Biostimulation to Promote Total Nitrogen Loss in a Coastal Aquifer

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Brent Lazenby[1], Frederic Cosme[1], Julie Konzuk[1], Kathy Phillips[1], Anthony Black[2], Brian Howarth[2] , Steve McCollin[2] and Ben Schultz[3]

[1] Geosyntec

[2] Yara

[3] Orica

Nitrogen cycling

Nitrogen cycling in the environment

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$NH_3 + NO_3^-$

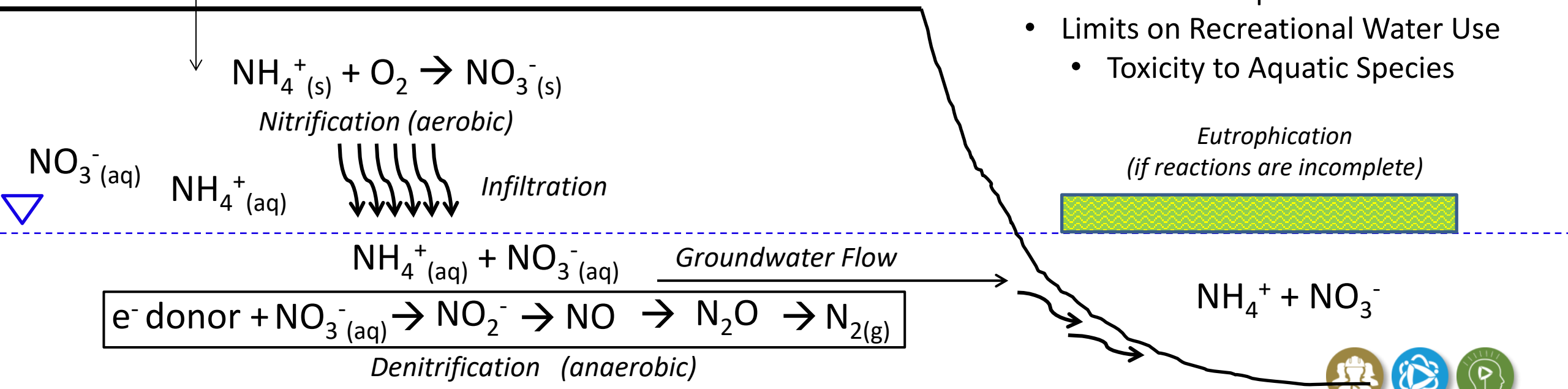
Anthropogenic Inputs
Septic, fertilizer, chemical sources

Nitrogen Cycling

- Microbially-mediated
- Well-known processes (global presence)
- Natural and synthetic (WWTP) environments
- Affected by changing geochemical conditions

