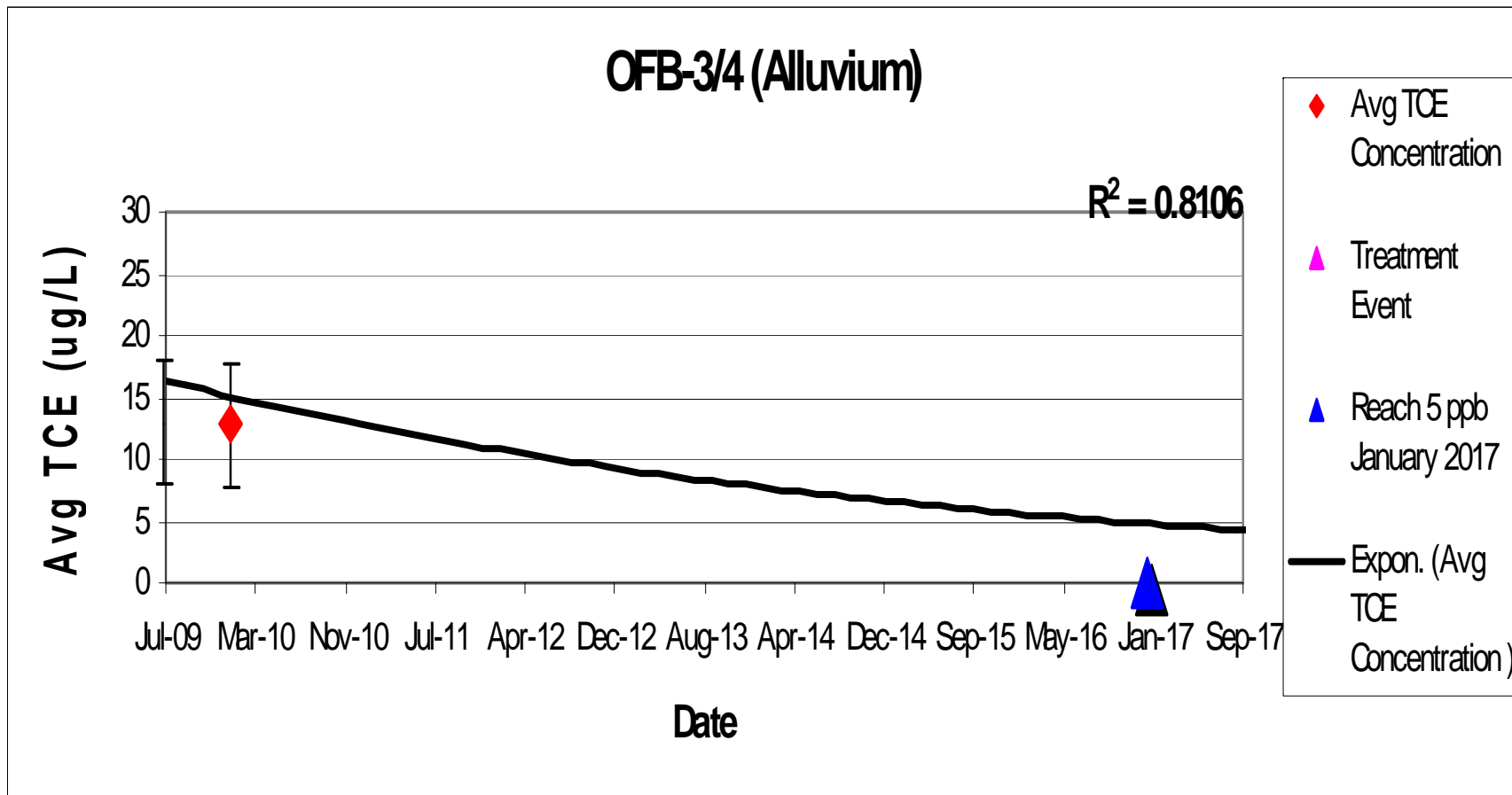


OFB-1/2 Average Concentration Projection



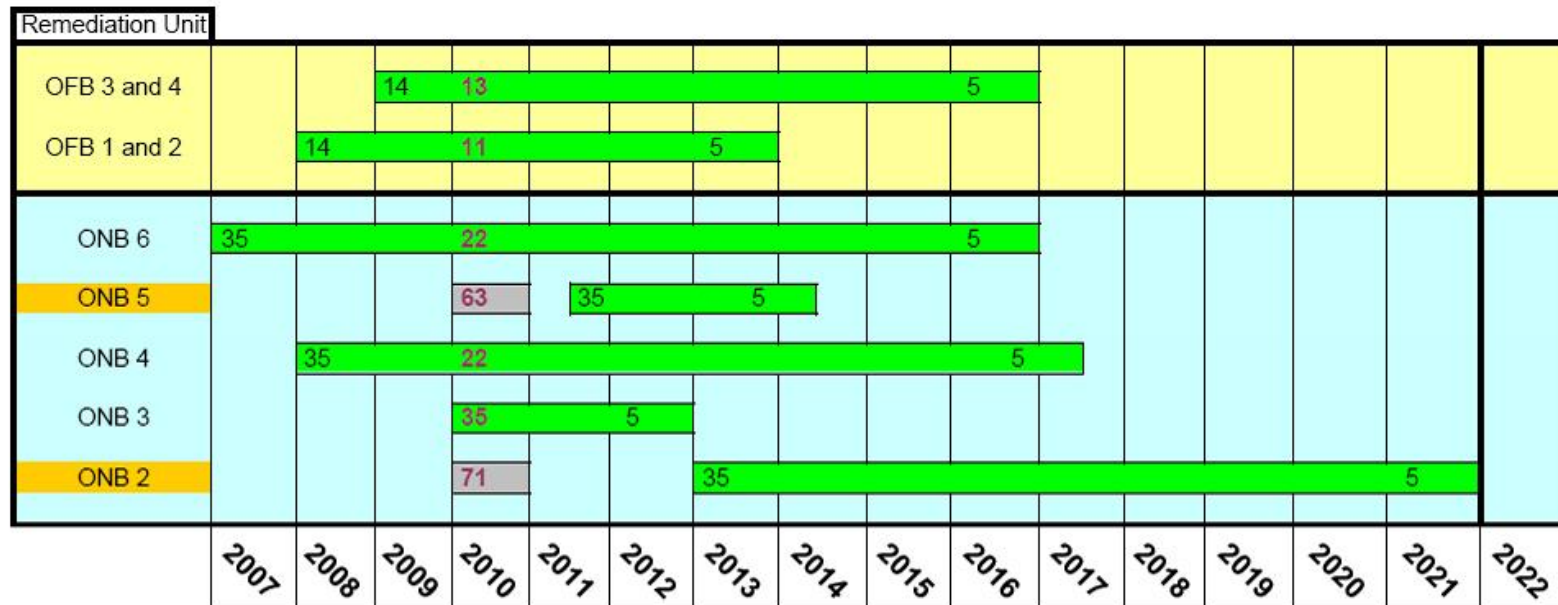


OFB-3/4 Average Concentration Projection





Estimated Completion Timeframe



Legend

- Risk-based Cleanup Target Zone (Based on JE Model Results and Statutory Limit for TCE)
- 14 - Average TCE Concentration Jan 2010 (µg/L) within Target Zone
- 63 - Average TCE Concentration January 2010 (µg/L) Exceeds Target Zone and Remedial Action Planned
- Institutional Controls to Protect Indoor Air are in Place (Radon Systems/Positive HVAC)
- No Institutional Controls for Indoor Air
- Remediation Units Located Within or Near Source Areas of TCE Plume



Risk Mitigation: 2010 Indoor Air Study

- 2010 Indoor Air Study
 - Area representing highest off-base concentrations (in an off-base residential area) was studied
 - 4th study since 1997
- Designed to assess changes in VOC concentrations in soil gas, subslab and indoor air with decreasing groundwater TCE concentrations
- Data compared to 1998, 2001, and 2007 indoor air studies, same houses and wells sampled where possible
- Groundwater data from 1996 to January 2010 evaluated

