SULFATE, MAGNETITE, SHEEP, AND CHLORINATED SOLVENT BIOREMEDIATION: BIODEGRADATION OF TCE IN A HIGH SULFATE FRACTURED BEDROCK ENVIRONMENT

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ACKNOWLEDGMENTS

- US EPA - Isabel Fredricks, RPM
- CDM Smith – Dr. Patrick Evans, Joseph Mayo, and others

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PRESENTATION OUTLINE

Site Description

Iron and sulfate Geochemistry

Background Lab Studies

Pilot Test Design & Implementation

Results

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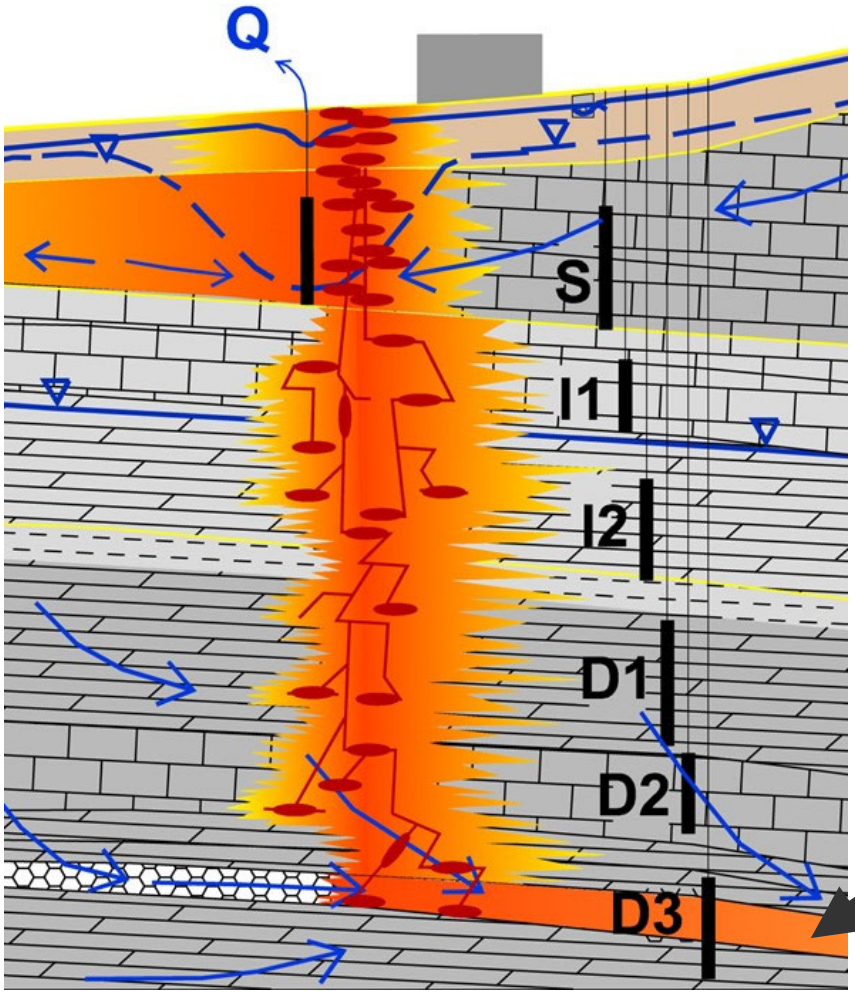
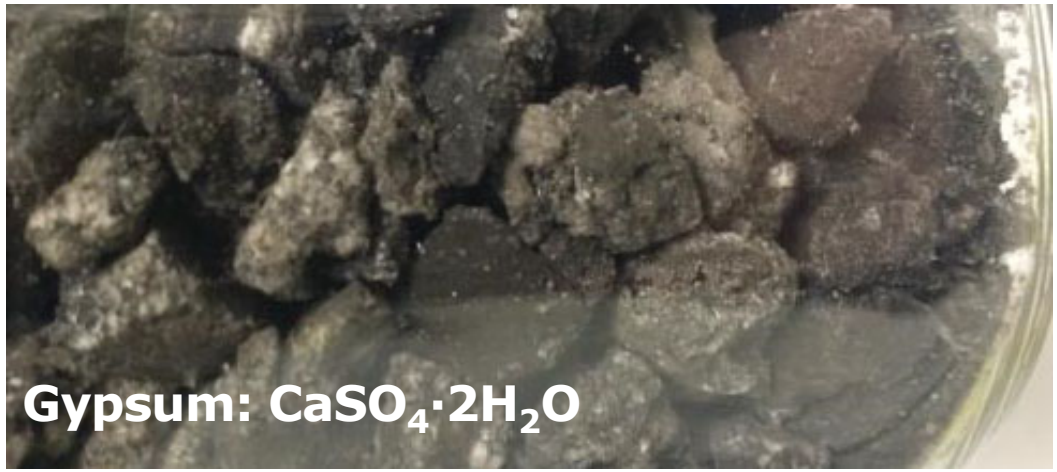
SITE DESCRIPTION

- Former plant site
- Electrical components manufactured from 1951-1990
- 55 acre site
- Storage and disposal of waste solvents (TCE, acetone, methanol)

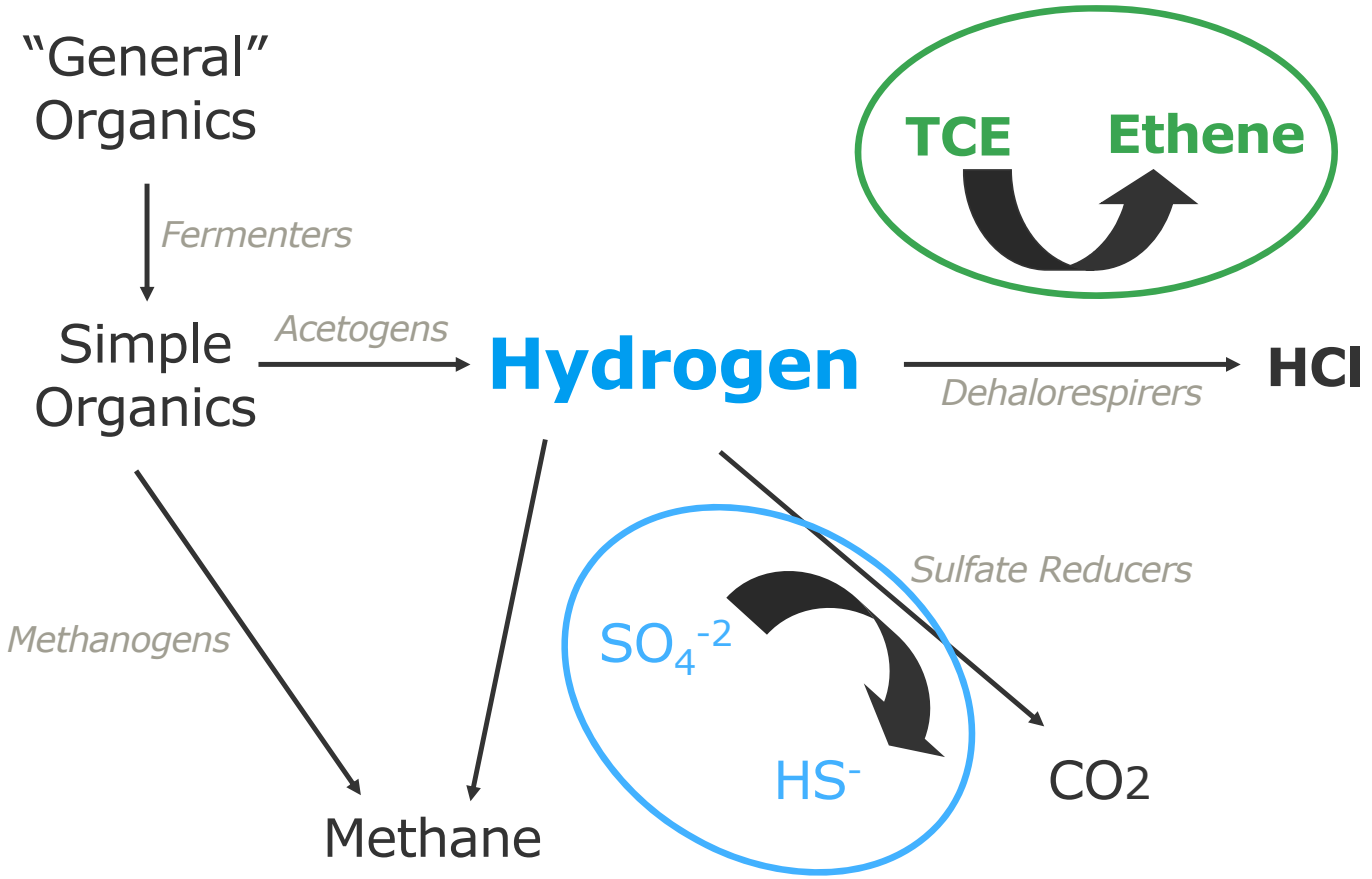
SITE DESCRIPTION – GYPSUM-RICH BEDROCK LAYER