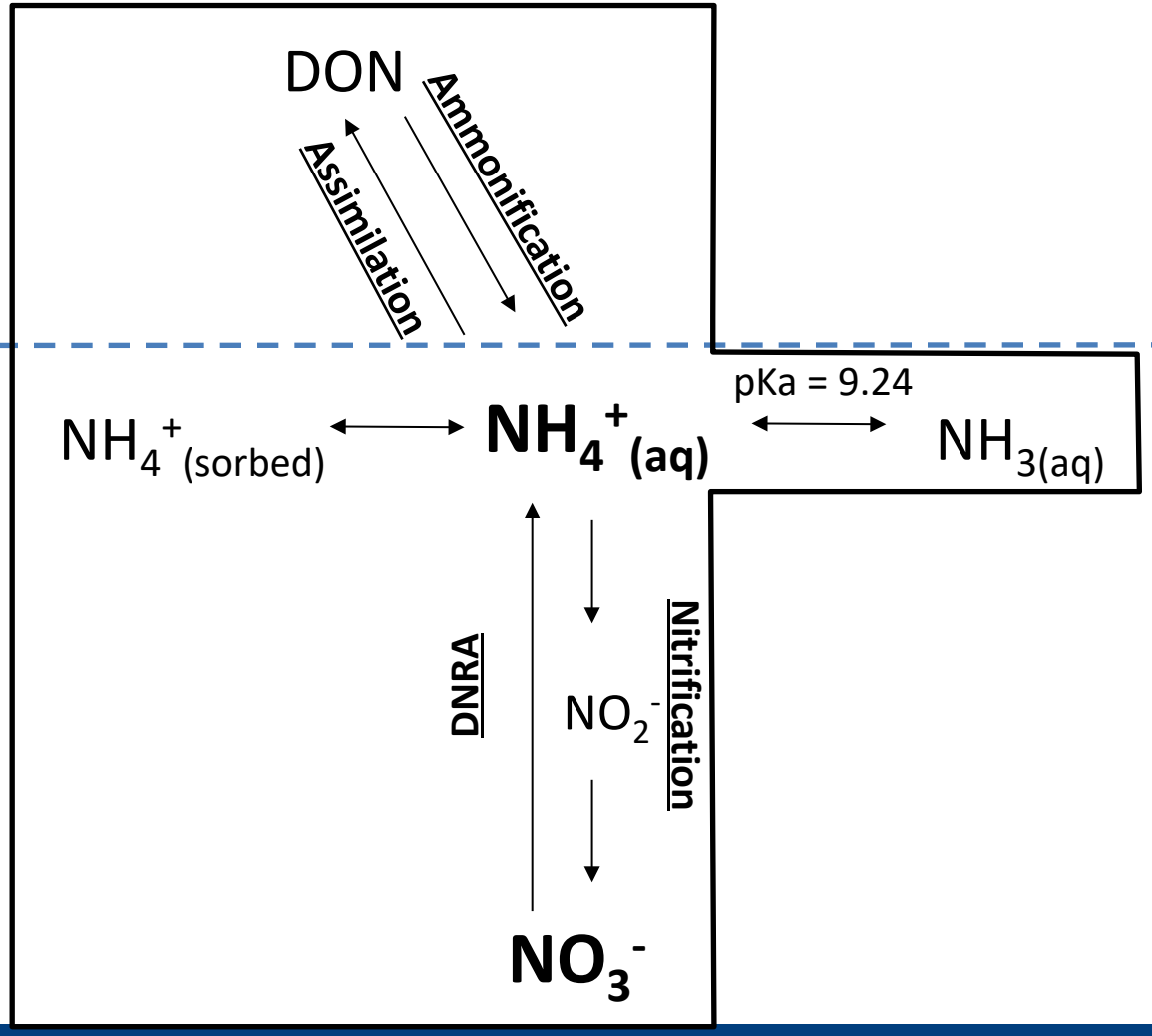
Elevated Nitrogen in Groundwater and Surface Water

- Drinking water use limits
- Eutrophication
- Limits on Recreational Water Use
- Toxicity to Aquatic Species



Nitrogen in groundwater - Transformation

Nitrification, ammonification, DNRA change nitrogen ***form*** but not overall nitrogen loss



DON – Dissolved Organic Nitrogen
NH_3 - Ammonia
NH_4^+ - Ammonium
NO_2^- - Nitrite
NO_3^- - Nitrate

