


In Situ Bioventing Performance In Presence of Mixed Suite of Aerobically and Anaerobically Degradable Hydrocarbons

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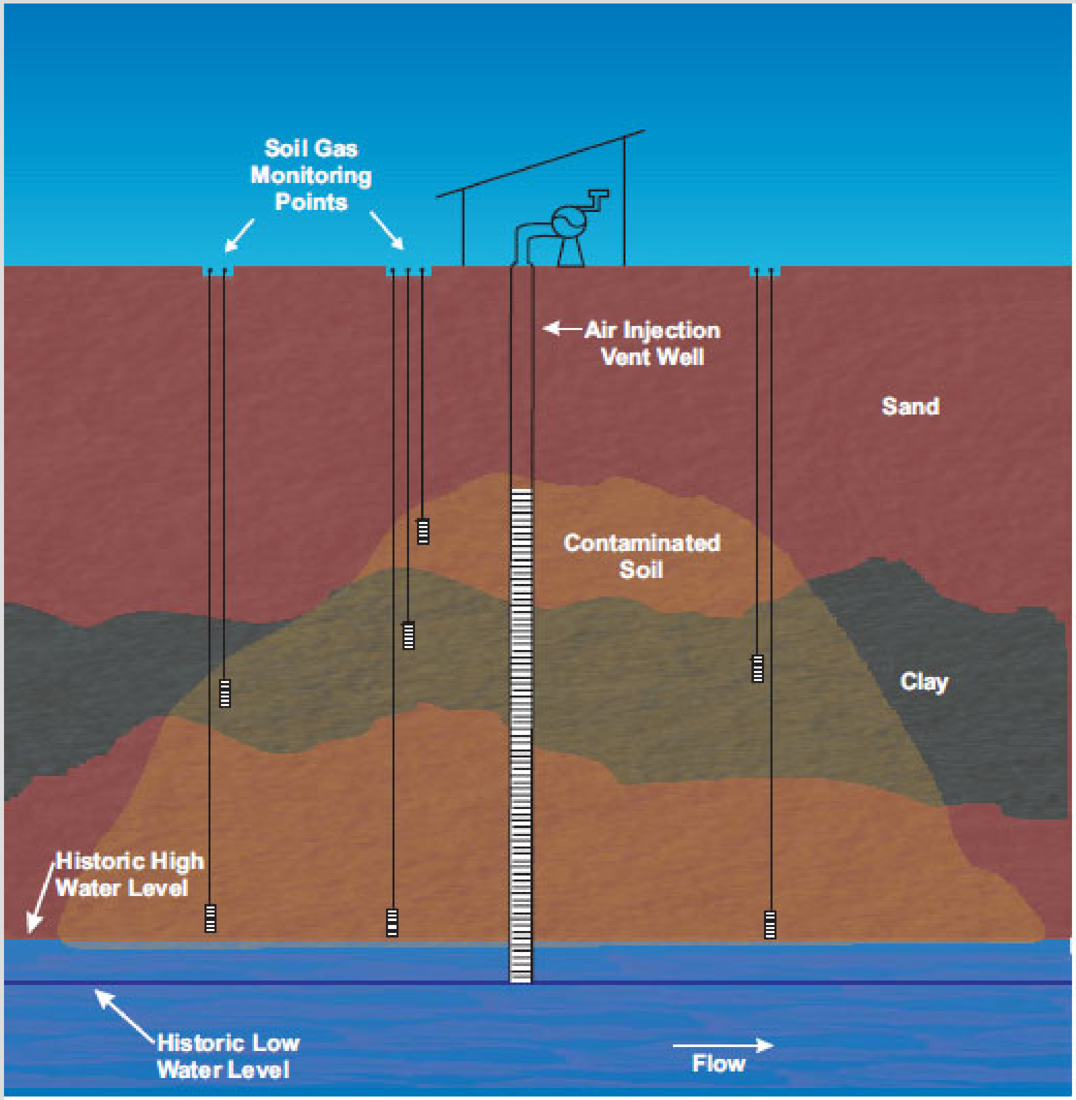
Bioventing Fundamentals

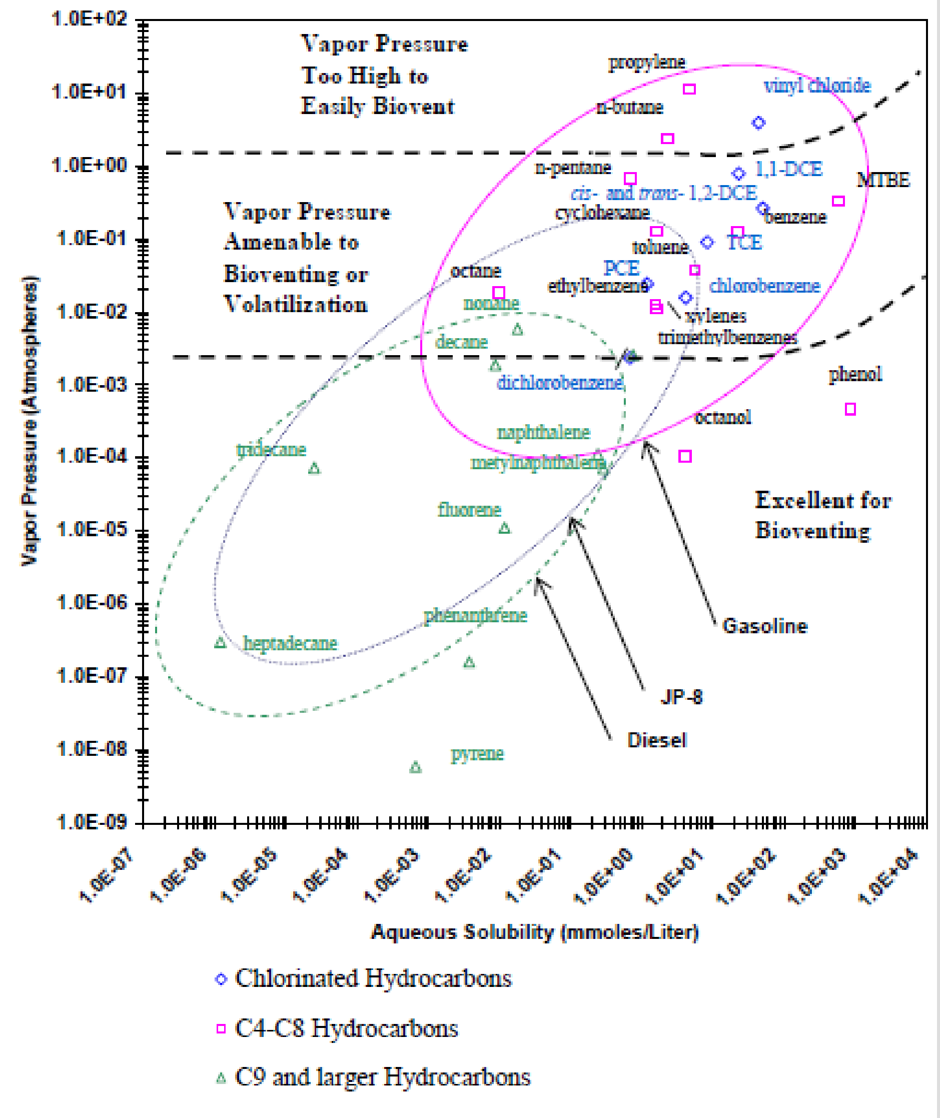
- Process of aerating soils to add oxygen to stimulate *in situ* biodegradation of wide-range of Hydrocarbons (HCs)
- As opposed to drawing vacuum with SVE, relies on injection of air into subsurface
- Operating at low air movement (pressure and injection rate) to minimize volatile migration or emissions



AFCEE (May 2004), Procedures for Conducting Bioventing Pilot Tests and LTM Bioventing Systems

Bioventing Fundamentals (cont'd)