Primary GW flow in gypsum-rich D3 unit located ~46 meters deep



CHALLENGES WITH HIGH SULFATE GROUNDWATER



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SOLUTION – ADD IRON

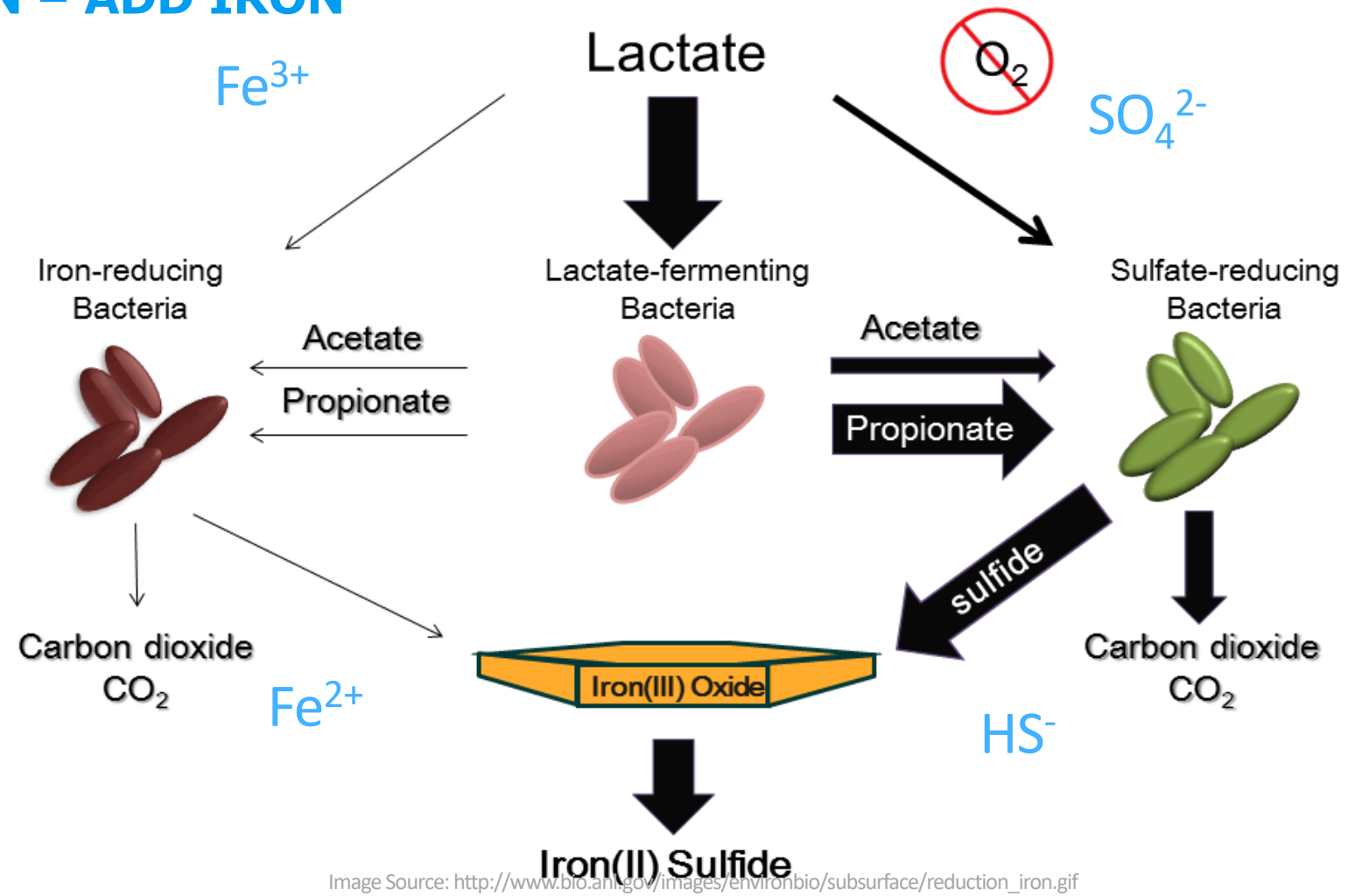

Image Source: http://www.bio.anl.gov/images/environbio/subsurface/reduction_iron.gif

MICROCOSM STUDY RESULTS

- Killed controls
- Unamended
- Magnetite (Fe_3O_4) (Rockwood)
- Magnetite (Fe_3O_4) (Alfa Aesar)
- Ferric citrate
- Ferric sulfate
- Ferrous chloride
- Ferrous lactate
- Ferrous sulfate

Matis, H., et al., 2015. Laboratory Study of Iron Amendments Used to Facilitate Reductive Dechlorination of TCE in High Sulfate Groundwater, in *Proceedings of the Third International Symposium on Bioremediation and Sustainable Environmental Technologies*, Battelle Memorial Institute, Columbus, OH.

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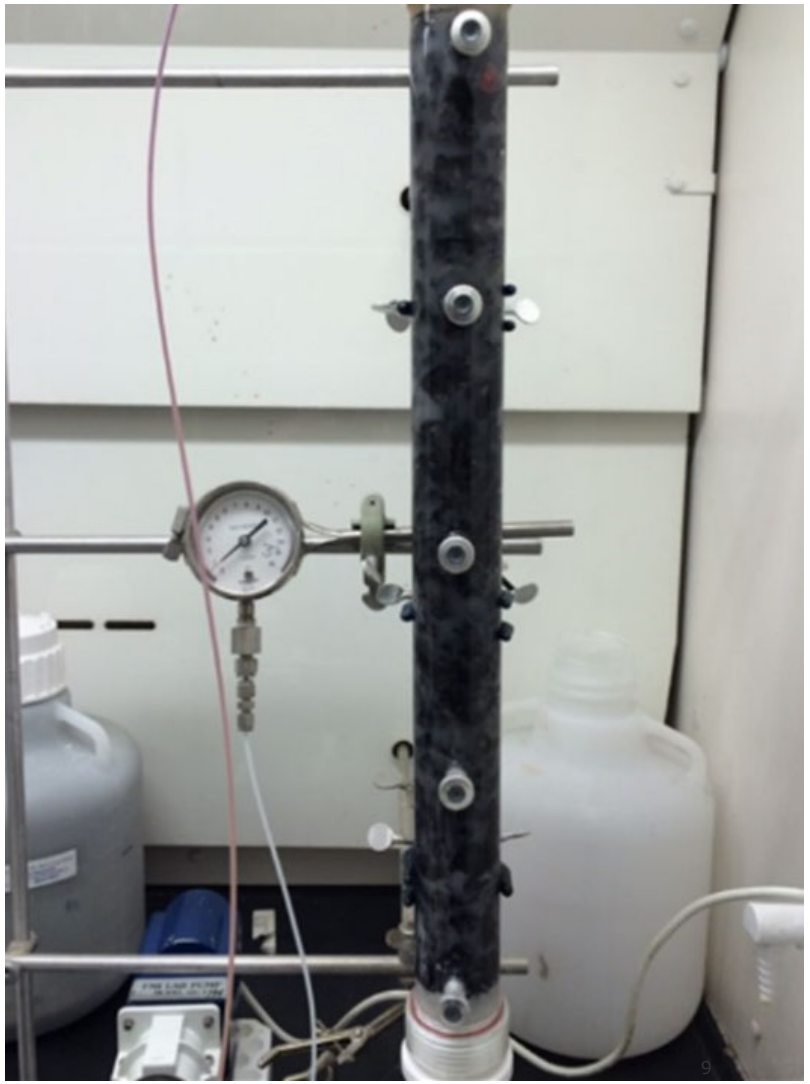
COLUMN STUDY RESULTS

Complete reductive dechlorination of TCE to ethene was achieved in bedrock columns containing EVO and magnetite under GW flow conditions

The periodic addition of supplemental nutrients and **vitamin B12** was critical to process

Availability of cobalt potentially affected by co-precipitation with iron-sulfide minerals



Harkness, M.R., et. al., 2017. Role of Iron and Vitamin B12 Amendments in Stimulating Reductive Dechlorination of TCE in High Sulfate Groundwater, in Proceedings of the Fourth International Symposium on Bioremediation and Sustainable Environmental Technologies, Battelle Memorial Institute, Columbus, OH.

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SITE DESCRIPTION

Remedy Component at Downgradient Site Boundary

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INNOVATION 1: INJECTABLE FORM OF MAGNETITE

INNOVATION 2: SLOW-RELEASE FORM OF VITAMIN B12

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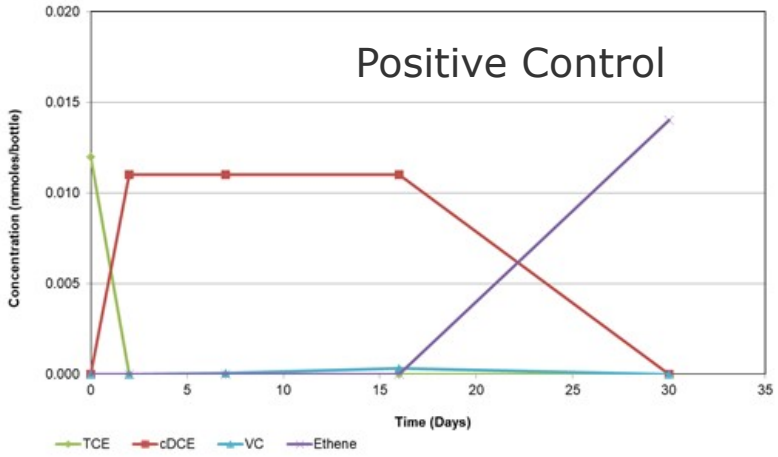
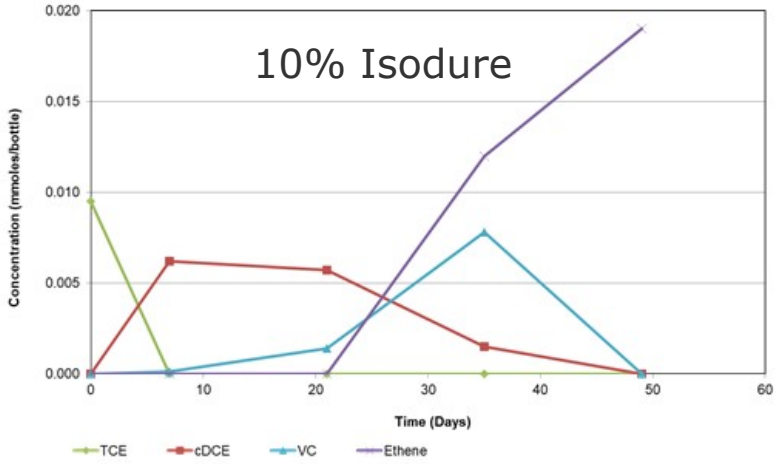
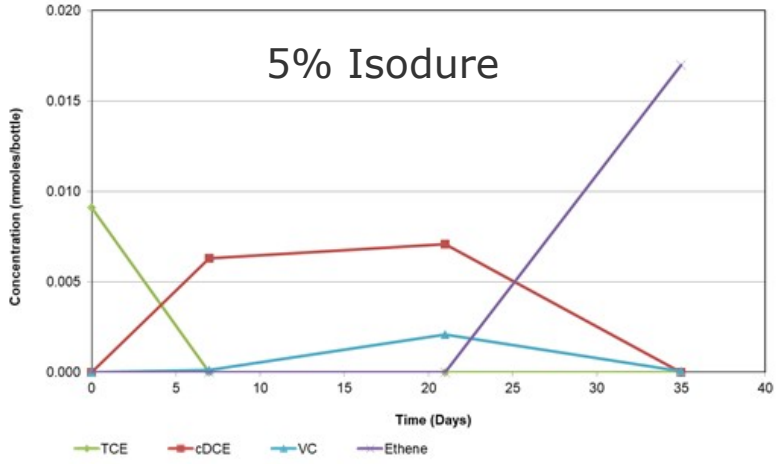
INNOVATION 3: SLOW-RELEASE FORM OF NITROGEN





Notes:
cDCE - cis-1,2-dichloroethene
mmoles/bottle - millimoles per bottle
TCE - trichloroethene
VC - vinyl chloride