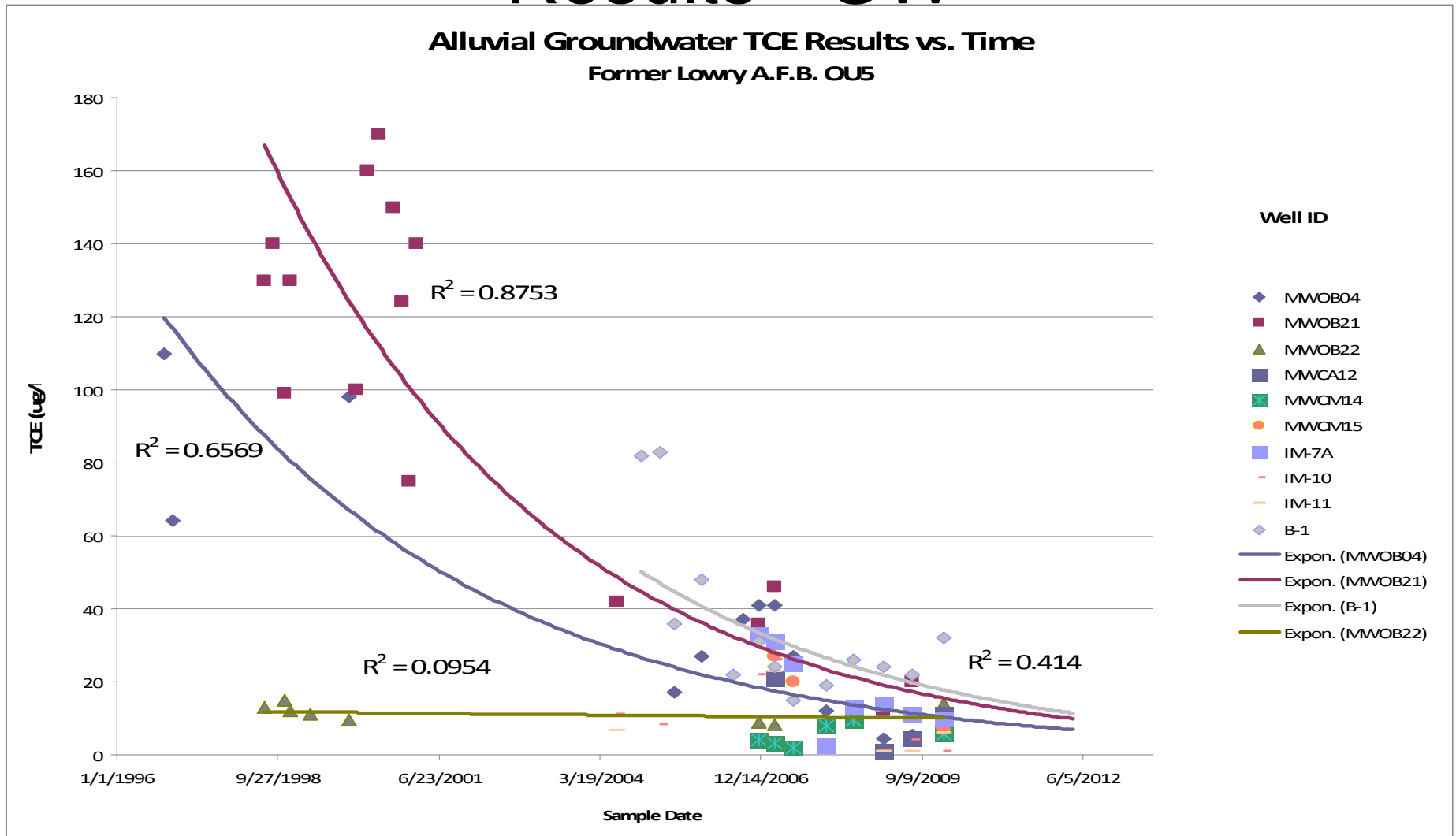


Risk Mitigation: Current Exposure Scenario

- Groundwater to Indoor Air, off-base, mitigation through Corrective Action Plan, aggressive groundwater remediation
- Exposures evaluated using empirical and modeled data
- 2007/2010 Comparison Data
 - From 2007 to 2010 average groundwater TCE concentrations were reduced approximately **65%** for the ten alluvial wells sampled in both studies
 - From 2007 to 2010 average soil vapor TCE concentrations decreased approximately **77%** for eleven probes sampled in both events
 - From 2007 to 2010 average sub-slab vapor TCE concentrations decreased approximately **65%** in three of the homes with the highest concentration in 2007
 - From 2007 to 2010 average indoor air TCE concentrations decreased approximately **75%** for the two homes with the highest concentration tested in both events.
 - Max TCE concentration in indoor air was 1.7 ug/m³ , sampled in winter for most conservative value

