Geosyntec consultants

Breakthroughs in 1,4-Dioxane Treatment: Cost Effectively Treating 1,4-Dioxane in a Chemically Complex Water Stream

Kirk Craig, P.E. || 22 March 2018

Co-Authors: Brian Petty, P.E., Geosyntec
Chao Zhou, P.E., Geosyntec

14th Annual Gatekeeper Regulatory Roundup

Our Path to 1,4-dioxane Treatment Breakthroughs

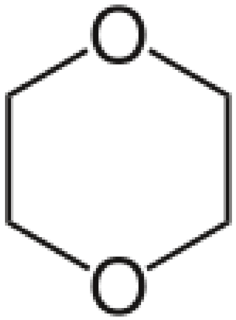
Needs Assessment

Challenge = Opportunity

Targeting Low Concentrations

Bioreactor Engineering Research

What's Next?



Our Path to 1,4-dioxane Treatment Breakthroughs

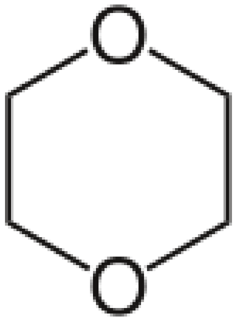
Needs Assessment

Challenge = Opportunity

Targeting Low Concentrations

Bioreactor Engineering Research

What’s Next?



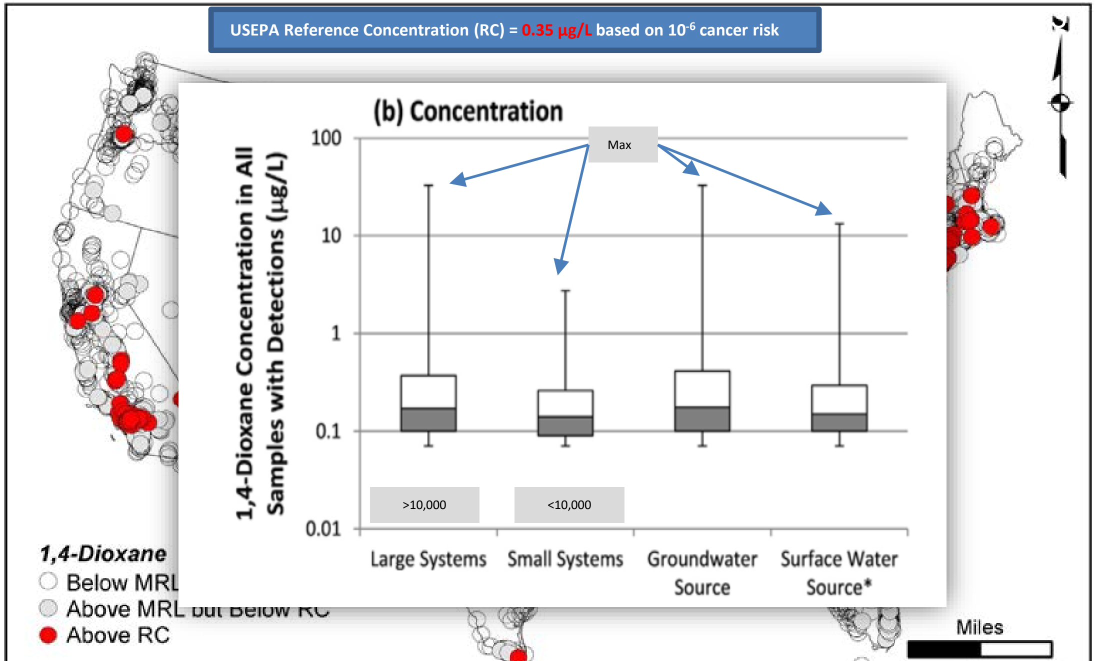
Potential Sources are Widespread

- Manufacturing:
  - Cellulose acetate membranes
  - (PET) manufacturing and recycling
  - Ethoxylated soaps, cosmetics, shampoos, etc.
  - Other ethylene glycol, or ethylene oxide-based industries (inks, dyes, paints, adhesives, etc.)
  - Plastic bottles (Type 1) and polyester fiber (clothing)
- Groundwater cleanups
  - Chlorinated solvent sites (especially if 1,1,1-TCA is present)
- Wastewater treatment pass-through
  - Domestic: personal care products, surfactants/detergents
  - Industrial: surfactants / detergents
- Airports (antifreeze, de-icing fluids)
- Landfills