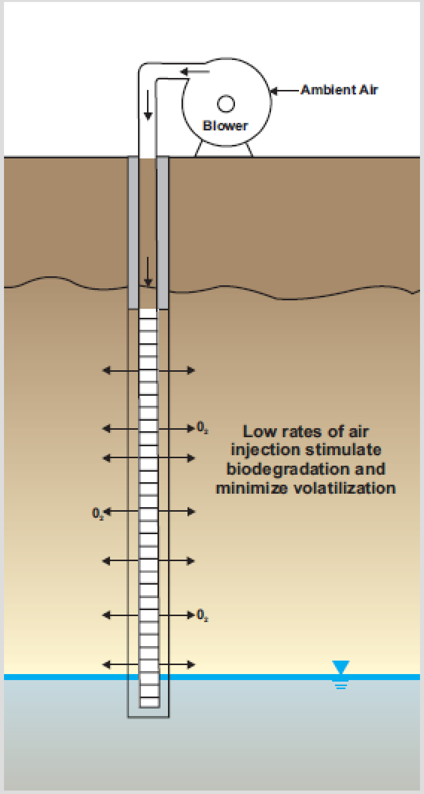
- Best suited for petroleum HCs with greater than 8 carbon atoms
  - Jet Fuels
  - Diesel
  - Heating Oil
- Amenable to aerobically degradable HC compounds with moderately low vapor pressure
  - Alkanes (C8+)
  - Aromatics
  - Chlorobenzene
  - Some Ketones
  - Others



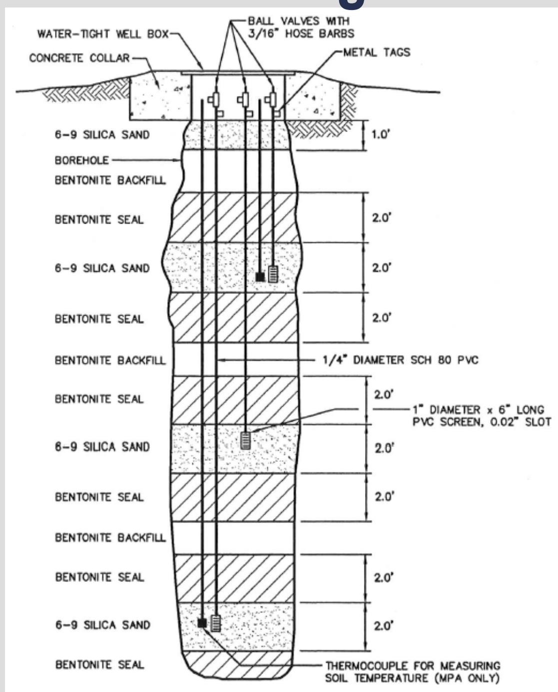
AFCEE (May 2004), Procedures for Conducting Bioventing Pilot Tests and LTM Bioventing Systems

Respirometry Testing

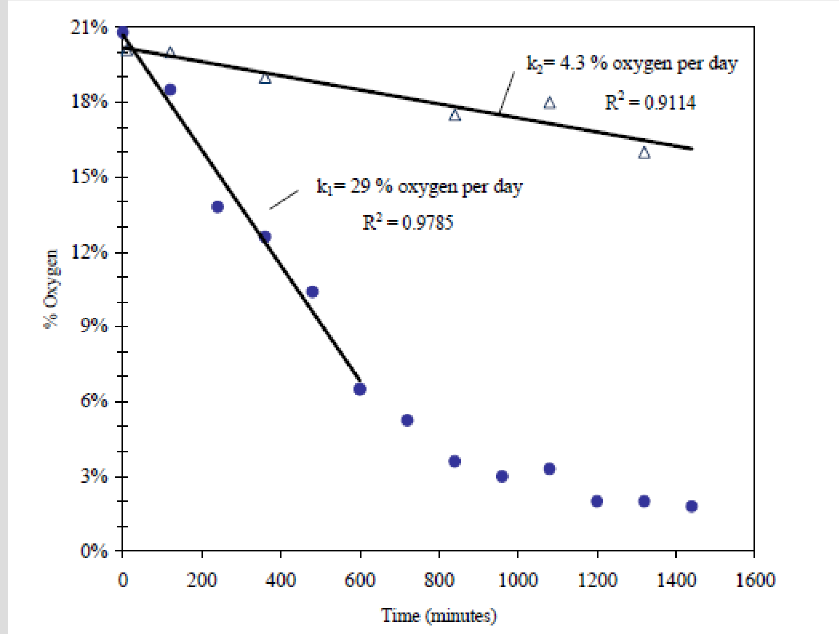
Blower Shutdown



Respirometry Testing



Oxygen Utilization Rates



$$k_B = \frac{-k_o}{100}\,\frac{\theta_a\,\rho o_2\,C}{(\rho_k)}$$

where:

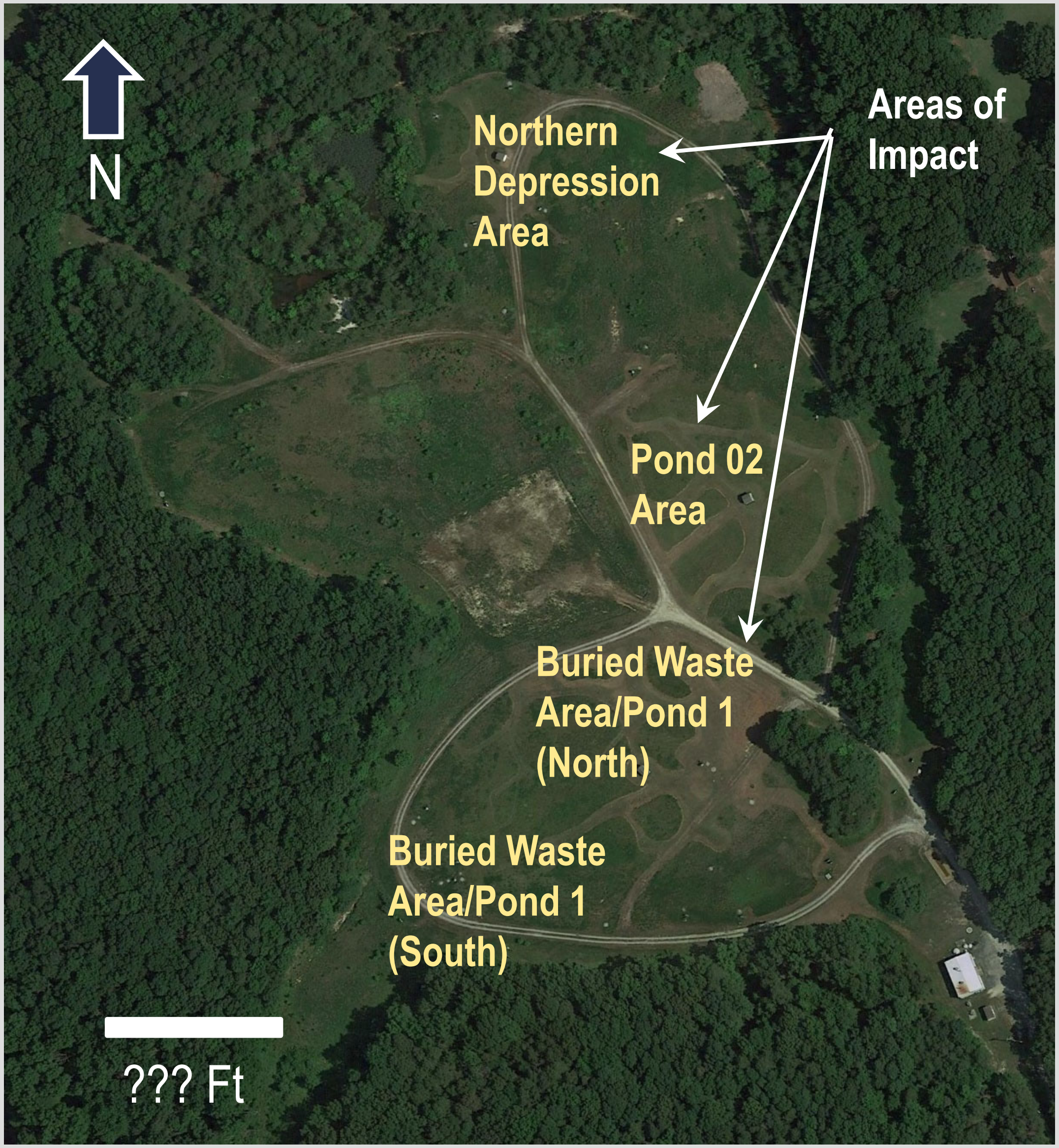
- k_o = the rate of oxygen utilization (% oxygen/day)
- θ_a = the gas-filled porosity of the soil (unitless)
- ρ_{O2} = oxygen density (mg/L)
- ρ_k = the soil bulk density (g/cm^3)
- C = hydrocarbon to oxygen ratio (1/3.5 or .29)
- **k_B** = the rate of hydrocarbon biodegradation (mg TPH/kg soil/per day)