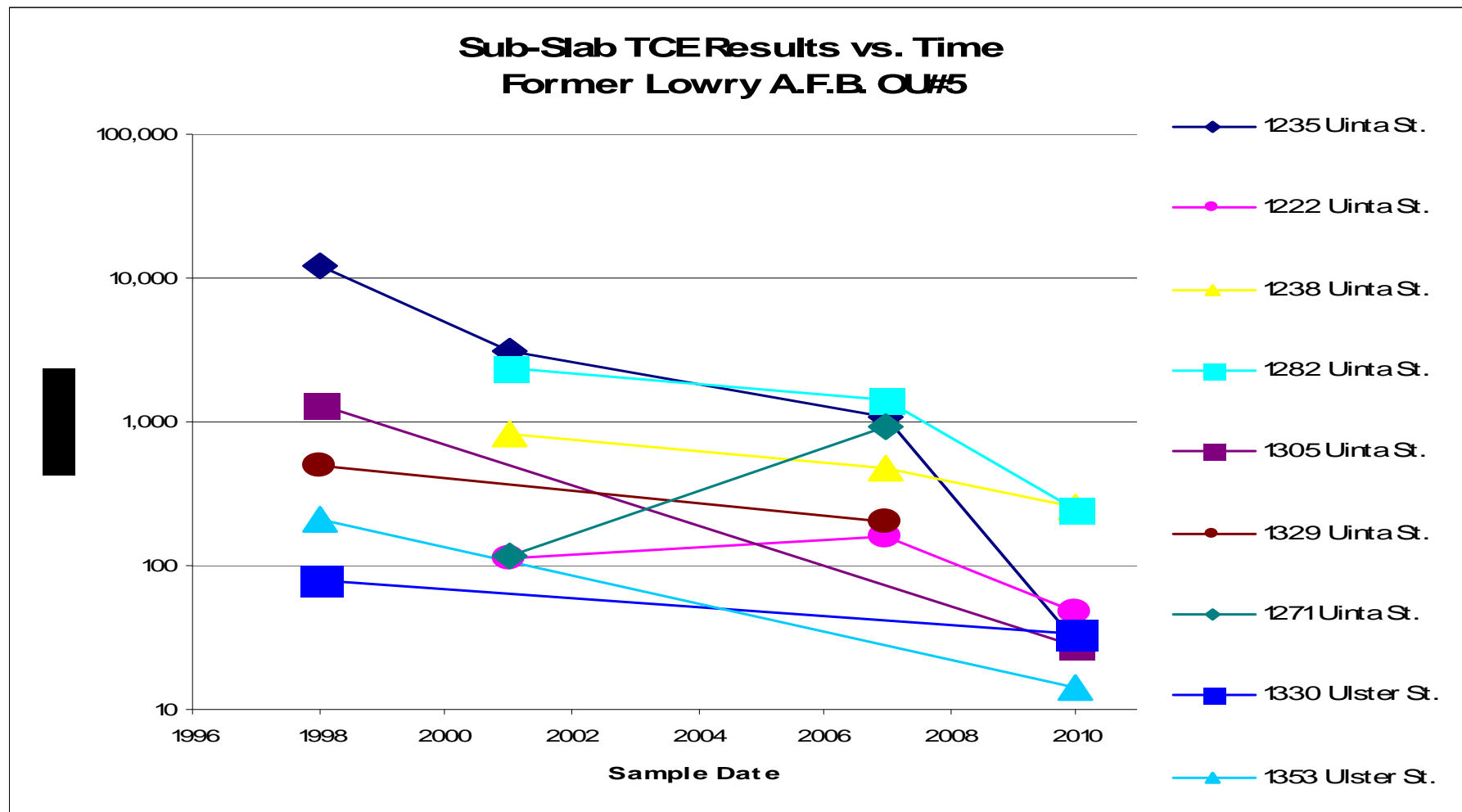


Risk Mitigation: Indoor Air Study Results - GW



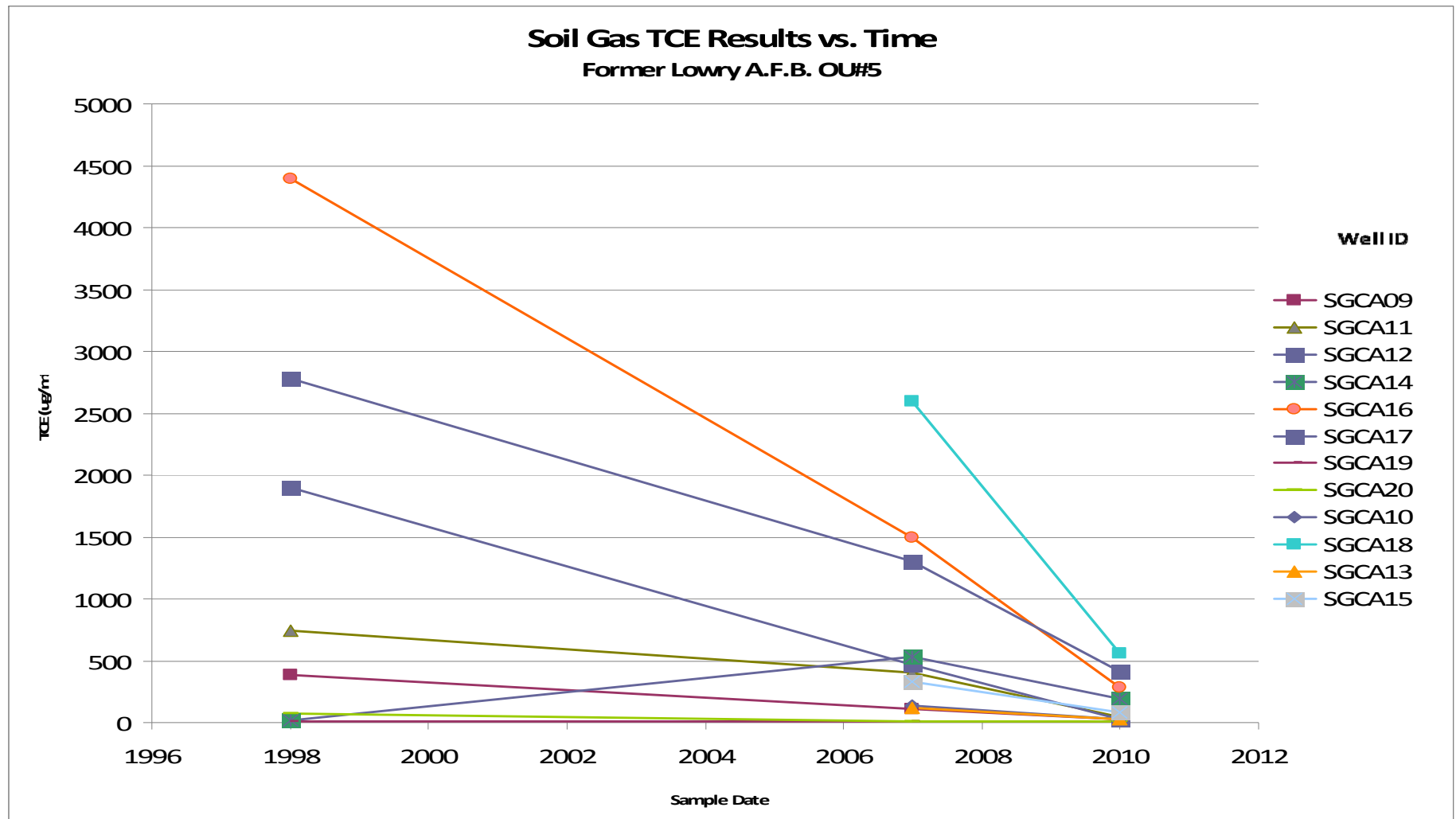


Risk Mitigation: Results of Indoor Air Study



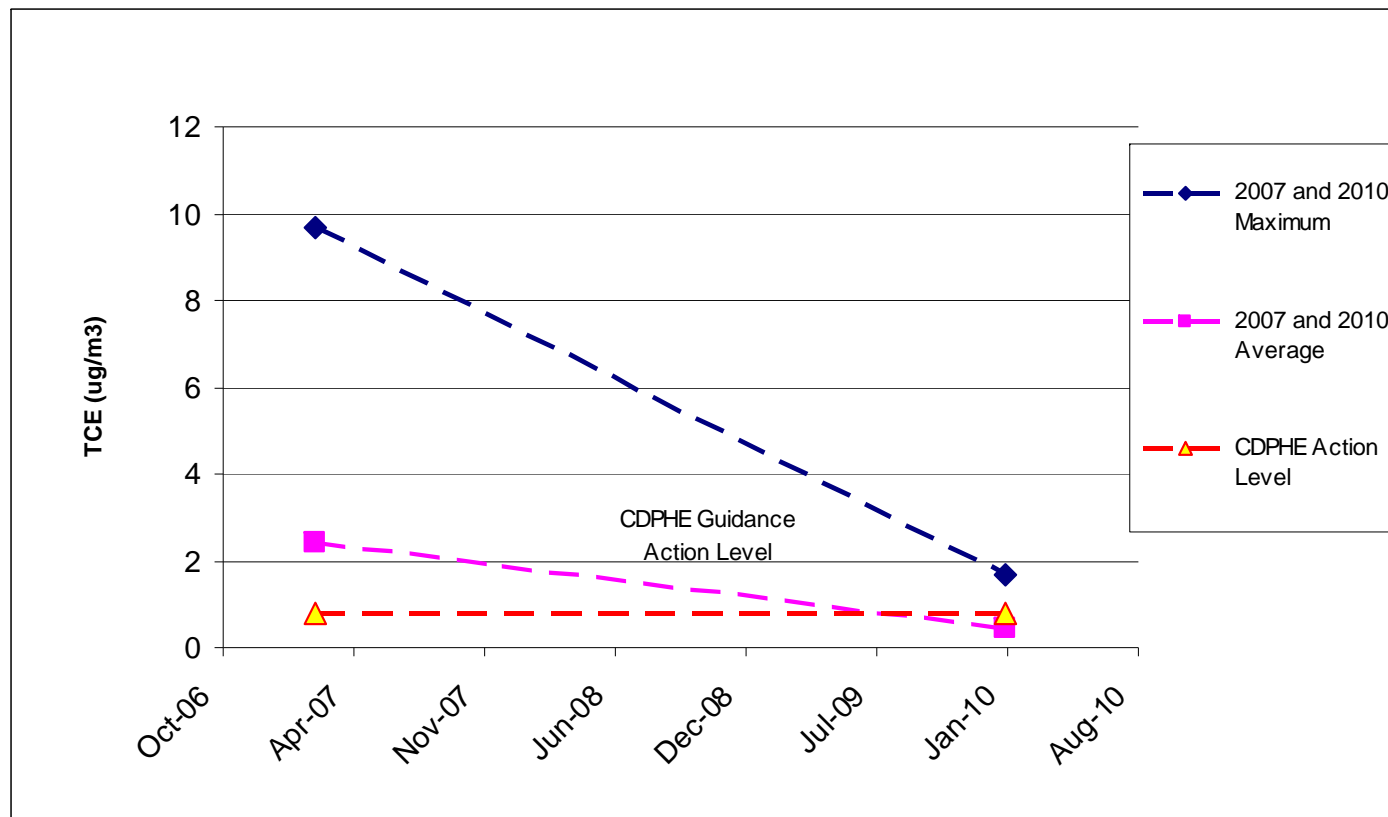


Risk Mitigation: Results of Indoor Air Study





Risk Mitigation: Maximum and Average Indoor Air Concentration Plot





Risk Mitigation: Estimated Indoor Air Values

- Correlation was observed during Indoor Air Study between decreases in groundwater and indoor air concentrations
 - Average decreases of 90% in GW since 2001 gave 75% decrease in indoor air
 - Average decrease of an additional 56% in GW gave an additional 44% decrease in indoor air since 2007 Study
 - Comparisons of trends and percent reductions in TCE over time suggest that sub-slab vapor and indoor air concentration reductions are lagging the reductions in groundwater and soil vapor, as would be expected theoretically due to the transport time of soil vapors from the water table, i.e., deep soil gas to the sub-slab and then indoor air.



2010 Indoor Air Summary

- CDPHE action levels of 0.8 and 1.6 ug/m^3 for indoor air mitigation
- Only two homes had TCE concentrations above 0.8 ug/m^3 ,
- The maximum indoor air TCE concentration in January 2010 was 1.7 ug/m^3 (one house, first floor, basement concentration was 1.6 ug/m^3)
- Samples were collected during the winter, and therefore most likely represent the

