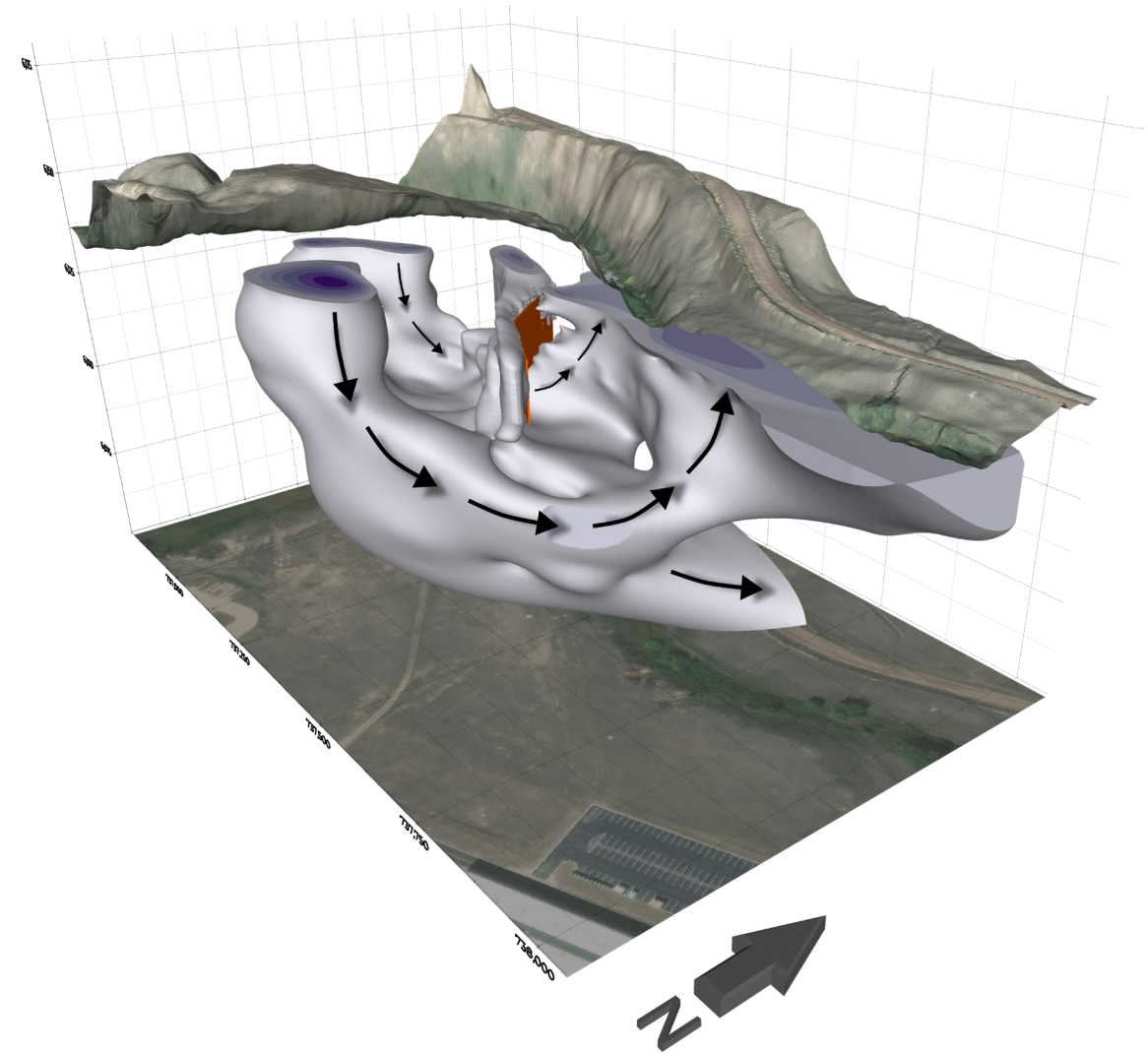


Post-Remedy Evaluation Using 3-D Modeling to Refine Remedial Strategy at a Legacy TCE Site

Jeffrey Temple
HydroGeoLogic, Inc.



Agenda

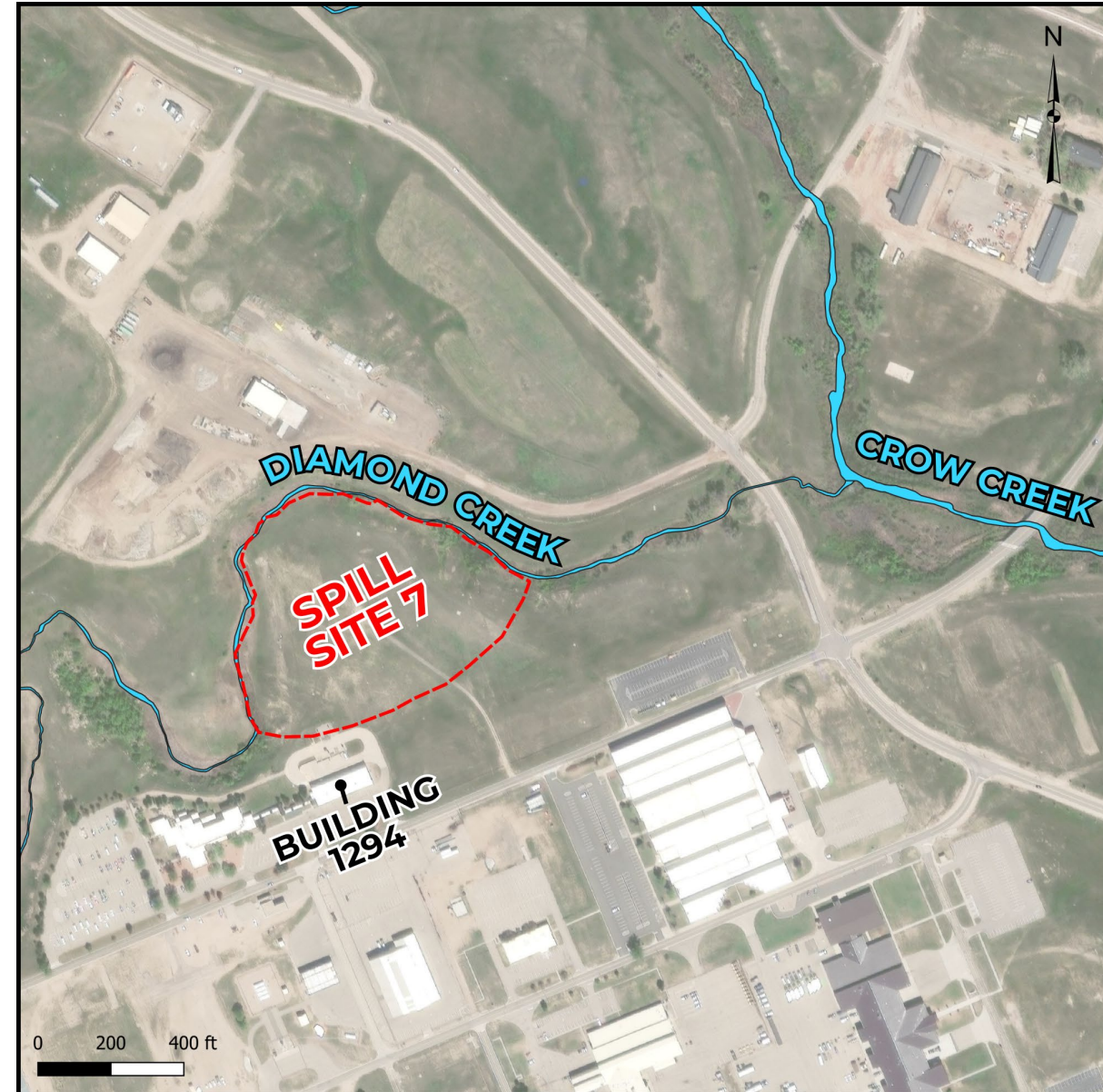
- Site Overview
 - Spill Site 7
 - Sources of Contamination
 - Remedial History
- Methodology
 - Field Investigation Summary
 - 3-D Modeling
- Results
 - TCE Plume Modeling
 - MIP/HPT Investigation
 - Geochemical & Microbial Sampling
- Next Steps
 - Pilot Study
- Summary & Conclusions



Site Overview

SPILL SITE 7

- Northeast of Building 1294 (Formerly 4000)
 - 1960 – 1966: Liquid-oxygen production facility for Atlas missiles
- Depth to Water: ~2 to 24 ft bgs
- Shallow & Intermediate GW zones
- Geology consists of weathered alluvial deposits of the Ogallala Formation
 - Predominantly clays and silts, with localized sands and gravels that could serve as preferential contaminant pathways



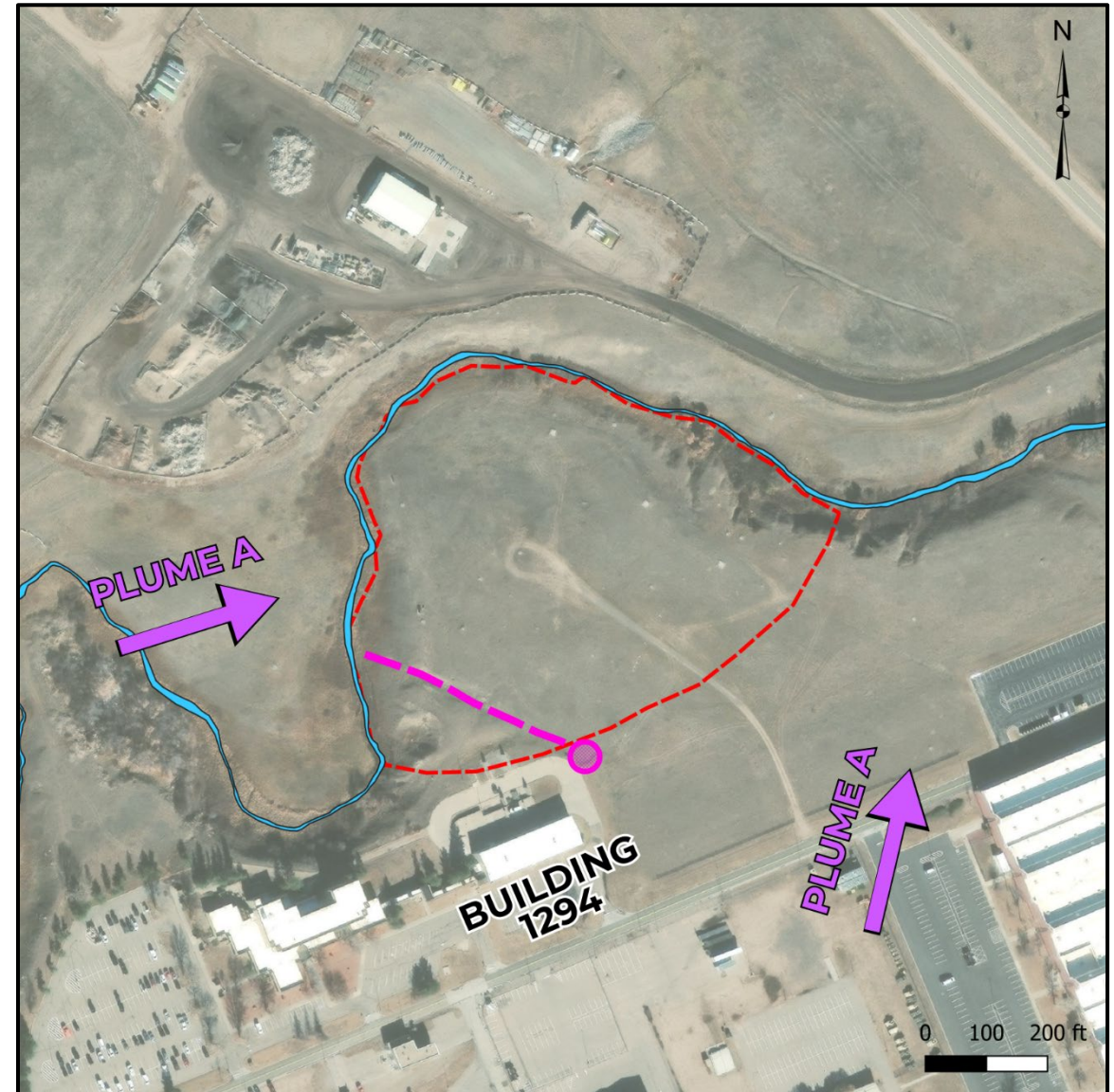
Site Overview

SOURCES OF CONTAMINATION

- **Grease Trap**

- Subsurface concrete structure located ~150 ft northeast of Building 1294
- Received liquid effluent from liquid-oxygen production at Building 1294
- Separated floating oil and grease from water, then discharged water to unlined **surface drainage ditch**
- Discharge to grease trap ceased in 1966, but an accidental overflow of oily sludge occurred in 1989