- Rarely is Bioventing performance evaluated by comparing k_O or k_B to individual COC degradation rate estimates

AFCEE (May 2004), Procedures for Conducting Bioventing Pilot Tests and LTM Bioventing Systems

Site Background

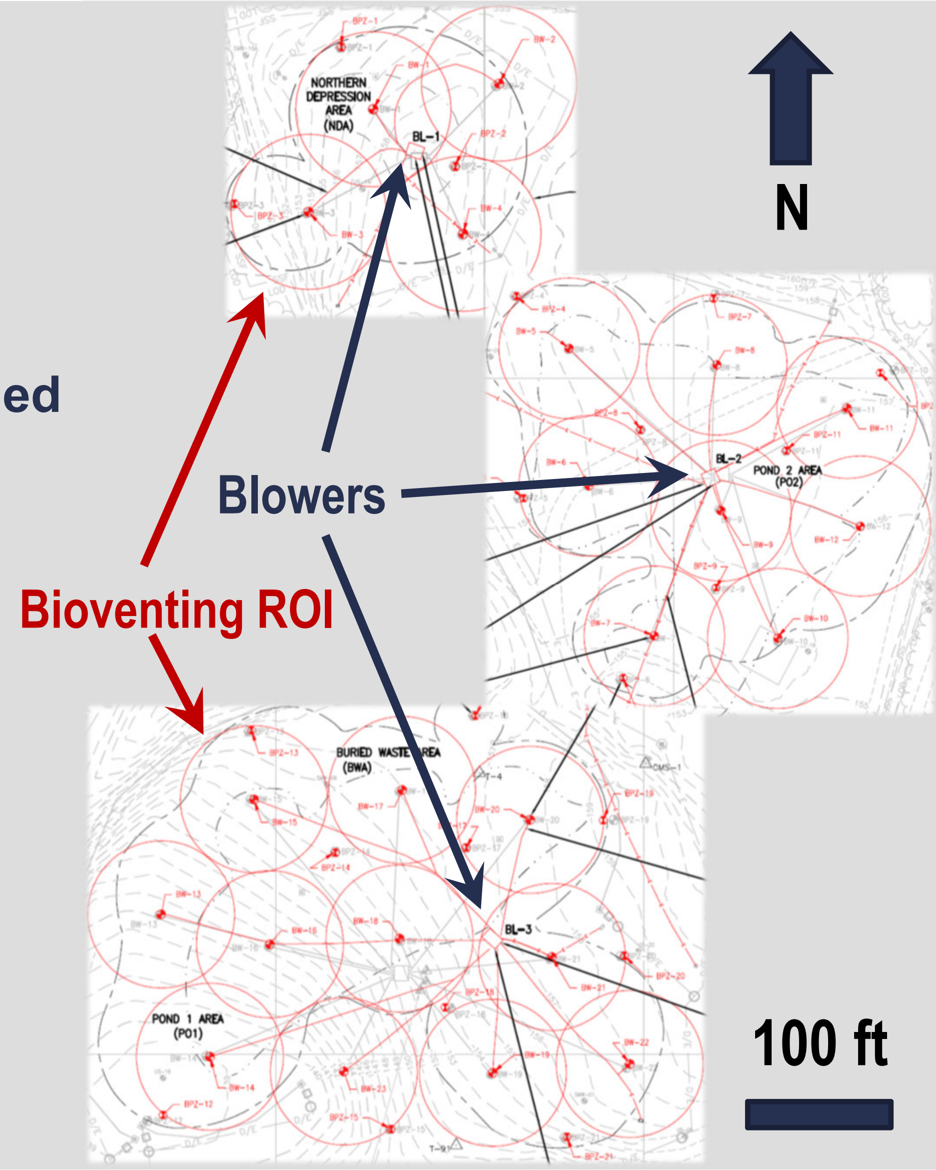
- **Former Sand and Gravel Quarry (NPL Site)**
- **Unpermitted Dumping of Drums and Industrial Waste**
- **COCs: VOCs, SVOCs, Metals, PCBs**
- **3 Treatment Areas: ~15 acres**
- **Remedial Approach**
  - **Principal Threat Materials – 10^{-4} Risk or Greater**
    - **Liquid Waste Removal (completed in 1976)**
    - **Buried Drum Removal (completed in 1992)**
    - **Excavation/Thermal Treatment (completed in 2010)**
  - **Low-Level Threat Materials – 10^{-4} to 10^{-6} Risk**
    - **Bioventing (completed in 2017)**
    - **Anaerobic Bioremediation (Future)**



Bioventing Summary

- **System Components**
  - 3 Blowers with VFDs
  - 21 Bioventing wells (50 foot ROI)
    - Some nested w/ different screened intervals
  - 27 Monitoring points (1-in. piezometers) with varying screened intervals in homogeneous sand aquifer

- **System Operation**
  - Flow: 11 to 18 cfm per well
  - Pressure: 10 to 30 in. H_20
  - Alarm (High Temp and Pressure) / Radio
  - Full-time operation (except during respiration testing)
  - Duration: 2011 - 2016



Site COCs That Primarily Aerobically Biodegrade

Contaminants of Concern (COCs)	Molecular Weight (g/mole)	Aerobic Biodegradation Half Life* (days)	1st Order Aerobic Biodegradation Rate (1/days)
1,4-Dichlorobenzene	147	42	0.0165
Benzene	78	13	0.0533
Chlorobenzene	113	143	0.0048
Toluene	92	15	0.0478
Methylene Chloride	85	42	0.0165
Vinyl Chloride	62	118	0.0059

*Suthersan S.S., 1997. Remediation Engineering Design Concepts, CRC Press, Boca Raton, FA.

Site COCs That Primarily Anaerobically Biodegrade

Contaminants of Concern (COCs)	Molecular Weight (g/mole)	Aerobic Biodegradation Half Life* (days)	1st Order Aerobic Biodegradation Rate (1/days)
1,1,1-Trichloroethane**	133	207	0.0034
1,1-Dichloroethane**	99	105	0.0066
1,1-Dichloroethene**	97	156	0.0044
1,2-Dichloroethane**	99	140	0.0050
Carbon Tetrachloride**	154	360	0.0019
Chloroform**	119	118	0.0059
Cis-1,2-Dichloroethene**	97	118	0.0059
Tetrachloroethene**	166	360	0.0019
Trichloroethene**	131	341	0.0020

*Suthersan S.S., 1997. Remediation Engineering Design Concepts, CRC Press, Boca Raton, FA.