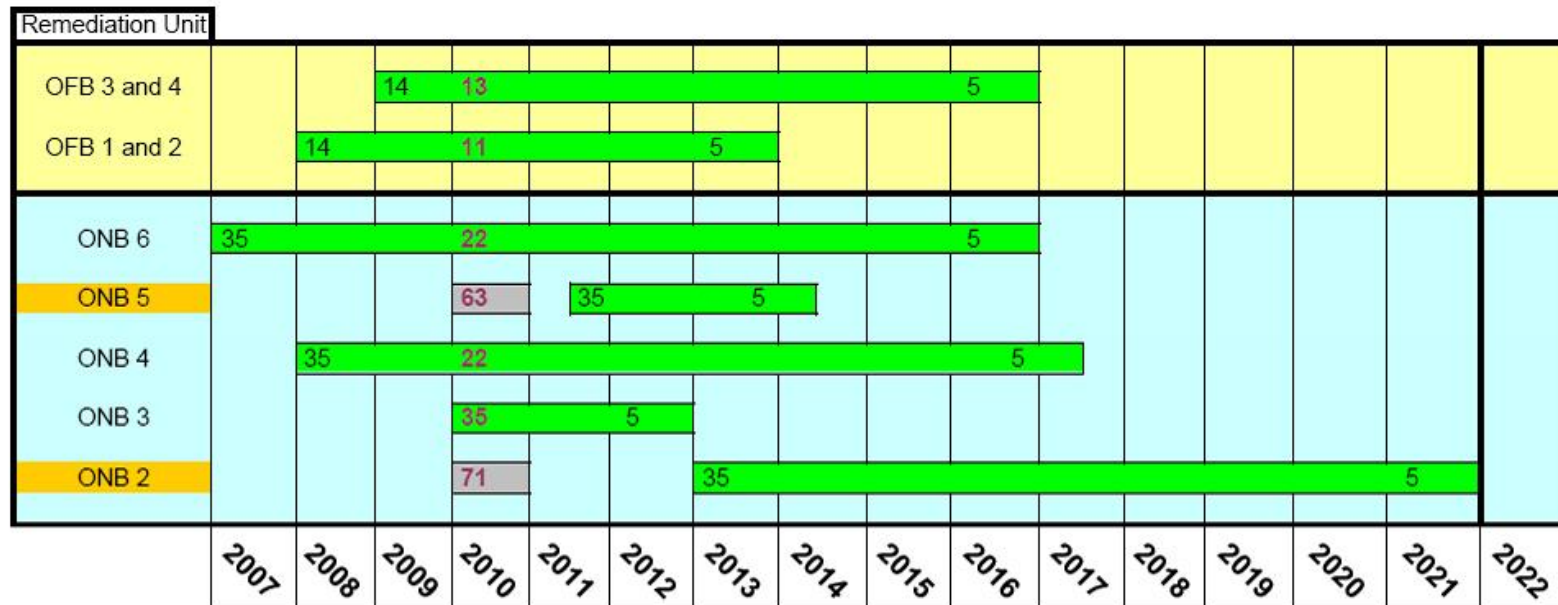


Risk Mitigation: Risk Milestones

- LAC calculated Risk Milestones through use of JE model
 - On-Base Exposure Units
 - Minimum 35 $\mu\text{g/l}$
 - Average 94 $\mu\text{g/l}$
 - Maximum 140 $\mu\text{g/l}$
 - **5th Percentile LCL 35 $\mu\text{g/l}$ (Conservative)**
 - Off-Base Exposure Units
 - Minimum 13 $\mu\text{g/l}$
 - Average 56 $\mu\text{g/l}$
 - Maximum 149 $\mu\text{g/l}$
 - **5th Percentile LCL 14 $\mu\text{g/l}$ (Conservative)**



Estimated Completion Timeframe



Legend

- Risk-based Cleanup Target Zone (Based on JE Model Results and Statutory Limit for TCE)
- 14 - Average TCE Concentration Jan 2010 (µg/L) within Target Zone
- 63 - Average TCE Concentration January 2010 (µg/L) Exceeds Target Zone and Remedial Action Planned
- Institutional Controls to Protect Indoor Air are in Place (Radon Systems/Positive HVAC)
- No Institutional Controls for Indoor Air
- Remediation Units Located Within or Near Source Areas of TCE Plume



Risk Mitigation: Mechanisms Contributing to Observed Progress

Why has Risk Mitigation been Successful?

- KMnO_4 Treatment
- Attenuation
 - Biodegradation/Abiotic Destruction (Likely Minor)
 - Dispersion/Dilution (Likely Secondary Removal Mechanism)
 - Volatilization (Likely Primary Removal Mechanism)
- Interim Actions
 - SARS
 - BAHCS
 - Heritage Estates Soil Vapor Mitigation



Summary: Remedial Progress Assessment for Main Plume

- Remedial Efforts Resulted in Significant Progress Towards Completion:
 - Estimated Avg. Groundwater Concentration Decline = 83 to 95% (Pre-remediation to January 2010)
 - Estimated TCE Mass Removal = 84% (January 2010)
 - Estimated Reduction in Plume Area = 65% (RI vs. January 2010)
 - Estimated Risk Reduction = 94% (RI vs. January 2010)
 - Indoor Air Concentrations are conservative and very close to CDPHE action levels in the Indoor Air Study Area
 - Risk milestones indicate that protection of human health and the environment has been accomplished or will be achieved in a reasonable timeframe in most remedial areas



