Adaptive Site Management via Innovative Monitoring of ISCO Remediation

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Battelle Chlorinated

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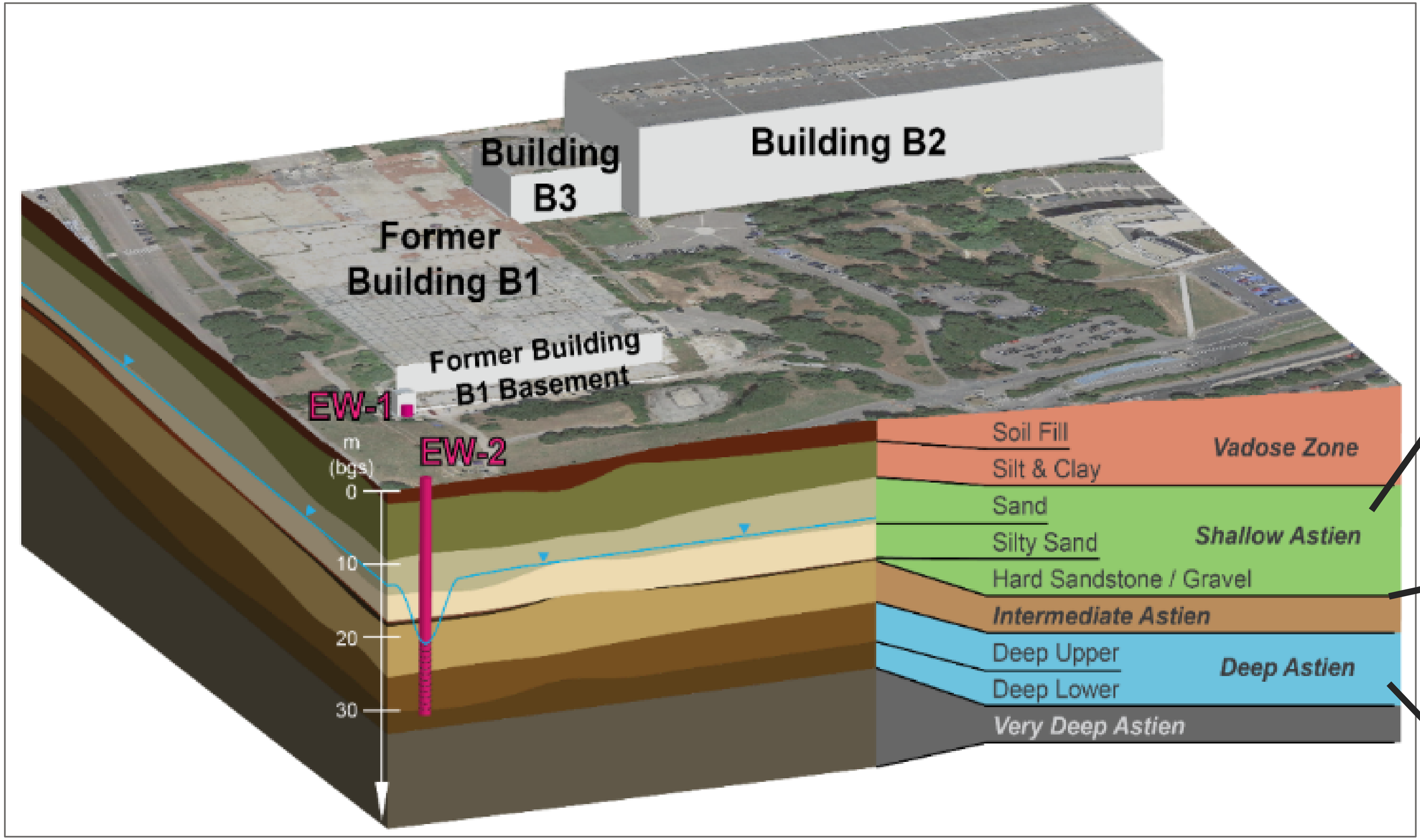
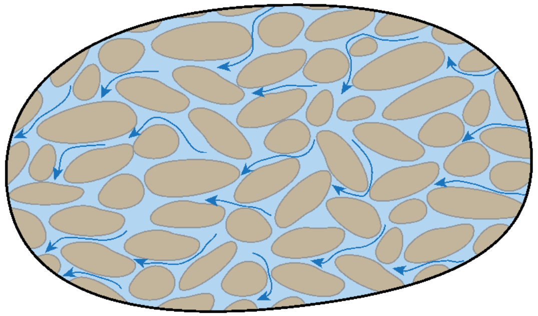
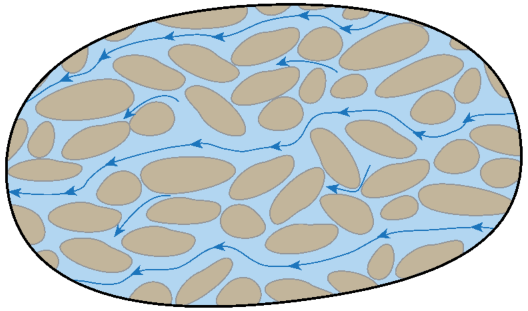
Aquifer Characteristics