- **Plume A:** Historical VOC plume originating from source south of Spill Site 7



Former Grease Trap
Location

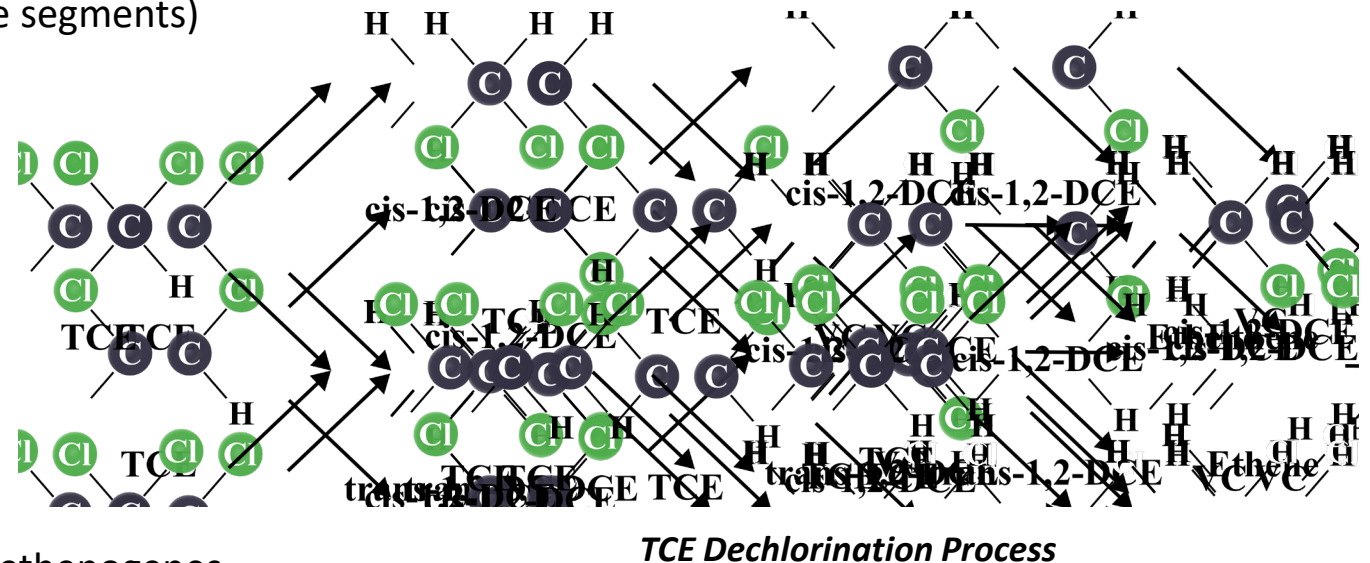


Surface Drainage
Ditch

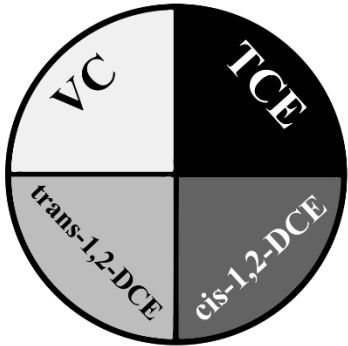
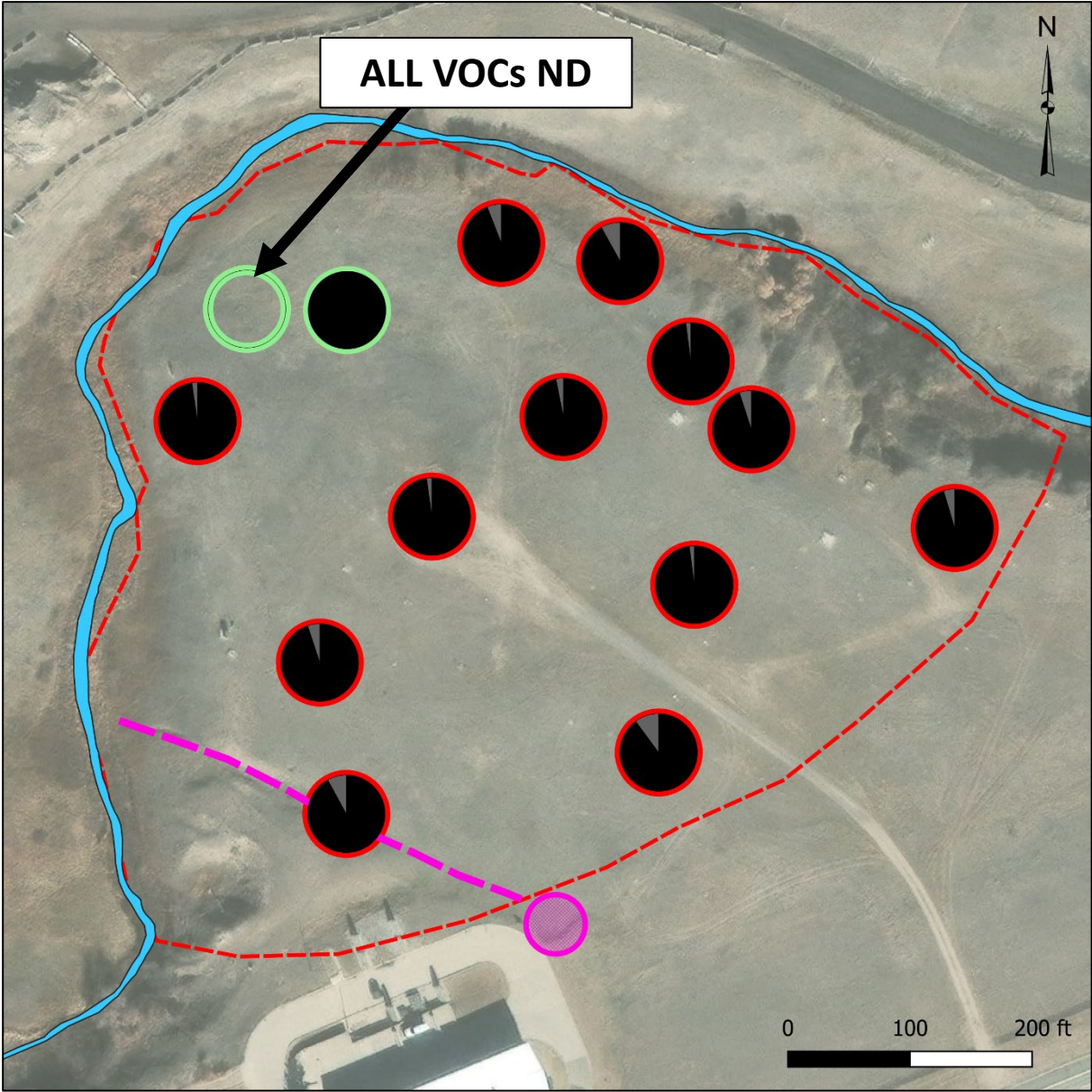
Site Overview

REMEDIAL HISTORY

- 1989 – Excavation of the grease trap, sludge, and some surrounding soils
- 1995 to 1996 – Operation of a groundwater pump and treat system
- **1999 – Installation of a trenched ZVI PRB**
 - 600-ft wall, 2-3 ft thick, 24-30 ft deep (three segments)
 - Peerless granular zero-valent iron mixed with sand/pea gravel
- 2003 to 2004 – Excavation of soils
- **2006 to 2008 – In-situ bioremediation**
 1. Hydraulic fracturing to deliver substrate into low K zones
 2. Substrate addition: EOS® (emulsified vegetable oil) + nutrients.
 3. Bioaugmentation addition: Dehalococcoides ethenogenes SDC-9® culture.
- 2008 to present – Long-term monitoring and MNA



- 1998
- 1999 - ZVI PRB Installed
- 2001
- 2006
- 2006 to 2008 - Bio Injections
- 2009
- 2011
- 2015
- 2023



- TCE > MCL (5 µg/L)
- TCE < MCL (5 µg/L)
- Former Grease Trap Location
- Unlined Surface Drainage Ditch

1998

1999 - ZVI PRB Installed

2001

2006

2006 to 2008 - Bio Injections

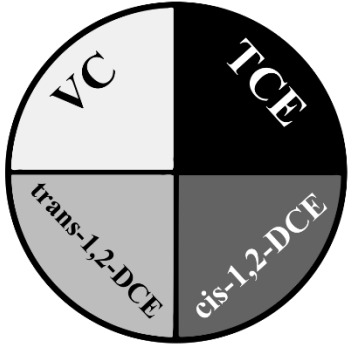
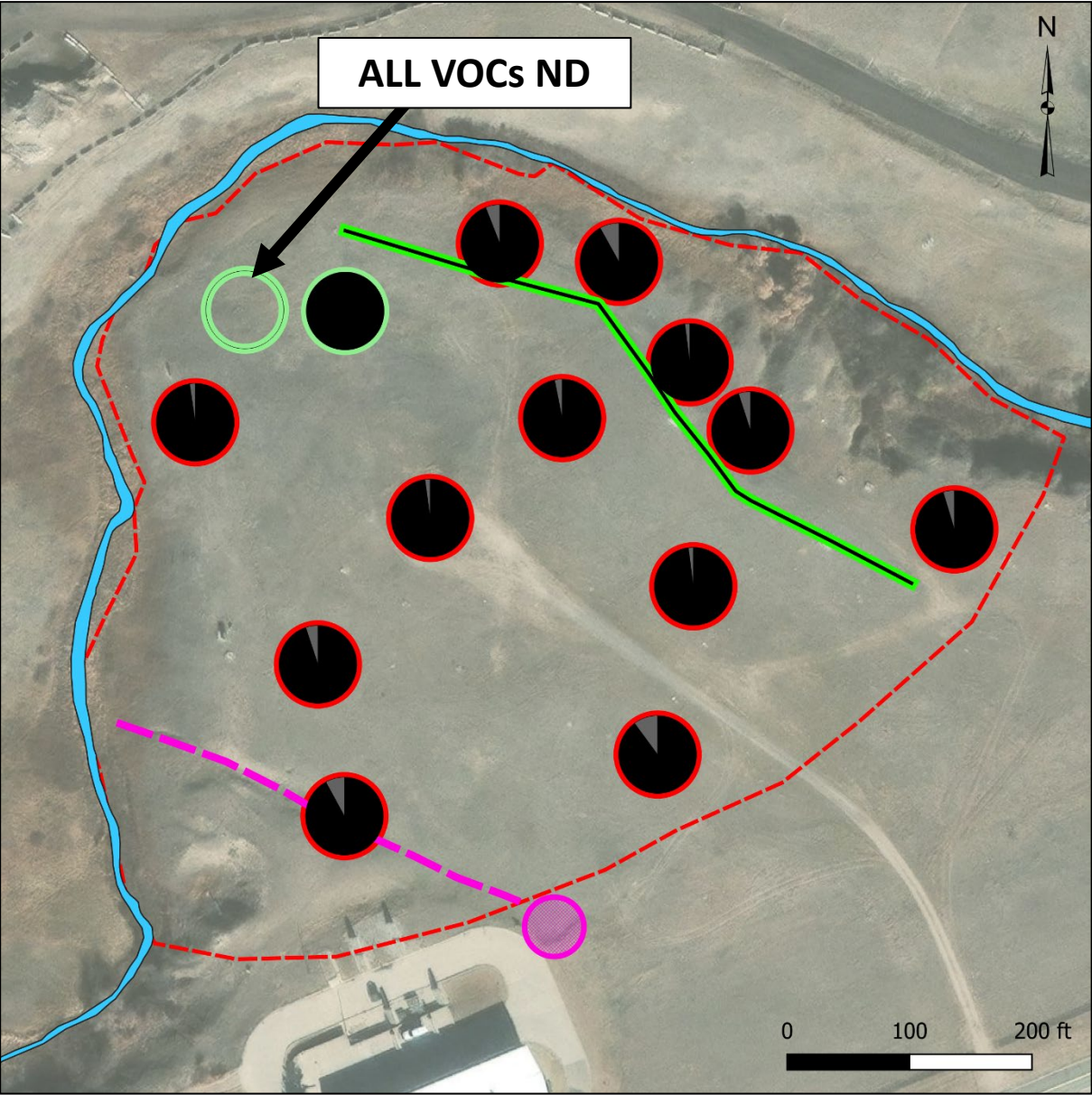
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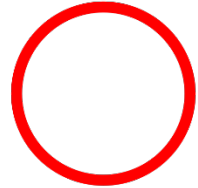
2011

