Results from a 1,4-Dioxane Biogeochemical Reactor Field Pilot Test

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COLLABORATION

- Project completed in collaboration with Jacobs, UCLA, and CSU

AGENDA

- Site Background
- Technology Overview: Subgrade Biogeochemical Reactors (SBGRs)
- 1,4-Dioxane Field Pilot Study
  - Phase 1: Overview
  - Phase 1: Results and Lessons Learned
  - Phase 2: Optimization and Implementation
  - Phase 2: Results
- Proposed Next Steps

SITE BACKGROUND

- Chemical manufacturing facility in North America
- Soil and groundwater impacted primarily by chlorinated volatile organic compounds (CVOCs), benzene and 1,4-dioxane
- Various remedial actions have been implemented to address CVOC and benzene contamination:
  - Air Sparge/Soil Vapor Extraction (AS/SVE) System
  - Aerobic cometabolic biosparging (ACB) System
    - ✓ Total CVOCs and benzene concentrations reduced 97% using these technologies
  - Elevated 1,4-dioxane concentrations persist in soil and groundwater

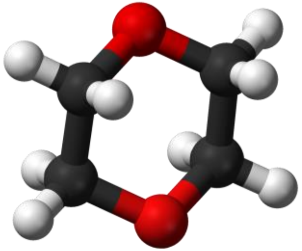
CHALLENGES ASSOCIATED WITH 1,4-DIOXANE

- 1,4-Dioxane was used as a stabilizer for 1,1,1-trichloroethane and has proposed cleanup guidelines as low as 0.3 micrograms per liter (ug/L)

- Treatment of 1,4-dioxane is challenging and costly

- Most treatment options that target CVOCs (e.g., soil vapor extraction, sorption, and biological treatments) are generally not very effective at treating 1,4-dioxane

- Some existing treatment methods, e.g., AOP, are expensive and can create other problems



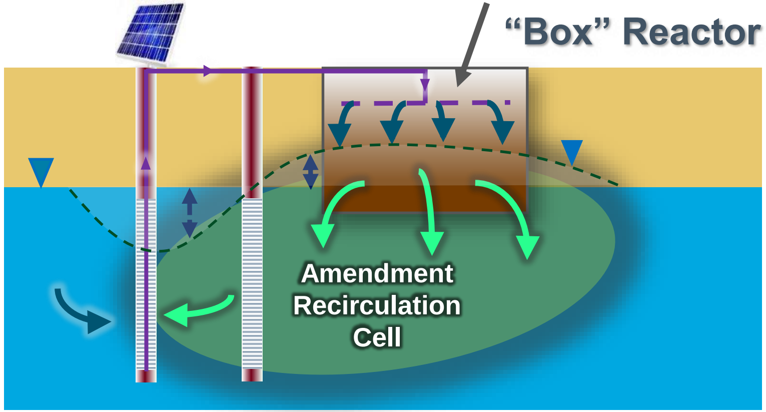
1,4-Dioxane

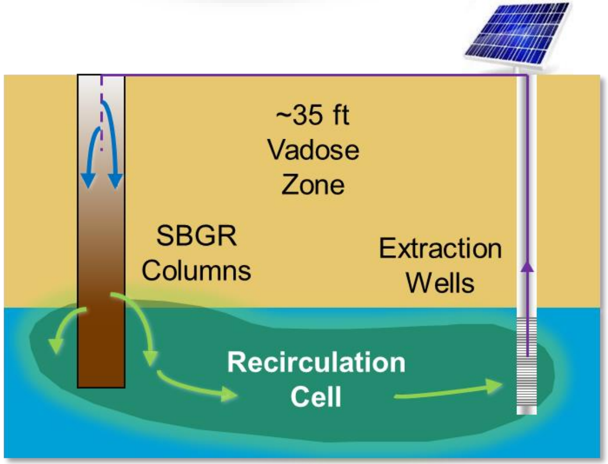
From public domain: Ben Mills and Jynto - Derived from File:Morpholine-from-xtal-3D-balls-B.png.