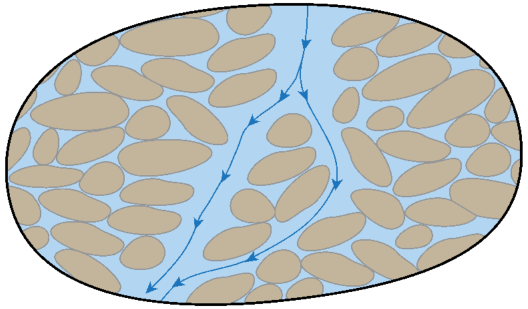




Primary porosity flow

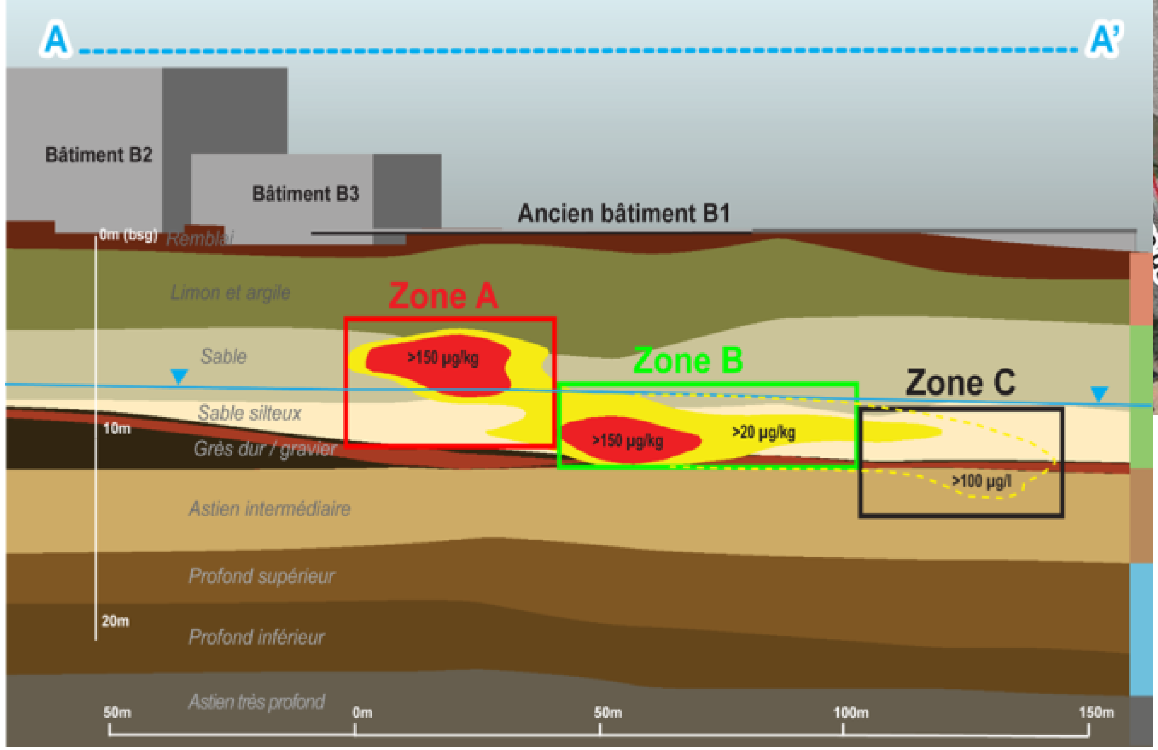


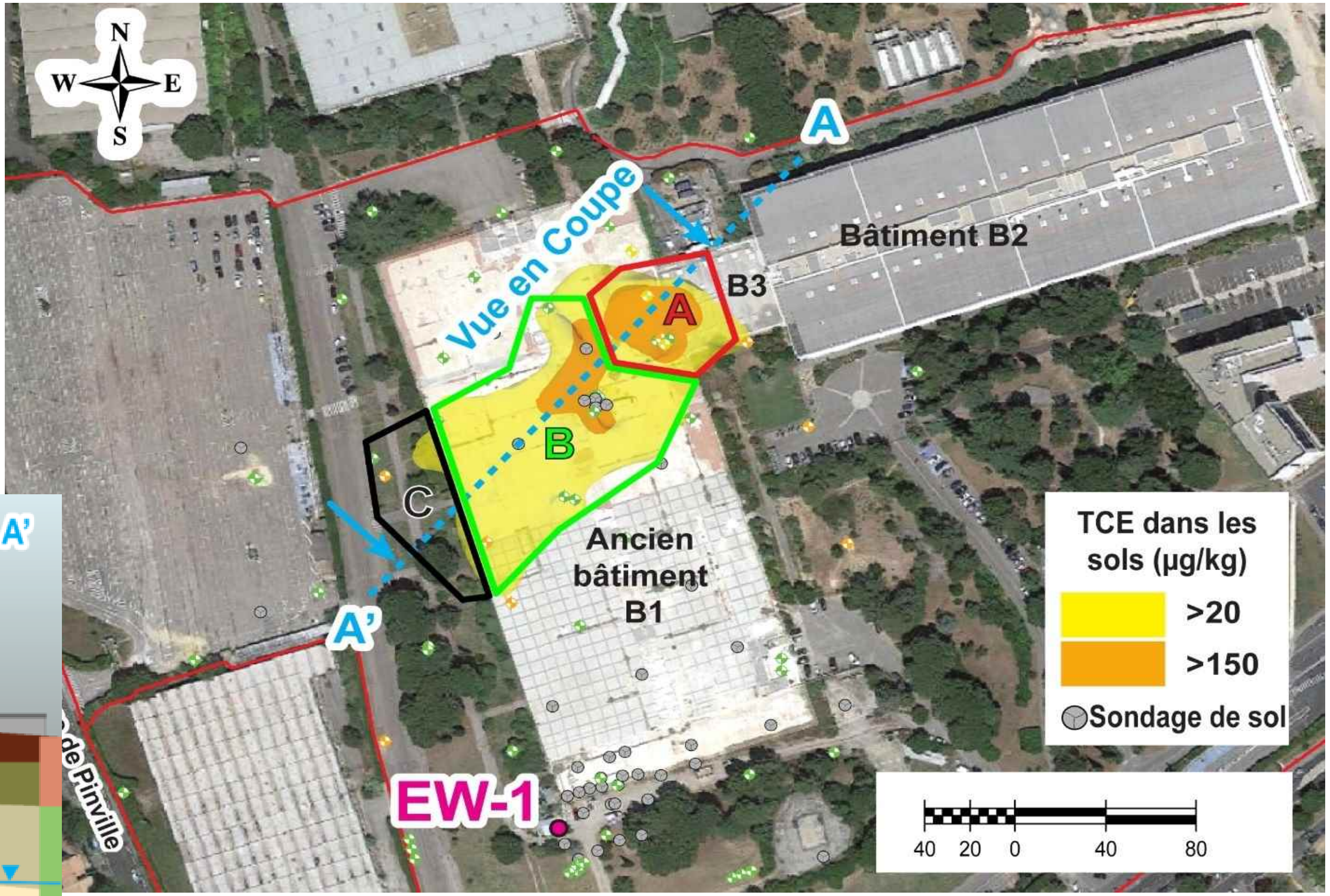
Dual porosity flow



Secondary porosity flow

TCE in soil





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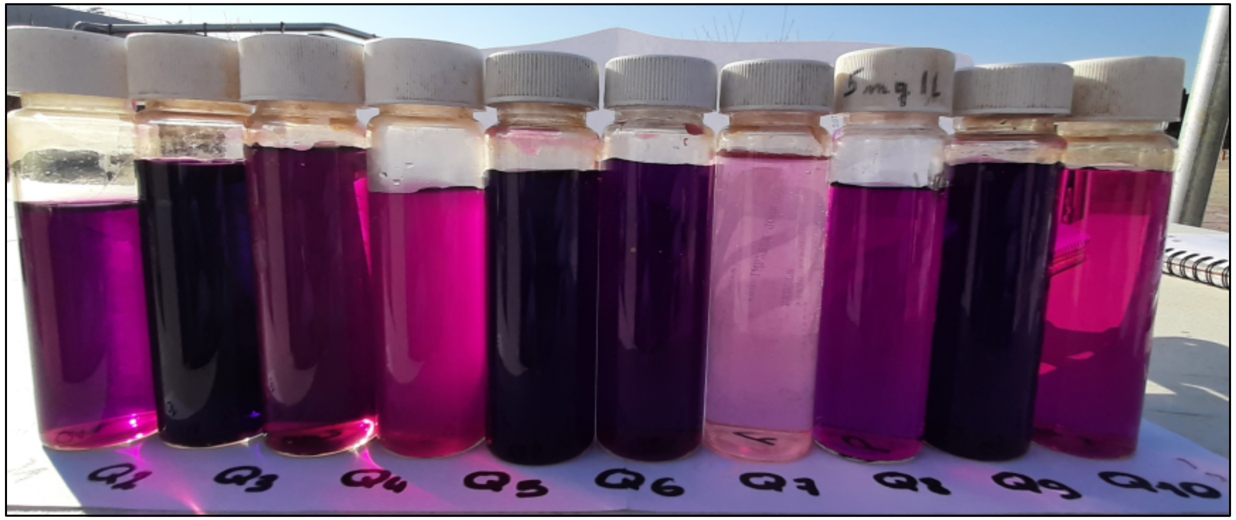
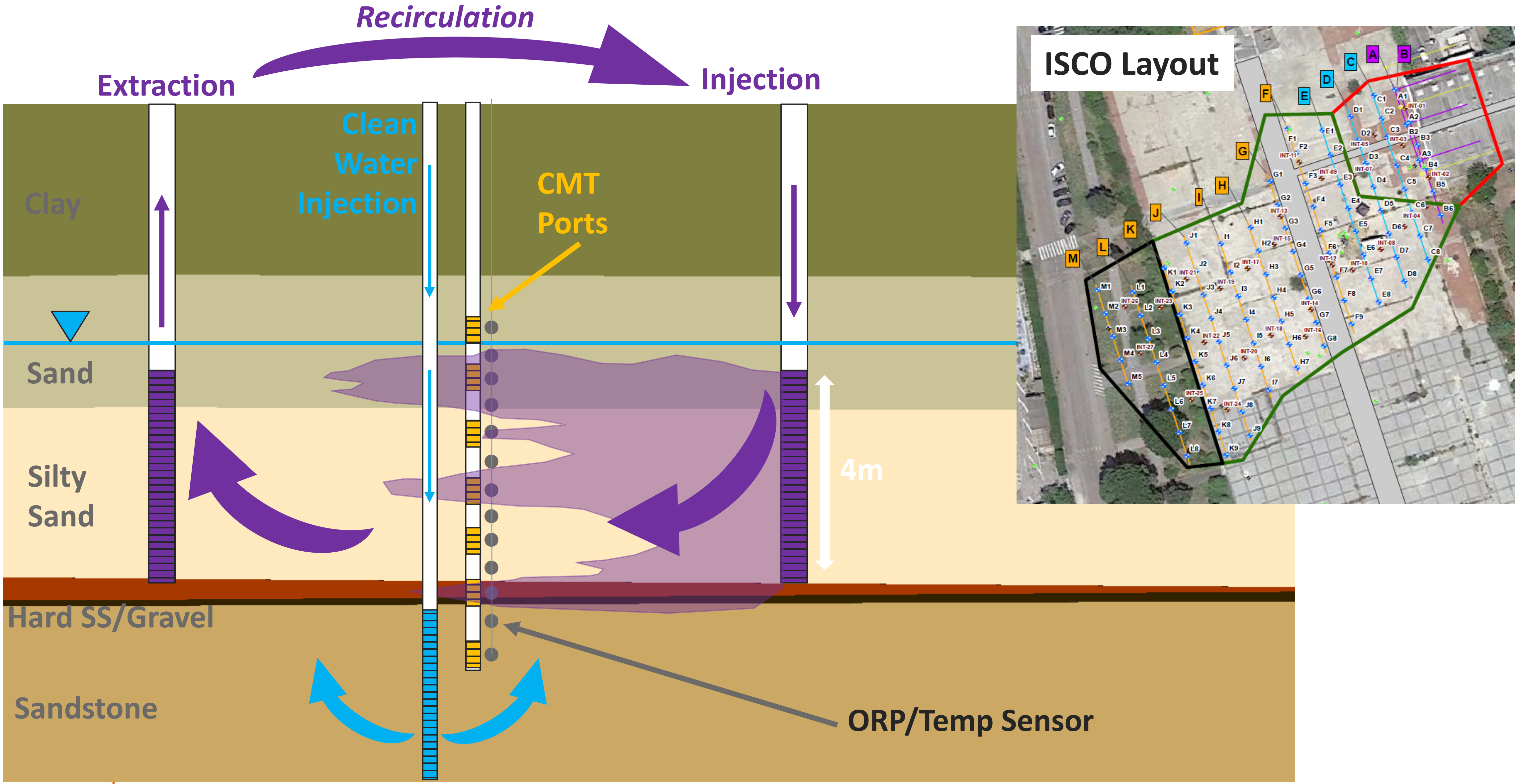
In-Situ Chemical Oxidation (ISCO)

- Sodium permanganate oxidizes TCE
  - Very strong oxidant – high oxidation reduction potential (ORP)
  - Easily visible
  - Relies on contact