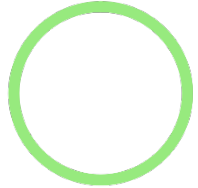
2015

2023

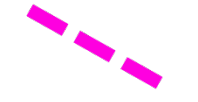
 ZVI PRB



 TCE > MCL (5 µg/L)

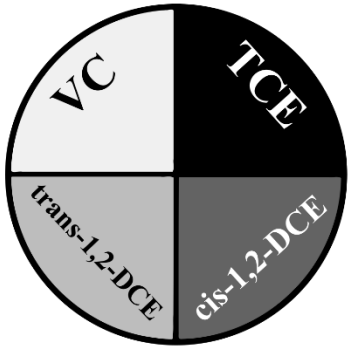
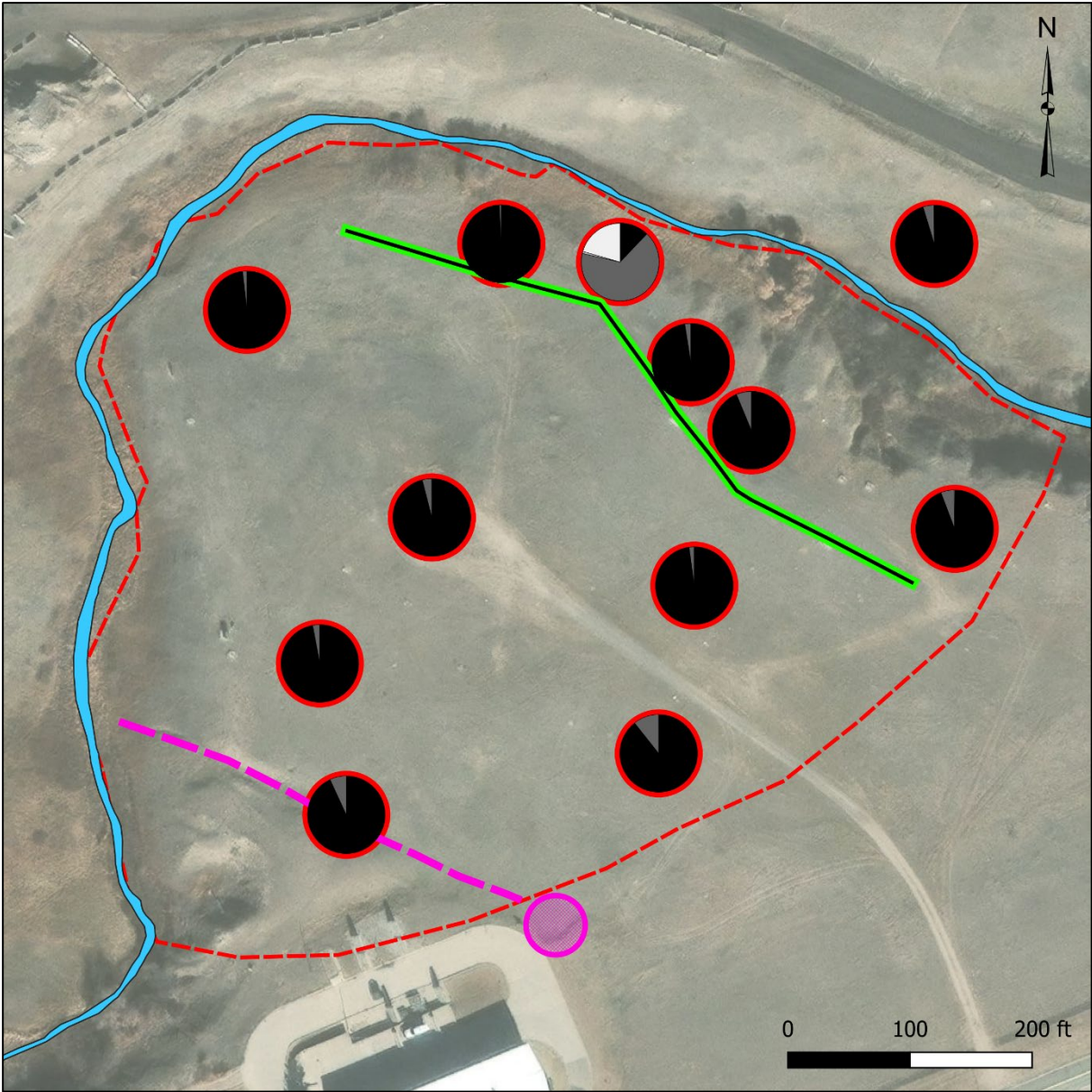
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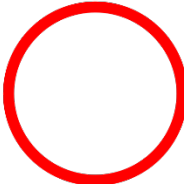
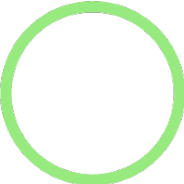
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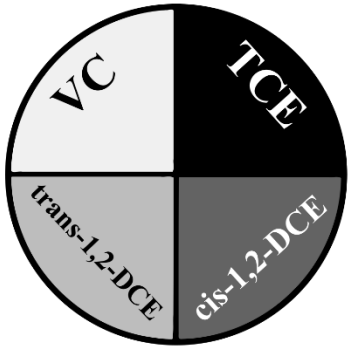
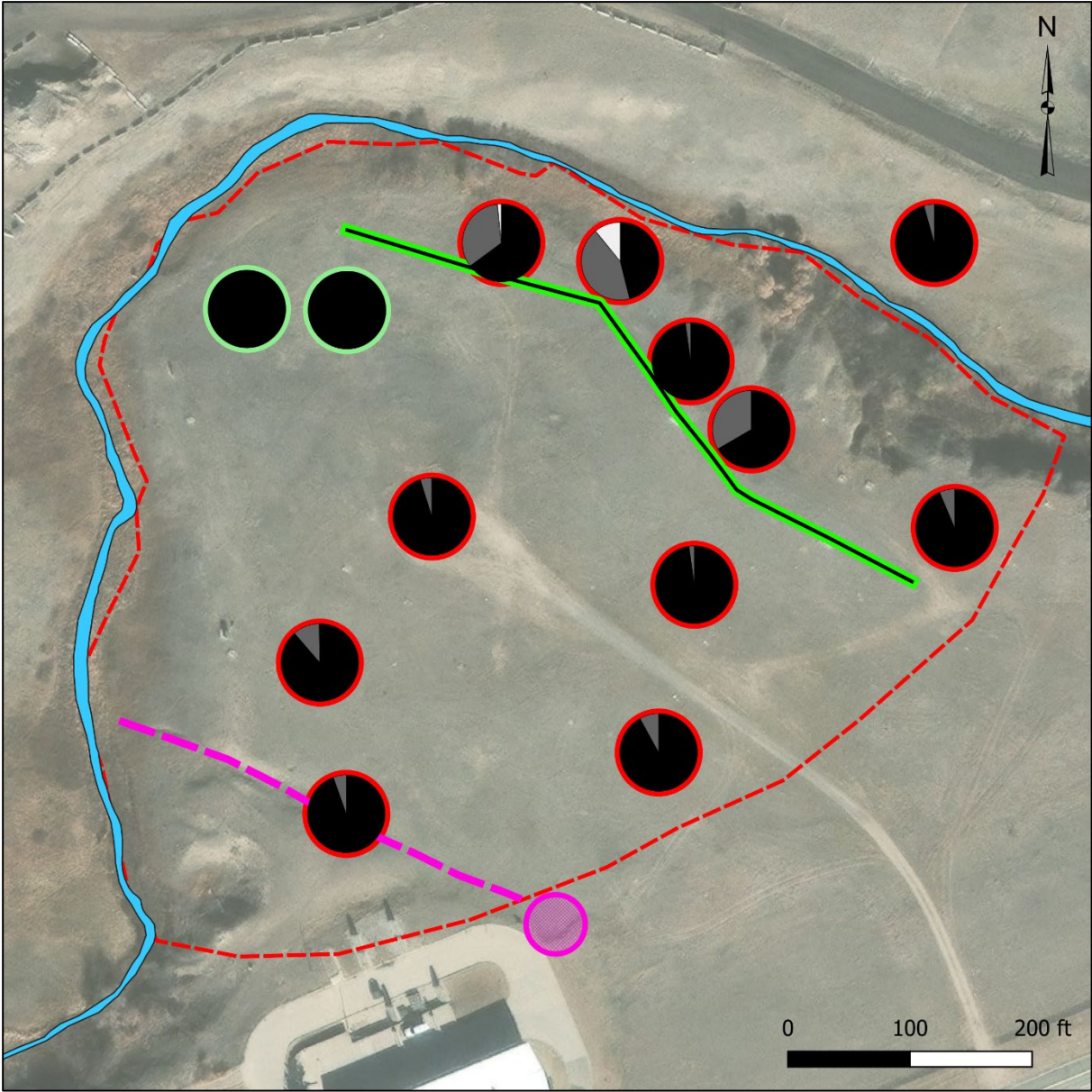
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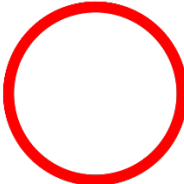
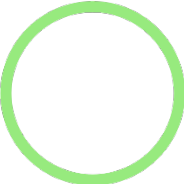