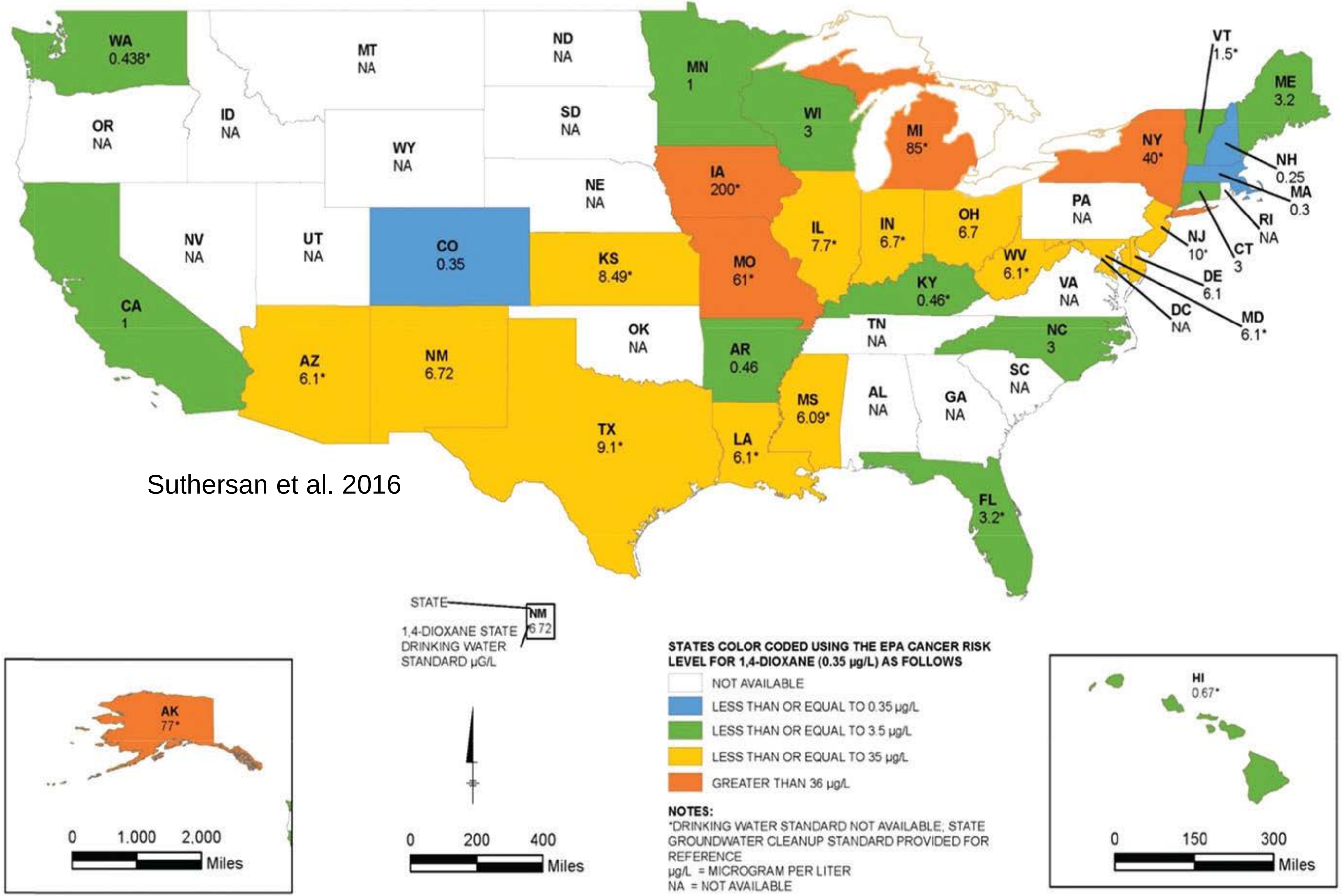

Recent Snapshot of Public Water System Testing



Anderson et al. (2017)

- 21% detection in 4,800 public water systems
  - MRL = 0.07 µg/L
- 7% above USEPA's 10^{-6} cancer risk concentration
- Widespread groundwater and surface water detections

Drive Toward Lower Regulatory Thresholds

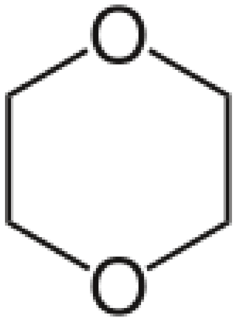


Suthersan et al. 2016

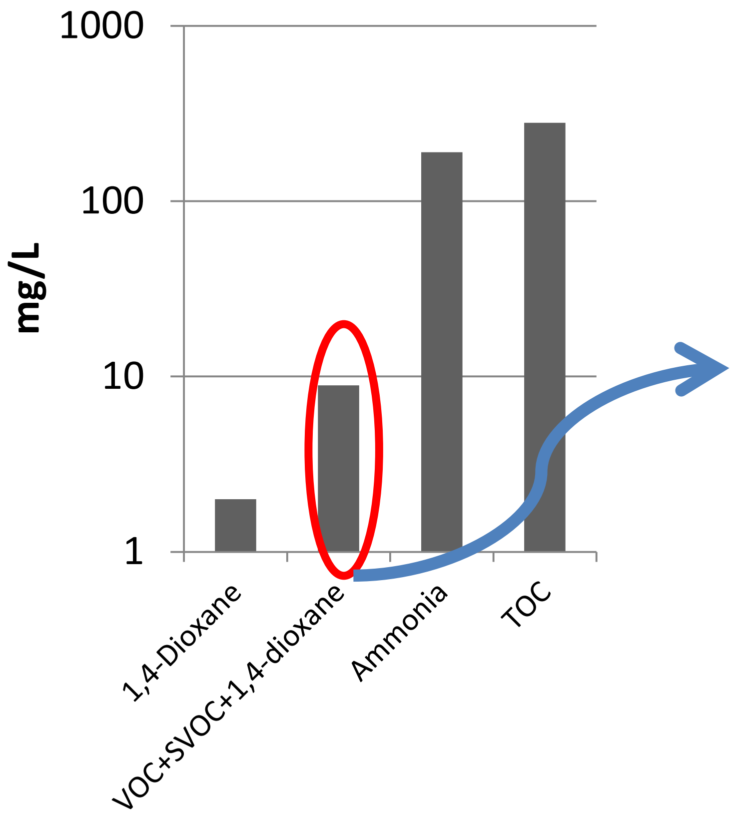
NJ and MI have lowered their regulatory levels since 2016

Our Path to 1,4-dioxane Treatment Breakthroughs

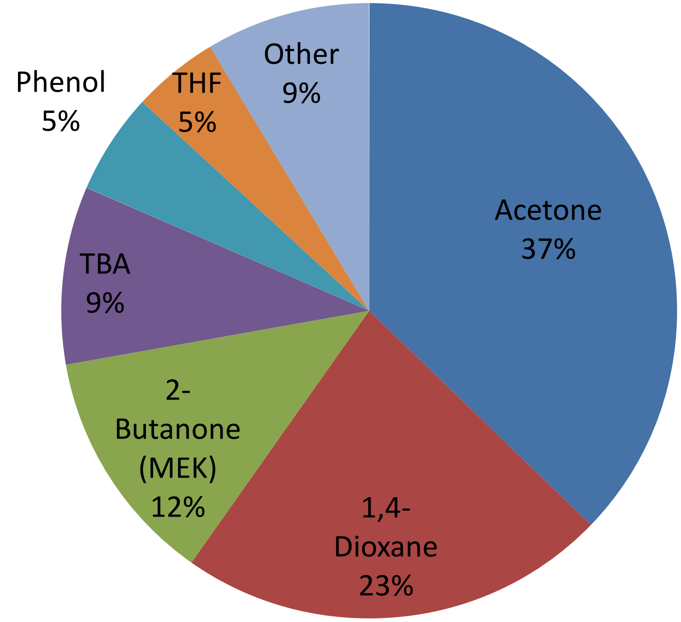
- Needs Assessment
- Challenge = Opportunity
- Targeting Low Concentrations
- Bioreactor Engineering Research
- What's Next?