Summary: Remedial Progress Assessment for Main Plume...con't

- Cumulative Full Scale KMnO_4 Injections:
 - Have been successful in mass removal and concentration reductions
 - Technology showed better success when TCE concentration was high
 - As decline curve flattens out it becomes more difficult to deflect curve
 - KMnO_4 decreased half-life that can be achieved through Attenuation Processes going forward
 - Clay/Silt Recalcitrant Areas and Bedrock remain more difficult to treat
- 2010 Scope of Work



Lowry OU5: 2010 Scope of Work

Path to Completion Begins with 2010 Scope:

- A. Project Management/Database Management
- B. Semi-annual Sampling/GMP
- C. Remedial Progress Assessment
- D. Bos-100 Treatment Carbon Tet Area
- E. Chemical Injection – On-Base Main Plume
- F. HQ & FTZ Plume Area Assessment/Closure
- G. SARS
- H. Indoor Air Study
- I. Well Abandonment
- J. Completion Activities



Lowry OU5: 2010 Scope of Work (con't)

A) Project Management/Database Management

- Continued Efforts to Manage Sub-contractors and Closure
- Management of Data
 - Historical/Current Sampling Data
 - Mapping
 - Trend Analysis for Closure



Lowry OU5: 2010 Scope of Work (con't)

B) Semi-annual Sampling/GMP

–July 2010 Sampling Event

- Includes Main Plume and HQ Plume

–Reporting



Lowry OU5: 2010 Scope of Work (con't)

C) Remedial Progress Assessment

- 2010 Work Resulting From 2010 RPA:
 - Finalize Indoor Air Study Report
 - CT Rebound Assessment and Treatment
 - BOS-100 Treatment to Address Localized Rebound
 - Main TCE Plume
 - KMnO₄ Treatment for Recalcitrant On-base Hot Spot Areas
 - Develop Lines of Evidence to Support Completion
 - Risk/Concentration Decline Model
 - Alternative Concentration Limits
 - Indoor Air Protection
- Ongoing Assessment of July 2010 Data



Lowry OU5: 2010 Scope of Work (con't)

D) Planned 2010 Treatment CT

- BOS 100[®] Carbon Tetrachloride Area
 - Work Plan Fall 2010
 - Field Injection Activities
 - Monitoring



Lowry OU5: 2010 Scope of Work (con't)

E) Chemical Injection – Main Plume

- Northern Off-site Plume (OFB1 through OFB4): No Treatment Planned
 - Assessment 2009 KMnO_4 Treatment
- ONB-6: Hot Spot Treatment
 - KMnO_4 Treatment Alluvium (33,600 lbs)
 - Approximately 100 KMnO_4 Injections
- ONB-5: Hot Spot Treatment
 - KMnO_4 Treatment Alluvium (16,800 lbs)
 - Approximately 50 KMnO_4 Injections



Lowry OU5: 2010 Scope of Work (con't)

E) Chemical Injection – Main Plume (con't)

- ONB-4: Hot Spot Treatment
 - KMnO_4 Treatment Alluvium (25,200 lbs)
 - Approximately 75 KMnO_4 Injections
- ONB-3: No Remedial Activity Planned
- ONB-2: Hot Spot Treatment
 - KMnO_4 Treatment Alluvium (33,600 lbs)
 - Approximately 100 Injection Points
- ONB-1: No Remedial Activity Planned
 - Assessment 2009 KMnO_4 Treatment



Lowry OU5: 2010 Scope of Work (con't)

F) Remedial Activity - HQ & FTZ Plumes

- HQ Assessment of 2009 KMnO_4 Treatment
(July 2010)

- No Anticipated Remedial Activity Going Forward
- Assess Closure Options

G) Remedial Activity – SARS

- Address Southern Portion of SARS with
BOS100



Lowry OU5: 2010 Scope of Work (con't)

H) Indoor Air/Risk Assessment Activities

- Indoor Air Report
 - Complete Report
 - Response to Comments
- Develop Risk/Attenuation Model
 - Baseline Risks from Previous Work
 - Risk/Indoor Air Association
 - Acceptable Exposure Point Concentration
 - Estimated Exposure Timeframe to Completion



Lowry OU5: 2010 Scope of Work (con't)

I) Well Abandonment

- Well Abandonment Fieldwork
- Approximate Number of Wells: 37

J) Closure Activities

- Completion Report To be Submitted
 - Based on FOSET Areas
 - ONB1-6
 - NW Neighborhood
 - Northern Off-site Plume
 - FTZ Plumes
 - HQ Plume