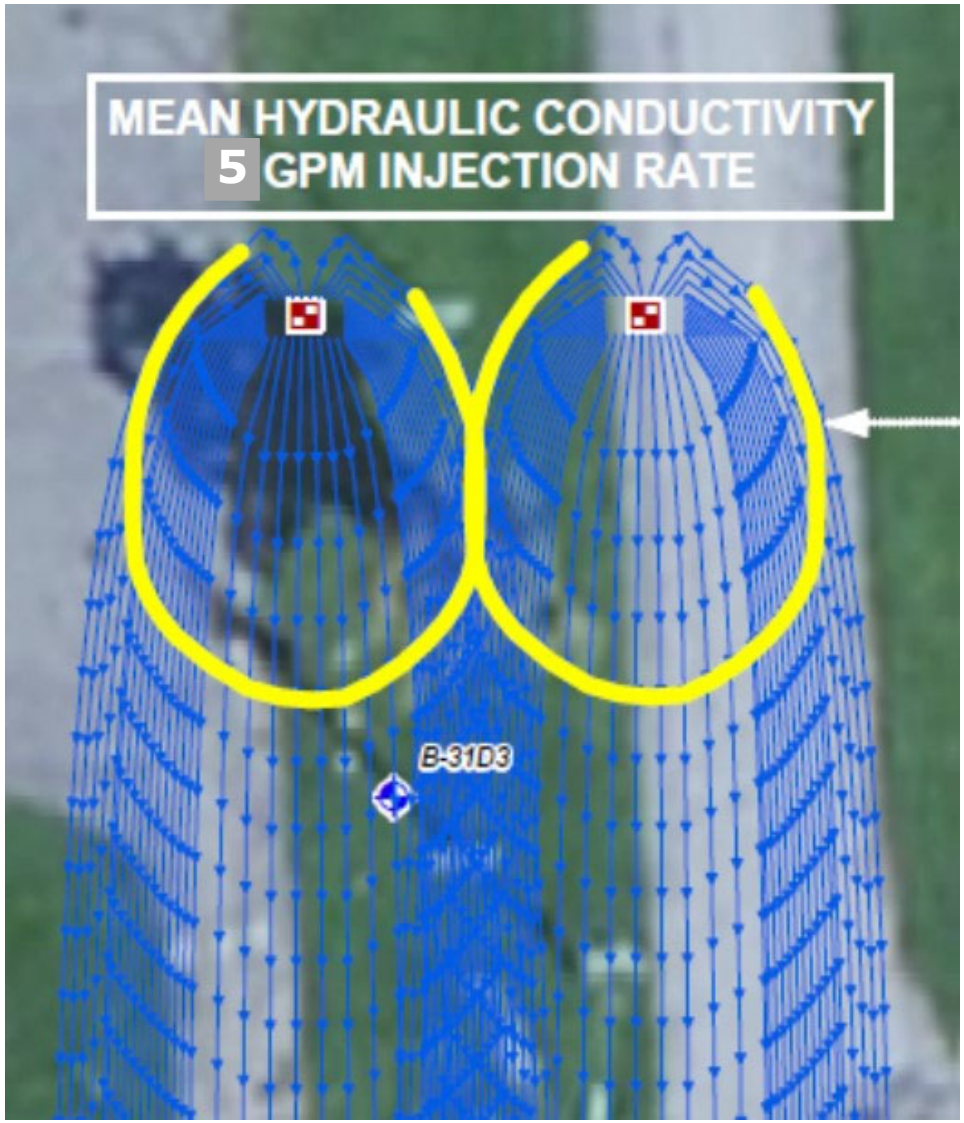


Notes:
cDCE - cis-1,2-dichloroethene
mmoles/bottle - millimoles per bottle
TCE - trichloroethene
VC - vinyl chloride

Isodure™ 31-0-0 isobutylidene diurea slow release fertilizer.

NUTRITE®

GW MODELING FOR PILOT TEST DESIGN



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PHASE 1 INJECTION PROGRAM SUMMARY

May 2018

Table 1. Amendment Group Recipes (Per Batch), in Order of Addition to Tote/Tank

Amendment	Group	Weight (lbs)	Volume (gallons)
GROUP 1			
CMAG[1]	1	1531	121
Water[2]	1	---	120
Isodure™ (dry)[3]	1	8.8	N/A
MKP (dry)[3]	1	2.2	N/A
Potassium bromide (dry)[3]	1	2.3	N/A
GROUP 2			
EOS 100™ [4]	2	648	83.5
Water[4]	2	---	1250 (350 + 900)
Microblend™ [5]	2	11.0	1.2
Wilclear™ [5]	2	45.9	4.1
Vitamin B12 (powder, dry)[6]	2	0.2	N/A
DAP (dry)[6]	2	5.5	N/A
Potassium bromide (dry)[6]	2	3.1	N/A
Vitamin B12 (microbeads)[7]	2	0.15	N/A

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PHASE 1 INJECTION PROGRAM SUMMARY

Table 2: Injection Volume by Amendment Group (per individual injection event)		
Amendment	Dilution Factor	Injection Volume (gallons)
Group 1 [1]	1:1	250
Intermediate Chase [2]	None	1000
Group 2	15:1	1250
Chase Water	None	10,800

- Injections performed continuously over 72 hours
- Three amendment cycles of 24 hours each
- Total of 40,000 gallons of water (amended + chase) injected per injection well

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PHASE 1 PILOT TEST SET-UP:
INJECTION WATER STORAGE FRAC TANKS (21,000 GAL CAPACITY)

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PHASE 1 PILOT TEST SET-UP:
C-MAG GRAVITY ADDITION

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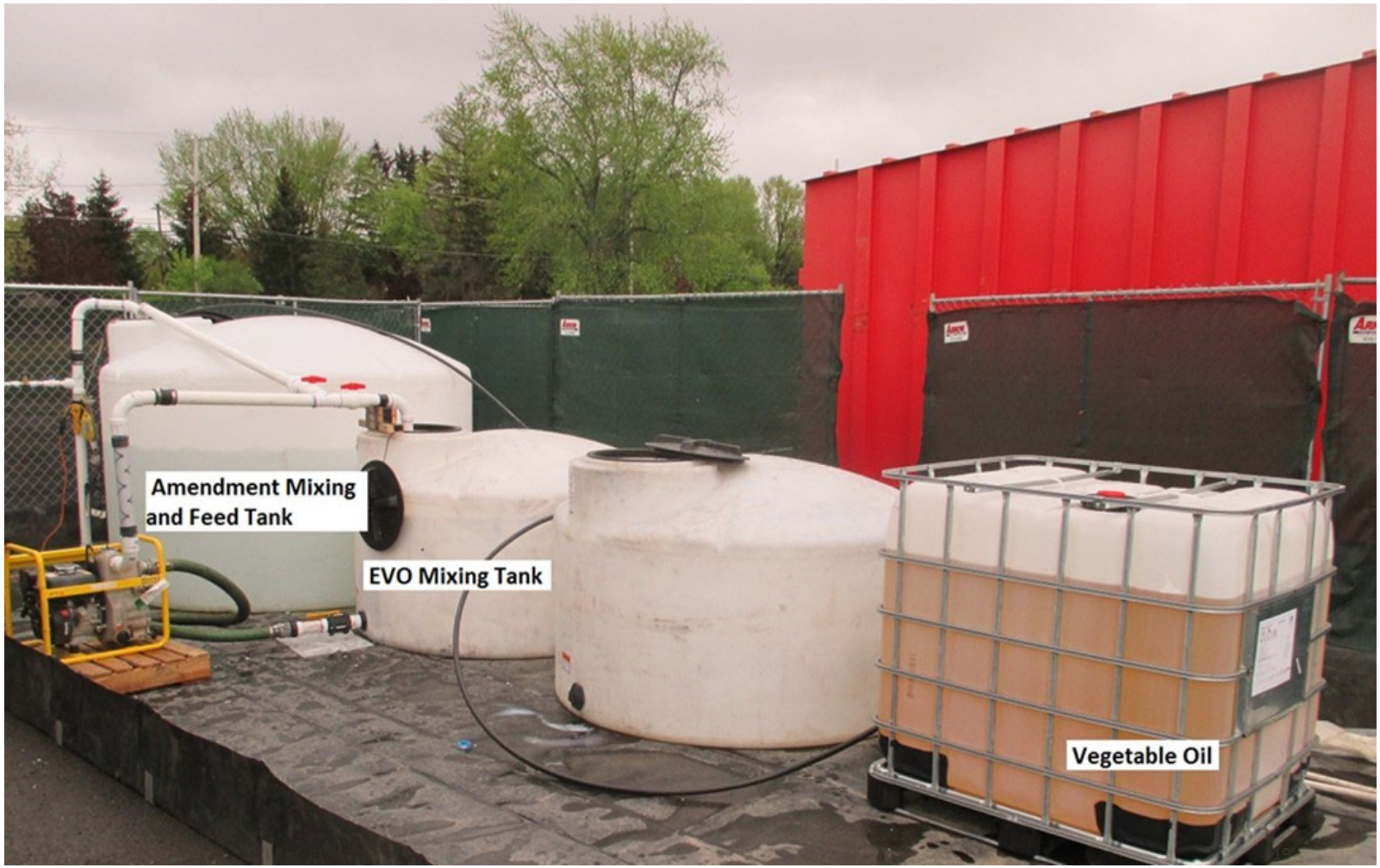
PHASE 1 PILOT TEST SET-UP: AMENDMENT MIXING TANKS



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PHASE 1 PILOT TEST:
VITAMIN B12 MICROBEAD ADDITION

PERFORMANCE MONITORING

Short-term amendment distribution

- Collect real-time data using down-hole probes (water-level, pH, DO, ORP, conductivity, temperature, turbidity)
- Support real-time data using periodic laboratory analyses (potassium, bromide, iron, TOC, cobalt)

Intermediate-term monitoring

- VOCs, CSIA, field parameters (pH, DO, ORP), MNA parameters (nitrate, dissolved iron, sulfate, sulfide, dissolved gases)