Typical Treatment Plant Influent Sample

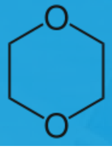


Breakdown of VOCs, SVOCs and 1,4-dioxane



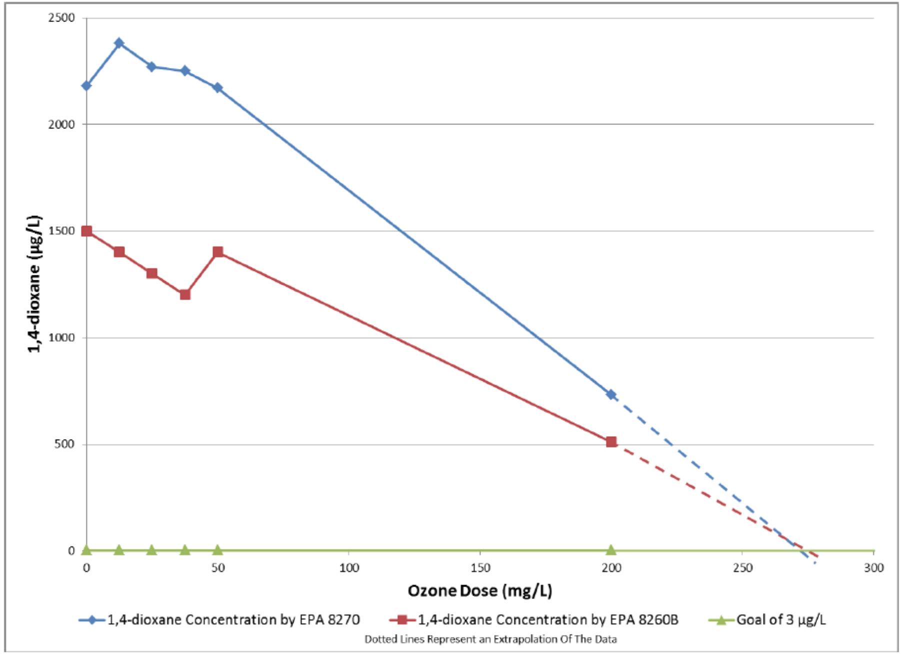
TBA: tert-butyl alcohol
THF: tetrahydrofuran

Limited Treatment Options



Technology	Applicability	Capital Cost	O&M Cost
GAC and Air Stripping	Not generally effective	-	-
Advanced Oxidation	Proven, widely used, potential interferences and byproducts	$$$	$$$
Synthetic Media Adsorption	Emerging technology, on-site steam regeneration, waste stream	$$$	$$
Biological Treatment	Few full-scale systems; basic science still being researched; ability to meet low regulatory limits not demonstrated	$$	$

APTwater HiPOx Bench Testing



- HiPOx is an H_2O_2/O^3 process
- Treated 1,4-dioxane to 1 µg/L
  - With highest ozone concentration not achieved
- APTwater predicted ozone concentration of >100 mg/L may be required to achieve treatment goal
- TOC thought responsible for high ozone requirement
- NOTE: full-scale biological treatment effluent was 128 µg/L during this test

Purifics Photo-Cat Test Results

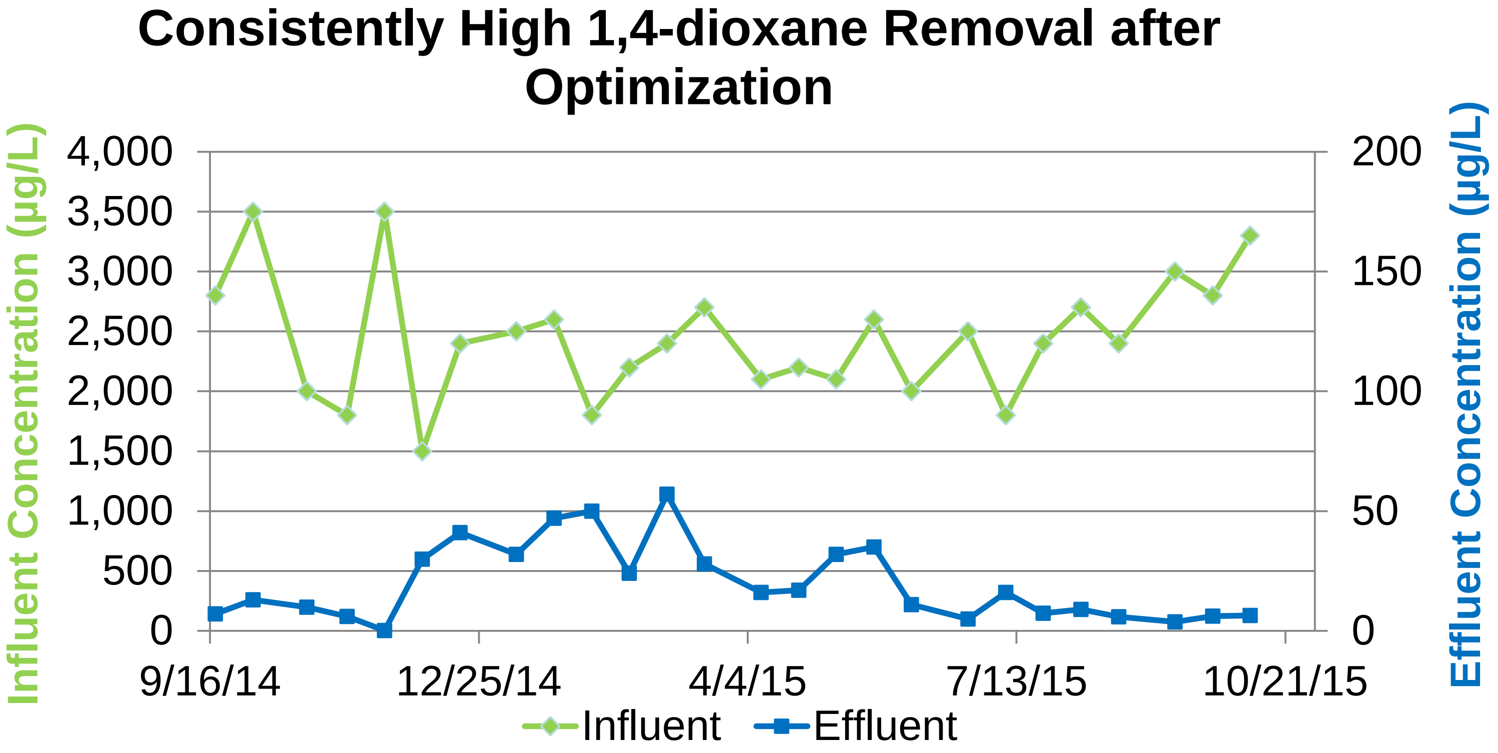
Source of Test Water	Test Water Starting Concentration (µg/L)	Lowest Concentration Achieved During Purifics Bench Test (µg/L)
Treatment Plant Influent	2,020	250