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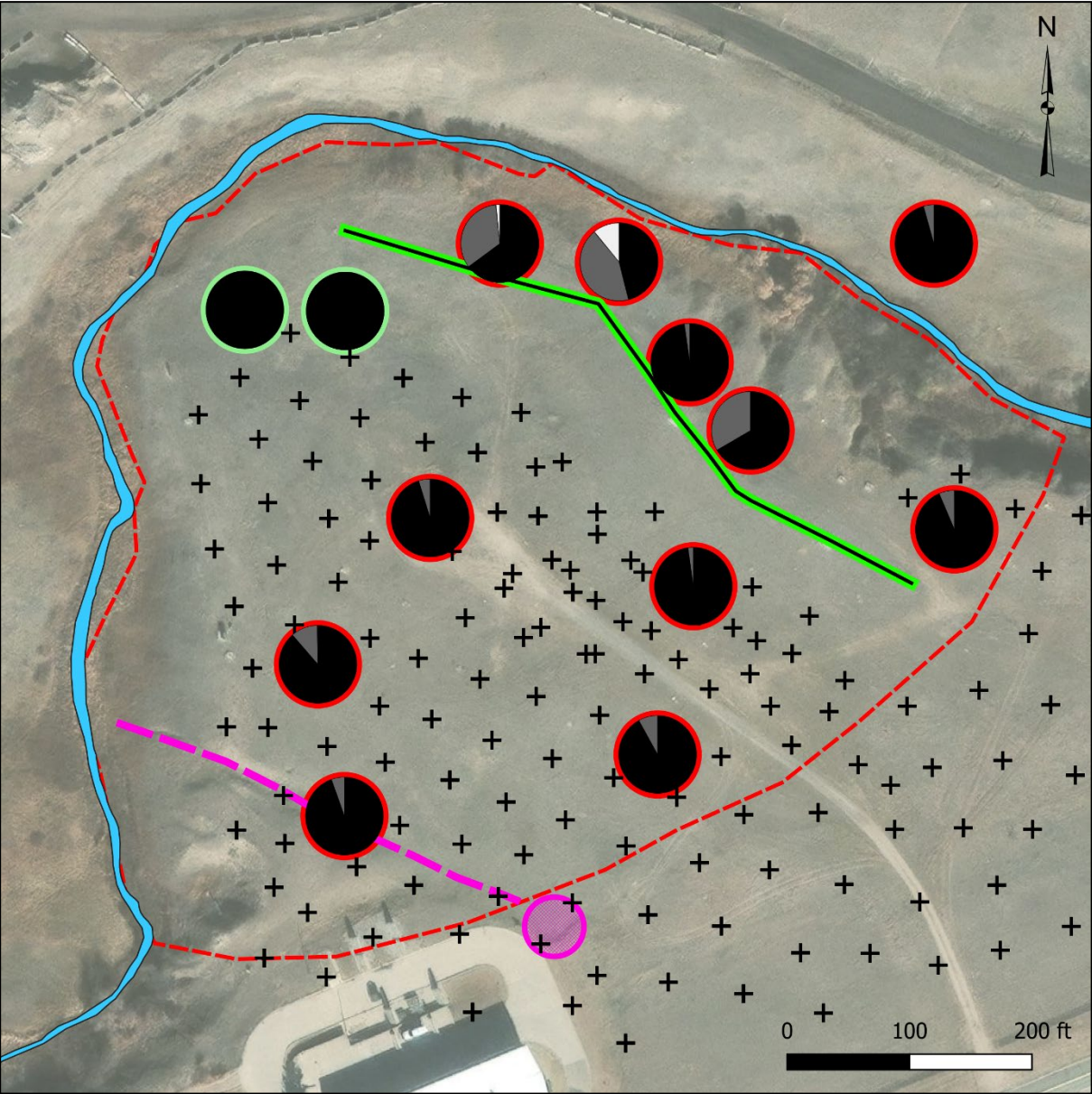
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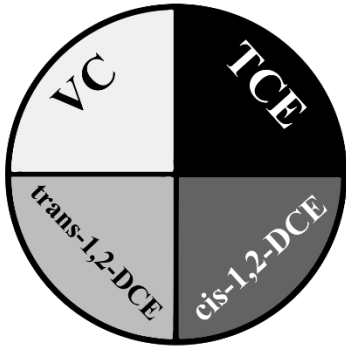


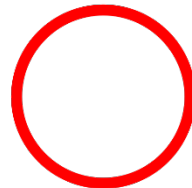
ZVI PRB



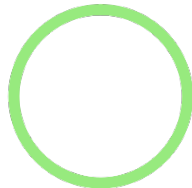
Bio-Injection Location







TCE > MCL (5 µg/L)



TCE < MCL (5 µg/L)



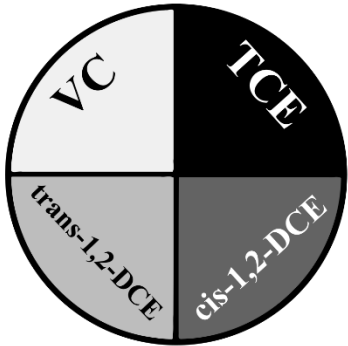
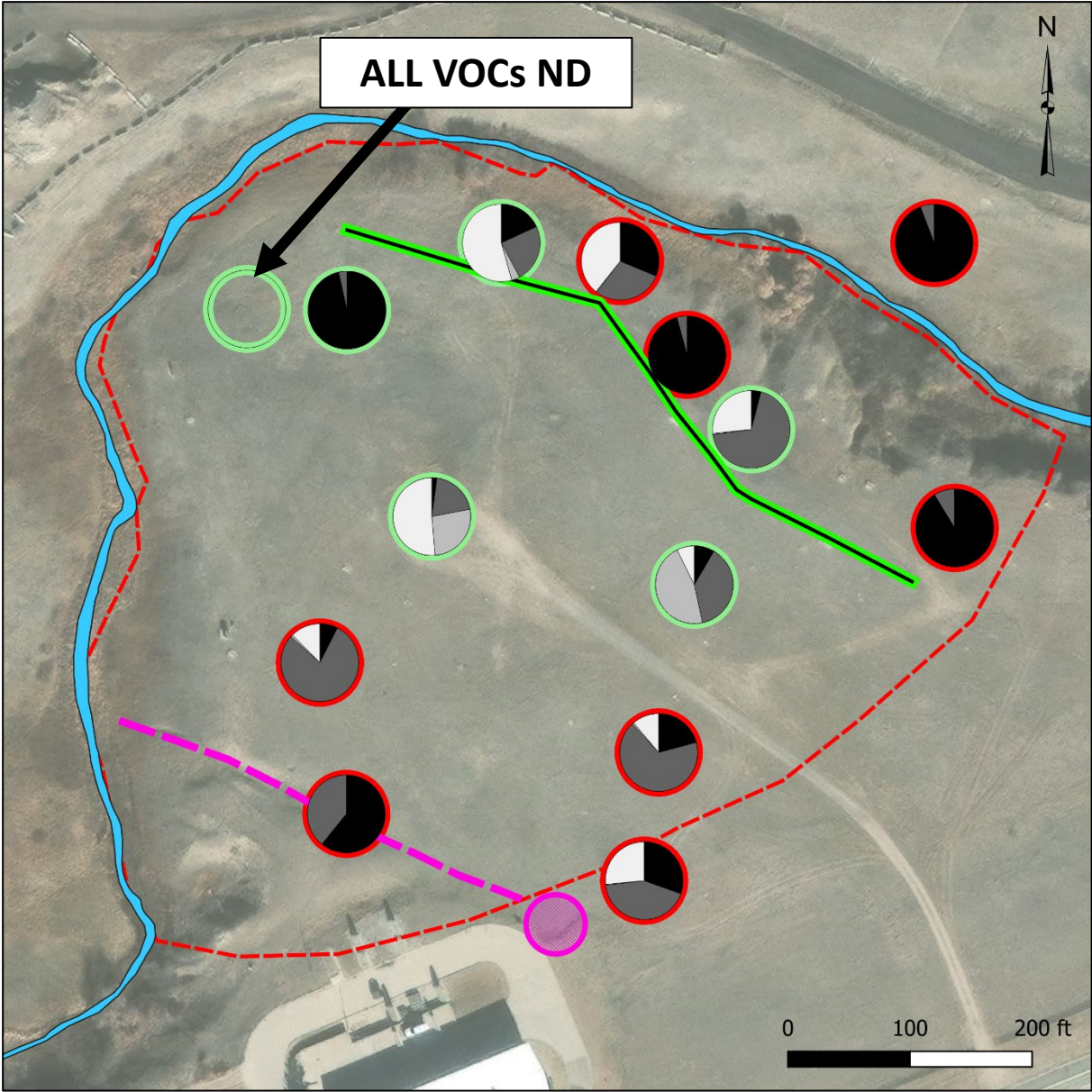
Former Grease Trap Location