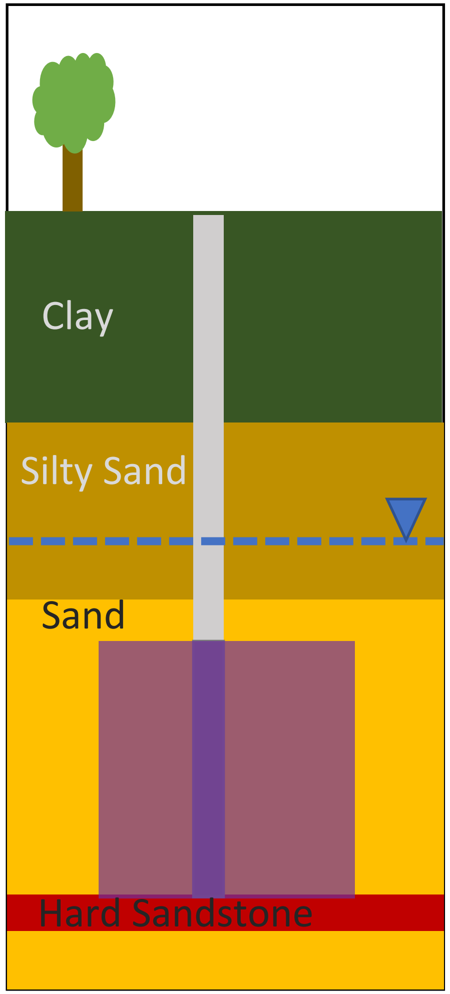


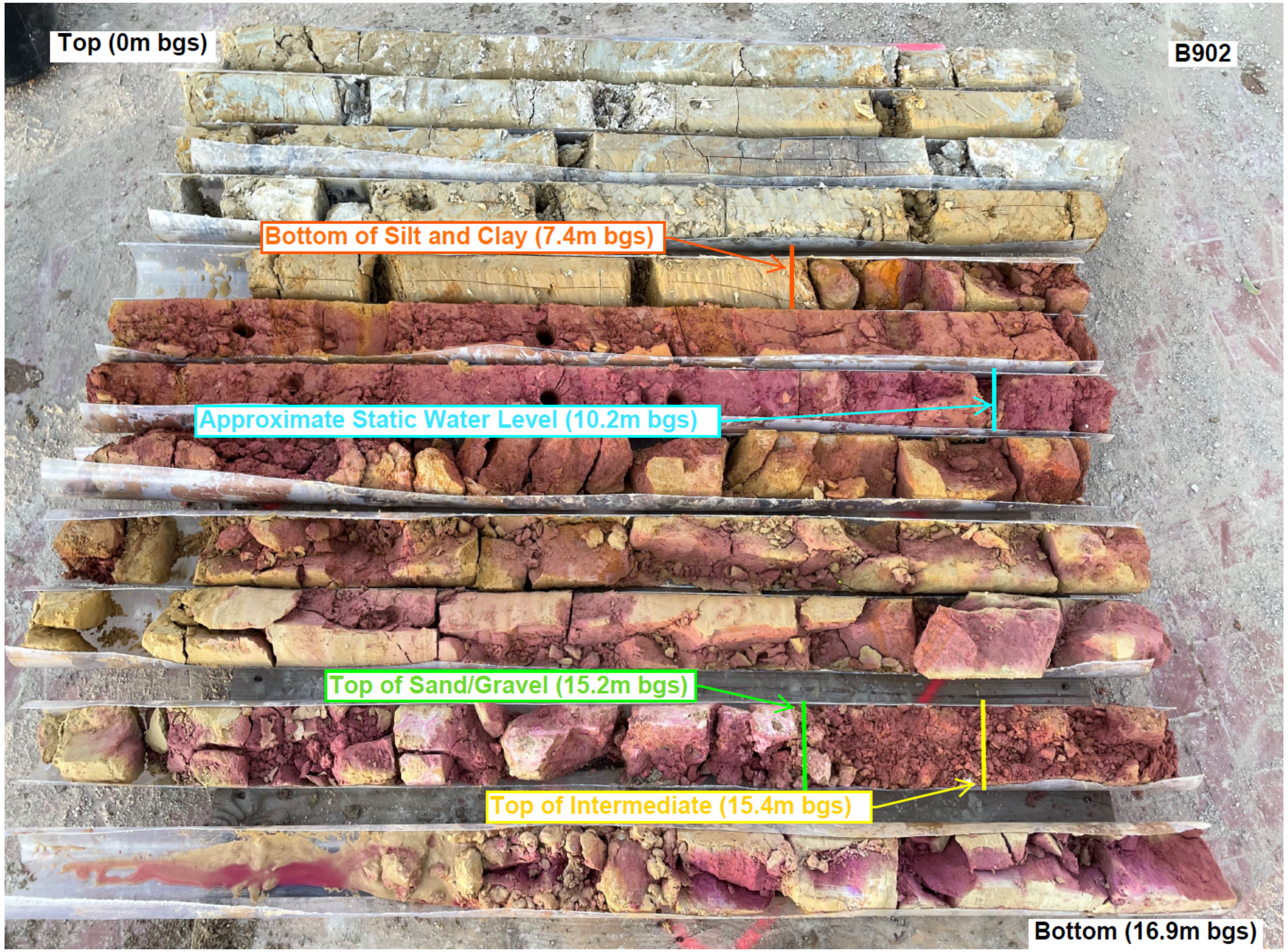
ISCO Design and ORP Sensors for remote performance monitoring



Expectations

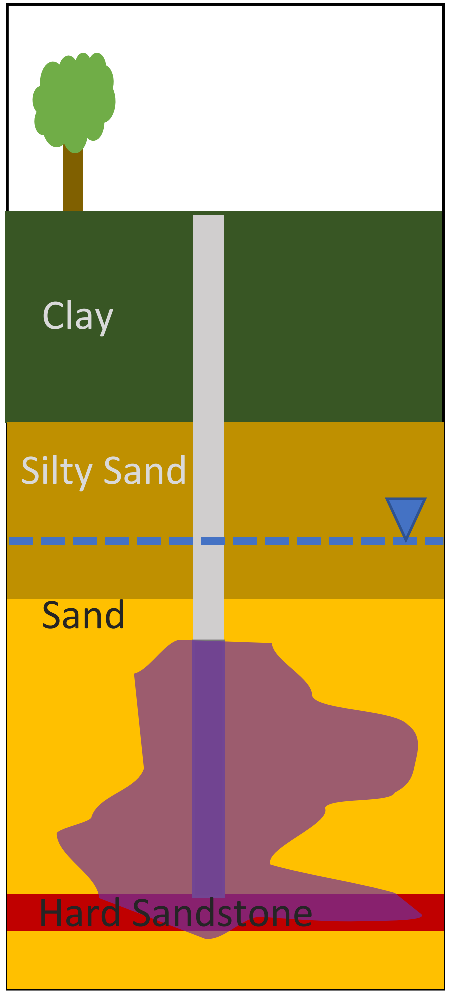
- Fill cylinder with amendment
  - “Flood the zone”
- Remediation design





Reality

- Heterogenous system
  - Porosity
  - Conductivity
- Contact is <u>KEY</u>
- Heterogenous TCE distribution



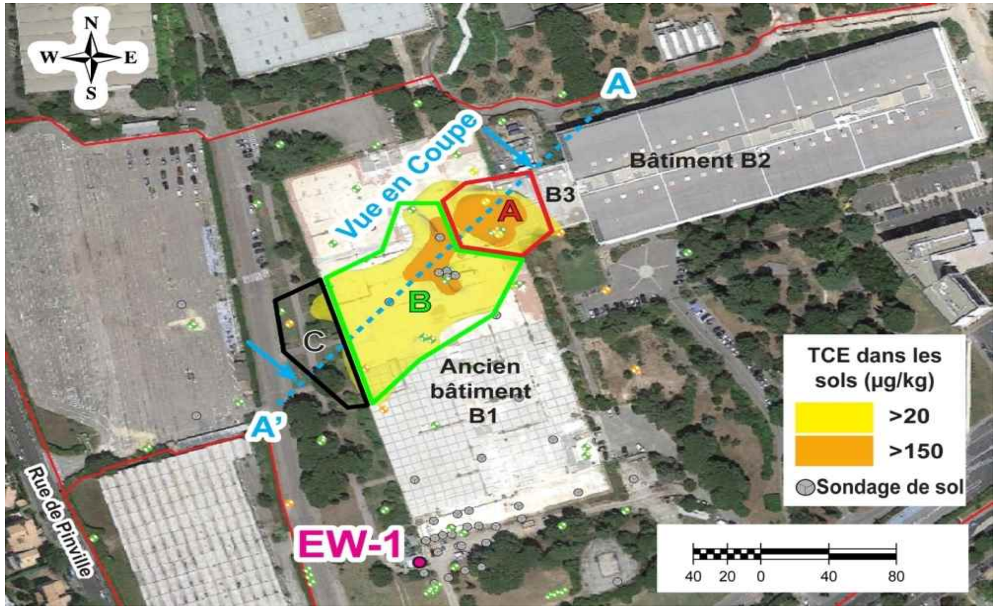
Phased / Adaptive Approach

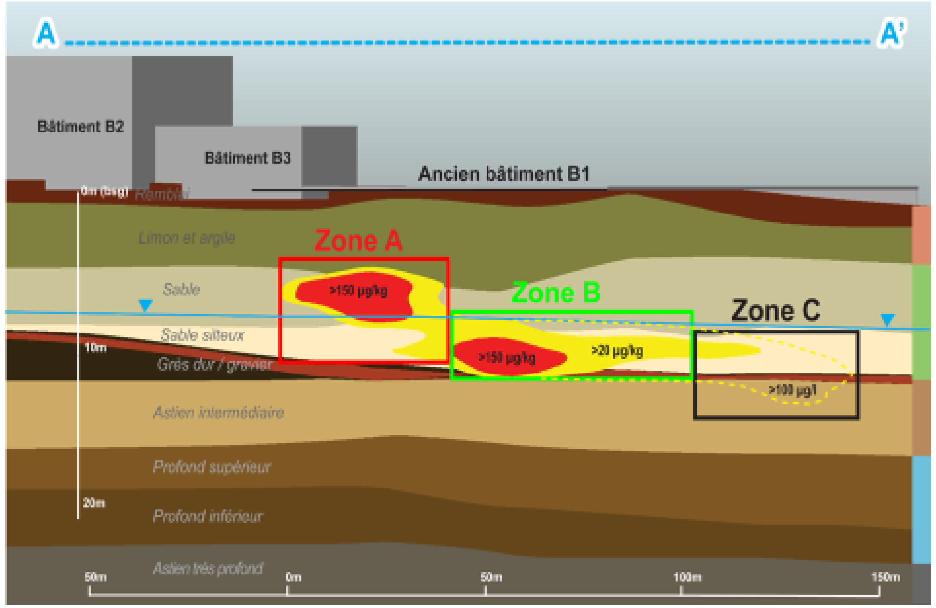
Phase I (Zone A)

Used ORP sensors, post-injection core data, and multi-level well monitoring to evaluate well spacing and preferred ISCO delivery approach (recirculation vs. inject and drift)

Phase II (Zones B/C)

Final design / operational approach contingent upon Phase I results - needed data quickly to avoid delays