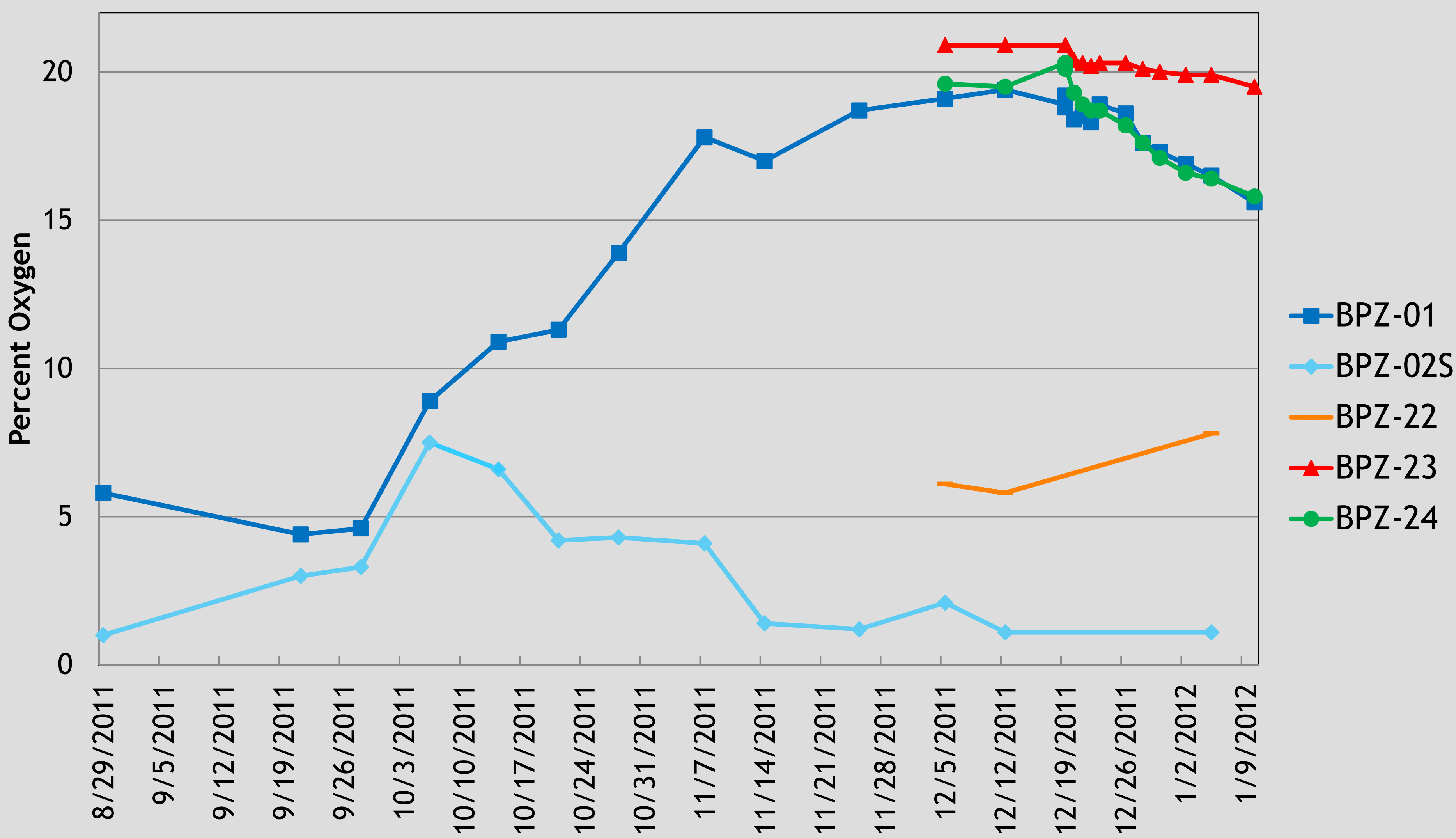
**COCs biodegrading faster under anaerobic than aerobic conditions.

Baseline Evaluation

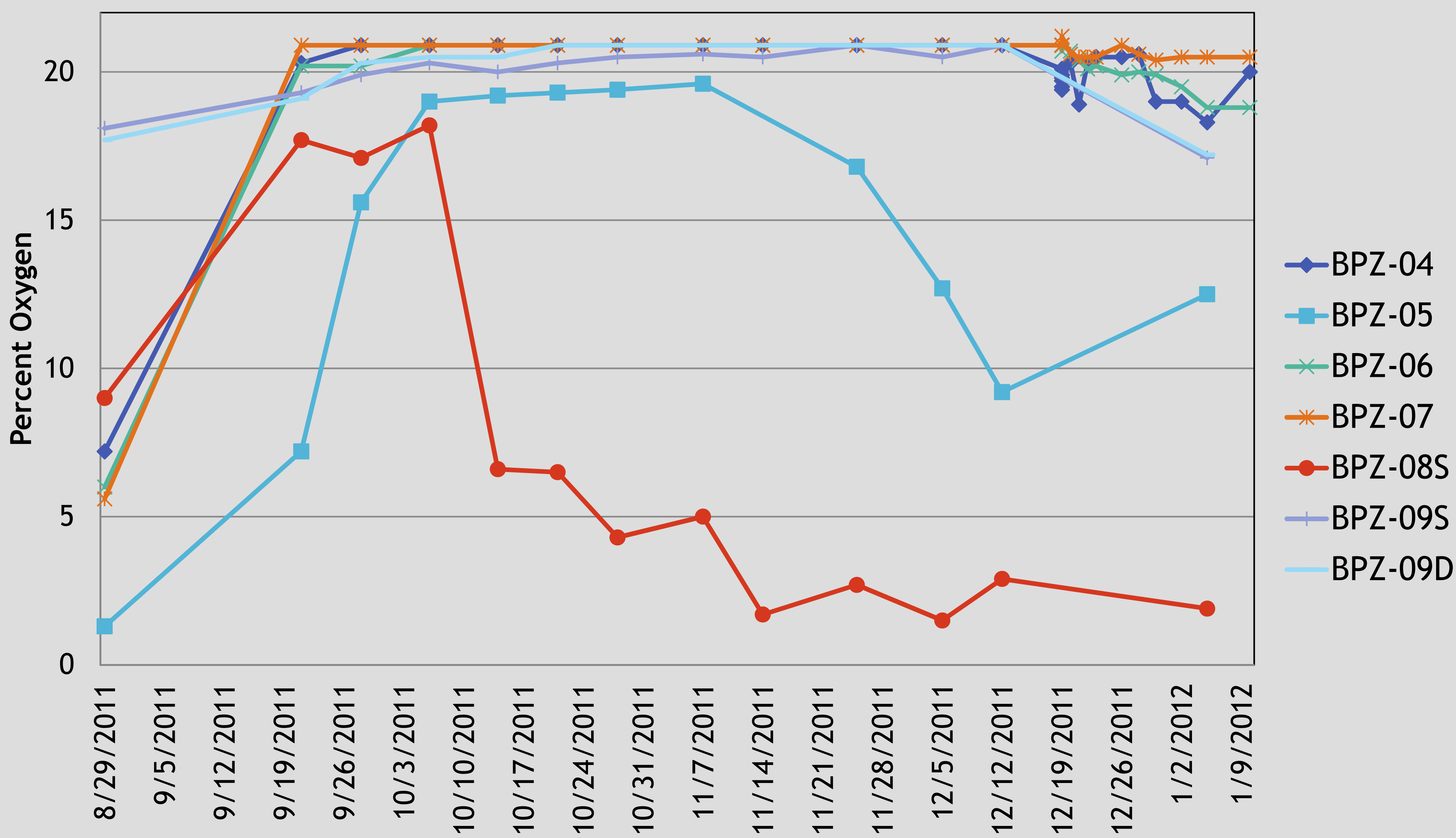
- Baseline O_2 Concentrations
  - Active Biodegradation Areas vs Non-Active Biodegradation Areas
- O_2 vs CO_2 Relationship
  - Low O_2 corresponding to high CO_2
  - High O_2 corresponding to low CO_2
- Total VOCs vs O_2 and CO_2 Concentration
  - Distinctive patterns not apparent excepting a few locations:
    - BPZ-10 (high TVOCs, low O_2)
    - BPZ-14S (low TVOCs, higher O_2)

Location	TVOC (ppm)	CO2 (%)	O2 (%)
BPZ-1	264	>5.0	5.8
BPZ-2S	26.4	>5.0	1
BPZ-2D	NC	NC	NC
BPZ-3	NC	NC	NC
BPZ-4	9.4	>5.0	7.2
BPZ-5	49.9	>5.0	1.3
BPZ-6	100	>5.0	6
BPZ-7	32.5	>5.0	5.6
BPZ-8S	25.7	>5.0	9
BPZ-8D	NC	NC	NC
BPZ-9S	29.6	1.78	18.1
BPZ-9D	28.8	2.19	17.7
BPZ-10	273	>5.0	0.4
BPZ-11S	61.8	3.96	16.9
BPZ-11D	55.1	3.82	16.4
BPZ-12	85.8	>5.0	0.3
BPZ-13	29.5	>5.0	1.9
BPZ-14S	17	3.72	16.4
BPZ-14D	NC	NC	NC
BPZ-15	115	>5.0	1.6
BPZ-16	85.5	>5.0	2.1
BPZ-17S	25.4	3.51	17.6
BPZ-17D	NC	NC	NC
BPZ-18	58.9	2.73	17.2
BPZ-19	57.6	>5.0	8.6
BPZ-20	13.8	>5.0	3.9
BPZ-21	11.8	>5.0	2.3