Technology Overview: Subgrade Biogeochemical Reactors (SBGR)

- SBGRs are a **sustainable treatment technology** that utilize locally-sourced, non-refined or "waste" products (such as wood mulch, spent brewery grain, agricultural byproducts, etc.) to support treatment of many types of contaminants
- Site-specific media and design configurations based on contaminant(s) of concern
- Different configurations are possible and based on site-specific needs, criteria, or restrictions

"Box" Reactor





"Column" Reactor

1,4-Dioxane Biogeochemical Reactor Field Pilot Test

Drum-scale pilot tests

- Important biochemical processes are difficult to simulate in the lab
- Pilot tests in U.S., Australia and Latin America have evaluated numerous combinations of amendments
- **Important microbial community members need specific types of organics or geochemical media to support optimal growth**



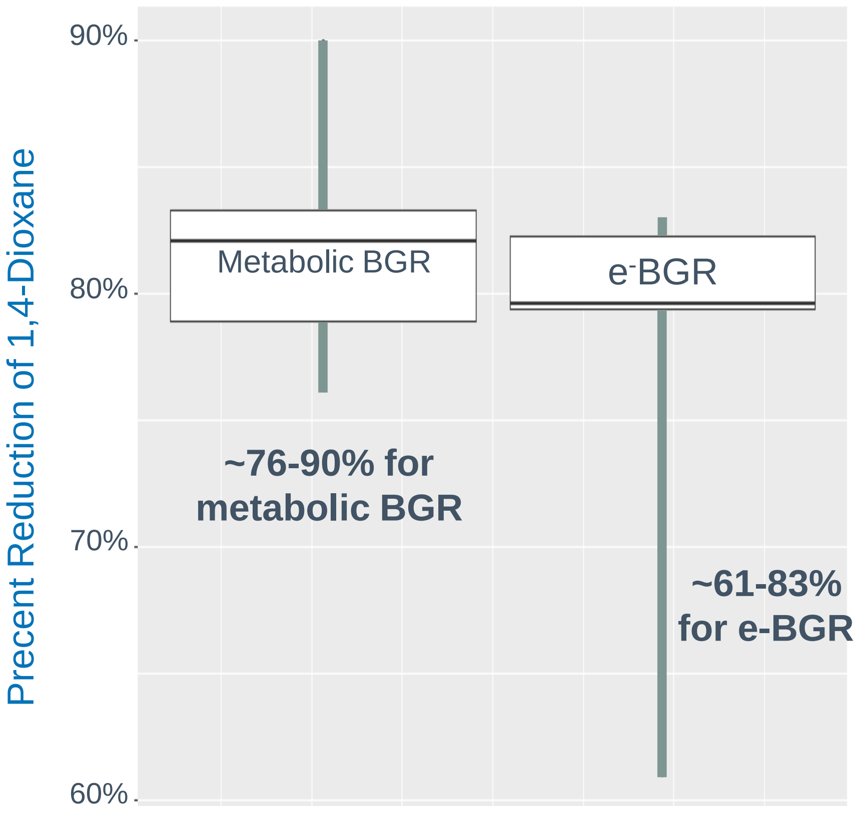

PHASE 1 SETUP

- **Treatment Train #1**: Metabolic BGR (organic media, air addition and CB1190)
- **Treatment Train #2**: e⁻BGR (electrochemical oxidation w/ CB1190 followed by organic media treatment of generated perchlorate)
- **Trains #3 & 4**: evaluated Soygold™ w/biosparging (not a focus of this presentation)
- 10- to 20-day hydraulic residence times (10 days per drum)