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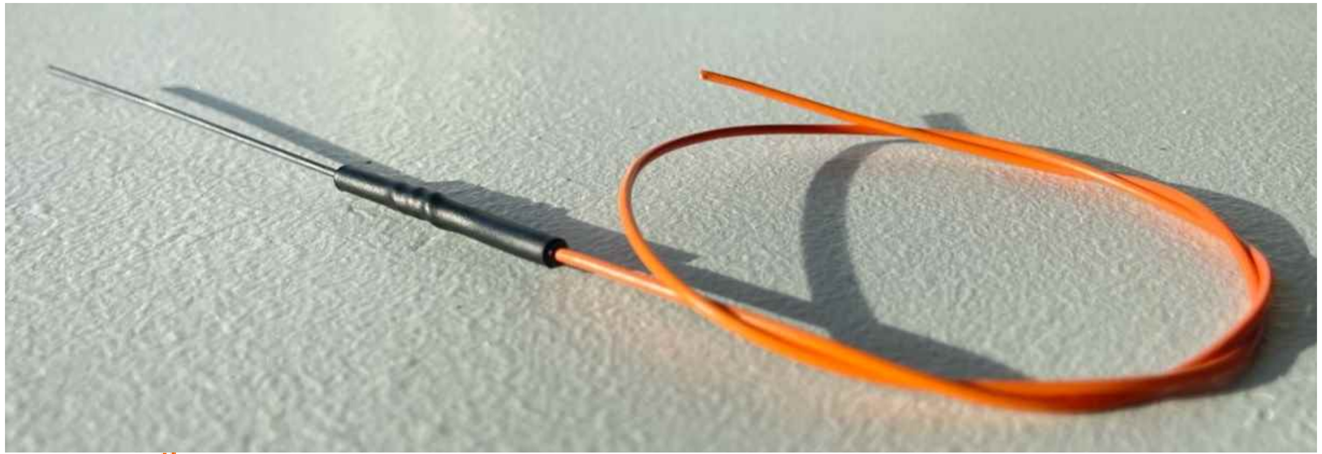
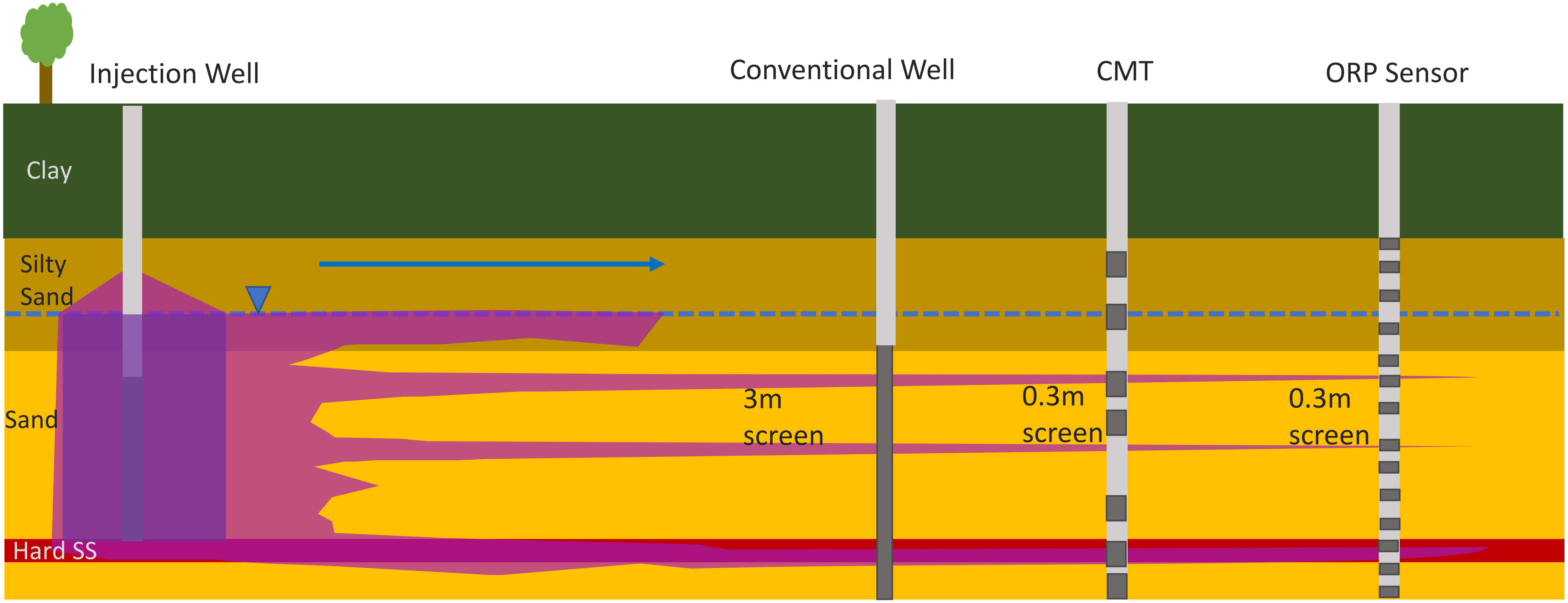
ORP Sensors

- 14 sensors per borehole, 44 boreholes
- >10M data points
- Continuous hourly ORP measurements
- Data available real-time via cloud
- Strengths
  - Coverage
  - Covid
  - Continuous
  - Cost



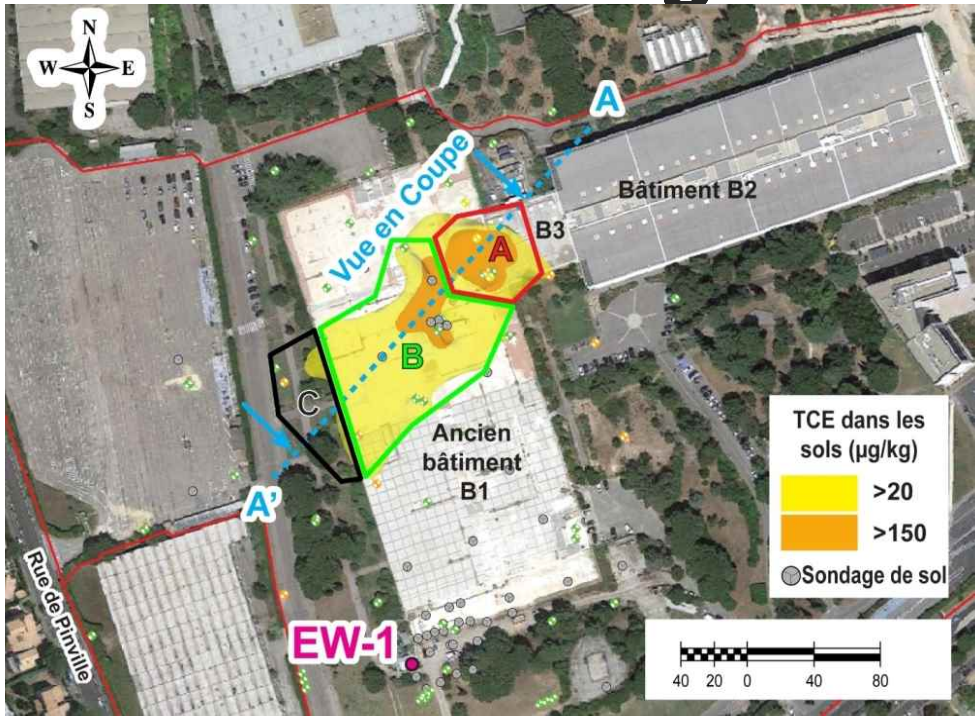
Typical Monitoring Program



ISCO monitoring Methods

Monitoring Method	Data Collected	Decision supported	Records Per year	Investigation Precision	Frequency	Cost
ORP Strings	Oxidation Reduction Potential (ORP)	Permanganate arrival	$1x10^6$	0.3 m	Hourly	Medium
Transducers	Hydraulic head	Hydraulic influence	$1x10^5$	1-3 m	Hourly	Low
Groundwater Screening	Permanganate & TCE concentration	Permanganate arrival/treatment	$1x10^4$	1-3 m	Daily	High
Soil Coring	Permanganate & TCE concentration	Permanganate arrival/treatment	$1x10^3$	0.1 m	Infrequent	Very high

ORP Monitoring Locations



Legend

- Monitoring Well
- Monitoring Well (CMT)
- Angled Monitoring Well
- ISCO Well
- Angled ISCO Well
- In-situ ORP Sensor Location

Phased / Adaptive Approach

Phase I (Zone A)

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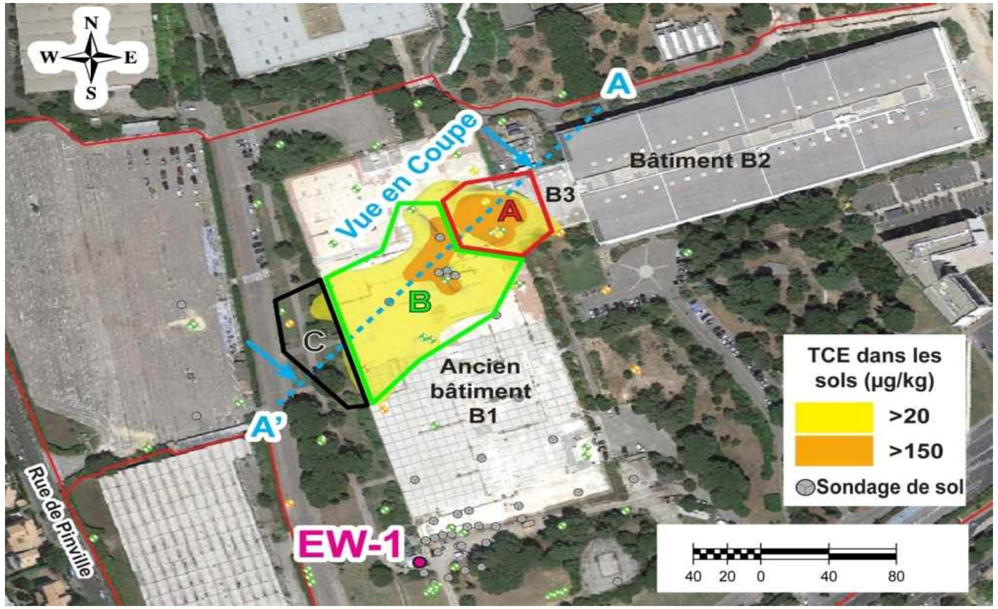
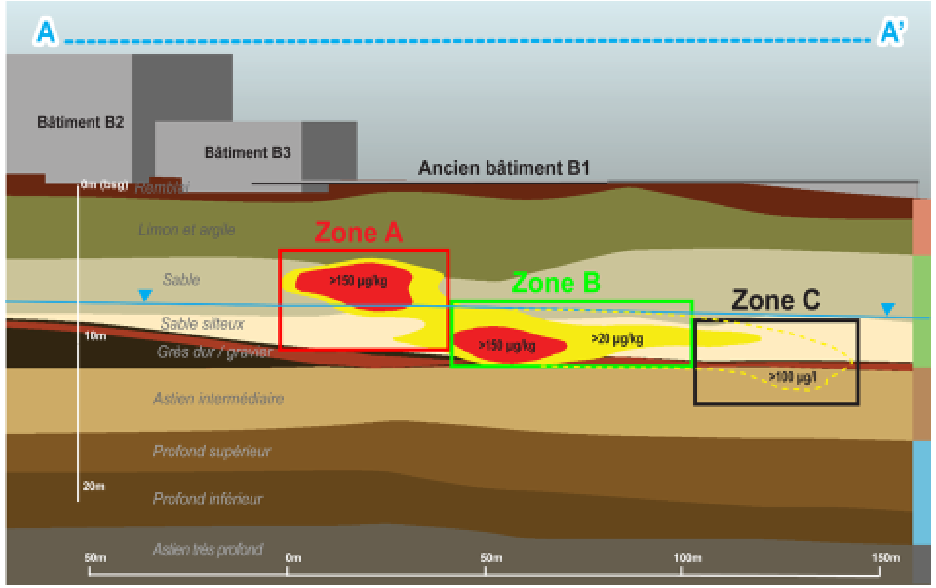