Image: http://www.purifics.com/

Notes:

- PhotoCAT is TiO_2/UV process
- Tests run at 4 different energy levels
- TOC destruction was limited: ~ 50%

Meanwhile, Treatment Plant was Achieving >99% Removal



Optimization of Operating Parameters

– Double organic loadings (divert flow to one of two aeration basins)

– Increase mixed liquor suspended solids

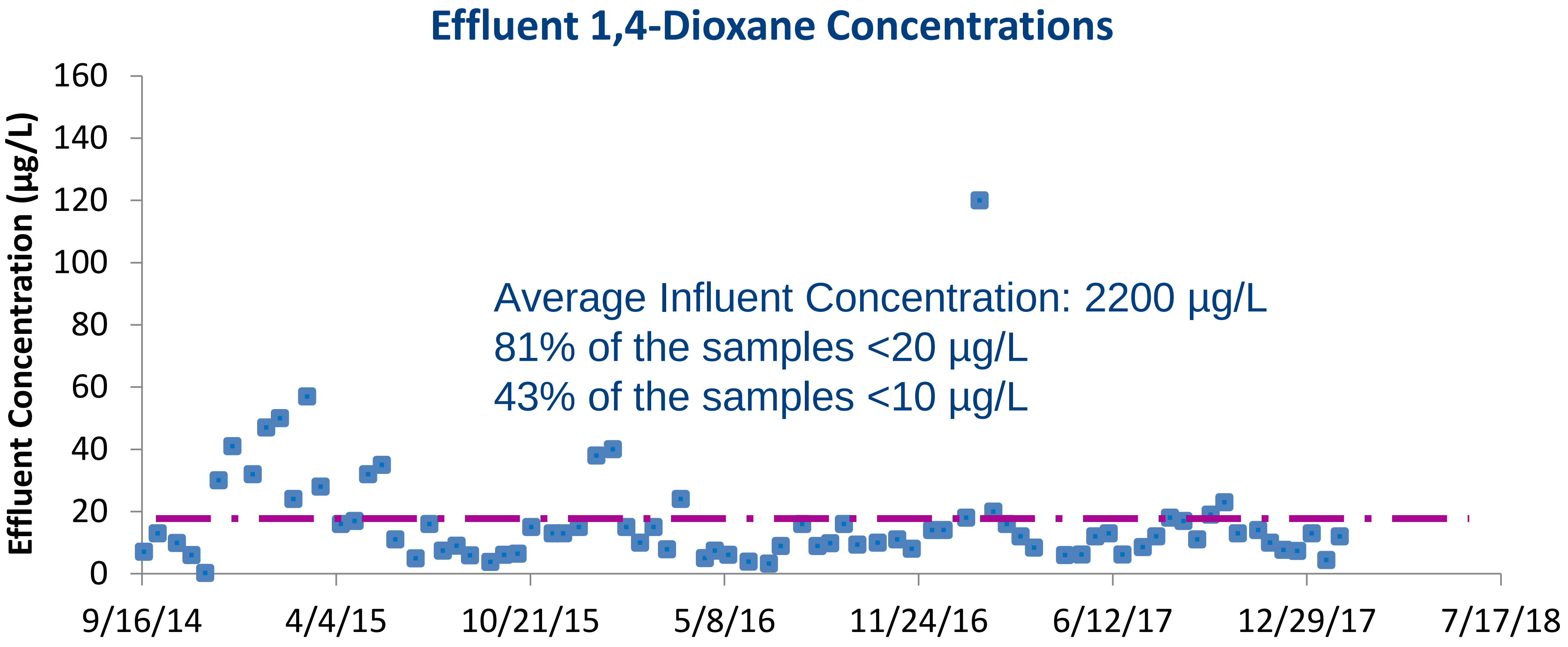
– Maintain solids retention time around 30 days

– Stop supplemental additions of powdered activated carbon

– Address nutrient deficiencies

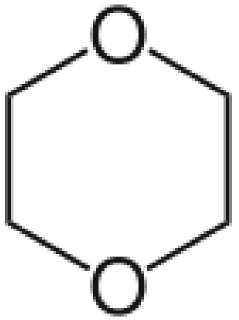
– Closely monitor temperature and pH

Sustained 1,4-dioxane Full-Scale Treatment



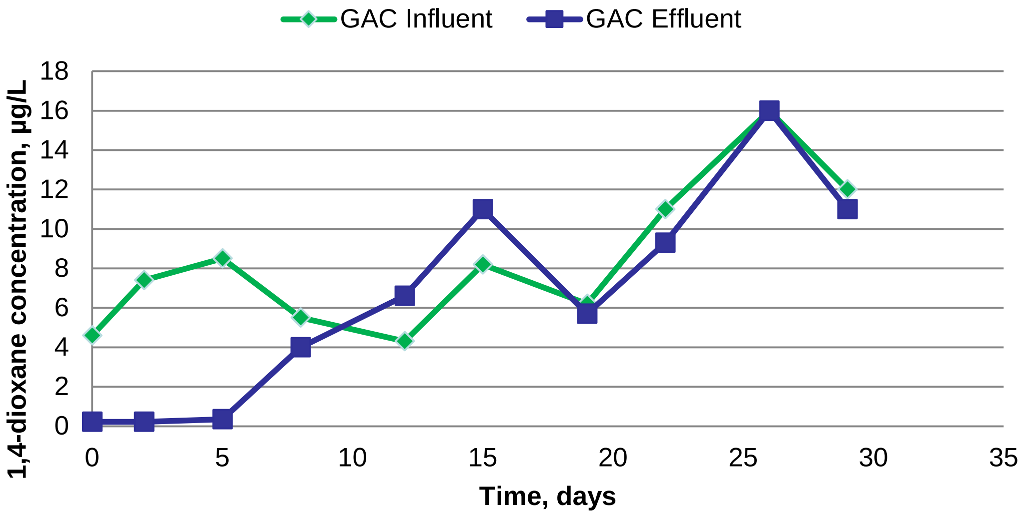
Our Path to 1,4-dioxane Treatment Breakthroughs

- Needs Assessment
- Challenge = Opportunity
- **Targeting Low Concentrations**
- Bioreactor Engineering Research
- What's Next?