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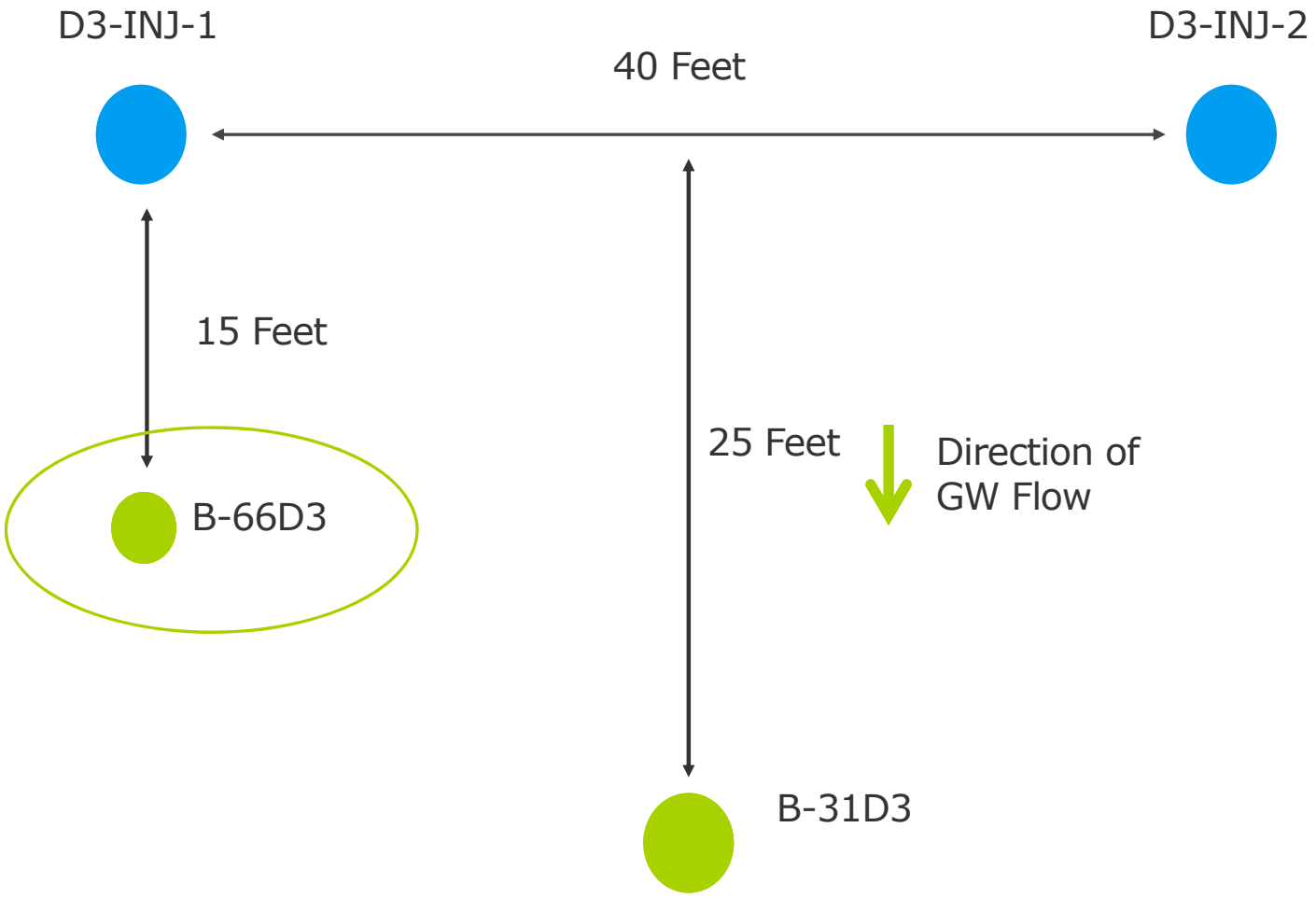
D3 PILOT TEST – PHASE 1 LAYOUT



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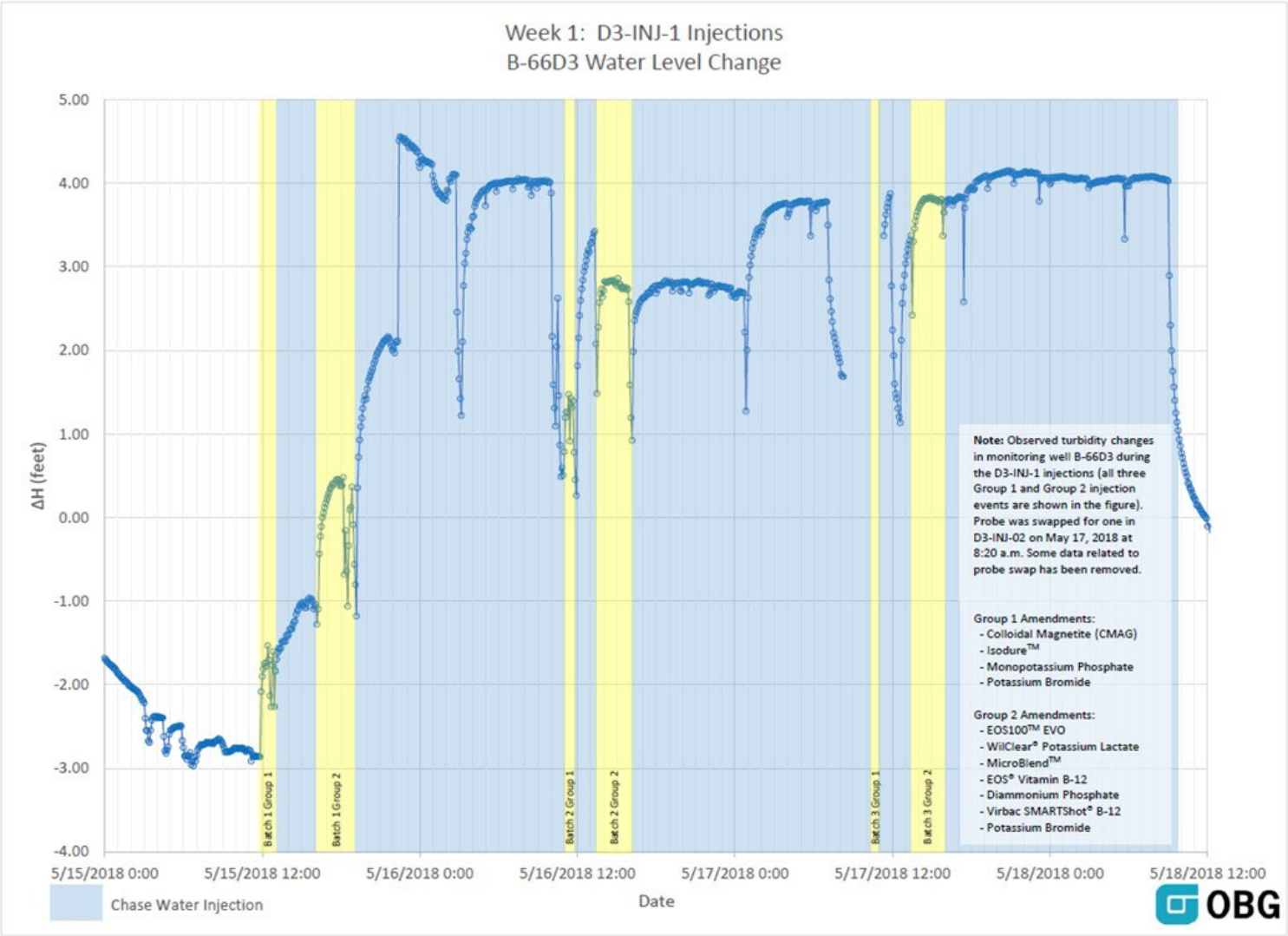
PROBE WATER LEVEL DATA

CMAG/EVO Injections

Phase 1 Pilot - Week 1



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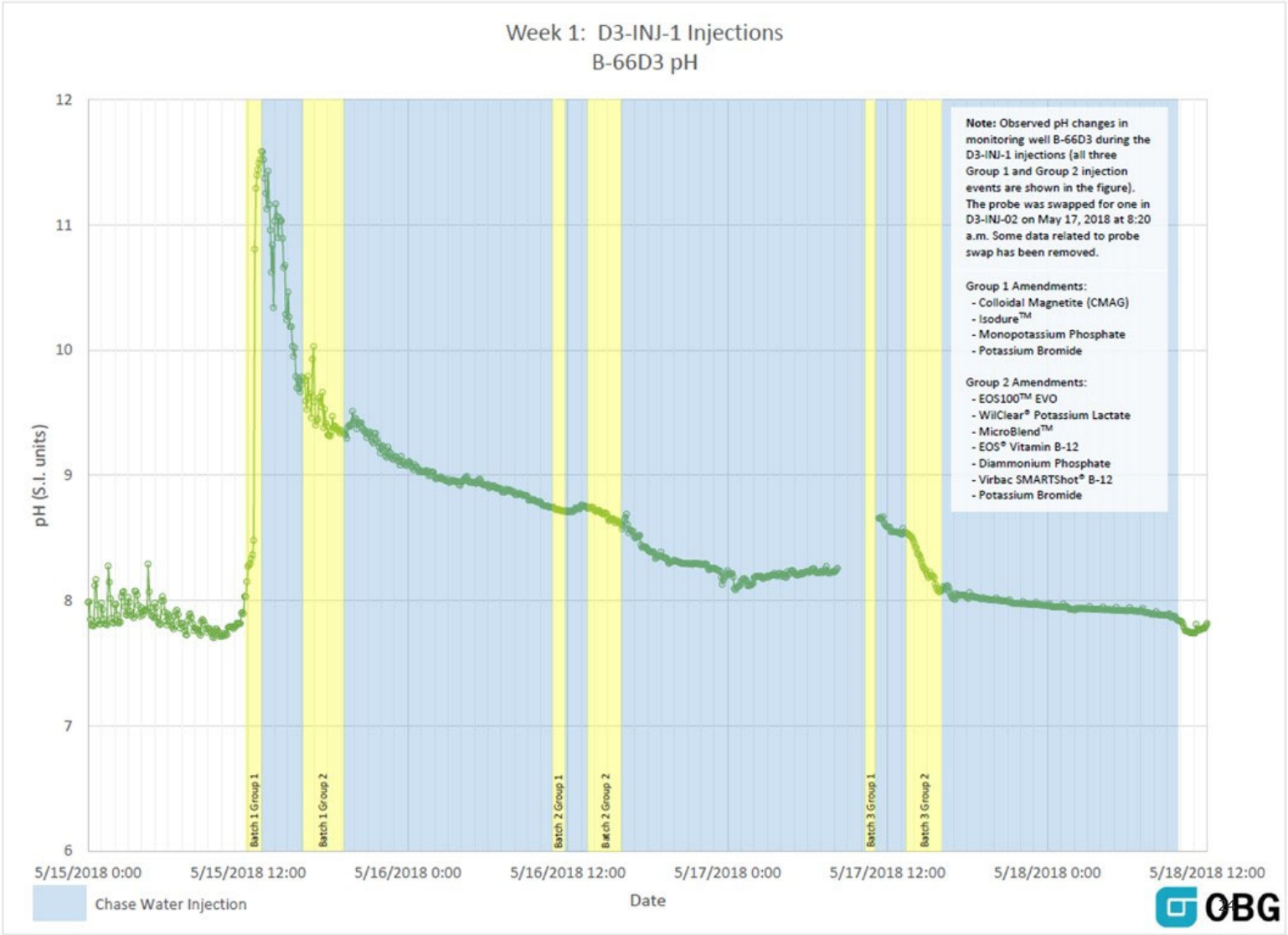
PROBE PH DATA