Phase II (Zones B/C)

Final design / operational approach contingent upon Phase I results - needed data quickly to avoid delays



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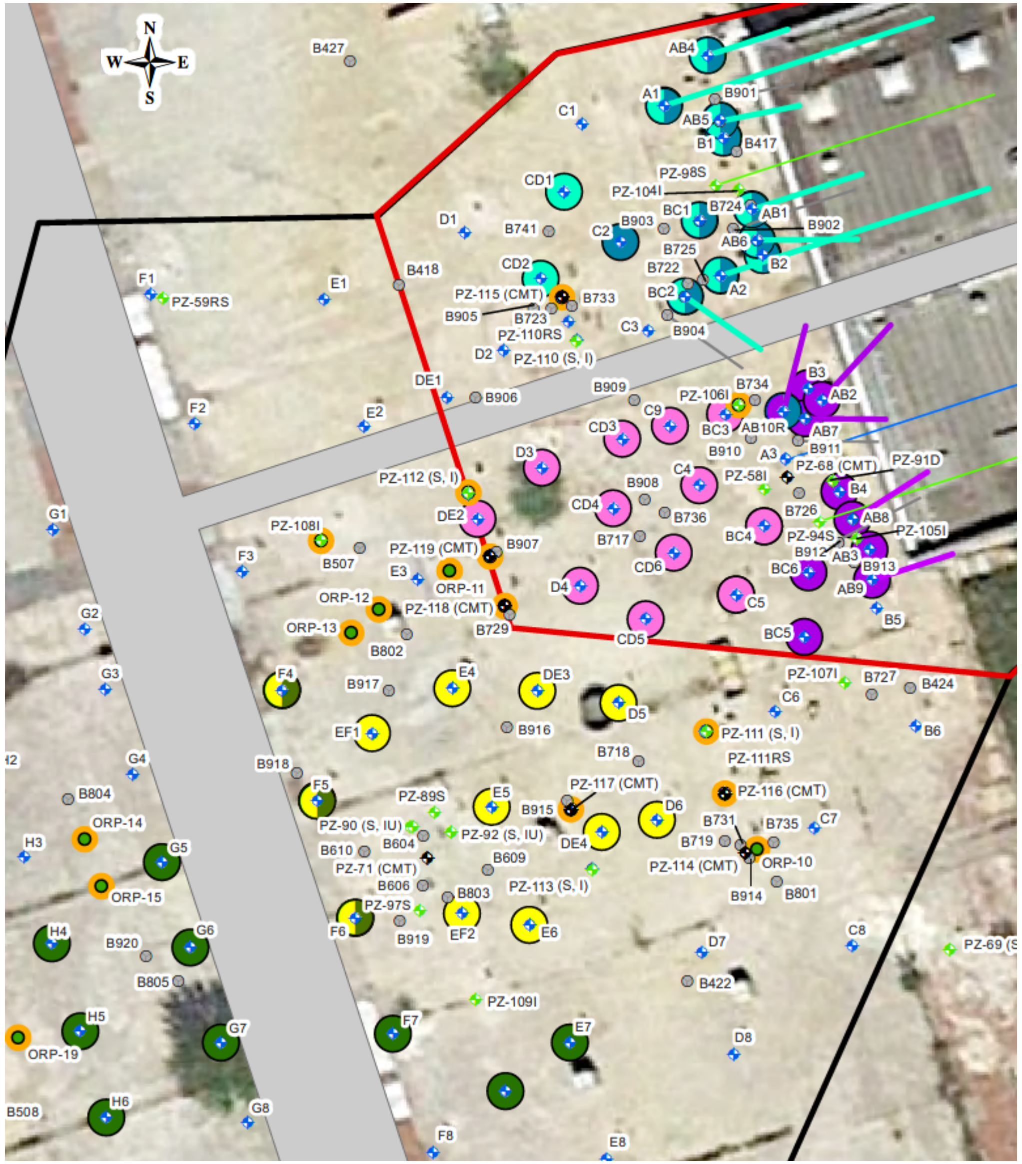
Adaptations from Zone A to Zones B/C

- Active recirculation
- Decreased well and row spacing
  - Enhance delivery
  - Decrease operational timeframe
- “Pod” or cluster-based injections
- ORP sensors as main monitoring for Phases B and C



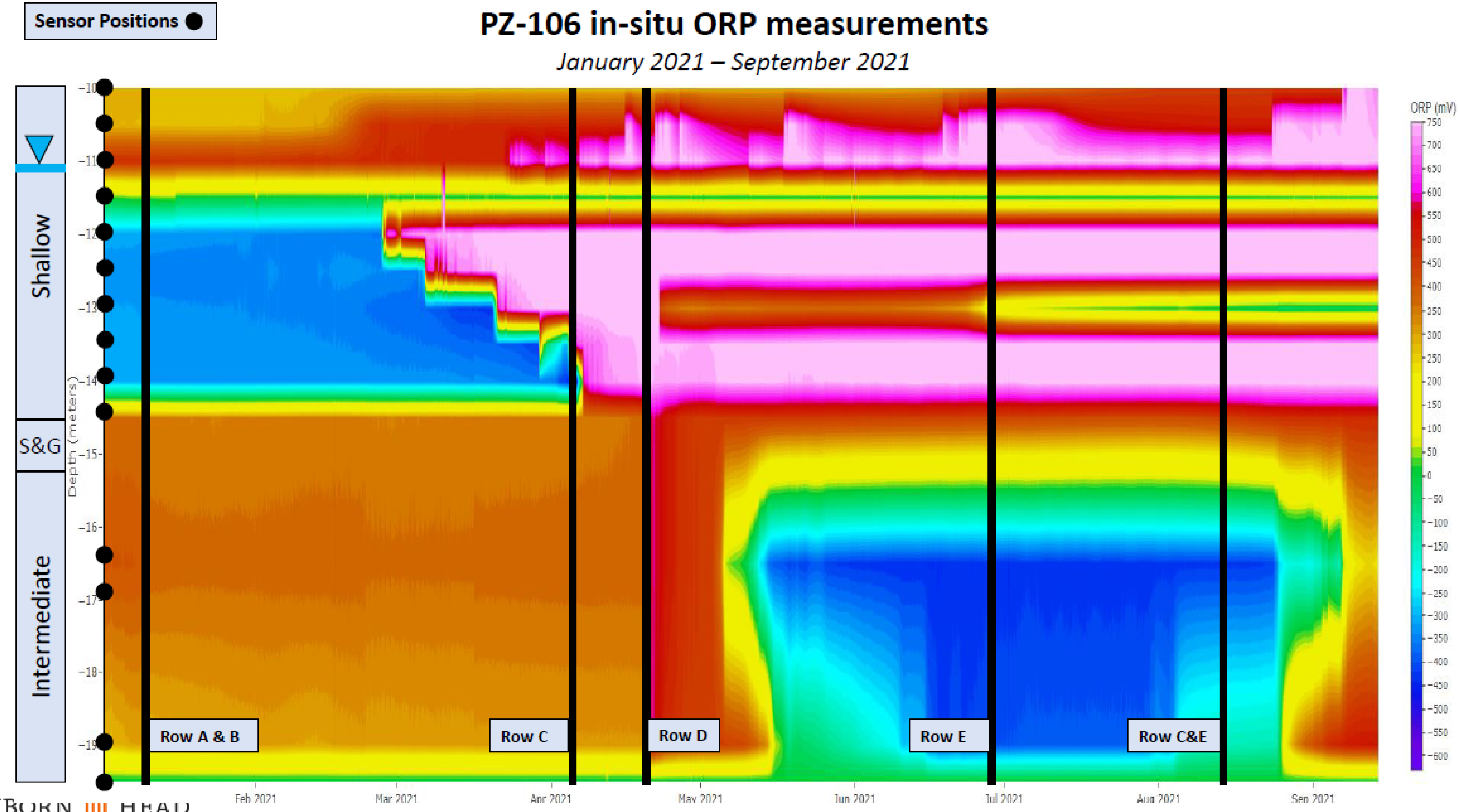
Legend

- Injection Pod 1
- Injection Pod 2
- Injection Pod 3
- Injection Pod 4
- Injection Pod 5
- Injection Pod 6