Unlined Surface Drainage Ditch

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ZVI PRB



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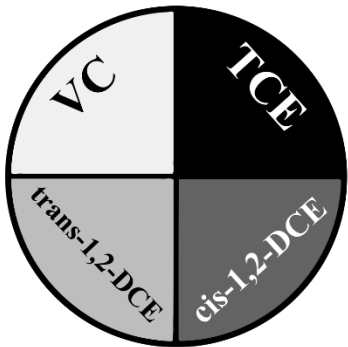
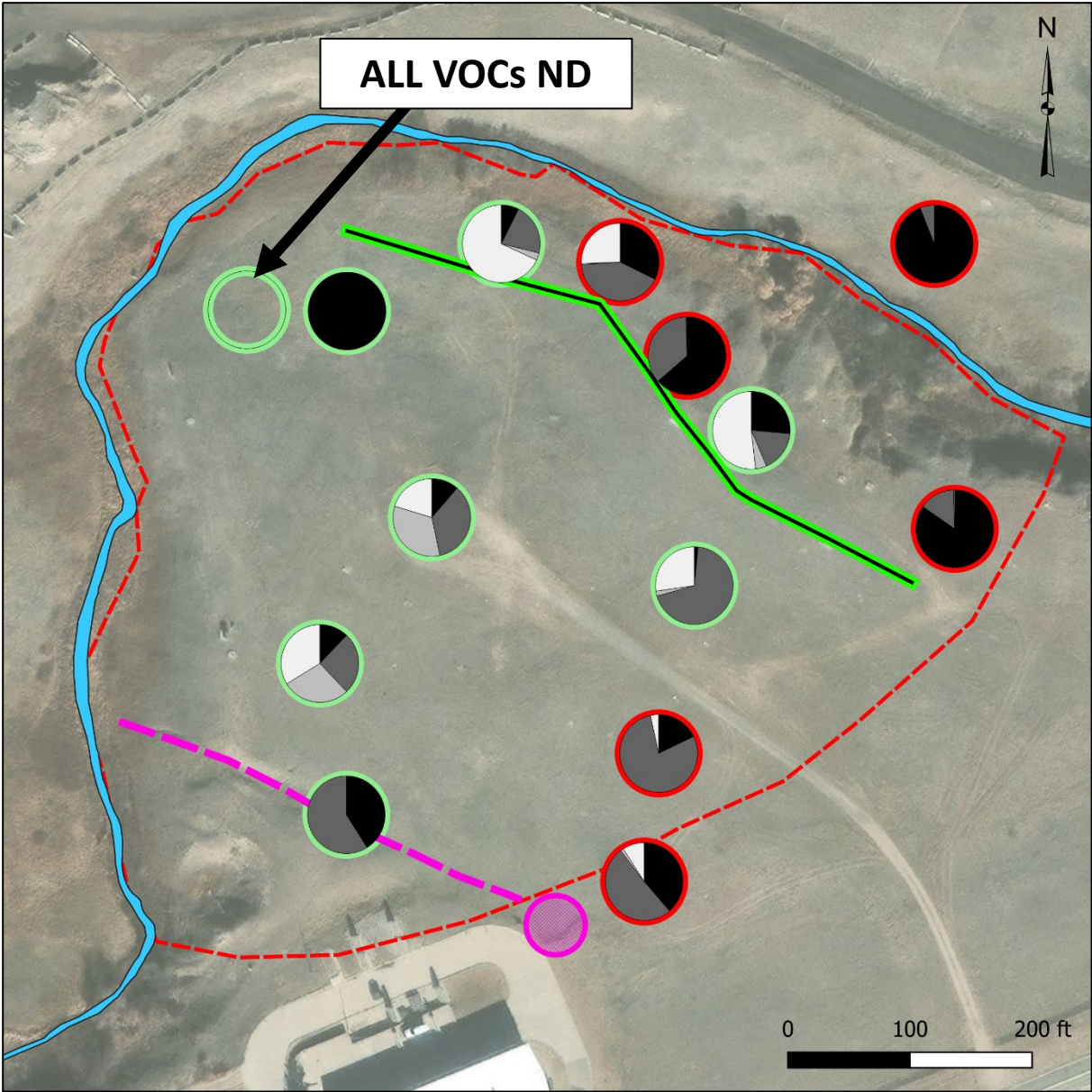
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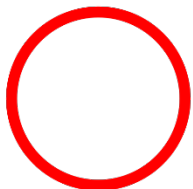
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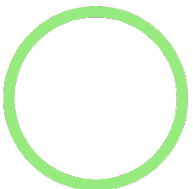
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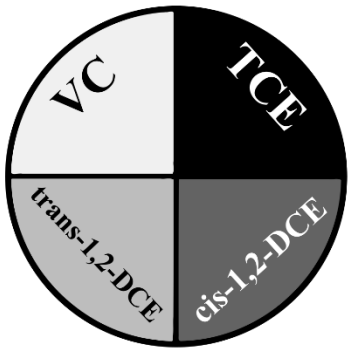
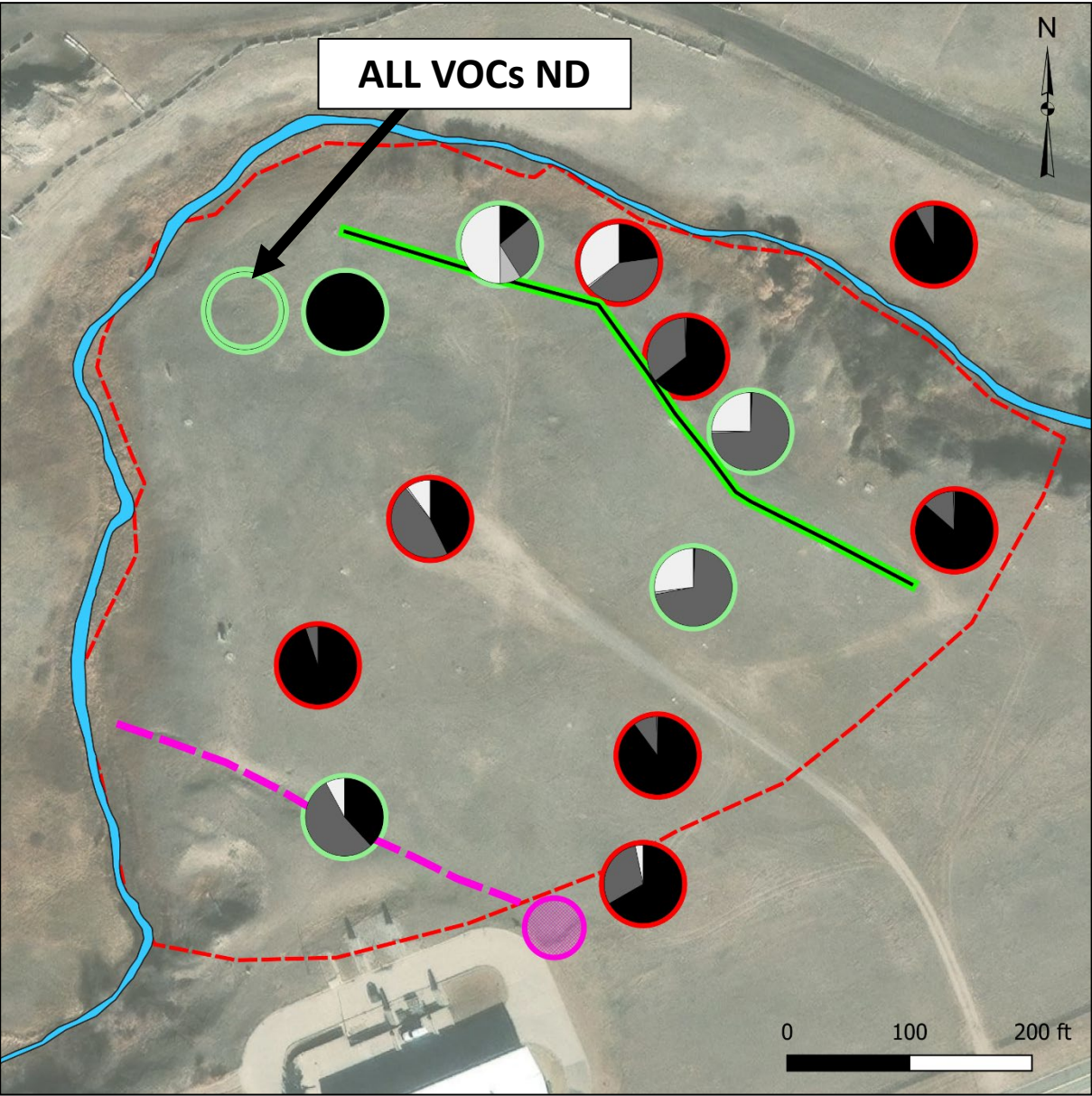
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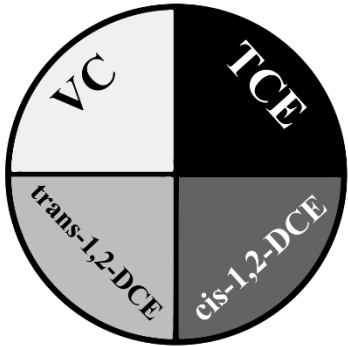
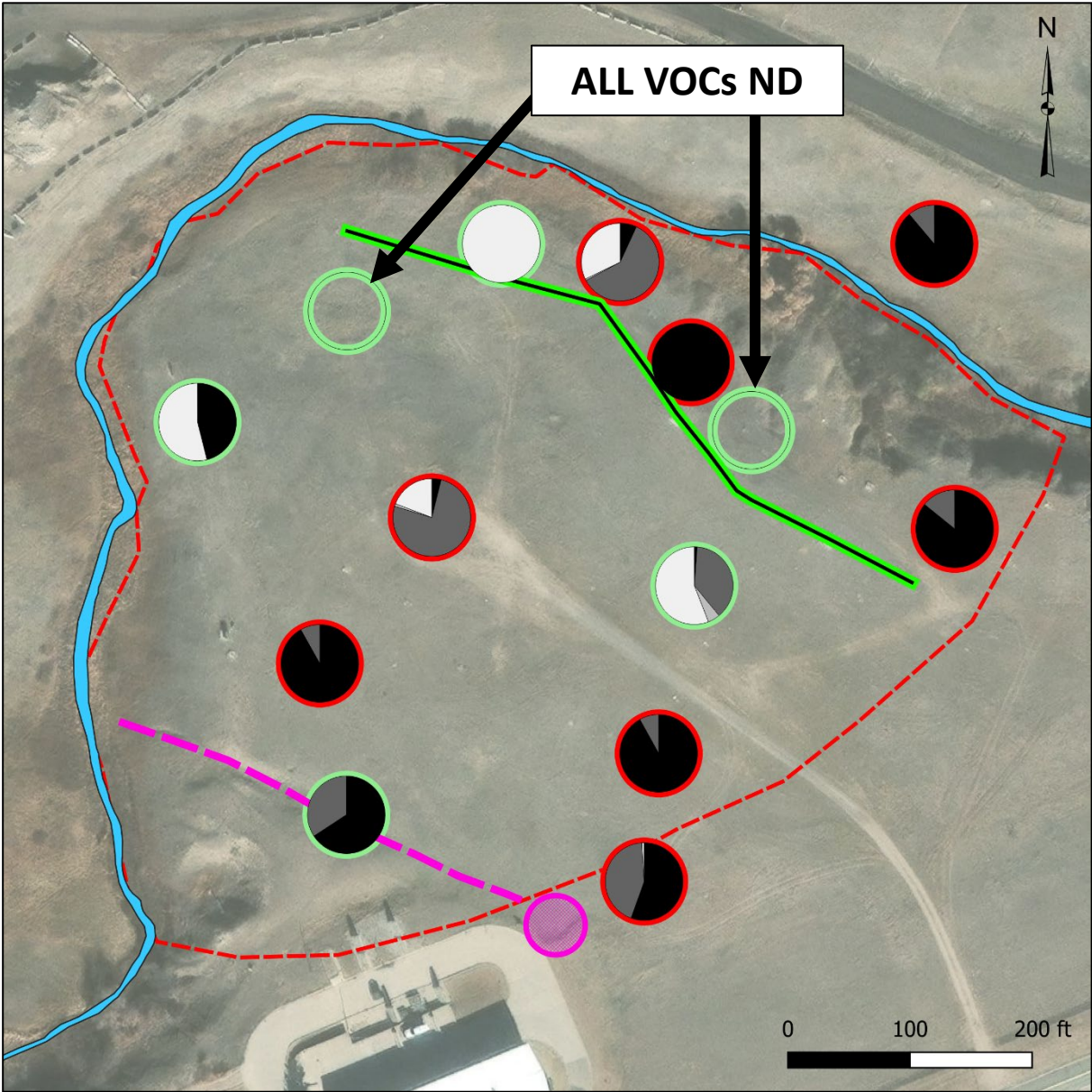
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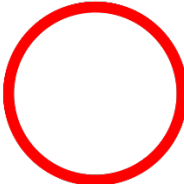
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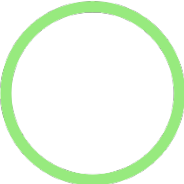
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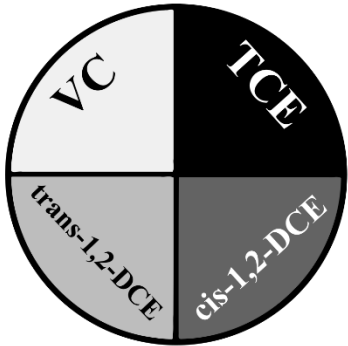
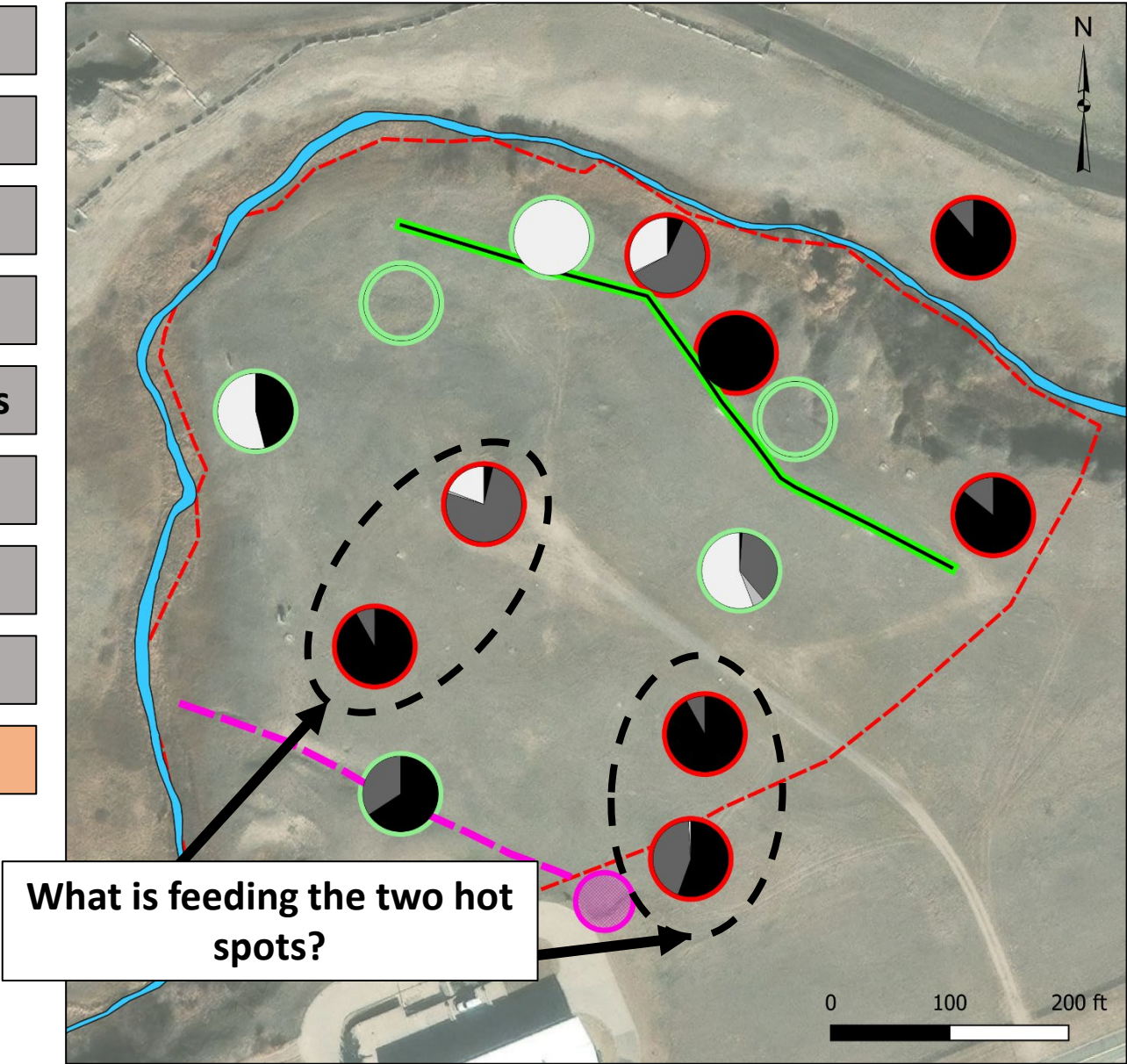
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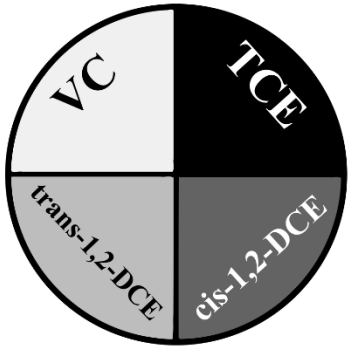
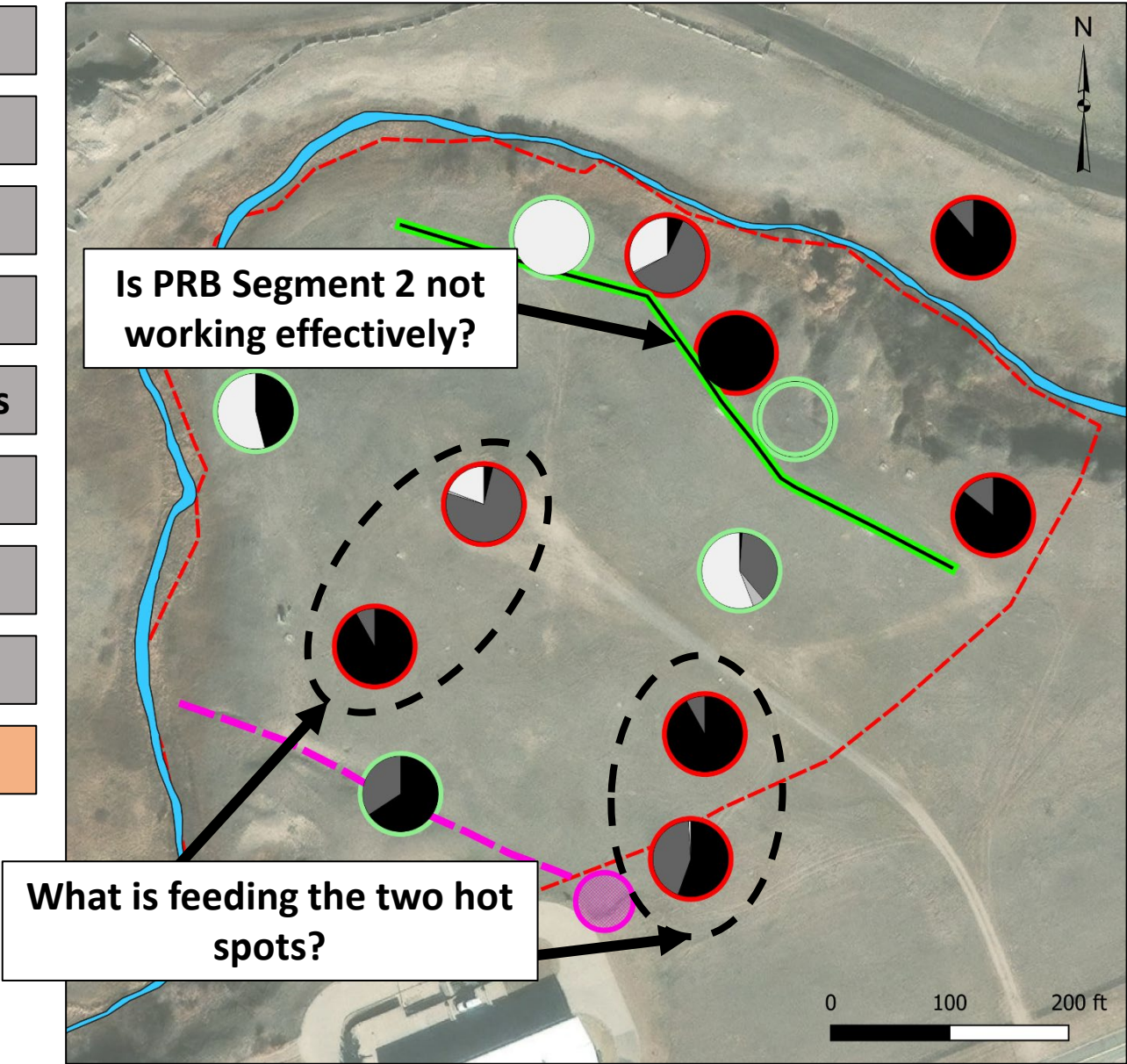
ZVI PRB