PHASE 1 RESULTS

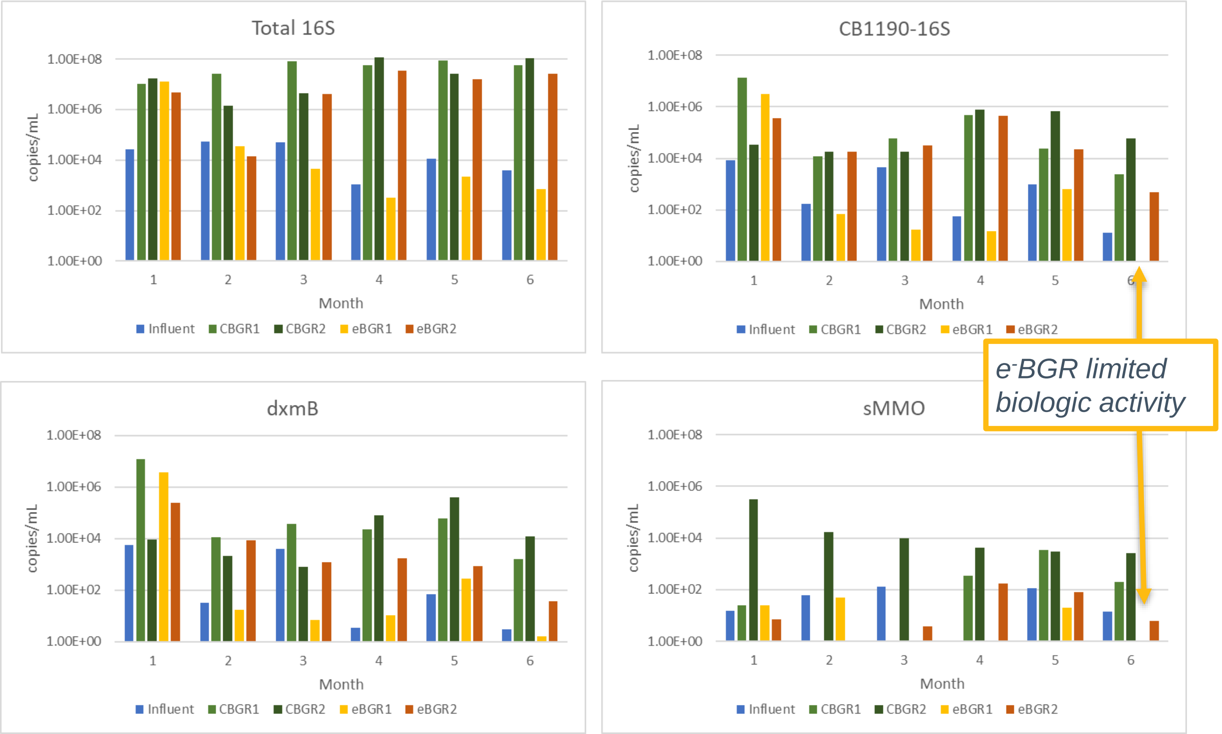
- Phase 1 completed in 2020
  - 1,4-Dioxane influent concentrations ranged: 10,000 to 35,200 µg/L

- Metabolic BGR was easiest of systems to operate (required no modifications during pilot test)



Phase 1 Microbial Interpretations

- Metabolic BGR (green) had robust populations throughout
- e^-BGR (orange) had generally depressed populations, especially in electrochemical oxidation portion of reactor (light orange bars)



Phase 2

- Phase 2 was completed in 2021:
  - Evaluate effectiveness of BGR treatment at very high concentrations (>100,000 µg/L)
  - Refine design criteria for a full-scale system