Existing Locations

- Oxidant Injection / Extraction Well
- Monitoring Well
- Monitoring Well (CMT)
- Soil Boring
- Remote ORP Sensor Location
- Trench
- ISCO Treatment Area
- ISCO Zone A

Example ORP sensor results



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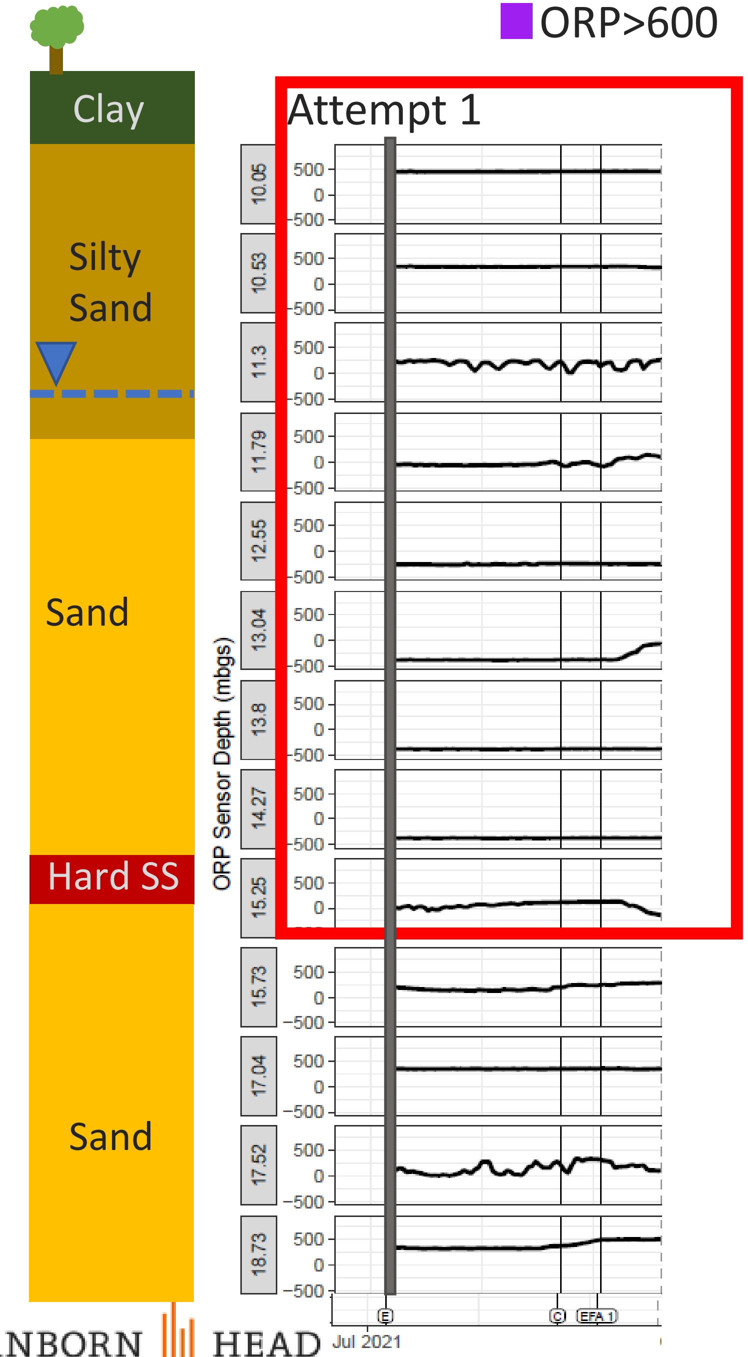
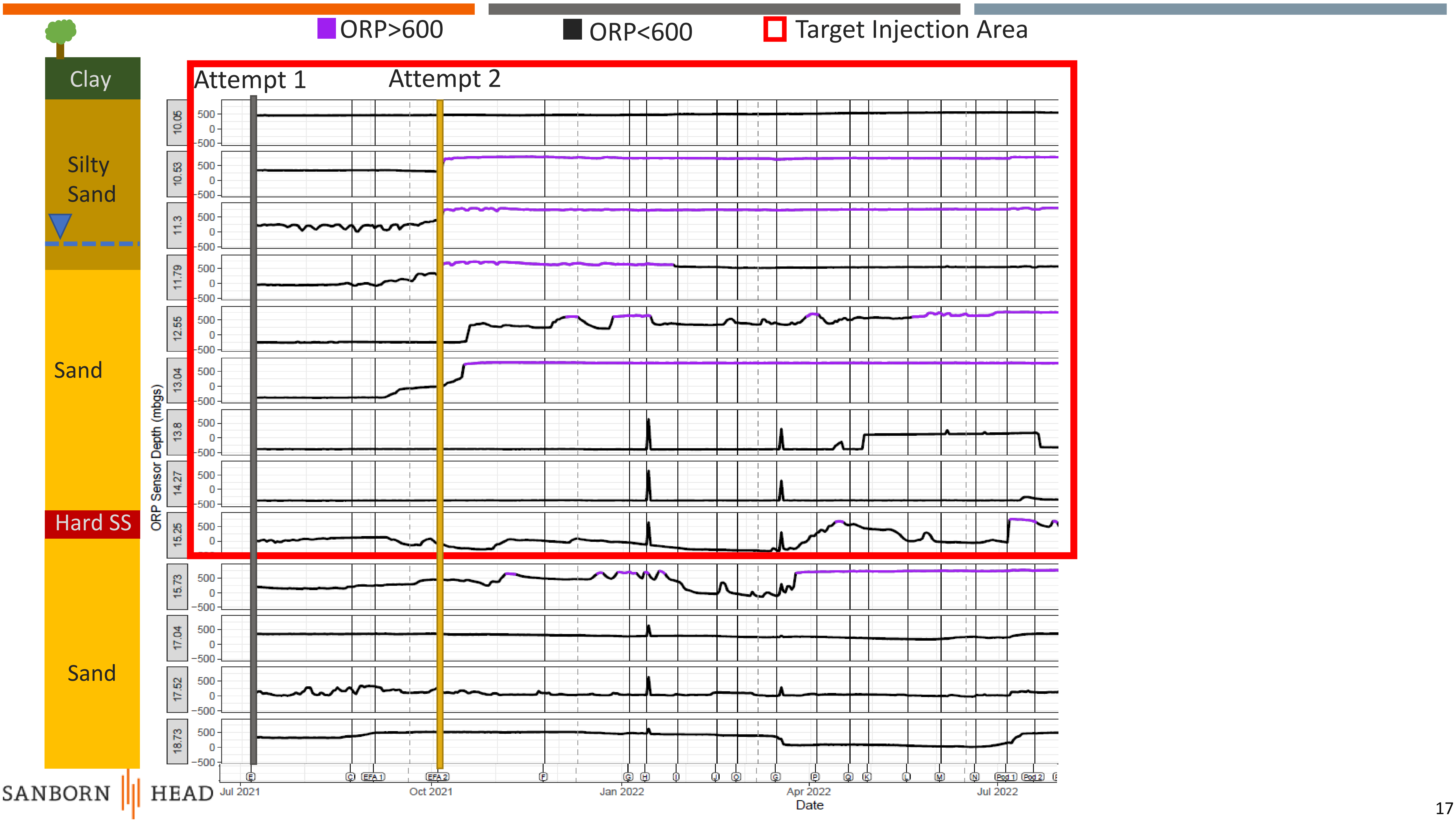
ORP>600

ORP<600

Target Injection Area





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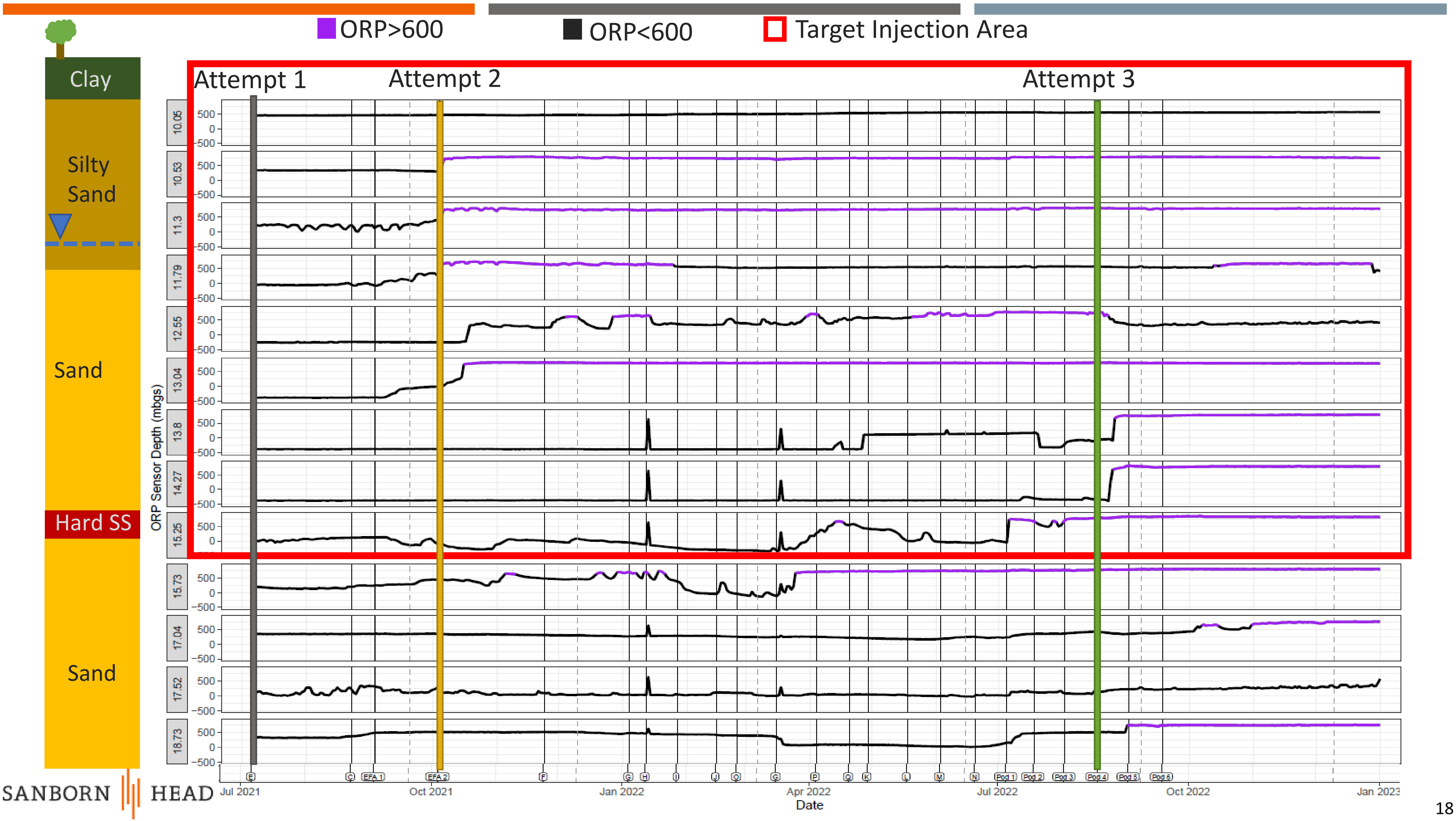
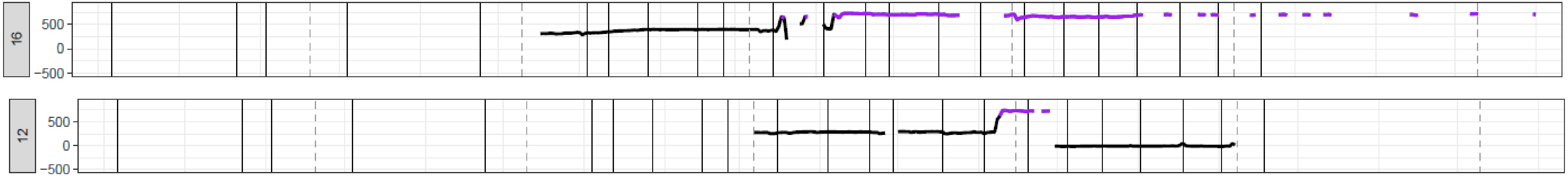