Nitrogen in groundwater - Attenuation

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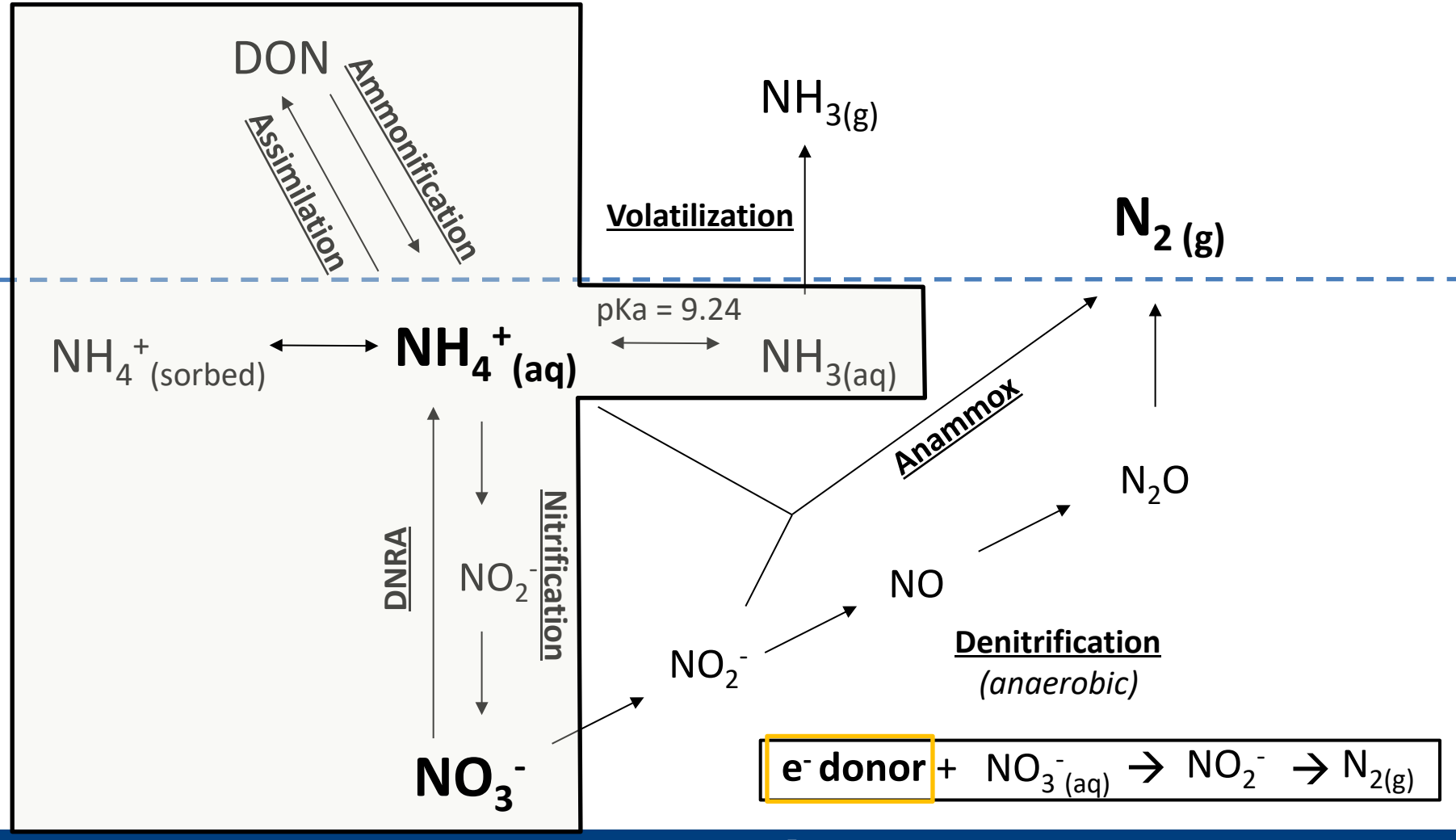
Denitrification and/or anaerobic ammonium oxidation (anammox) reactions result in overall ***loss*** of nitrogen from groundwater