CMAG/EVO Injections

Phase 1 Pilot - Week 1



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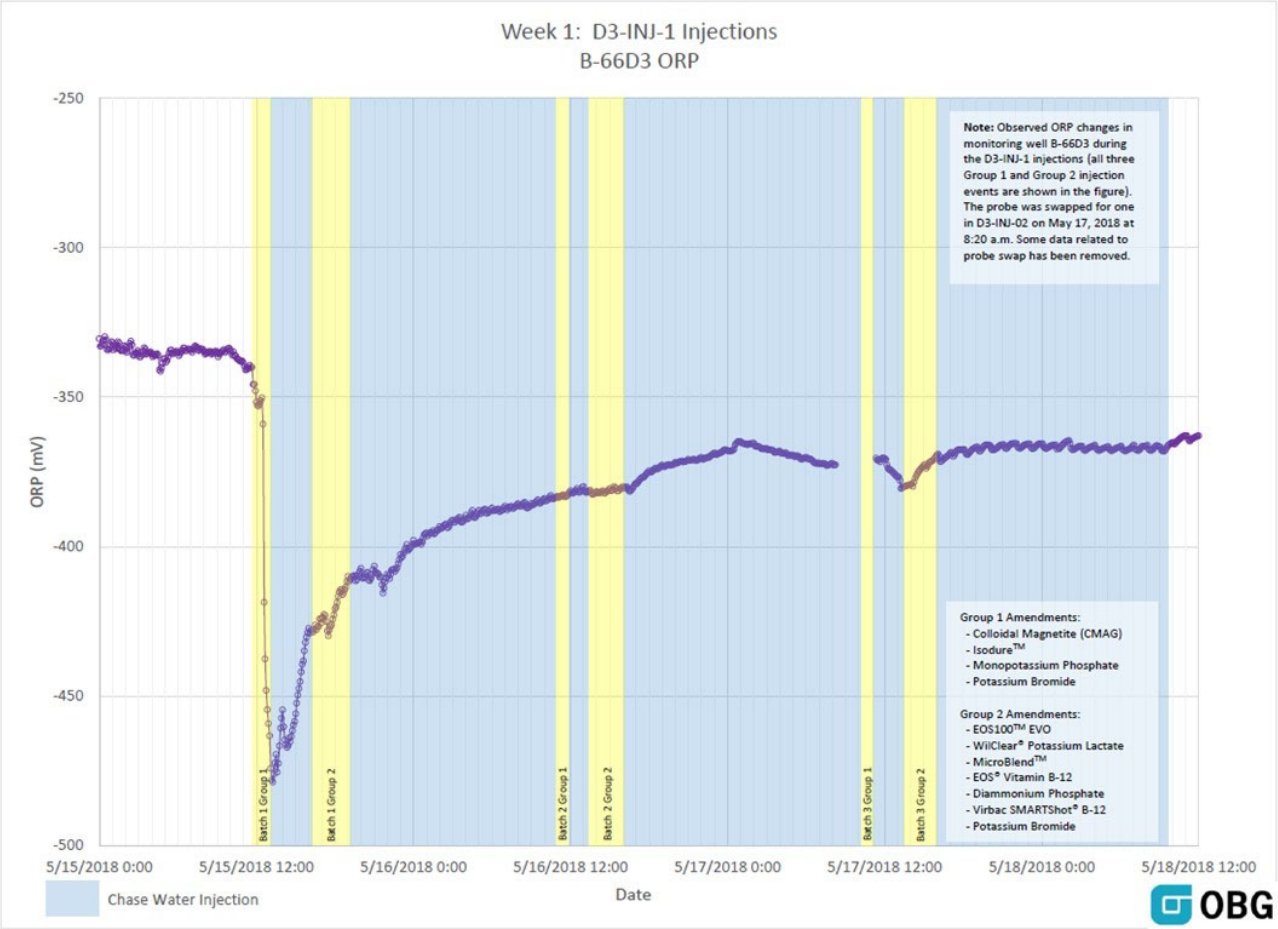
PROBE ORP DATA

CMAG/EVO Injections

Phase 1 Pilot - Week 1



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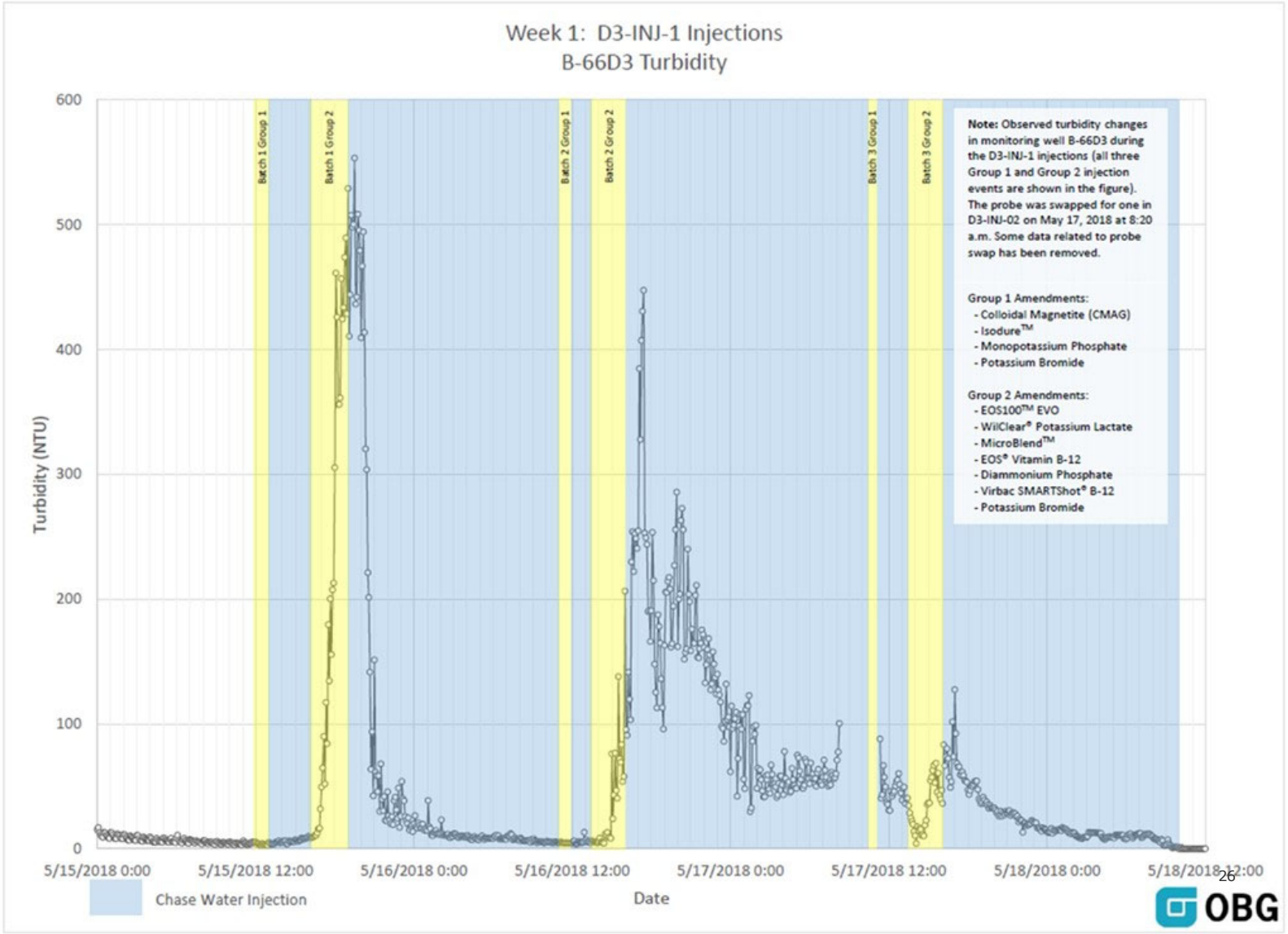
PROBE TURBIDITY DATA