ORP>600
ORP<600
Target Injection Area
Attempt 1
Attempt 2
Attempt 3
Clay
Silty Sand
Sand
Hard SS
Sand
ORP Sensor Depth (mbgs)
10.05
10.53
11.3
11.79
12.55
13.04
13.8
14.27
15.25
15.73
17.04
17.52
18.73
500
0
-500
E
C
EFA 1
EFA 2
F
G
H
I
J
O
G
P
Q
K
L
M
N
Pod 1
Pod 2
Pod 3
Pod 4
Pod 5
Pod 6
Jul 2021
Oct 2021
Jan 2022
Apr 2022
Jul 2022
Oct 2022
Jan 2023
Date

Challenges of ORP sensors

- Damage during installation
- Battery, cell issues, water damage
- Short circuiting along borehole



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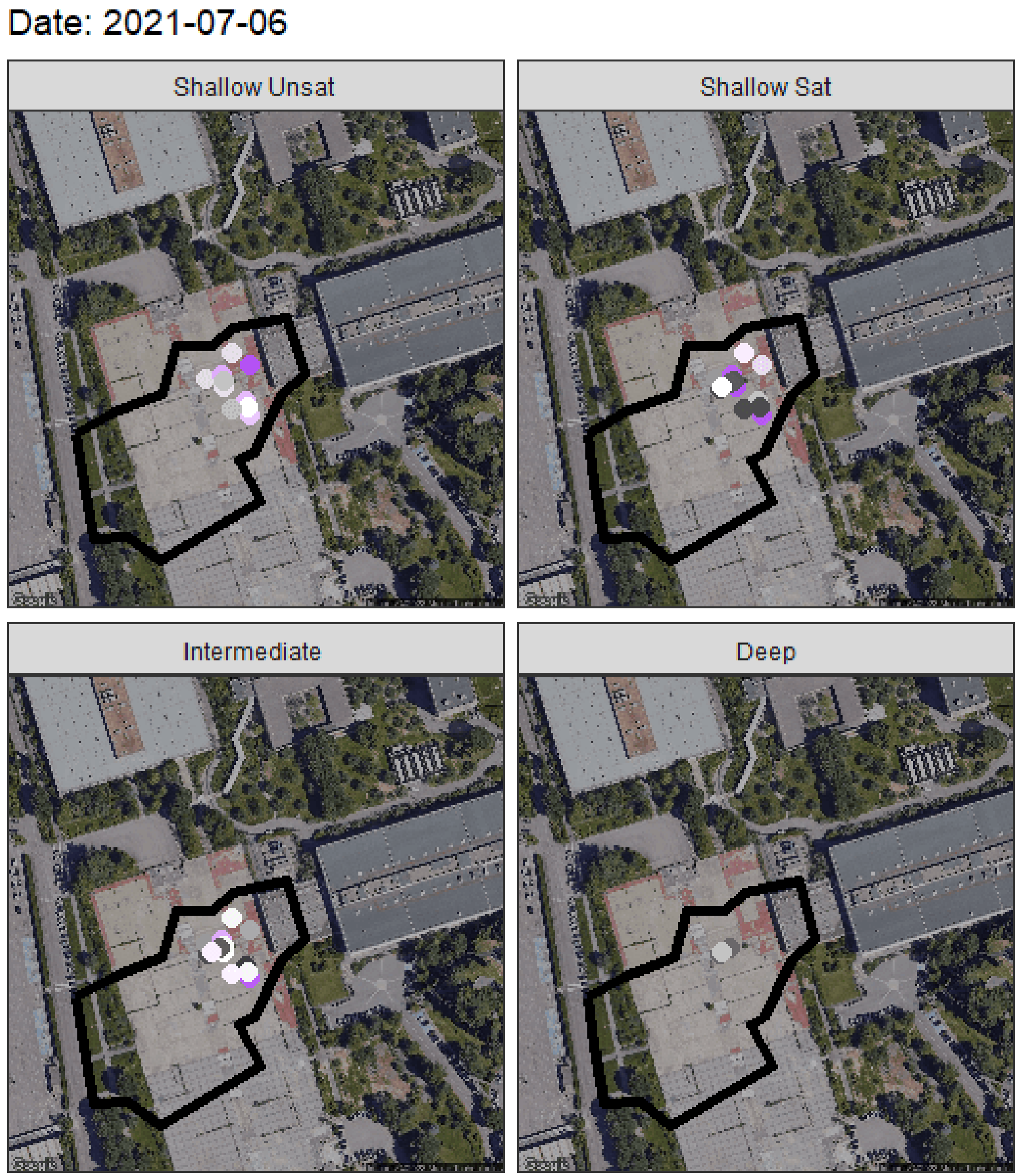
Conclusions

- Data from sensors provided a refined understanding of hydraulic conditions and allowed real-time adaptation of operations to improve ISCO effectiveness
- The quantity of sensor-based data dwarfed what was possible with conventional monitoring approaches, which ultimately allowed full elimination of conventional groundwater monitoring resulting in significant cost savings (~$500K)
- Real-time results helped avoid the potential need for expensive re-mobilization
- Elimination of conventional groundwater monitoring avoided potential health and safety issues for site workers associated with permanganate



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Thank you!

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Morwick G360 Groundwater Research Institute

Extra Slides

Active Operational Data

Coarse

- Theoretical Pore volume mass/Volume
- Arrival in Extraction well(s)
- Permanganate arrival in monitoring well(s)
- ORP increase in all sensors

Fine

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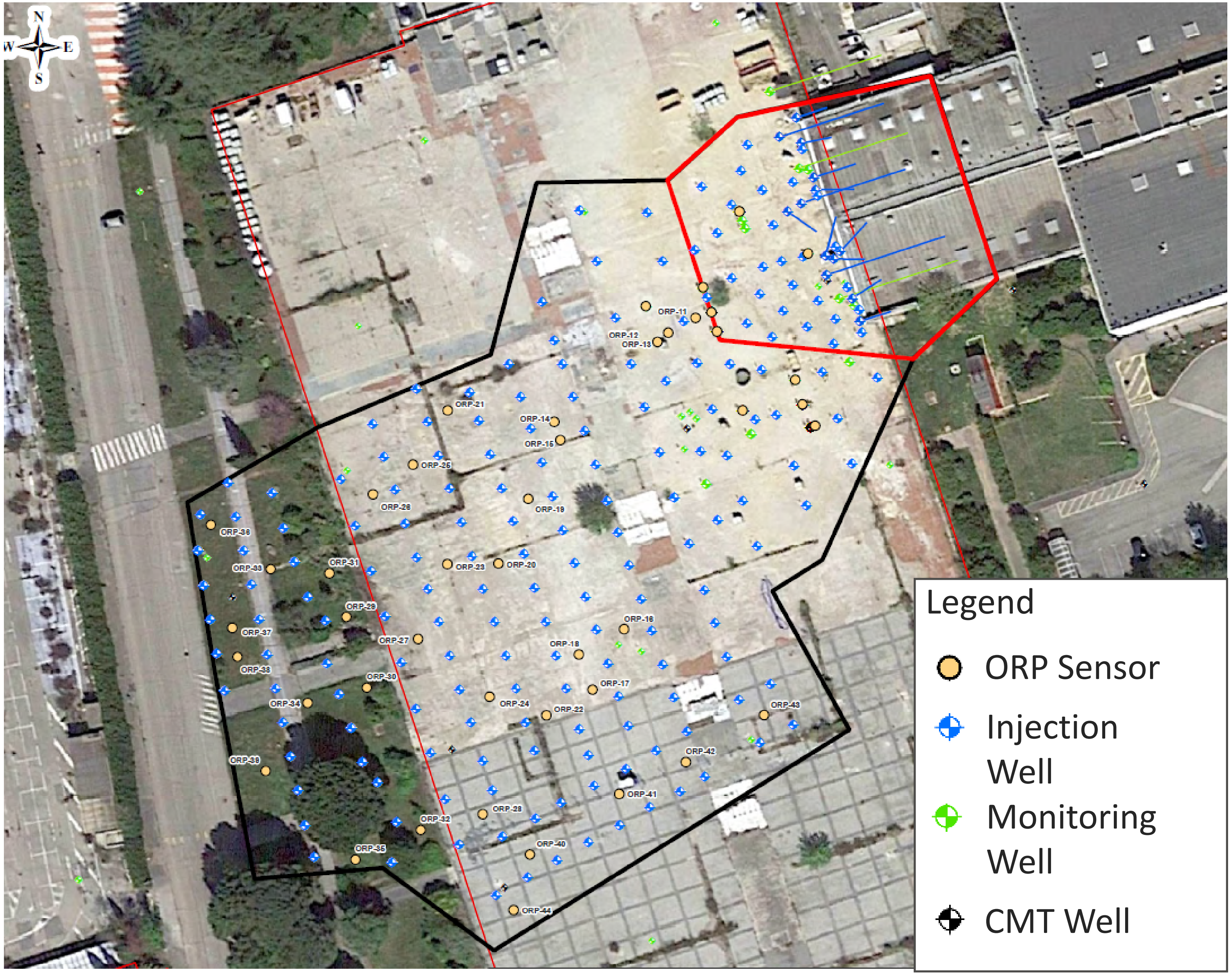
Site Background