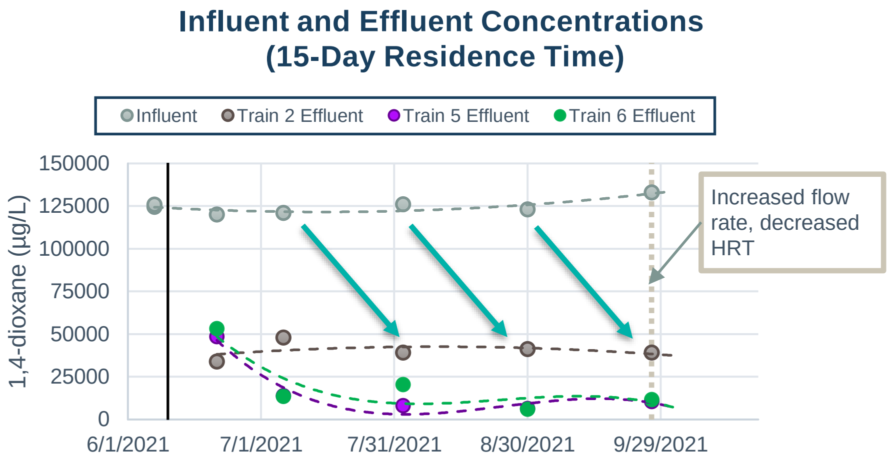
- **Treatment Train #2**: e^-BGR (continued from Phase 1, reduced voltage to address pH issues), 2 drums

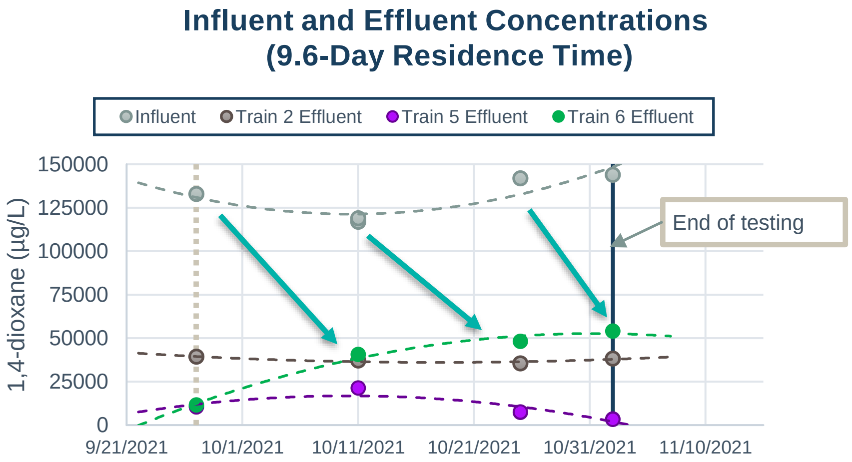
- **Treatment Train #5**: Metabolic BGR (organic media with air addition and CB1190), 3 drums

- **Treatment Train #6**: Metabolic BGR (organic media with air, but **<u>without</u>** CB1190), 3 drums

PHASE 2 RESULTS

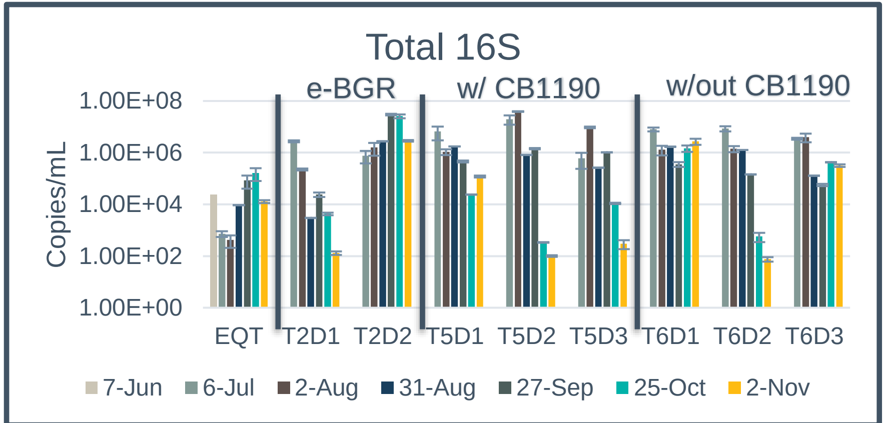
- **Train 5 & 6**: BGR reactors (with and without UCLA's CB1190 culture)
  - 1,4-dioxane reductions through September: **between 88-95% at 15-day residence time (Train 5, with CB1190)** and **between 83-95% at 15-day residence time (Train 6, without CB1190)**
  - All other contaminants were **non-detect** in the Train 5 and Train 6 effluent samples
- Hydraulic residence times (HRT) were decreased in September 2022
  - **Train 5 continued to perform well (up to 98% reduction in 1,4-dioxane)**
  - Performance in Train 6 decreased wit lower HRT (**up to 69% reduction**)