N_2 – Nitrogen gas
NO – Nitric Oxide
N_2O – Nitrous Oxide

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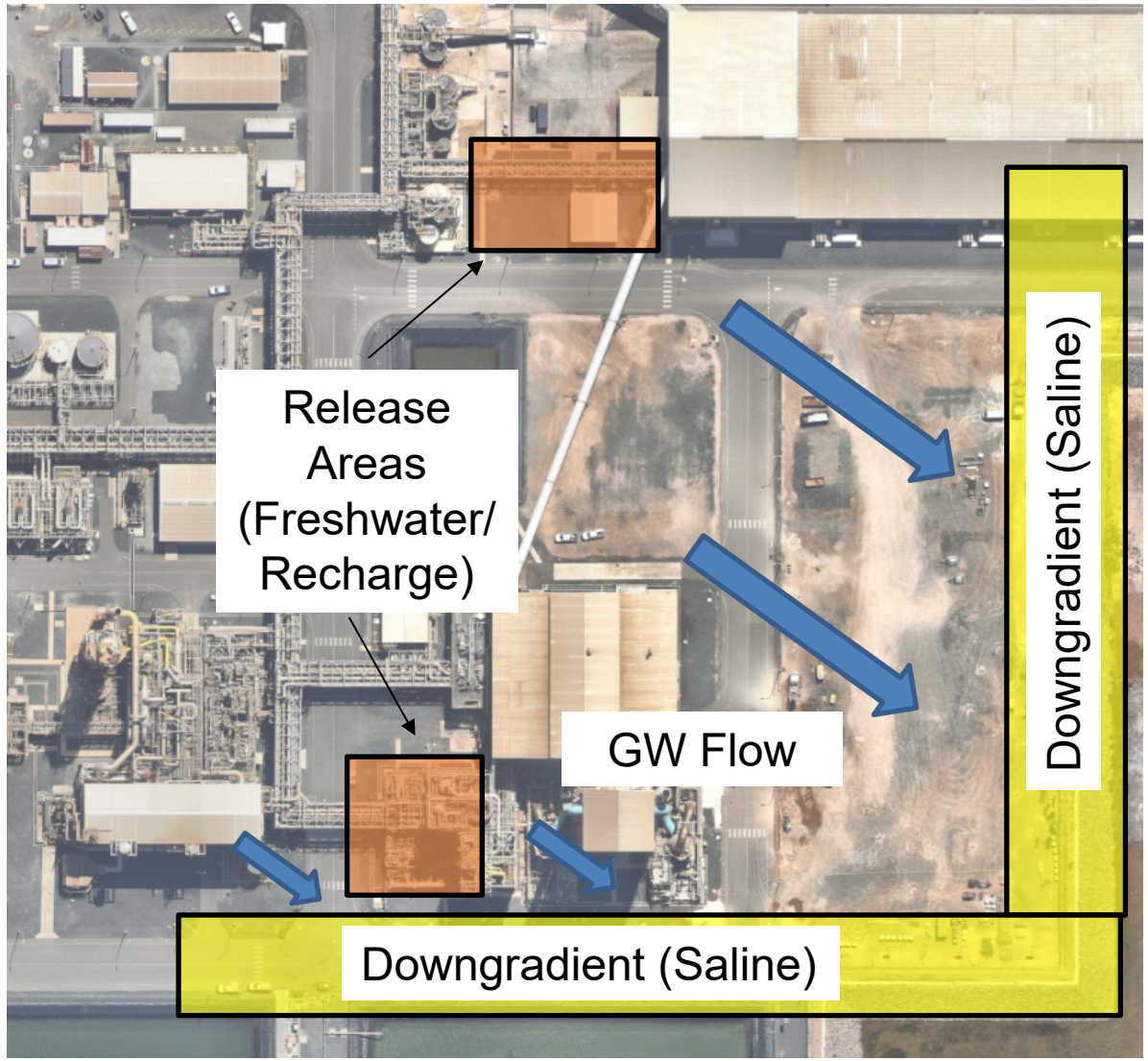
Baseline assessment