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ZVI PRB



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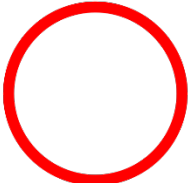
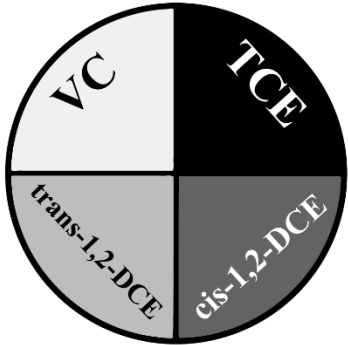
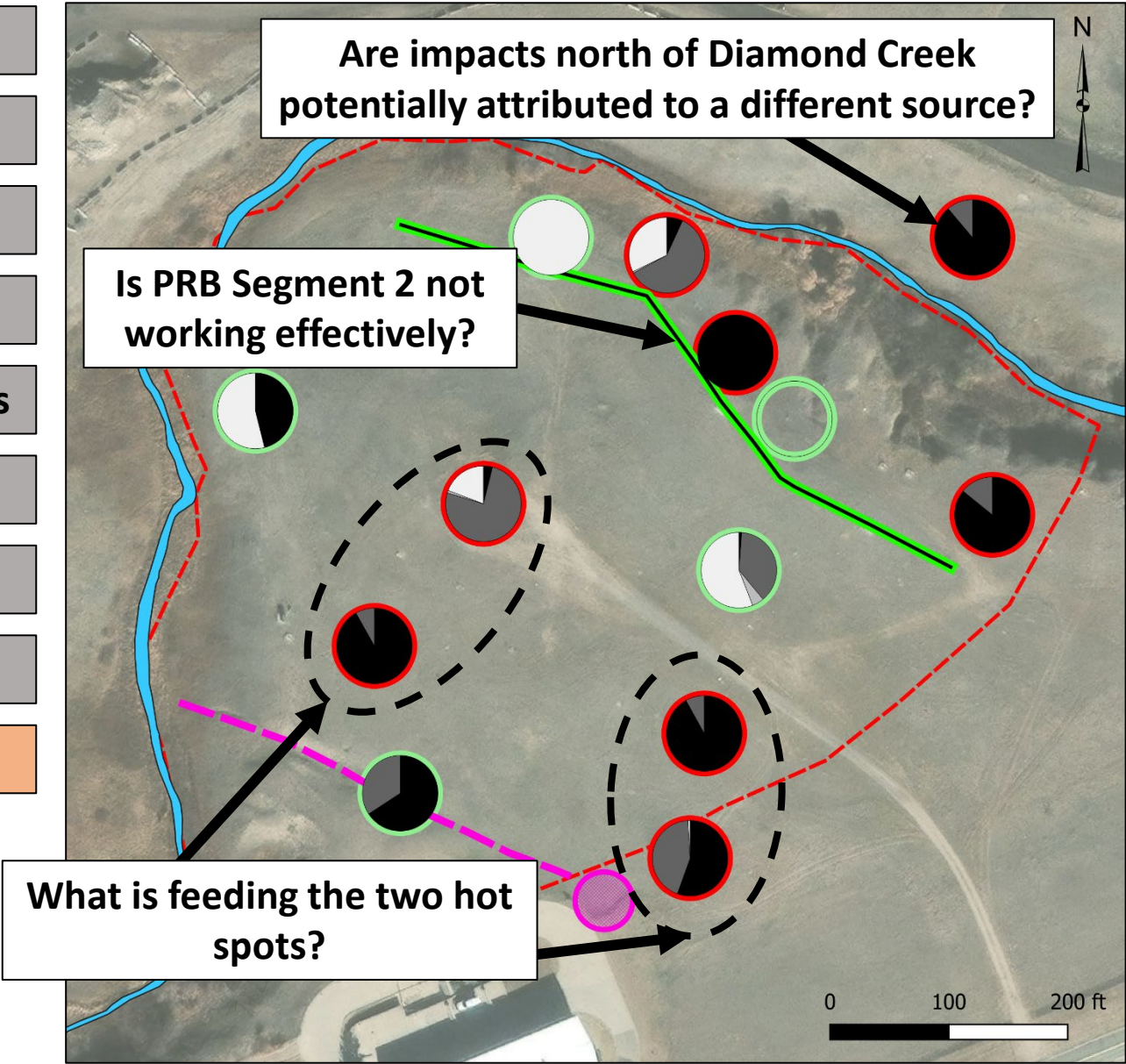
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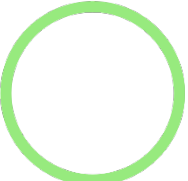
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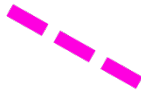
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Former Grease Trap Location

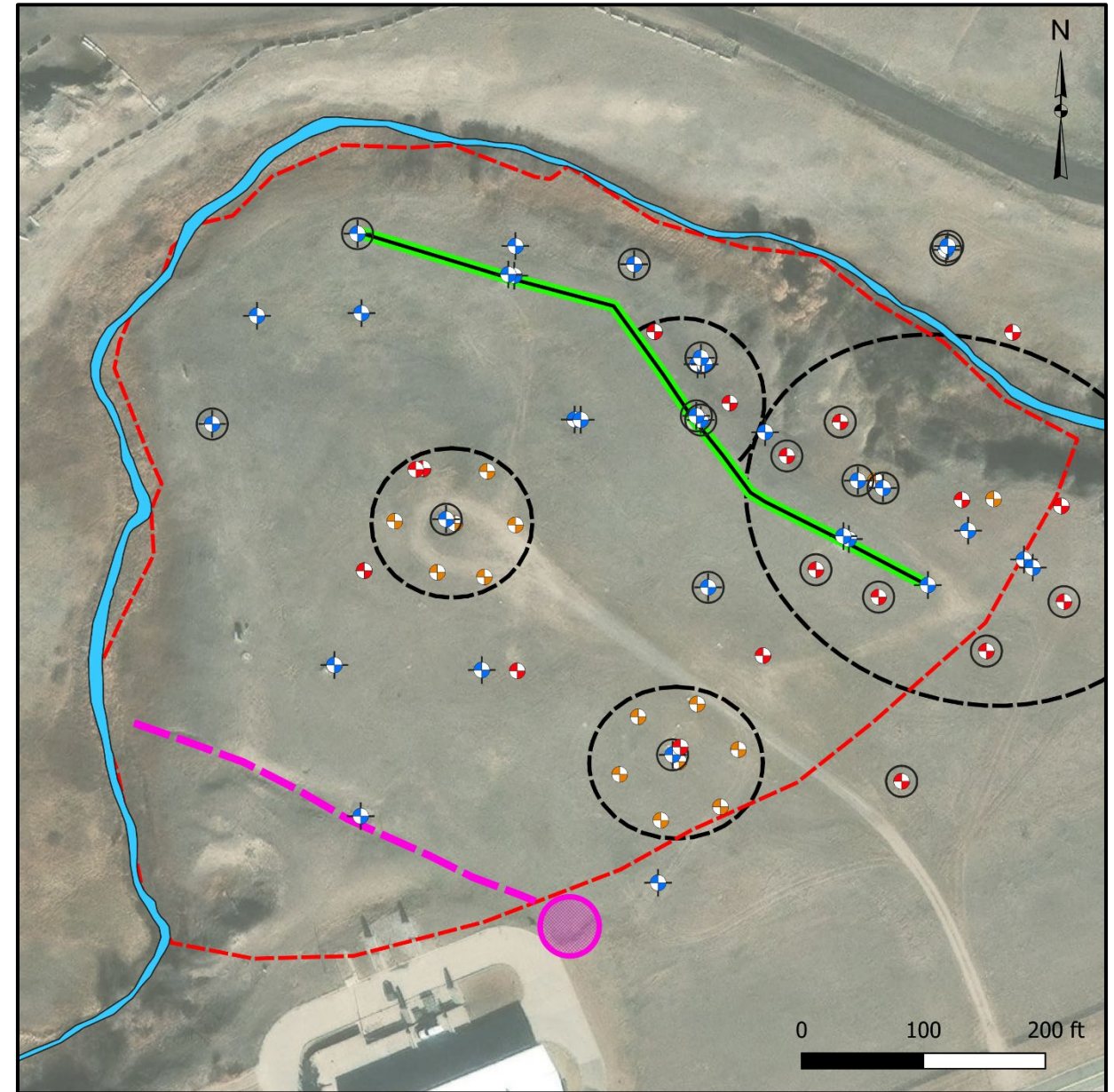


Unlined Surface Drainage Ditch

Methodology

FIELD INVESTIGATION SUMMARY

- November 2022 – February 2024
-  GW samples collected from 40 wells
-  Vertical Aquifer Sampling (VAS) at 17 borings
 - Borings completed using roto sonic drilling methods reaching up to 85 ft bgs
 - 102 GW samples collected both via K-packer and push-ahead samplers
-  Geochemical and microbial sampling at 27 locations
 - TOC / Methane / DHC
-  MIP/HPT at 16 boring locations
 - ECD / FID / PID / XSD / HPT / EC