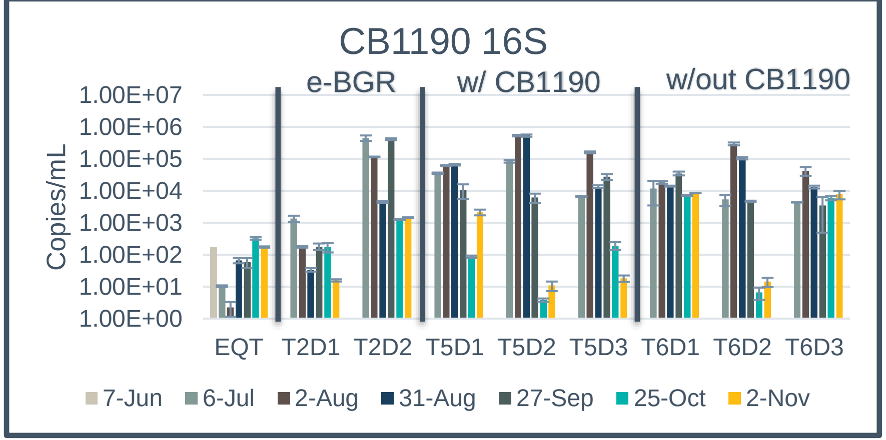




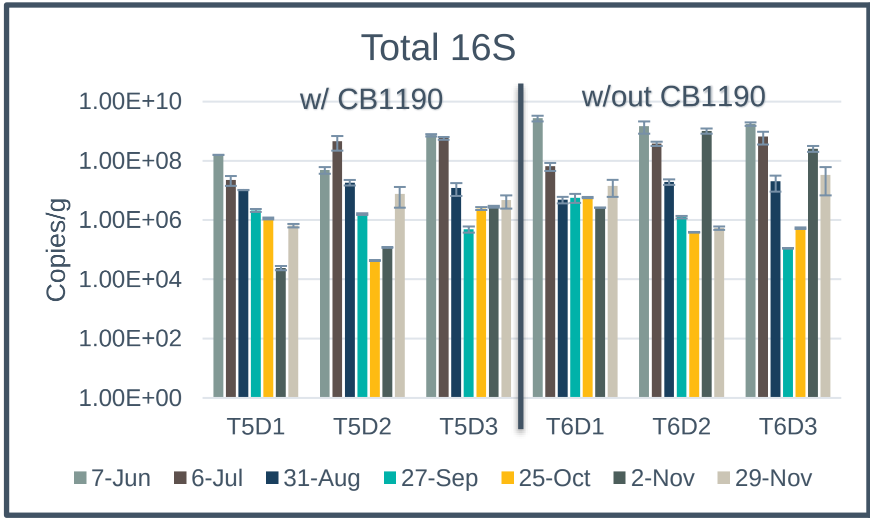
Phase 2 Microbial Interpretations in Groundwater