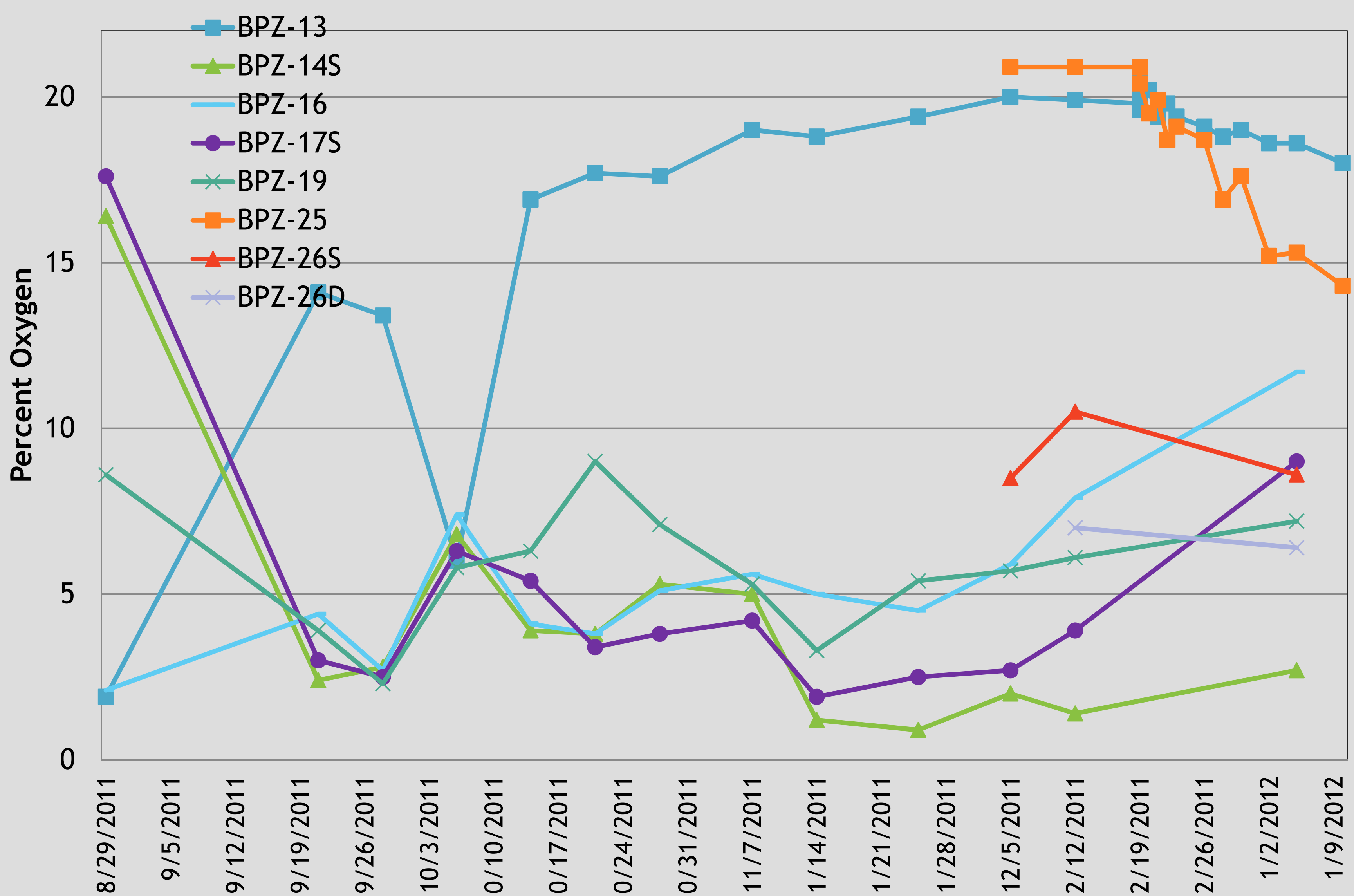
Northern Depression Area
Percent Oxygen vs Time