CMAG/EVO Injections

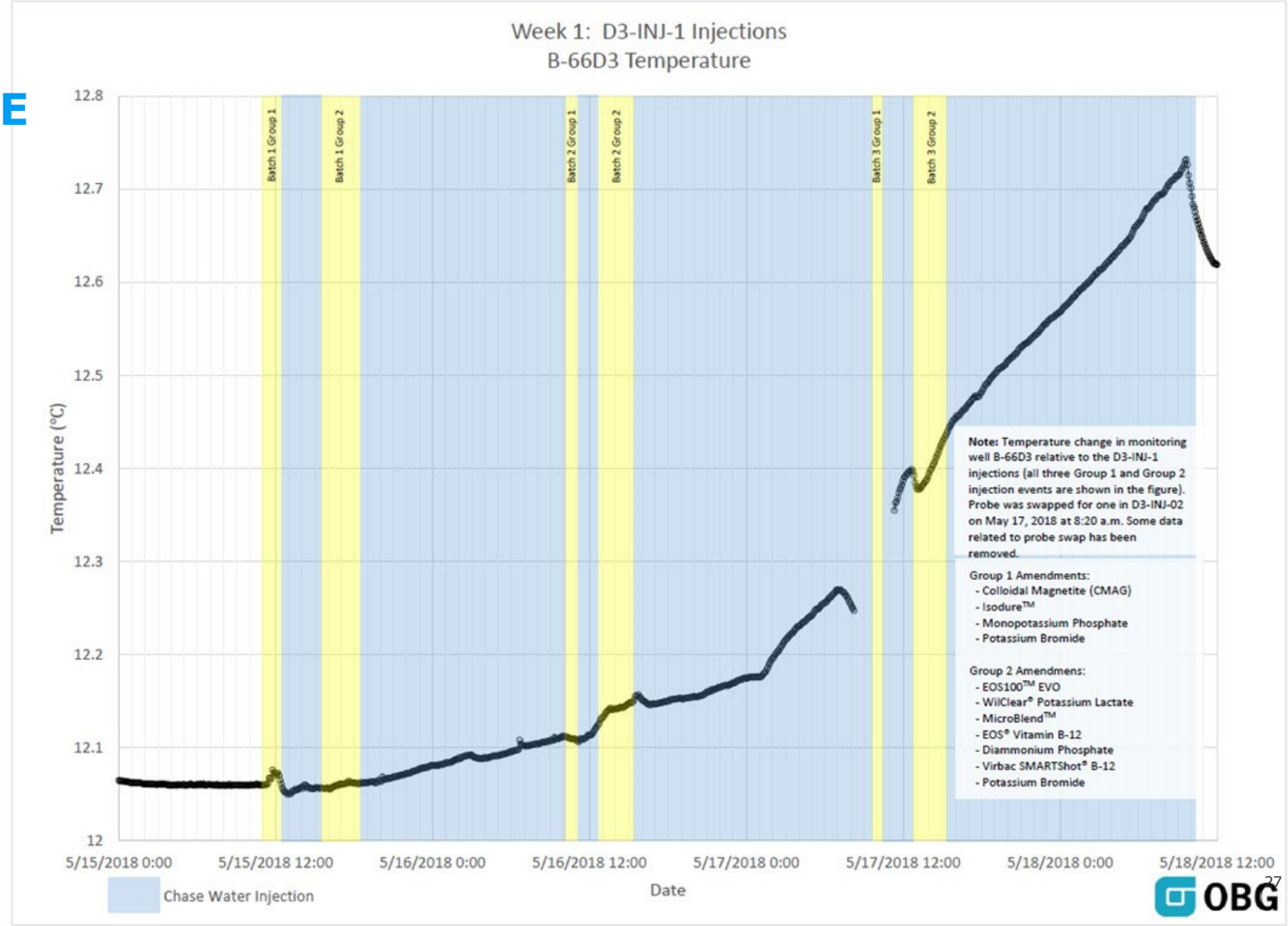
Phase 1 Pilot - Week 1



PROBE TEMPERATURE DATA

CMAG/EVO Injections

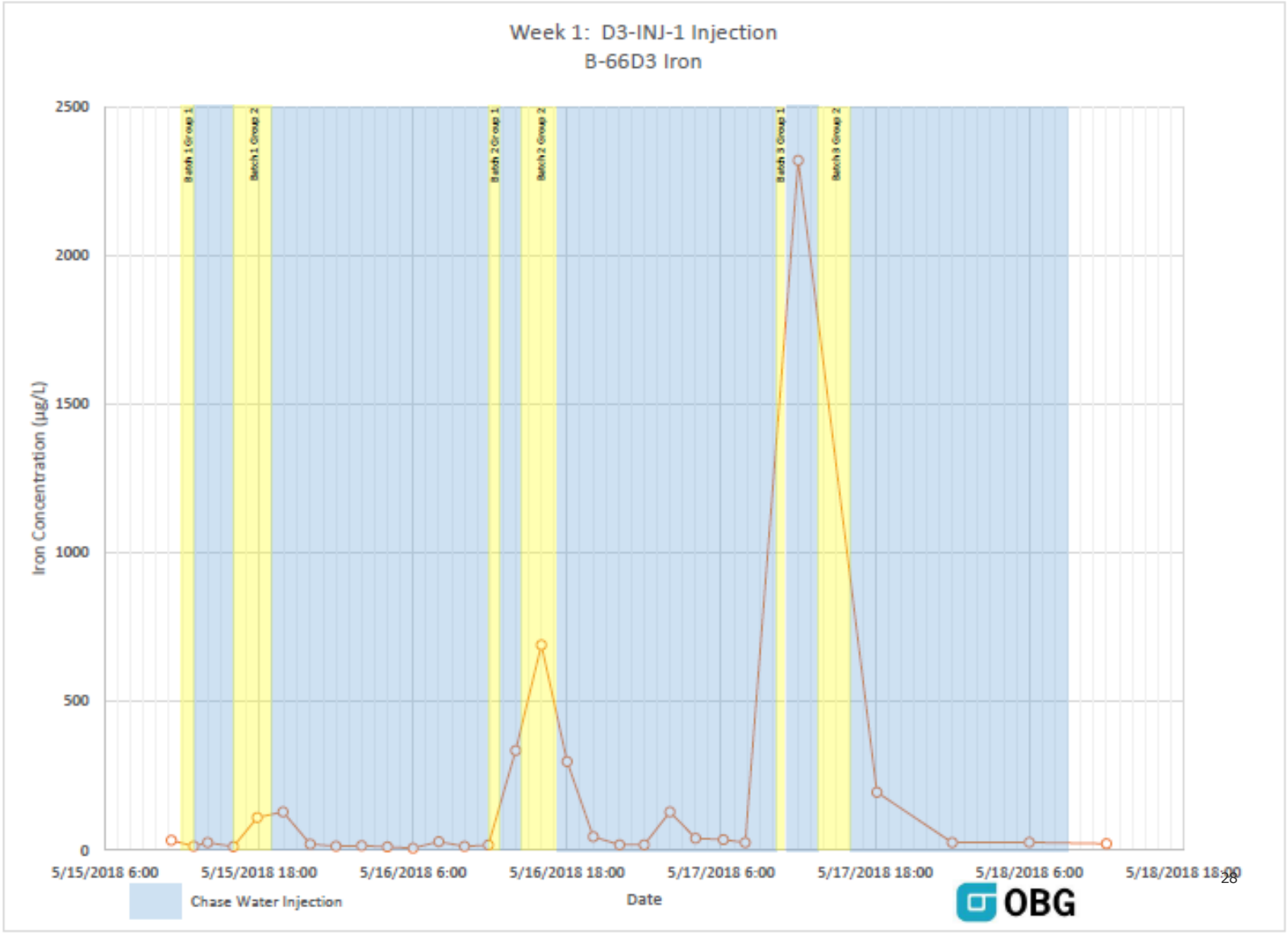
Phase 1 Pilot - Week 1



LABORATORY IRON DATA

CMAG/EVO Injections

Phase 1 Pilot - Week 1



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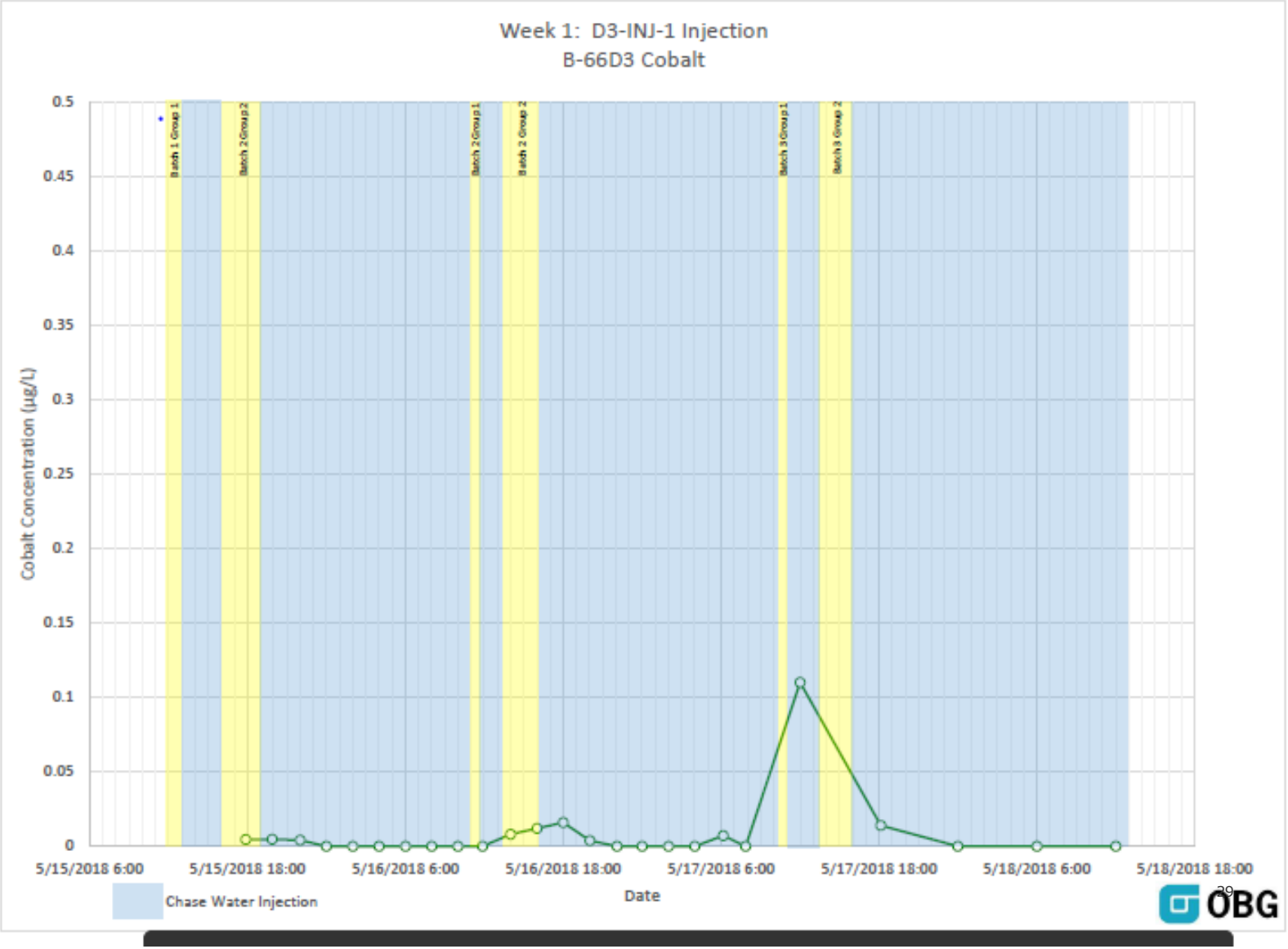
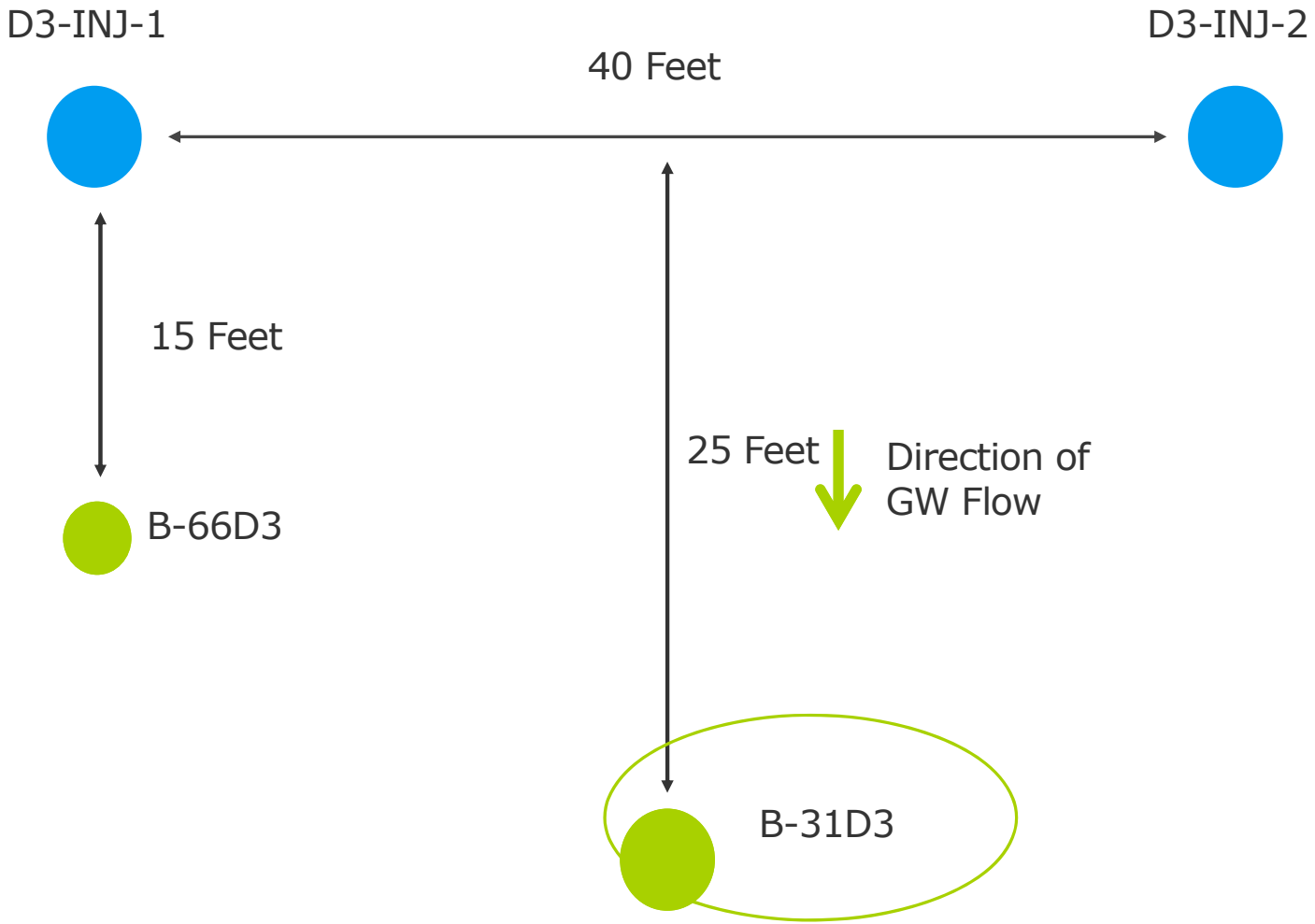
LABORATORY COBALT DATA