Polishing Option: GAC Column Test

- GAC influent concentration between 5 to 8 µg/L during first three weeks of test
- GAC breakthrough occurred within two weeks
- GAC effluent above 3 µg/L after 5 days.

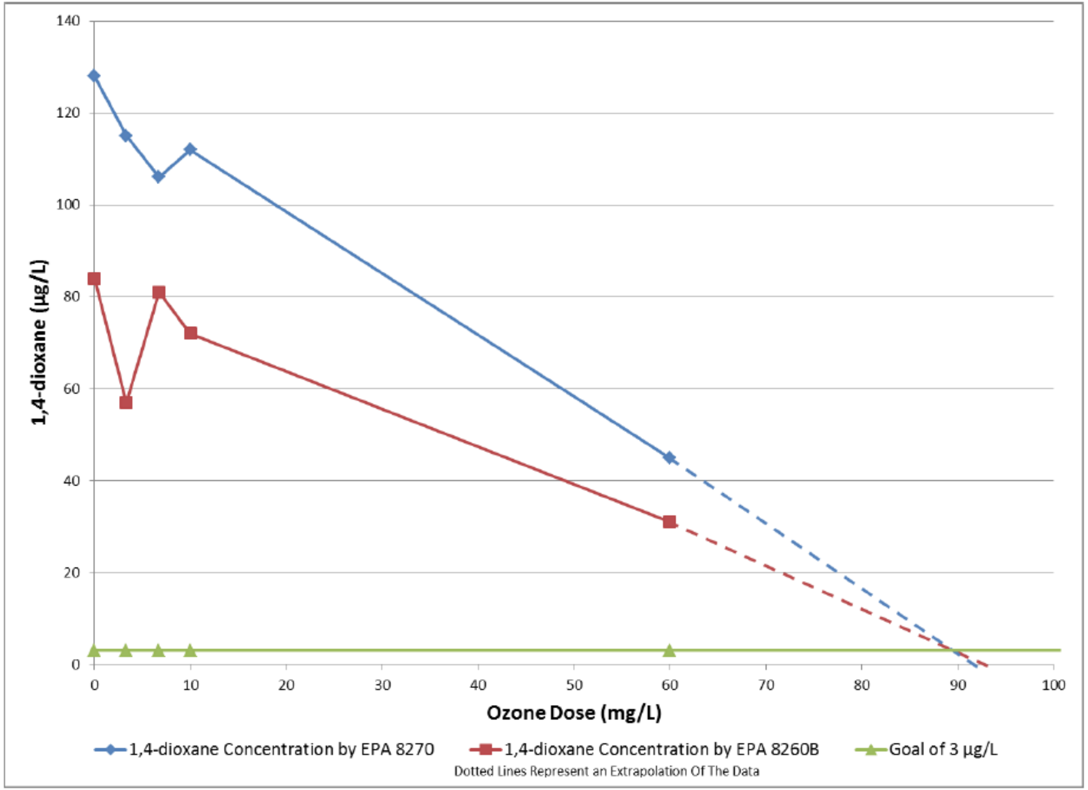


Polishing AOP Option: PhotoCAT

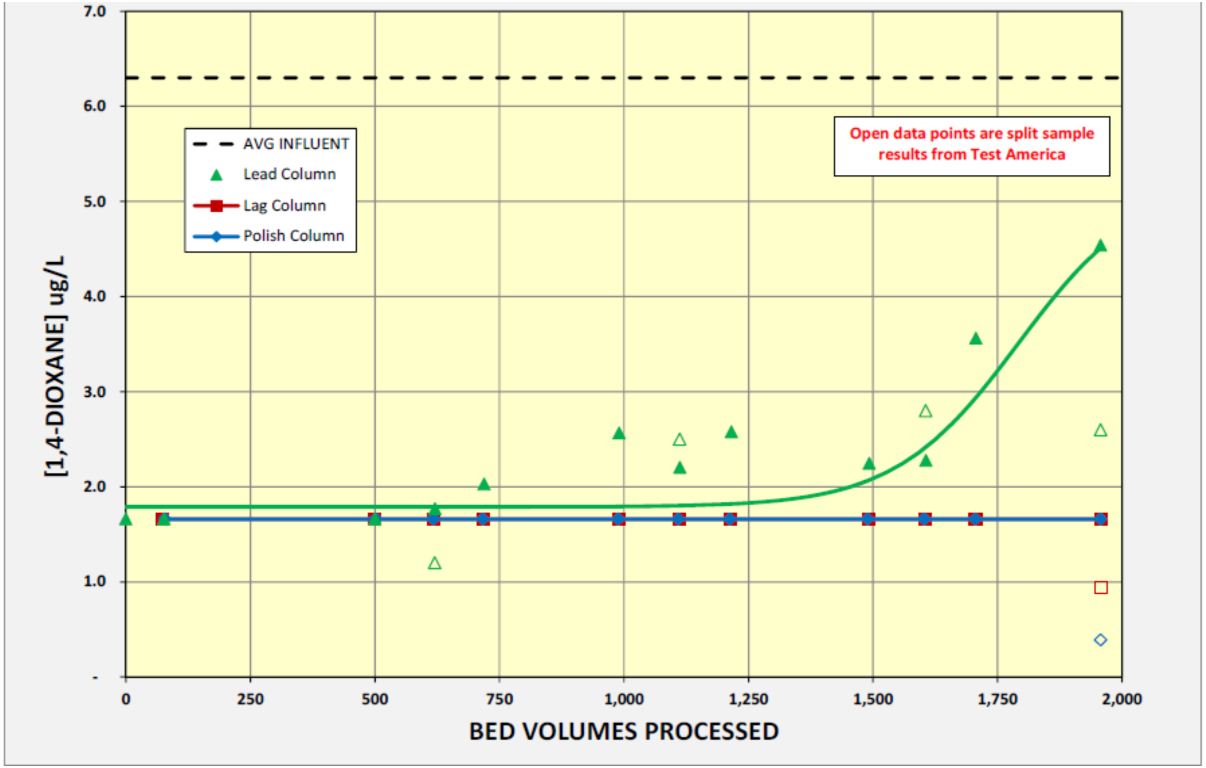
Source of Test Water (collected Nov. 2011)	Test Water Starting Concentration (µg/L)	Lowest Concentration Achieved During Purifics Bench Test (µg/L)
Treatment Plant Effluent	130	30