Methodology

FIELD INVESTIGATION SUMMARY

- GW samples screened on site via portable FROG-5000™ gas chromatography system
- Field screening allowed real-time updates of 3-D model
- 29 samples sent to off-site lab for additional analysis:
 - Strong correlation ($R^2 = 0.79$) with FROG screening TCE concentrations



Methodology

3-D MODELING



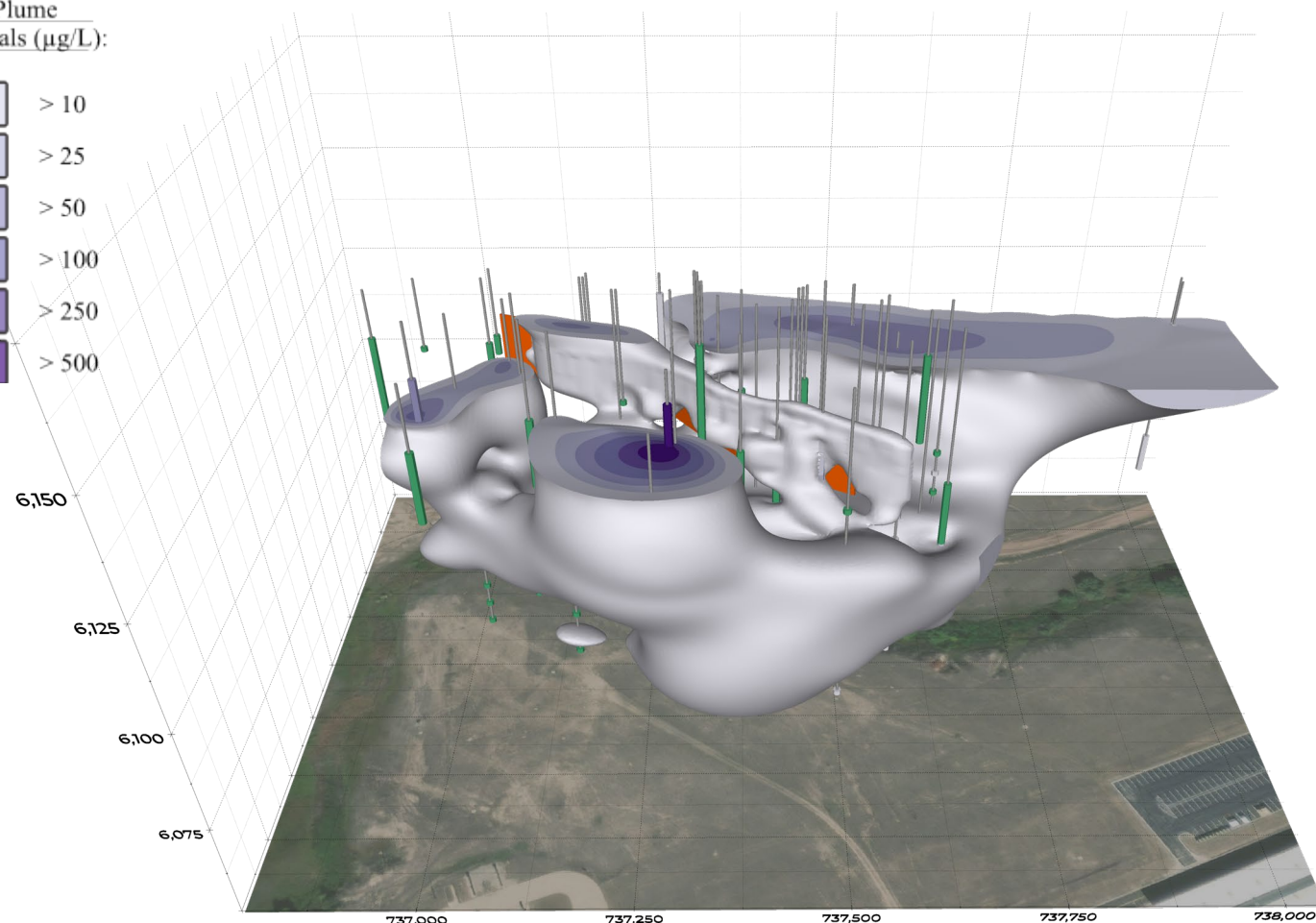
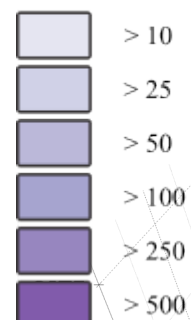
- Completed using Earth Volumetric Studio™
- Topography
 - Surveyed ground surface elevations from 201 locations & high-resolution LIDAR
- Lithology
 - Lithologic data from 136 historical and 17 VAS borings
- Hydrogeology
 - Depth to water measurements from 81 existing MWs
- VOC Data
 - Concentration data collected from 40 MWs
 - FROG-5000™ VOC screening data from 17 VAS borings (102 samples)
- Previous Site Remedies
 - ZVI PRB & bioaugmentation injections
- MIP/HPT
 - ECD, FID, PID, XSD, HPT, EC measurements from 16 borings modeled locally to focused investigation areas

Results

TCE PLUME MODELING

- Two distinct hot spots identified
 - One near former grease trap location
 - One north of drainage ditch
- Hot spots separated by low-permeability clays in shallow subsurface
- Plumes originated from two hot spots commingle in intermediate zone before migrating downgradient
- Vertical gradients drive downward “underflow” of plume below PRB, before upwelling near Diamond Creek
- Lower concentration impacts do extend deeper into the subsurface

TCE Plume
Intervals ($\mu\text{g/L}$):



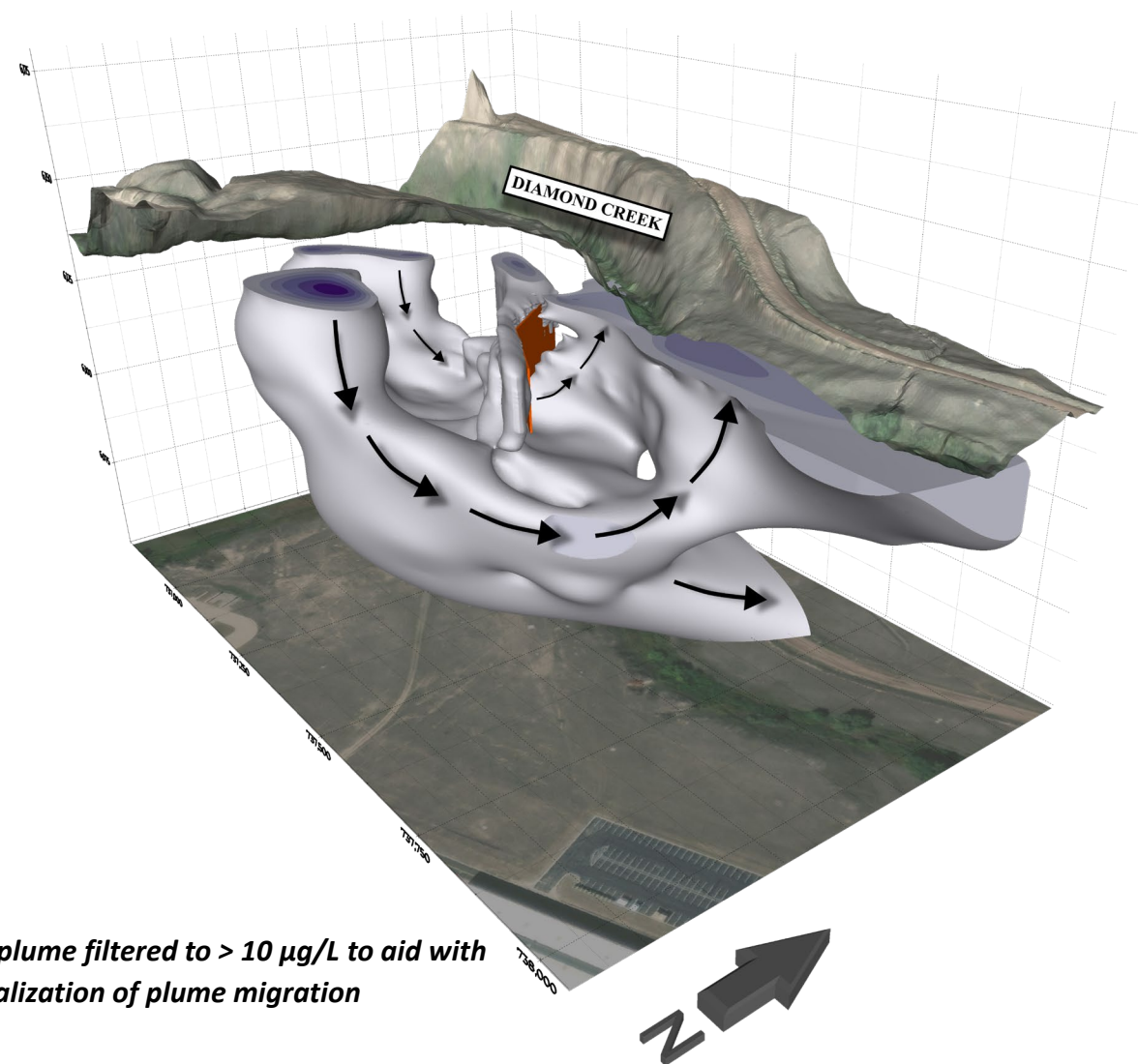
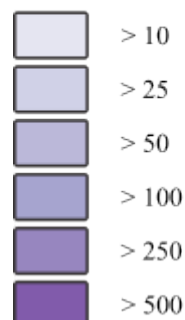
TCE plume filtered to > 10 $\mu\text{g/L}$ to aid with visualization of plume migration