CMAG/EVO Injections

Phase 1 Pilot - Week 1



D3 PILOT TEST – PHASE 1 LAYOUT



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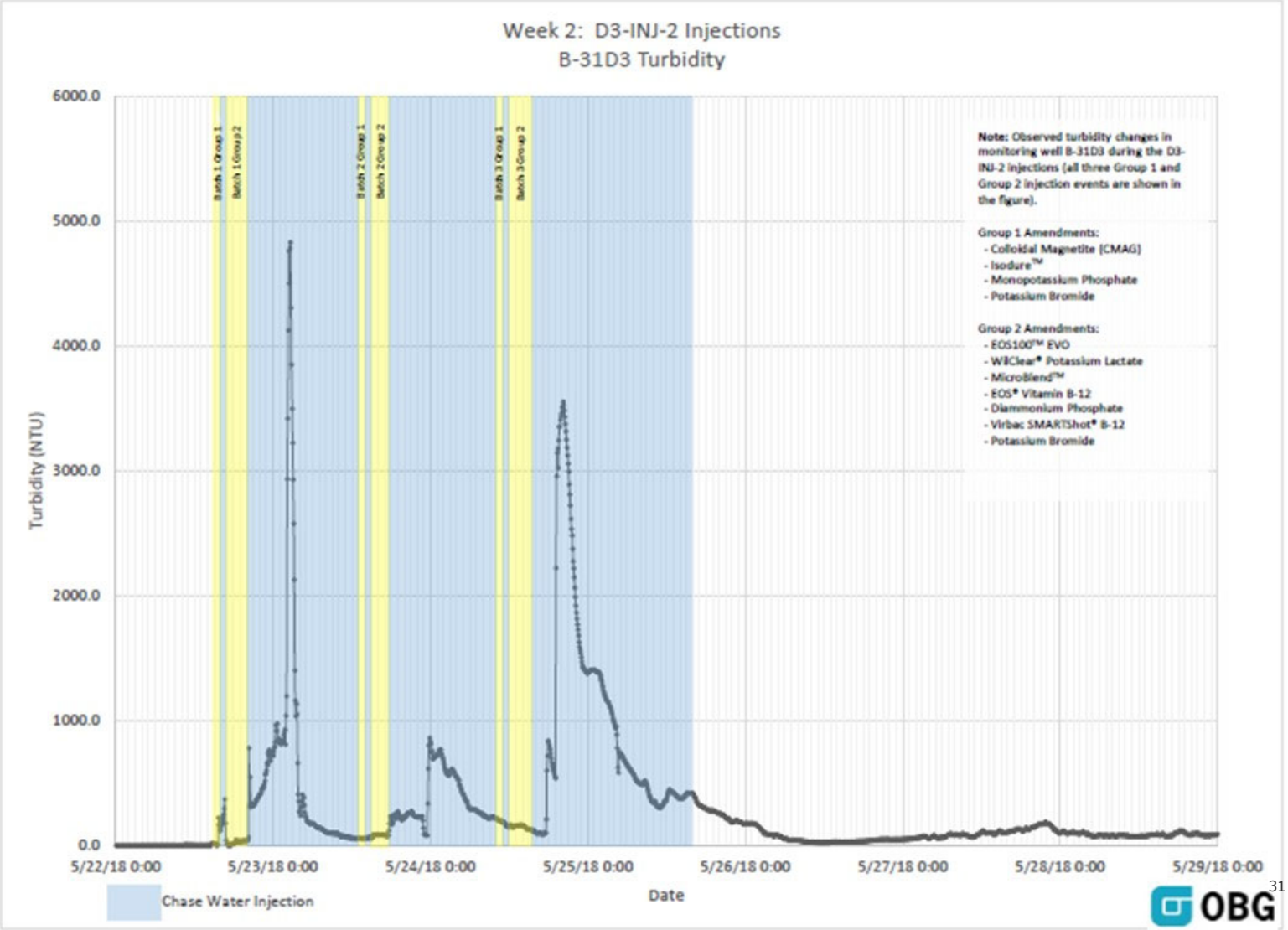
PROBE TURBIDITY DATA

CMAG/EVO Injections

Phase 1 Pilot - Week 2



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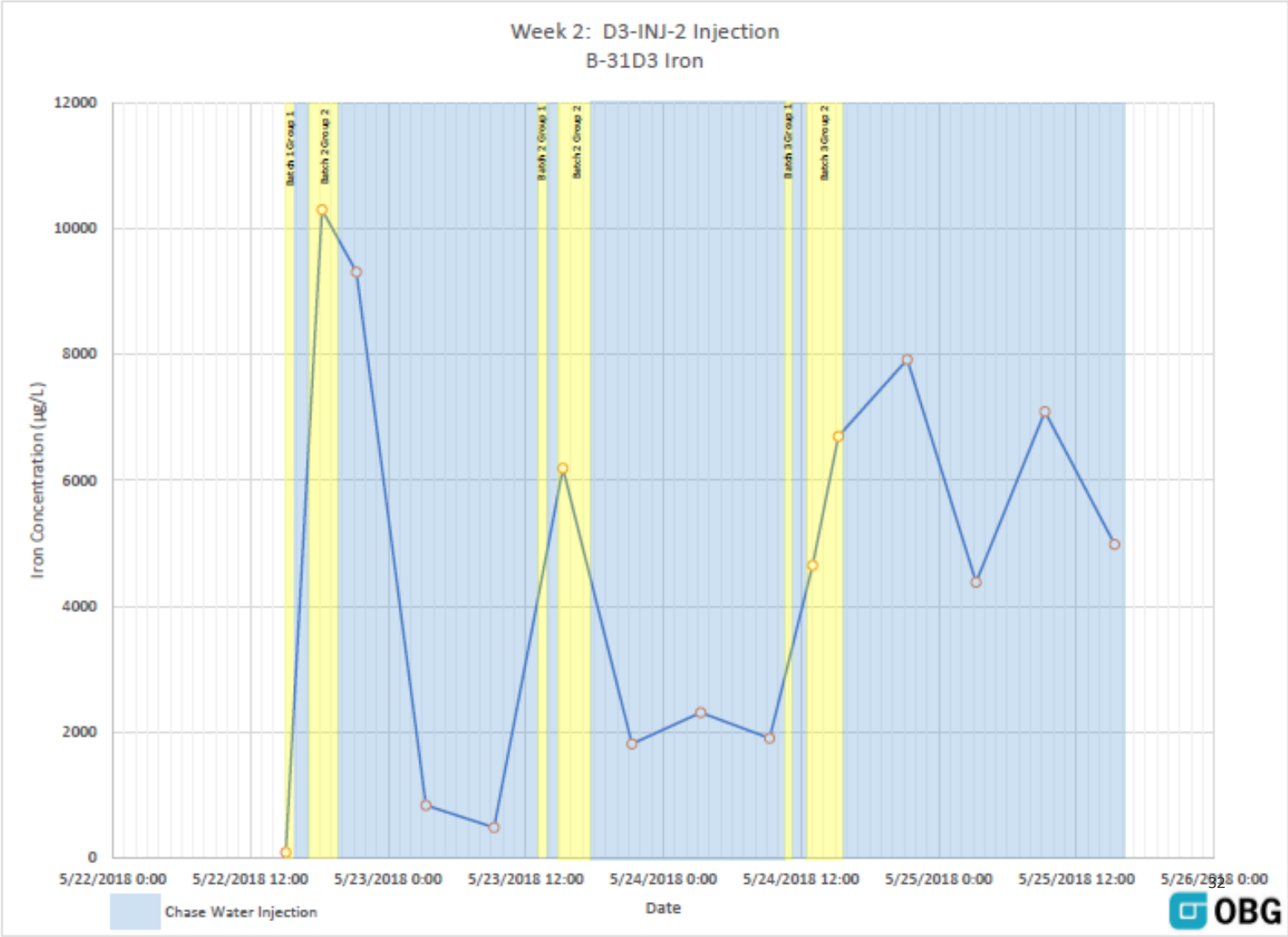
LABORATORY IRON DATA