Image: http://www.purifics.com/

Polishing AOP Option: HiPOx



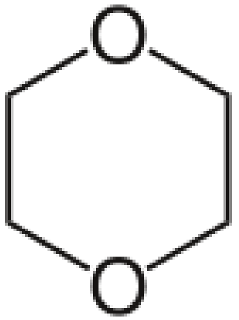
Polishing Option: Ambersorb™ 560 Pilot (ect$_2$)



– Small pilot scale system (0.12 gpm)
– Inf. 1,4-dioxane at 5.1 to 9.4 µg/L
– 1700 µg/L of trihalomethanes
– 3 columns in series w/a steam regeneration system
– Effective at removing 1,4-dioxane to ND (<1.7 µg/L)
– <1,000 bed volumes to breakthrough

Our Path to 1,4-dioxane Treatment Breakthroughs

- Needs Assessment
- Challenge = Opportunity
- Targeting Low Concentrations
- Bioreactor Engineering Research
- What's Next?

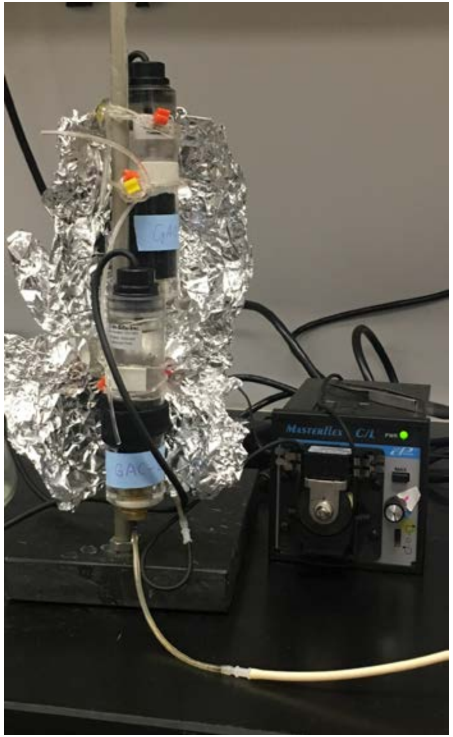


Bioremediation

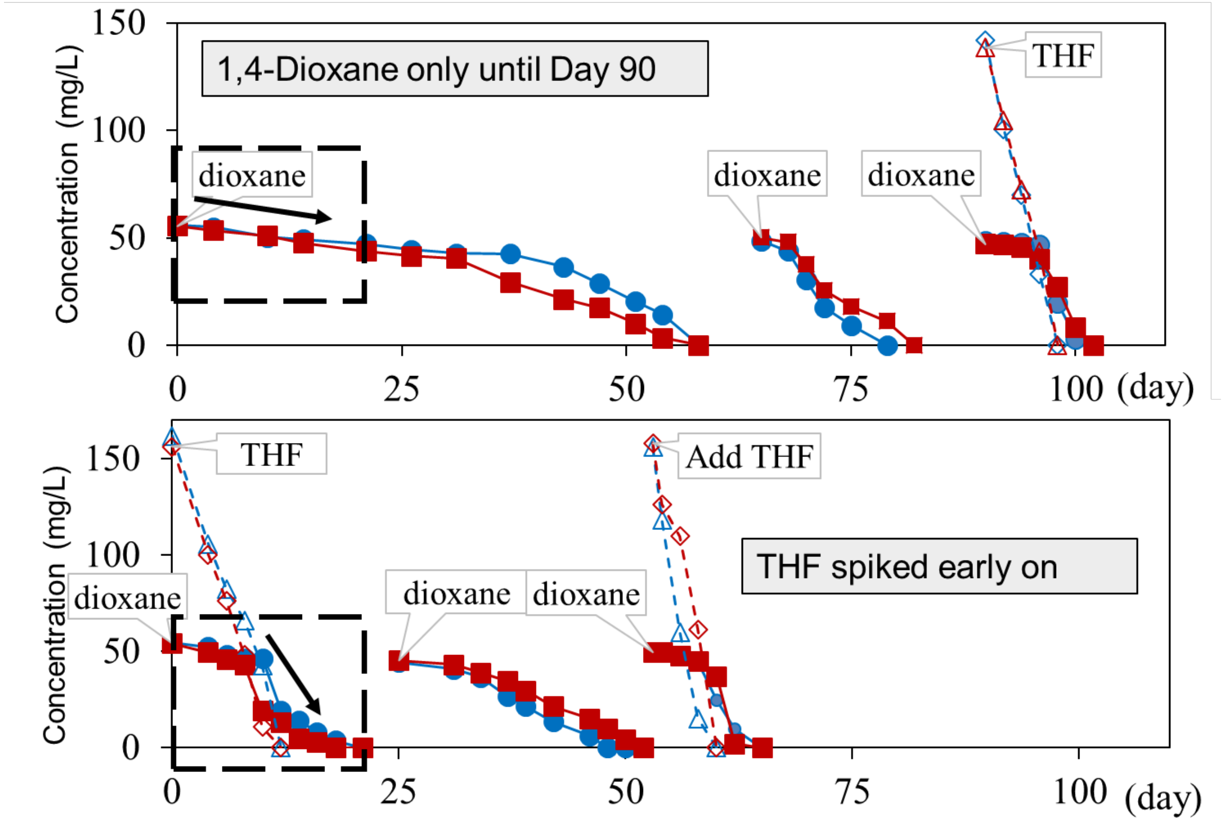
- 1,4-dioxane degraders form clumps/filaments and tend to attach to surfaces rather than remaining suspended in solution
- Presence of 1,1,1-TCA and 1,1-DCE inhibit biodegradation of 1,4-dioxane
- Challenge of adequate oxygen delivery
- Significant recent advances in fundamental research and applications in aerobic 1,4-dioxane biodegradation
  - Cometabolic degradation:
    - With tetrahydrofuran: observed in full-scale facilities
      - Lowry Landfill Superfund Site, Colorado
    - With propane and other alkanes: observed and being field tested
      - Vandenberg Air Force Base , CA
  - Direct metabolic degradation:
    - Pure strains, e.g., Pseudonocardia Dioxanivorans CB1190