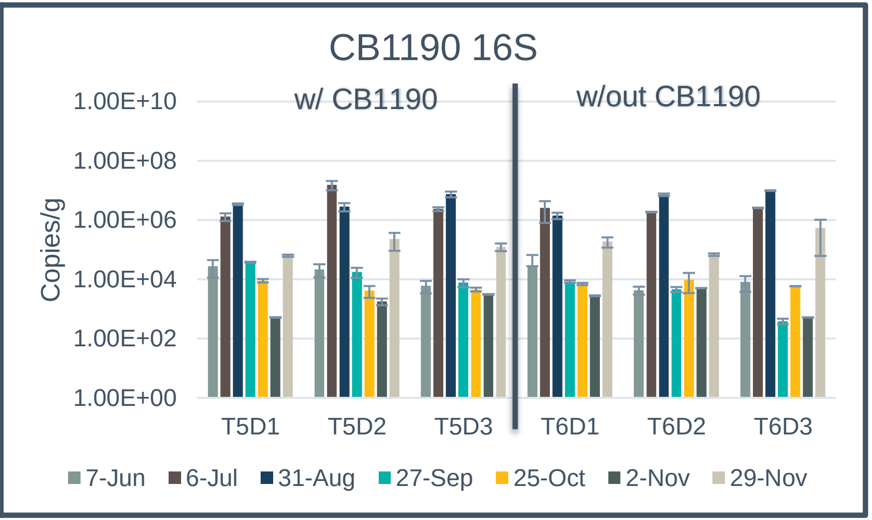
- Bacterial abundance remained highest and most consistent in specific BGR drums: T2D2, T5D1, T6D1 and T6D3
  - Trains 5 and 6 had high bacterial abundance through September
- CB1190-like bacteria showed similar trend to Total 16S
  - **Train 6 had higher gene abundance** than Train 5 drums when hydraulic residence times were **lower (increased flow-rate)**
  - Biomarker genes **increased in T6D1 and T6D3**, generally **decreased in Train 5 and T6D2**





PHASE 2 MICROBIAL INTERPRETATIONS IN SOLIDS

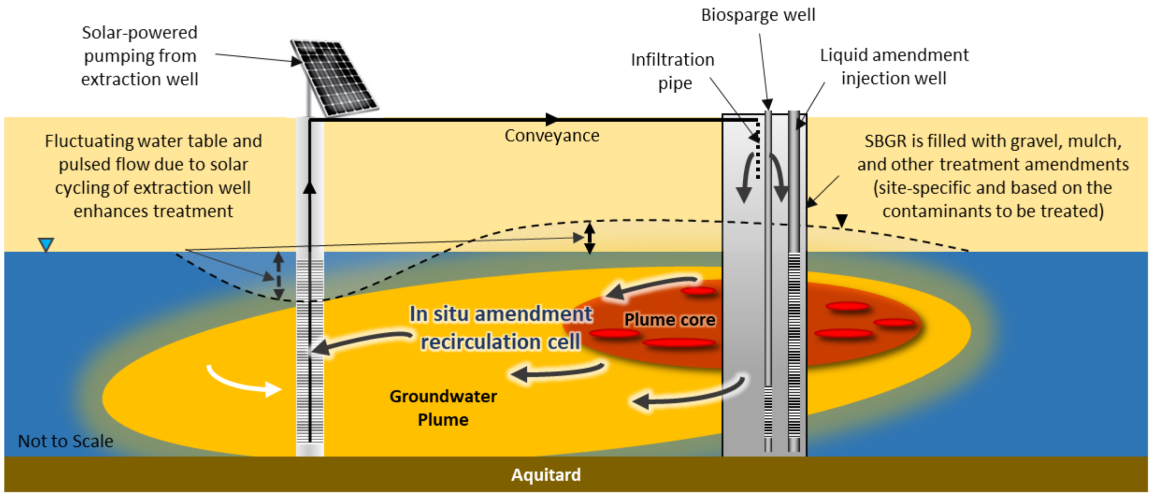




1. Overall bacterial abundance was relatively stable in all drums before demolishing, except T5D1 and T6D2.
2. CB1190-like bacteria decreased in all drums in September, but increased after winterization processes (Nov 2nd), likely due to elimination of groundwater flow through the system