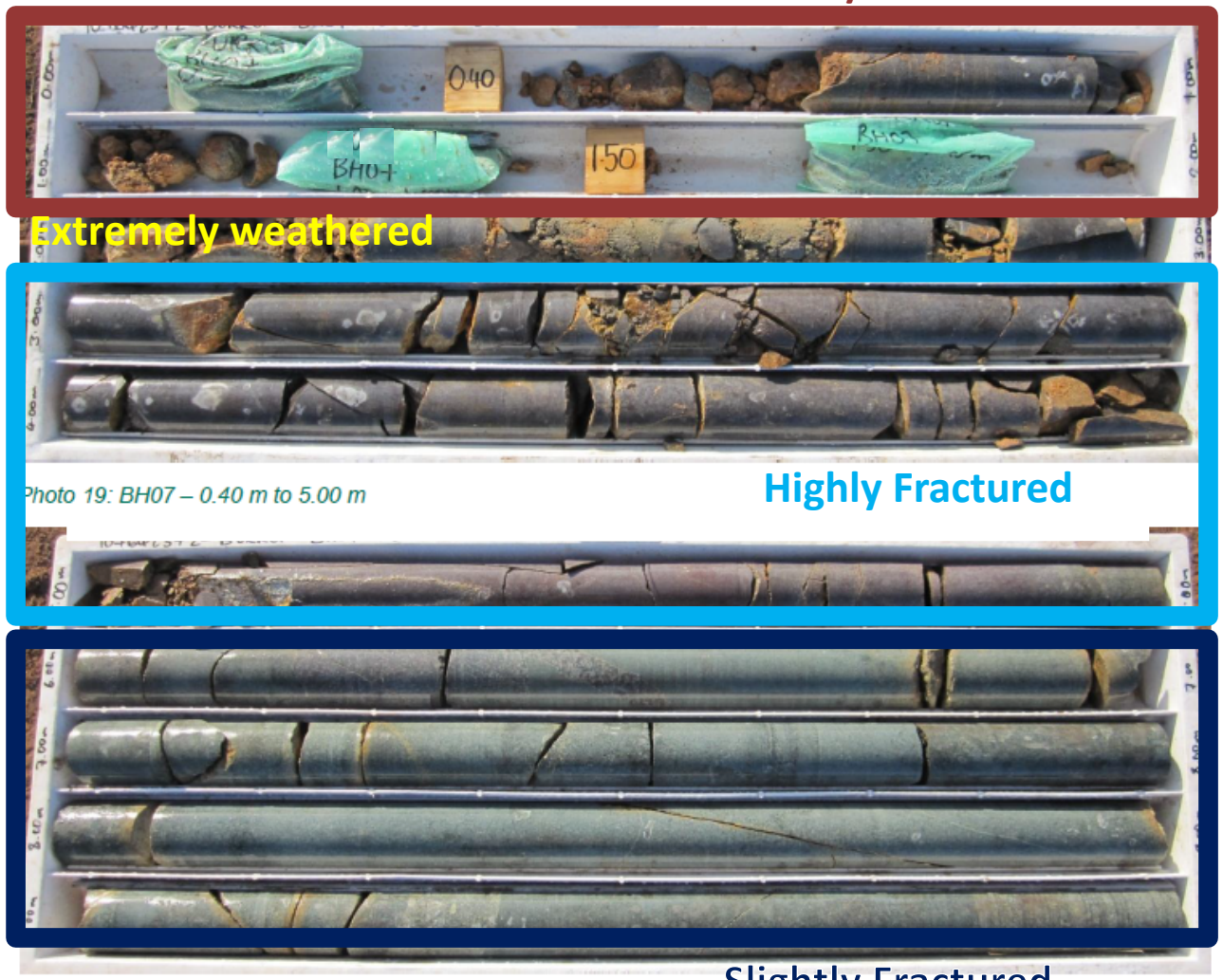
Site setting and considerations

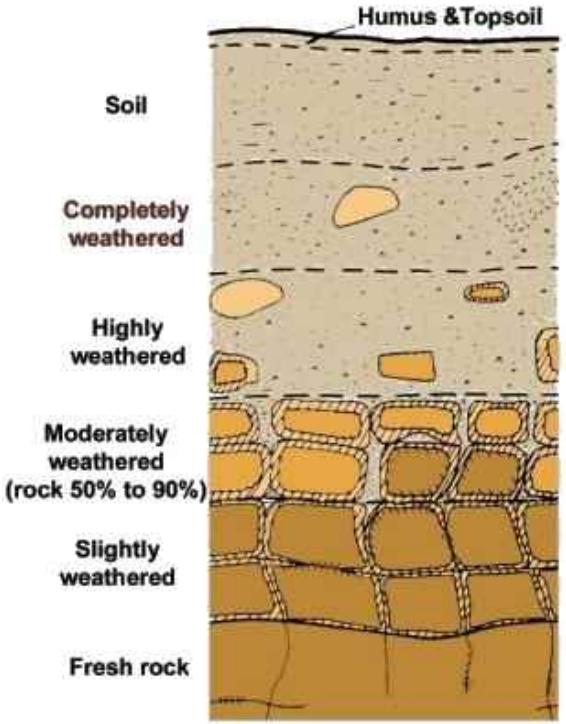


- Shallow geology
  - Fractured bedrock
  - N distribution, injectability
- 'Freshwater' release areas
  - Aerobic, ammonia-N dominated