1,4-Dioxane Polishing: BioGAC

- Biofiltration (BioGAC):
  - Appealing capital and O&M cost profiles if successful
  - Bench testing at FSU began in summer 2016
  - Confirmed metabolic degradation
  - Identified amendments that improve 1,4-dioxane removal

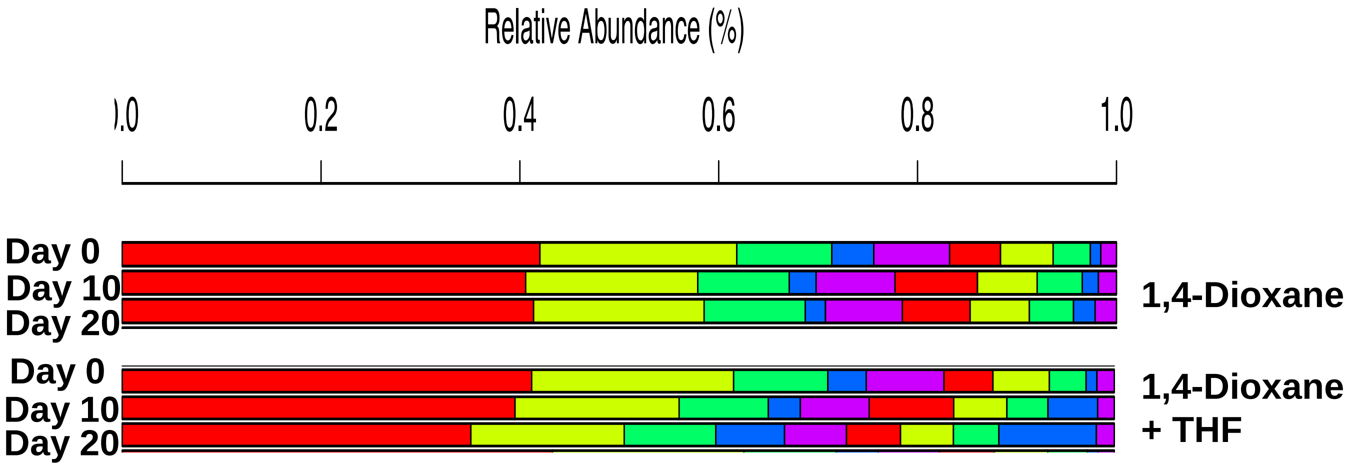


Adding Tetrahydrofuran (THF) Promotes 1,4-Dioxane Treatment



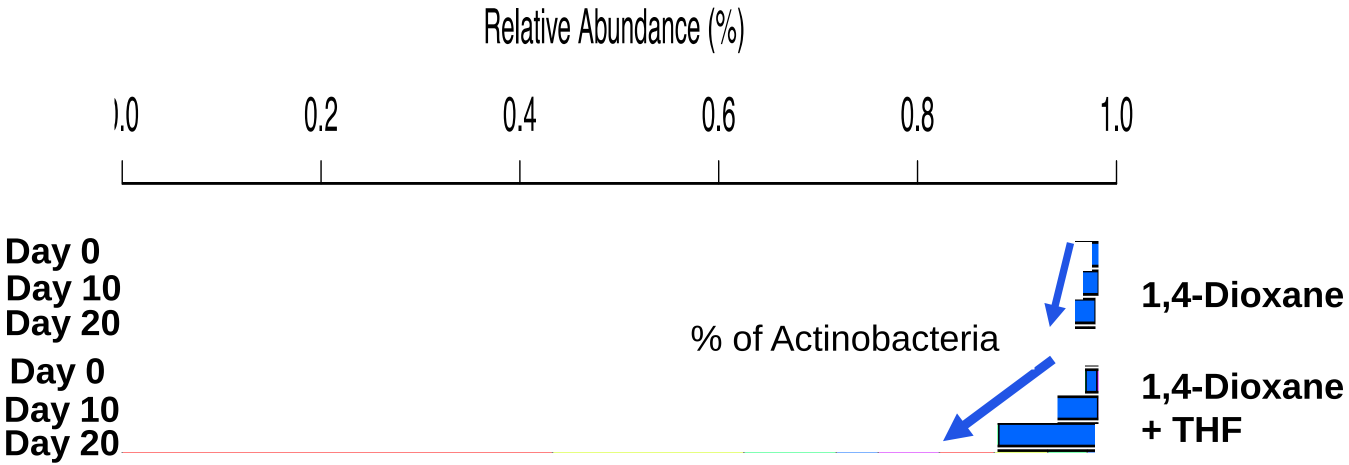
FSU, unpublished data

Molecular Methods Tracking Changes in Microbial Population



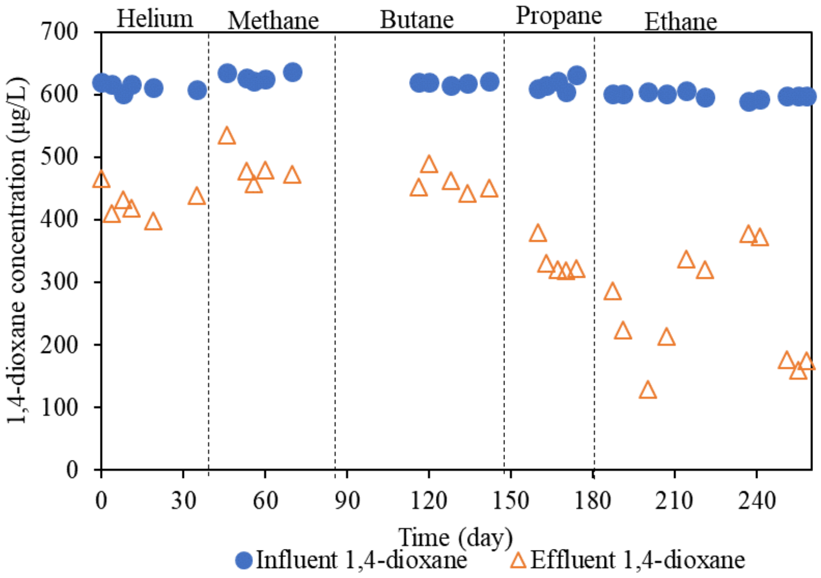
FSU, unpublished data
Functional gene data not shown