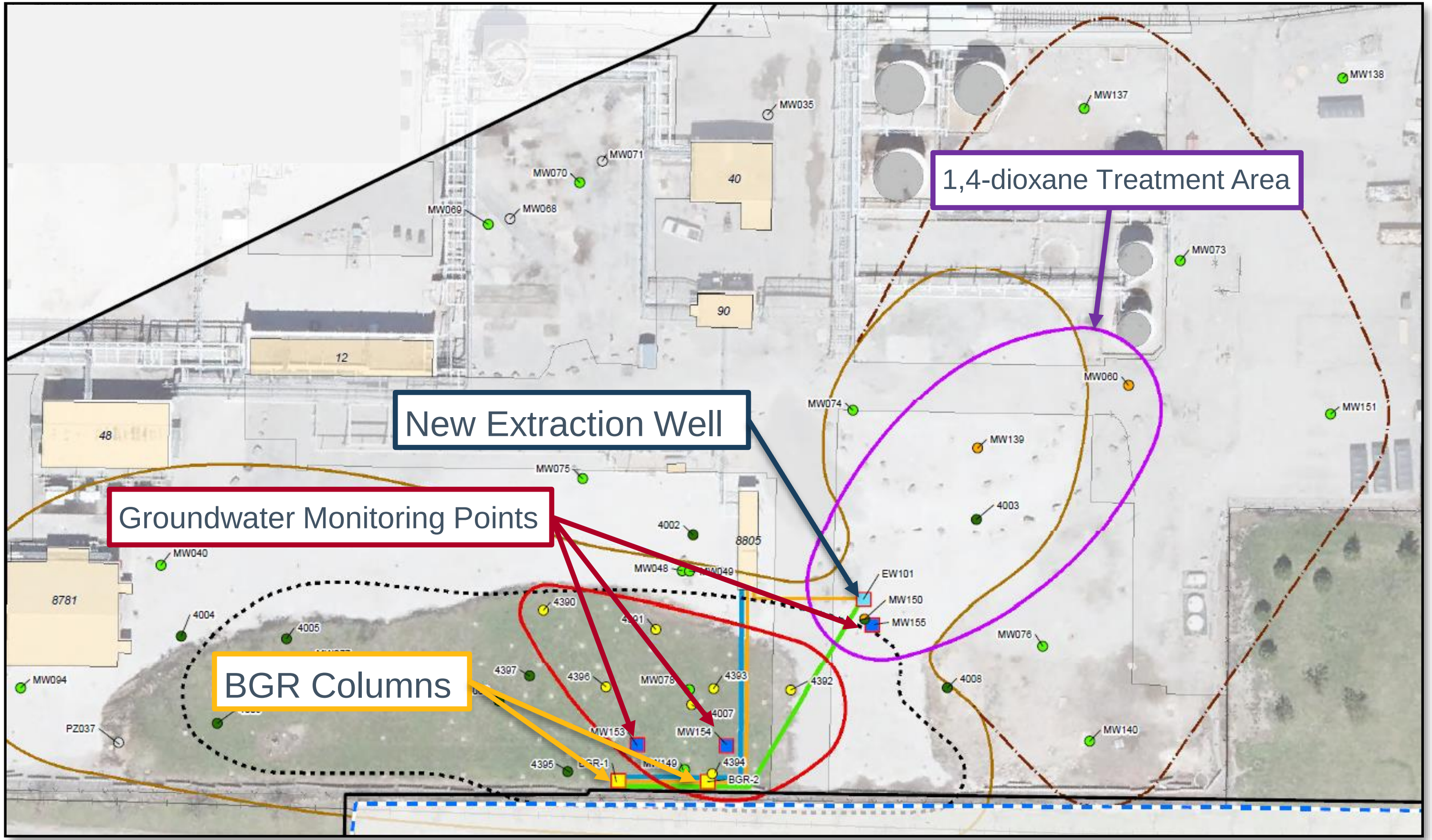
Next Steps

- Due to the success of the drum-scale pilot (**up to 98% 1,4-dioxane reduction observed**), an in-situ pilot study will be constructed at the Site with two BGR columns, which may be expanded into a **full-scale remedy** to treat 1,4-dioxane and residual CVOCs.
- This technology may be used to treat 1,4-dioxane at other contaminated sites
  - Offers potentially lower treatment costs
  - Offers more sustainable solution for the treatment of 1,4-dioxane



Example of a similar SBGR to be installed at the Site.

NEXT STEPS: BASIS OF DESIGN FOR IN-SITU SBGR



Thank you!

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