CMAG/EVO Injections

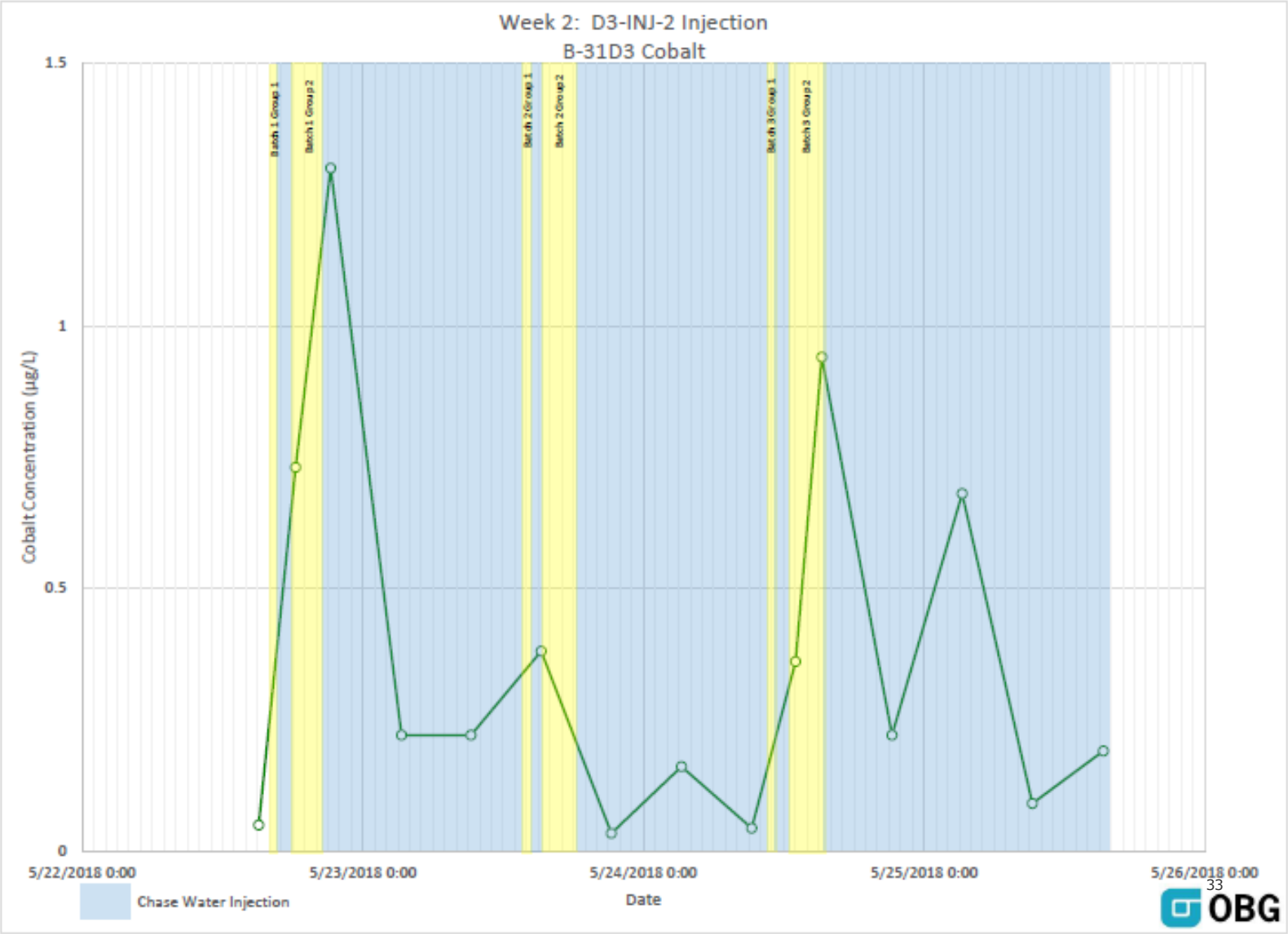
Phase 1 Pilot - Week 2



LABORATORY COBALT DATA

CMAG/EVO Injections

Pilot
Week 2



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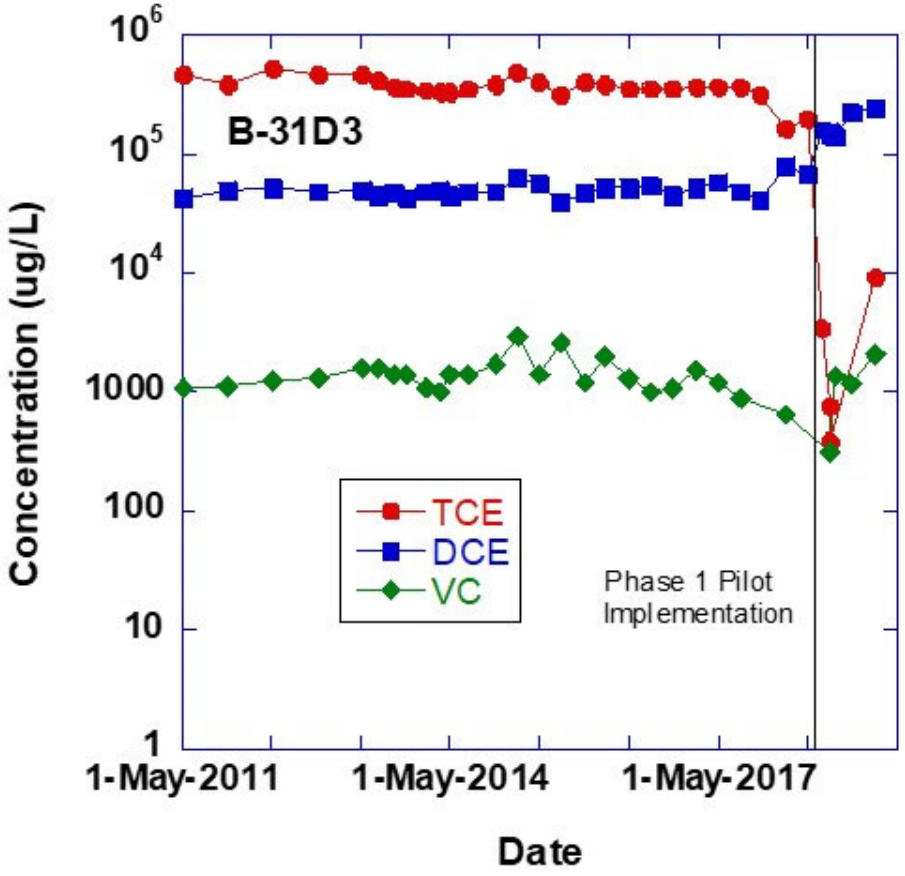
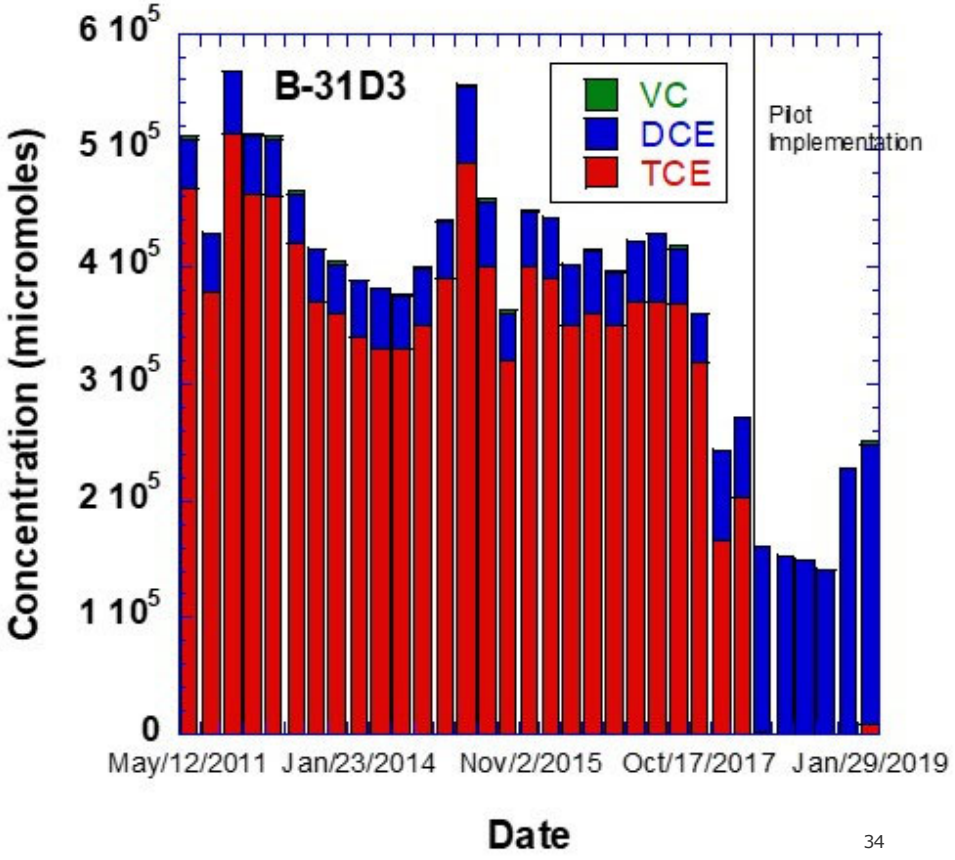
LONGER-TERM PERFORMANCE MONITORING

VOCS IN WELL B-31D3





LONGER-TERM PERFORMANCE MONITORING

CSIA IN WELL B-31D3

Date	$\delta^{13}C$ TCE	$\delta^{13}C$ cDCE	$\delta^{13}C$ VC
7/9/2013	-22.8	-28.2	-30
11/2/2015	-22.4	-27.8	
7/26/2016	-22.5	-28.1	
8/2/2017	-20.6	-26.4	-31.9
8/2/2018	-9.5	-21.7	-24.5

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CONCLUSIONS AND NEXT STEPS

Conclusions

- Injection program successful at injecting amendments
- Injection well spacing of 40-feet verified in pilot test
- Observed accelerated reductive dichlorination of TCE

Next Steps

- Eight additional injection wells installed in fall 2018 (treatment zone now 400 feet wide)
- Phase 2 injections will occur in spring/summer 2019

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THANK YOU

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