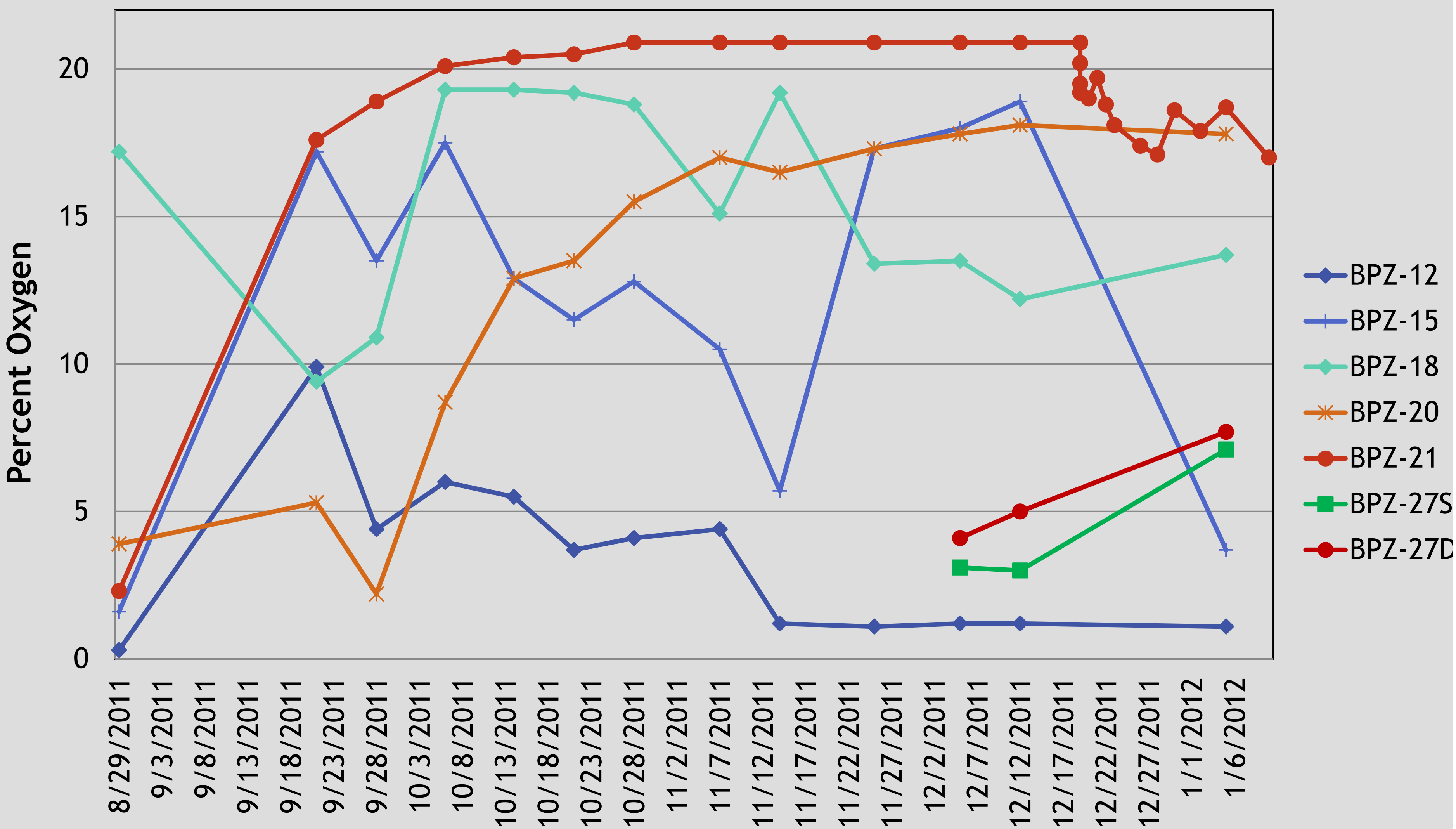
Pond 02 Area
Percent Oxygen vs Time



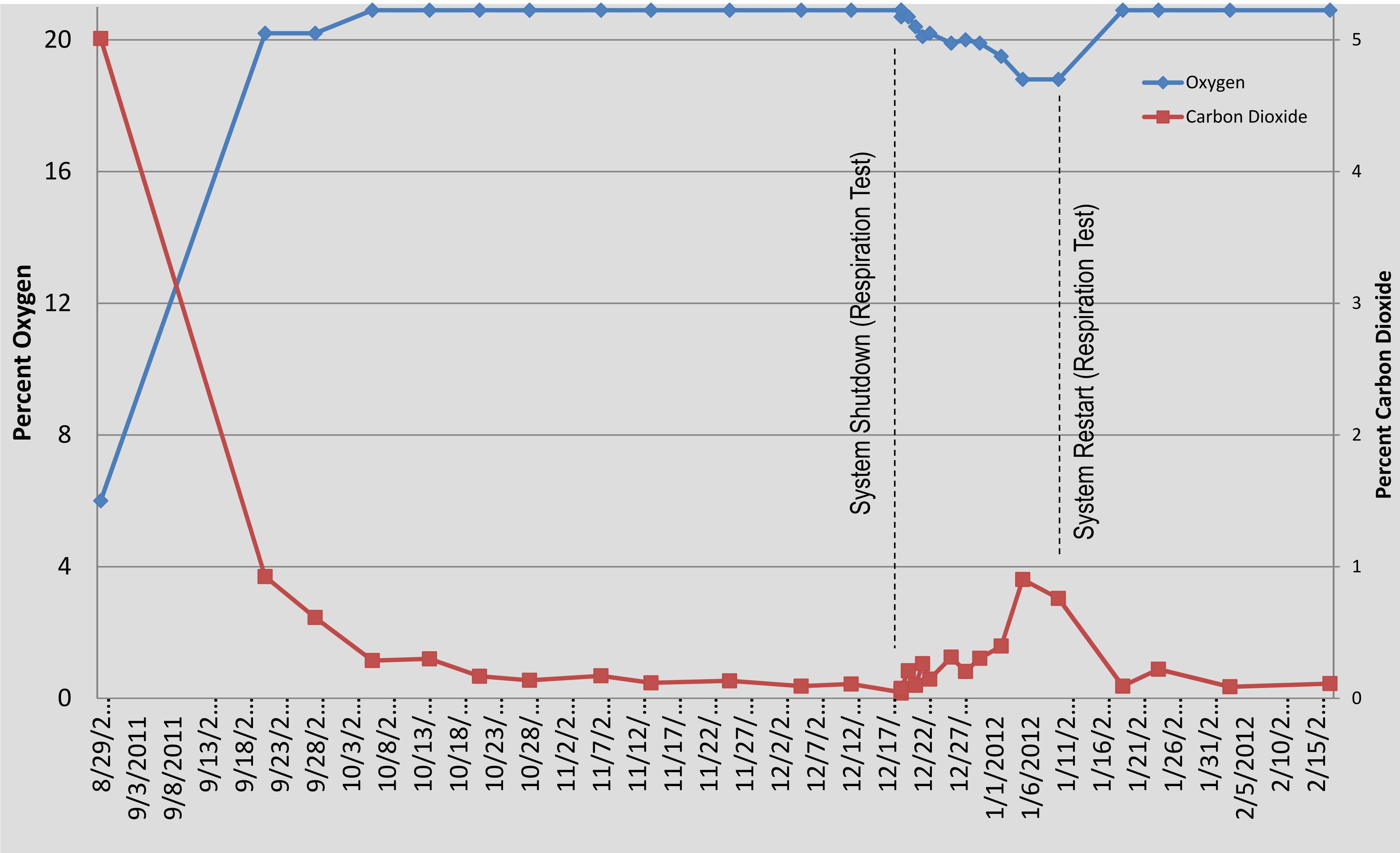
Buried Waste Area/Pond 01 (North)
Percent Oxygen vs Time



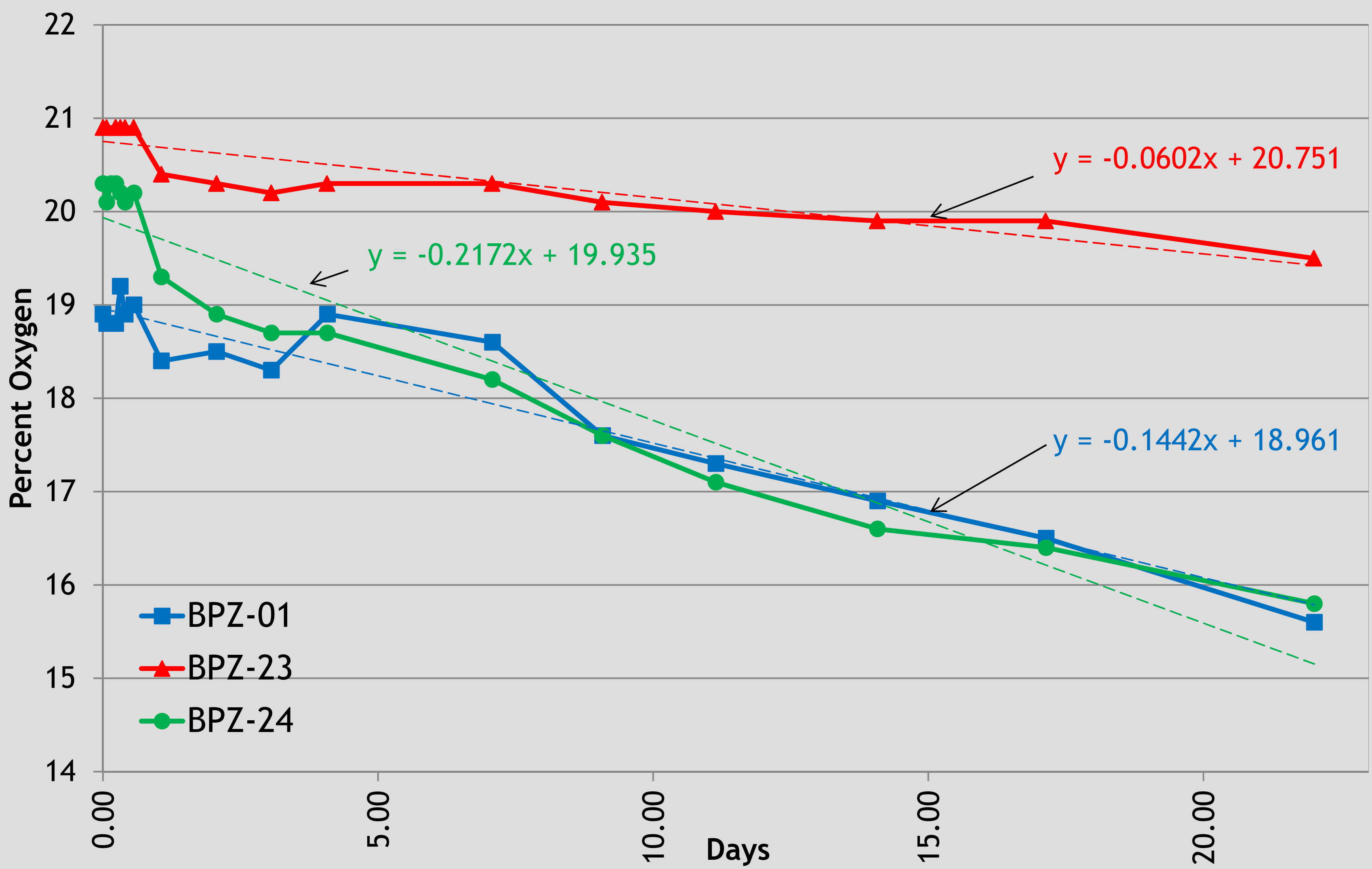
Buried Waste Area/Pond 01 (South)
Percent Oxygen vs Time