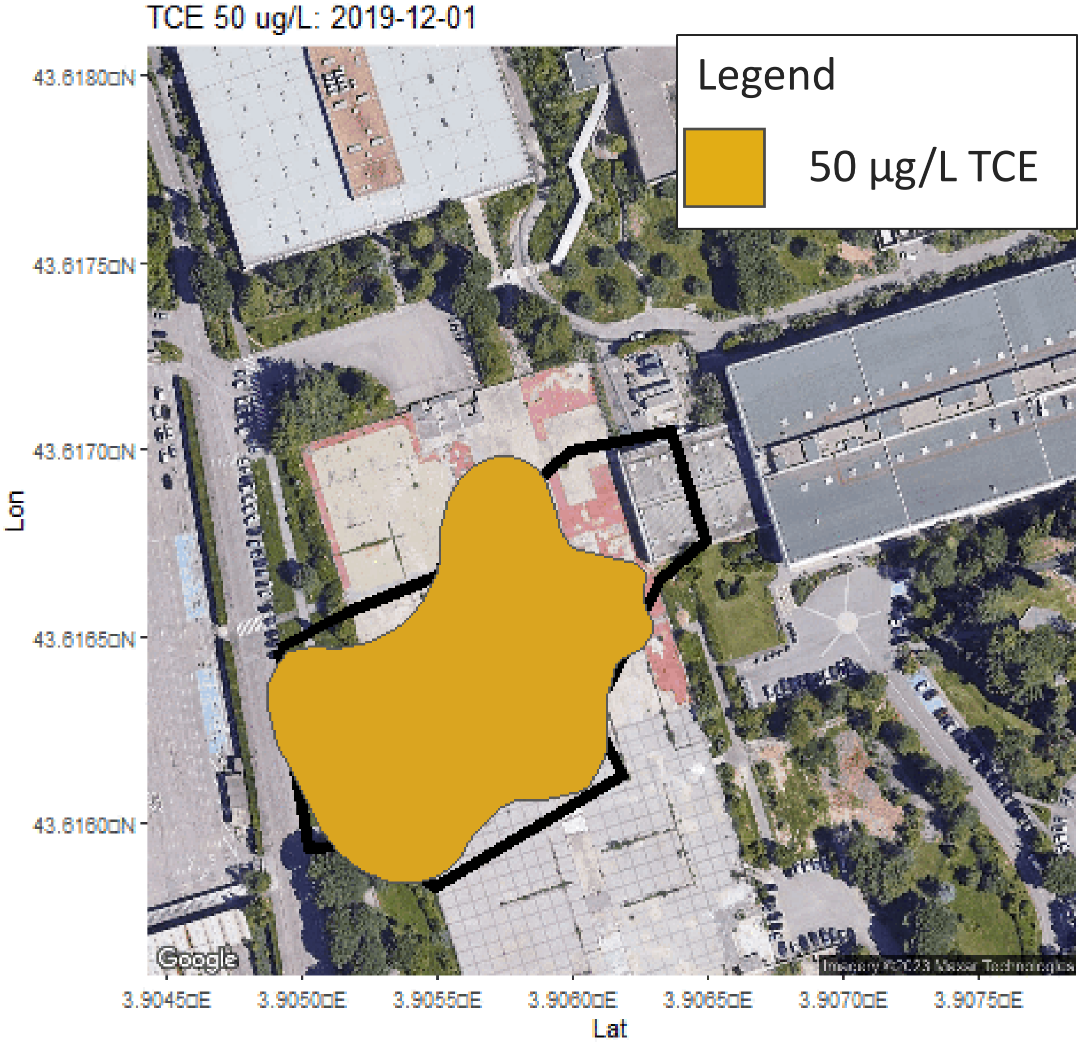
- Location: Southern France
- Former manufacturing facility
- TCE in Soil and Groundwater
- Decades of work
  - Starts in ~2005
  - Earnest characterization in 2018
  - ISCO in 2021-2023



Site Background

Early returns on remediation are Positive!

- Marine Clayey-silt/Sand/Sandstone
  - Increasing consolidation with depth
- ~150 wells, 12 injection pumps
  - Injection pattern key
  - Sensors to evaluate arrival
  - Transducers to understand flow direction
- Automated remediation system
  - Per pump/well control on injectant



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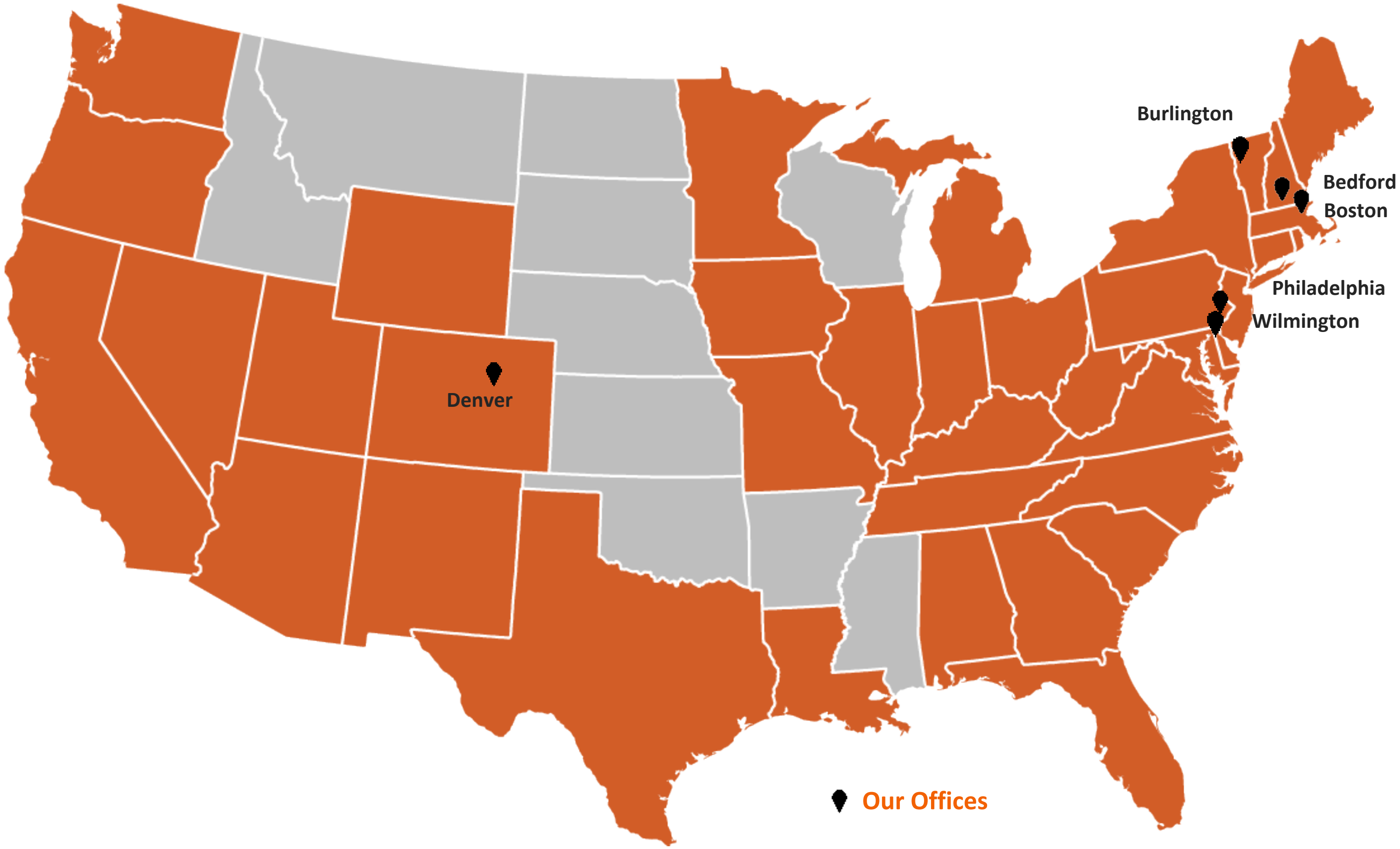
OVERVIEW

- Employee-Owned, Est. in 1993
- Multi-disciplinary:
  - solid waste
  - environmental
  - hydrogeology
  - geotechnical
  - civil
  - chemical
  - mechanical
  - electrical
  - risk assessment
- Approximately 180 employees
- Bedford, NH (Headquarters)

Where We're Registered



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SERVICES

- Air Services and Modeling
- Brownfields Redevelopment
- Data Management & Visualization
- Due Diligence
- Geotechnical Design
- Landfill Gas Management
- Legal Support
- Natural Gas Infrastructure Design
- Permitting & Compliance
- Renewable Energy
- Site Characterization & Remediation
- Solid Waste Facility Design
- Water Resources

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Solid Waste

Energy

Industrial

Development

CLIENT SERVICE AREAS