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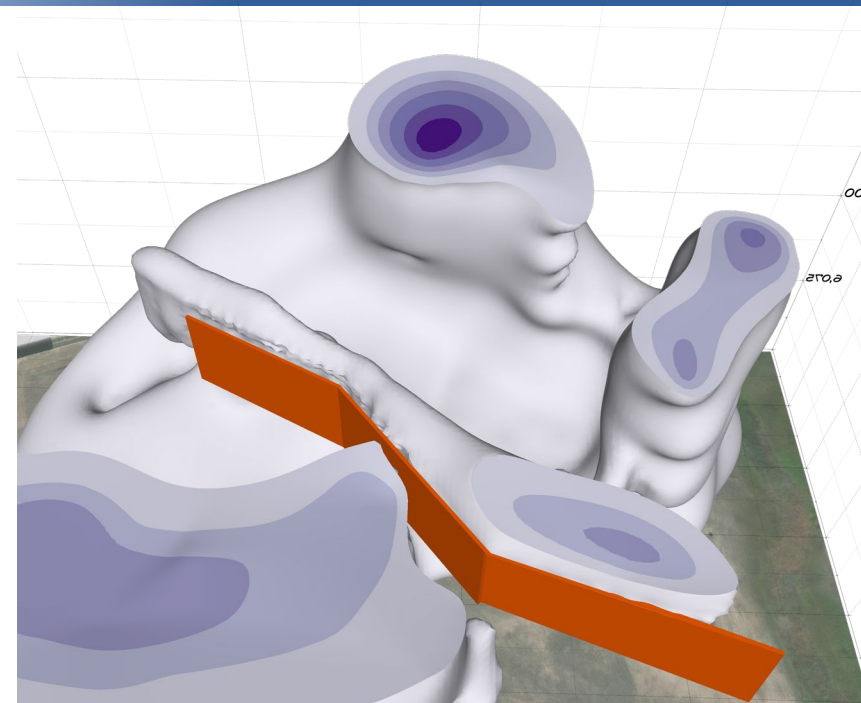
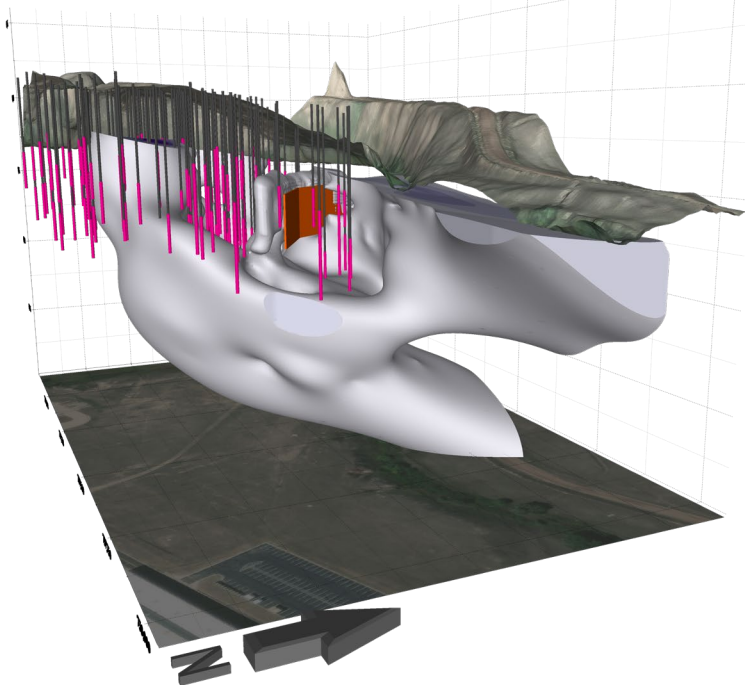
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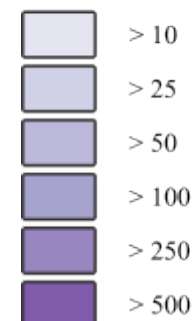
Results

TCE PLUME MODELING

- **ZVI PRB** continues to mitigate most shallow-zone migration
 - 90% TCE flux reduction within 20 ft downgradient
- Underflow beneath PRB segment 2 identified
- **Bioaugmentation injections** effectively reduced TCE in shallow zone
 - Intermediate zone untreated → Continued untreated downgradient migration
- Model results show remedies effectively control lateral movement but have limited vertical capture



TCE Plume
Intervals ($\mu\text{g/L}$):



In-Situ Bioaugmentation
Injection Interval

ZVI PRB

*TCE plume filtered to $> 10 \mu\text{g/L}$ to aid with
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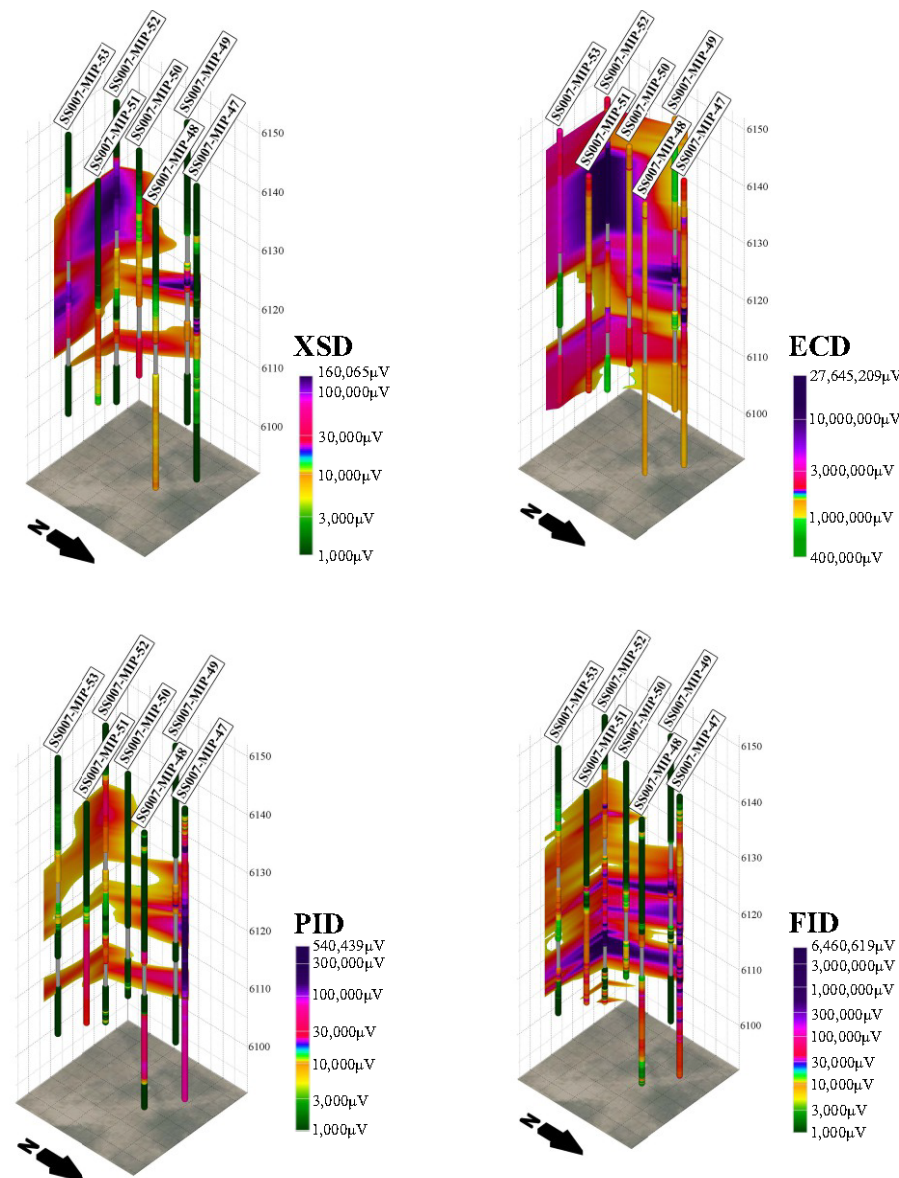
Results

MIP/HPT Investigation

- **Strong ECD/XSD responses** confirmed two TCE hot spots
- HPT and EC data revealed **variable hydraulic conductivity and lithologic layering**, indicating preferential pathways for TCE transport

Geochemical & Microbial Sampling

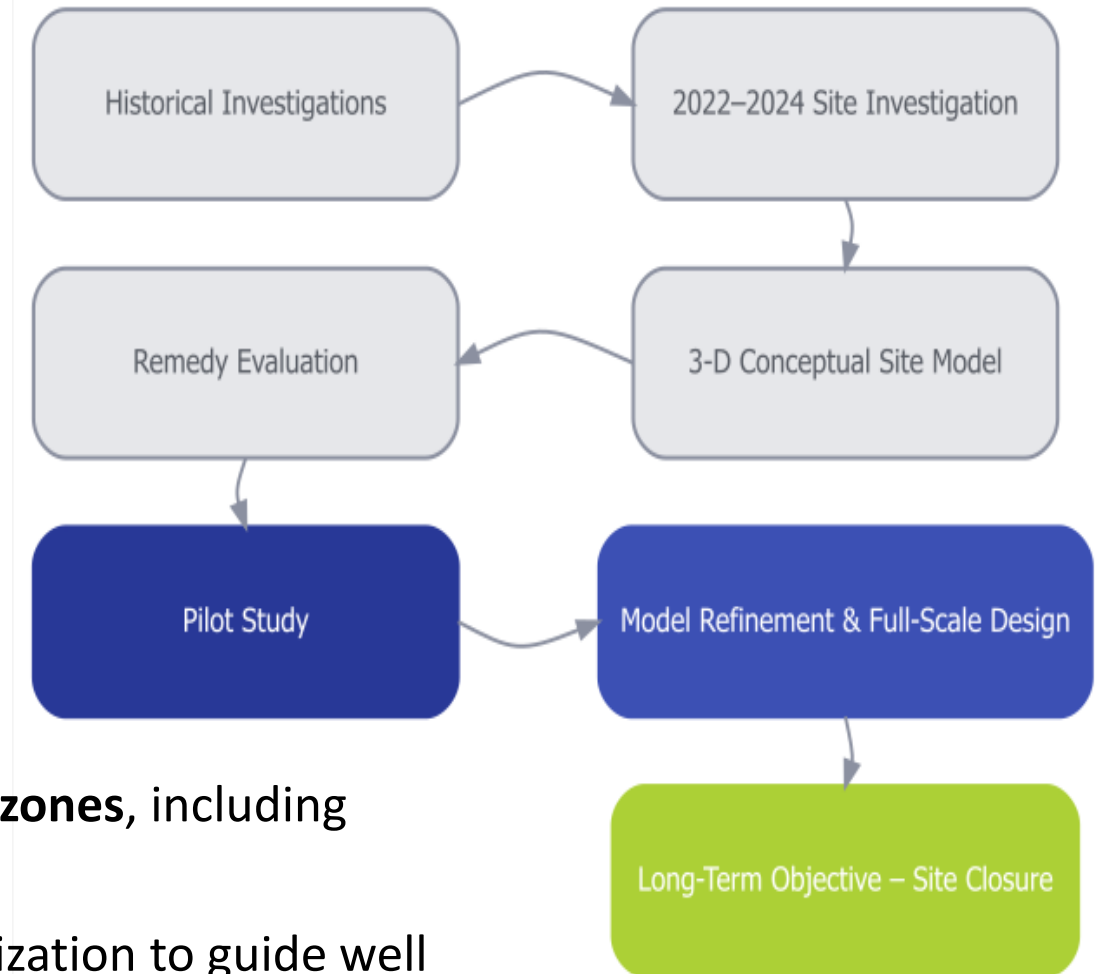
- **Reducing conditions** present in shallow groundwater
 - Low ORP, depleted sulfate, elevated methane, and dissolved iron
- **Active dechlorination indicated** by high DHC concentrations (10^5 - 10^6 copies/L) in shallow zones. Limited activity in deeper intervals
- Data suggests **biological degradation is occurring**, but is primarily confined to the shallow portions of the TCE plume



Next Steps

PILOT STUDY

- Pilot study planned to evaluate **delivery methods** for enhanced in-situ bioremediation using EVO substrate and microbial culture
- Objective is to **test amendment delivery** through permanent wells with no hydraulic fracturing to determine a more cost-effective implementation approach
- Focused on hot spot and downgradient areas where residual TCE mass was identified
- Will target impacts in **both shallow and intermediate zones**, including beneath and downgradient of the PRB
- 3-D model fully integrated into pilot design and optimization to guide well placement, injection volumes, and performance tracking



Summary & Conclusions

- Previous remedial actions (ZVI PRB and bioinjections) have substantially reduced TCE mass and controlled lateral plume migration in shallow intervals.
- The 3-D model integrates recent site investigation data to define current plume extent and vertical distribution.
- Results indicate residual impacts in the intermediate zone beneath and downgradient of the PRB
- MIP/HPT and geochemical data confirm heterogeneous subsurface conditions and biologically active but shallow-limited degradation.
- The 3-D model will guide future remedy optimization, helping refine injection locations, volumes, and long-term performance monitoring.

THANK YOU