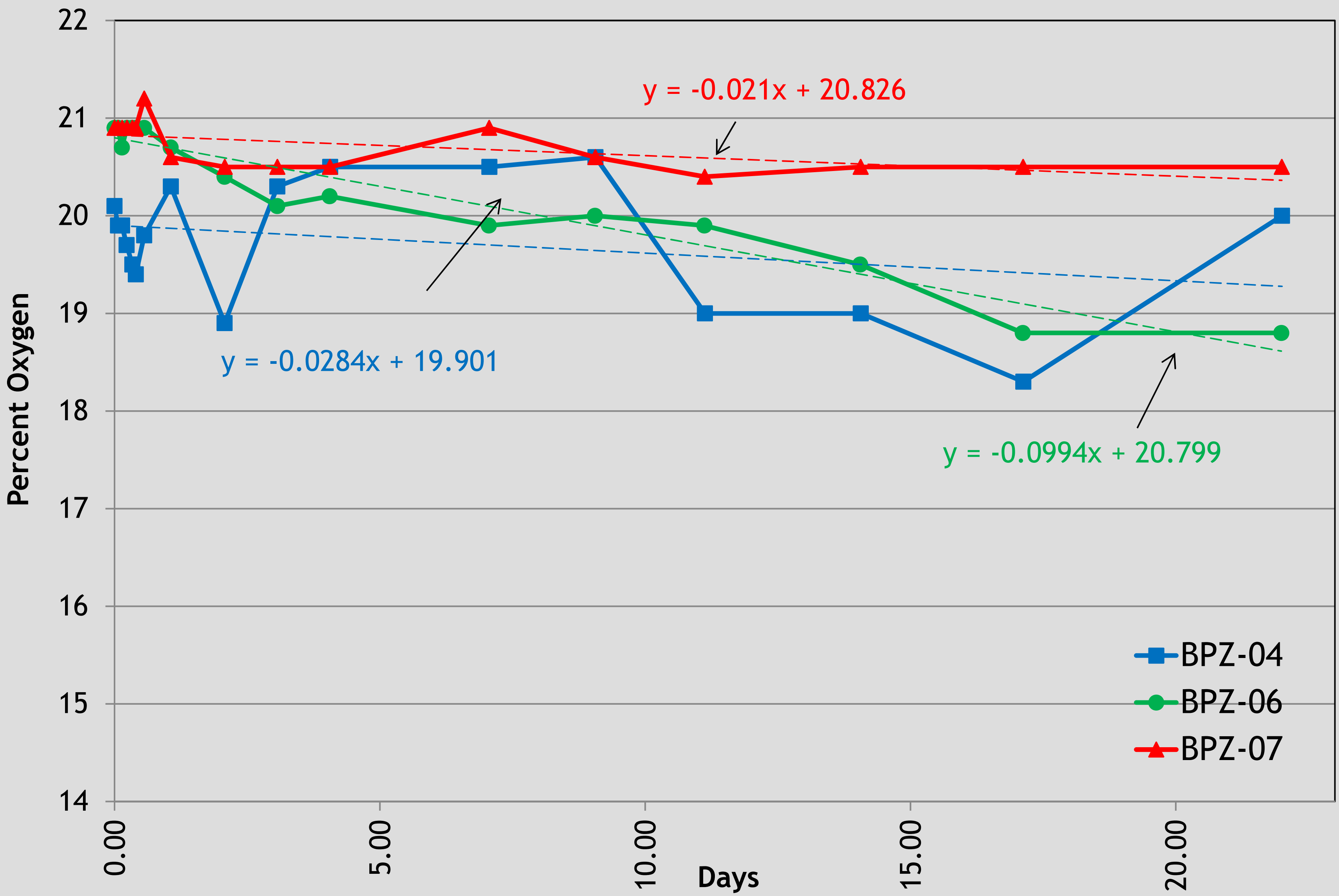
BPZ-06 (Pond 02 Area)
Percent Oxygen and Carbon Dioxide vs Time



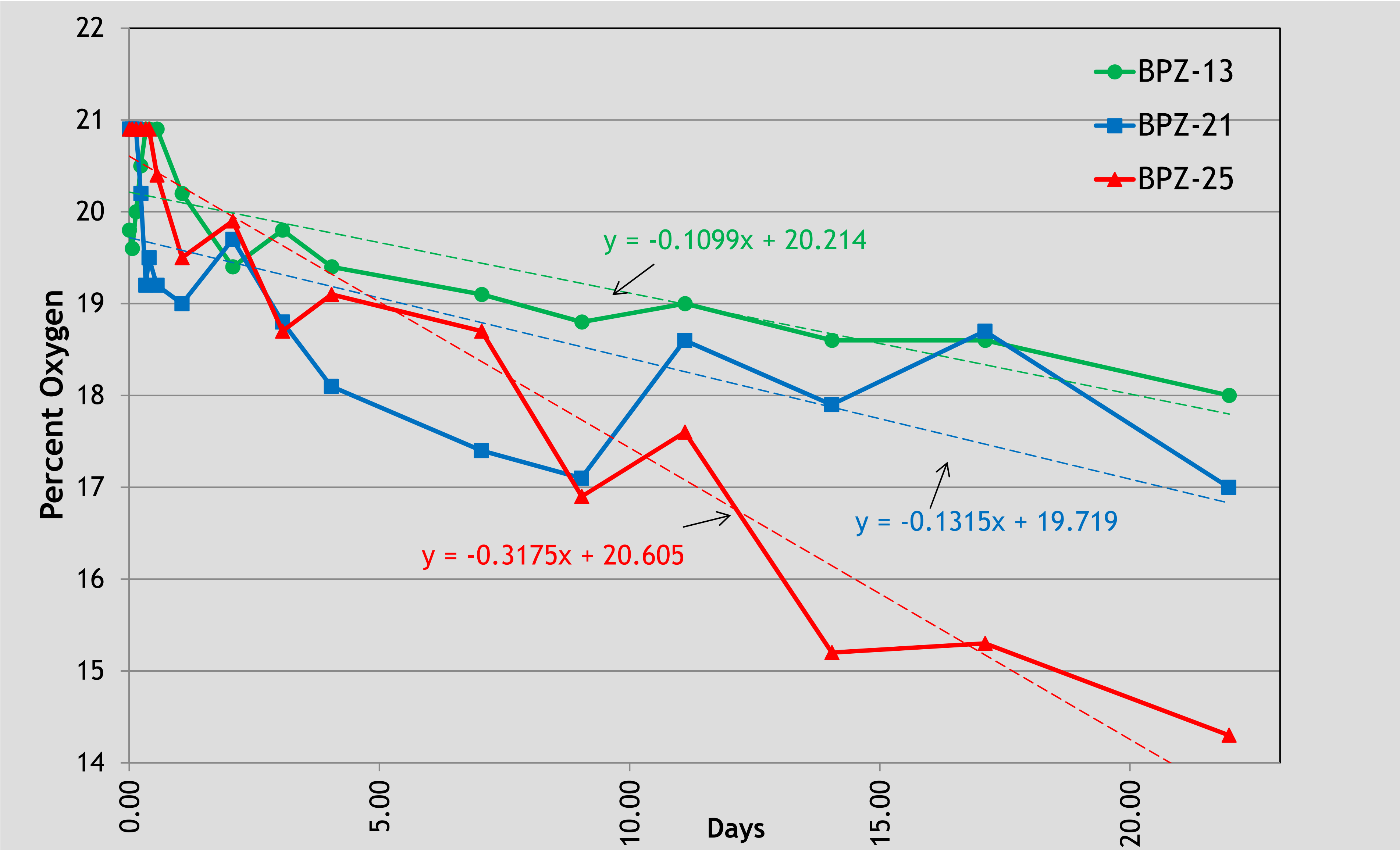
NDA Oxygen Utilization
December 2011 Respirometry Test



P02 Oxygen Utilization
December 2011 Respirometry Test



BWA/P01 Oxygen Utilization
December 2011 Respirometry Test



In Situ Oxygen Utilization Rates[1]

	NDA (%/day)	PO2 (%/day)	BWA/PO1 (North) (%/day)	BWA/PO1 (South) (%/day)	Background (%/day)
Range of % O_2 Utilization Rate	-2.1 to -0.03	-2,4 to -0.015	-1.03 to -0.01	-0.95 to -0.0012	-0.56 to 0
Average of % O_2 Utilization Rate	-0.36	-0.22	-0.16	-0.26	0

Overall Average Oxygen Utilization Rate[2] = -0.25%/day

1. Oxygen Utilization Rates measured from March 2014 through September 2015
2 . Average Utilization Rate without background

Site-Specific Oxygen Utilization Rate

$$k_B = \frac{-k_o}{100} \frac{\theta_a \rho o_2 C}{(\rho_k)}$$

where:

k_o = the rate of oxygen utilization (% oxygen/day)

θ_a = the gas-filled porosity of the soil (unitless)

ρ_{O2} = oxygen density (mg/L)

ρ_k = the soil bulk density (g/cm^3)

C = hydrocarbon to oxygen ratio (1/3.5 or .29)

k_B = the rate of hydrocarbon biodegradation (mg TPH/kg soil/per day)