Molecular Methods Tracking Changes in Microbial Population



FSU, unpublished data
Functional gene data not shown

Investigating Gas Amendments



- Methane and butane did not promote 1,4-dioxane biodegradation
- Propane increased 1,4-dioxane removal from ~25% to ~50%
- Ethane had best result with removal of ~70%.

Our Path to 1,4-dioxane Treatment Breakthroughs

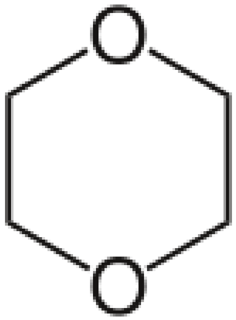
Needs Assessment

Challenge = Opportunity

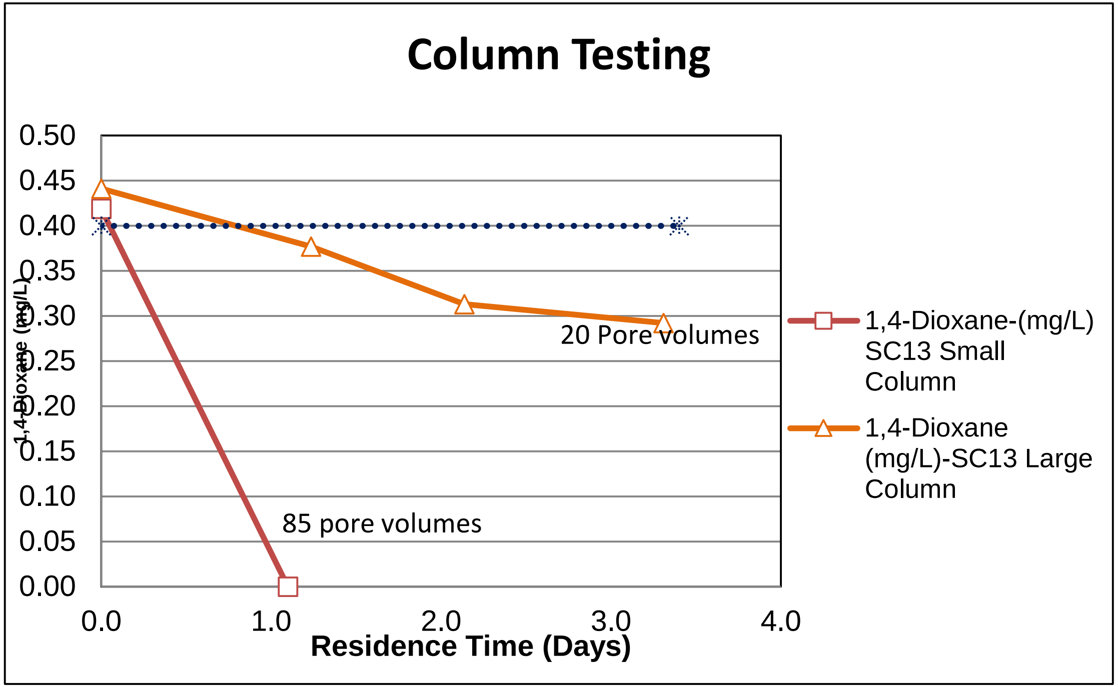
Targeting Low Concentrations

Bioreactor Engineering Research

What’s Next?



Sand Column (In Situ Application)



- Sand column seeded with enriched culture
- Rapidly reduced 1,4-dioxane from 400 µg/L to 43 µg/L in 1.1 days
- Highly diverse and redundant microbial community
- Adaptive to field conditions?

Biofiltration Testing for Ex Situ Polishing

- Test the removal at even lower concentrations
  - e.g., 10 or 2 µg/L)
- Pilot/Demonstration
  - longer term objective
- Test promising amendments
- Continue optimizing EBCT

Conclusions

- Significant need for more 1,4-dioxane treatment options
  - Especially at the low concentrations being targeted
- Biological treatment demonstrated to remove >99% 1,4-dioxane.
- Preliminary data show a diverse mixed culture with potentially highly efficient 1,4-dioxane-degrading strains.
- More fundamental and applied research work is underway.

Thank You

Kirk Craig, P.E.
Senior Principal
Geosyntec Consultants, Inc.
kcraig@Geosyntec.com
602-513-5815

Co-Authors
Brian Petty, P.E.
Senior Principal
bpetty@geosyntec.com

Chao Zhou, P.E.
Engineer
czhou@geosyntec.com

KIRK CRAIG, P.E.
Principal Environmental Engineer and Manager
Geosyntec Consultants
11811 N. Tatum Blvd., Suite P-186
Phoenix, AZ 85028

602.513.5812
kcraig@geosyntec.com

- Kirk Craig, P.E., is a Principal Environmental Engineer and manager of Geosyntec Consultants' Phoenix office. He has worked in the professional engineering and environmental fields for more than 20 years. His primary expertise is in the remediation and reclamation of impacted groundwater as well as the characterization and remediation of impacted soil, and soil gas for municipal, industrial and commercial clients.
- Kirk has overseen operations and activities associated with the remediation and reclamation of groundwater at a variety of sites throughout the United States. His environmental engineering experience includes the design, construction, optimization, and/or operation and maintenance of more than 50 treatment systems using a multitude of different treatment technologies.
- Kirk's ability to relate to clients and regulators, combined with his technical expertise and regulatory compliance experience enables him to effectively understand client needs and provide regulatory agencies with acceptable cost effective solutions.