θ_a	ρ_{O2}	ρ_k	C
0.25	1300	1.8	0.29

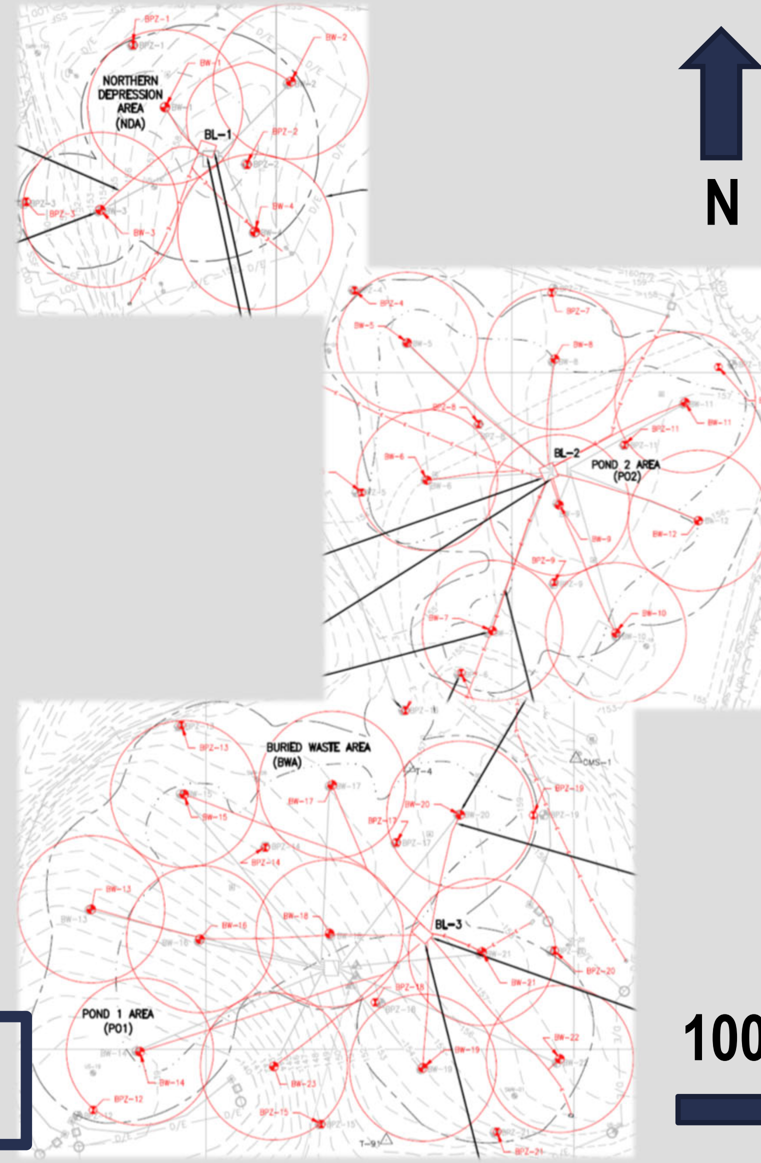
	k_O	k_B
NDA	-0.36	-0.19
PO2	-0.22	-0.12
BWA/PO1 (N)	-0.16	-0.08
BWA/PO1 (S)	-0.26	-0.14
Avg	**-0.25**	**-0.13**

Overall K_B= -0.13 mg Hydrocarbons (HCs)/kg soil/per day

Estimated Mineralized HCs

- **NDA**
  - Soil Volume = 480,000 cu ft
  - Soil Mass = 20,784,000 Kg
  - HCs Mineralized = 7,069 Kg
- **PO2**
  - Soil Volume = 870,000 cu ft
  - Soil Mass = 37,671,000 Kg
  - HCs Mineralized = 7,920 Kg
- **BWA/PO1**
  - Soil Volume = 1,050,000 cu ft
  - Soil Mass = 45,465,000 Kg
  - HCs Mineralized = 2,489 Kg

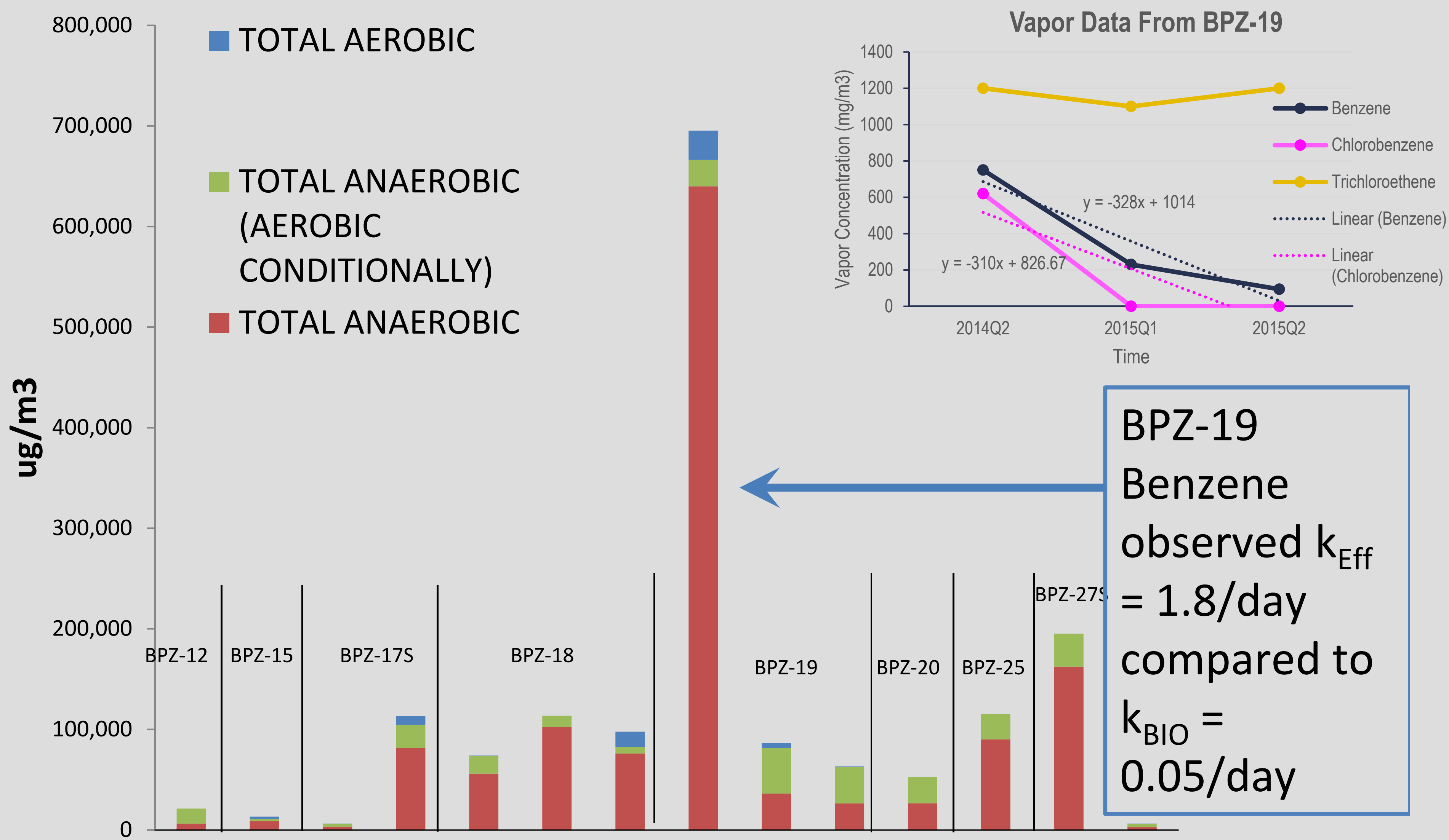
Total HCs Mineralized = 17,479 Kg



N

100 ft

Trends of Aerobically and Anaerobically Degradable HCs in Vapor Samples from BWA/PO1



BPZ-19 Benzene observed k_{Eff} = 1.8/day compared to k_{BIO} = 0.05/day

Conclusions

- ✓ Although Oxygen Utilization Rates are often used to empirically calculate Hydrocarbon Degradation Rates, many bioventing actions are not planned to confirm these conclusions with temporal soil and/or groundwater analytical data.
- ✓ Percent Oxygen Utilization of Hydrocarbons is expected to be low for Sites undergoing prior cleanup with thermal treatment.
- ✓ Even for homogeneous aquifer settings, *in situ* bioventing performance, as measured by Oxygen Utilization via Respirometry, can be highly variable.
- ✓ Effective decay constants (K_{eff}), as expected, are observed to be higher than literature-based biodegradation rate constants because they incorporate additional processes including volatilization and vapor dispersion.

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