- Saline downgradient areas
  - Anaerobic, nitrate-N dominated
- N attenuation
  - Current/potential
- Electron Donor
  - Type, dose, distribution

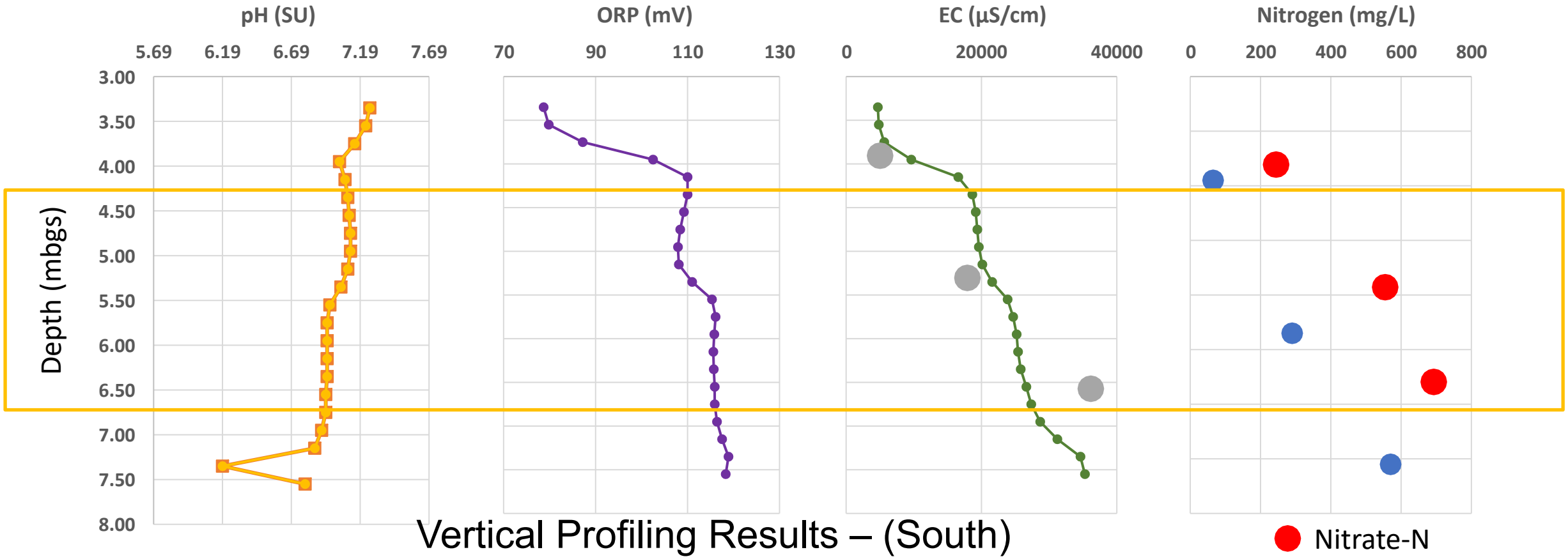
Shallow geology

Colluvium / Residual soil



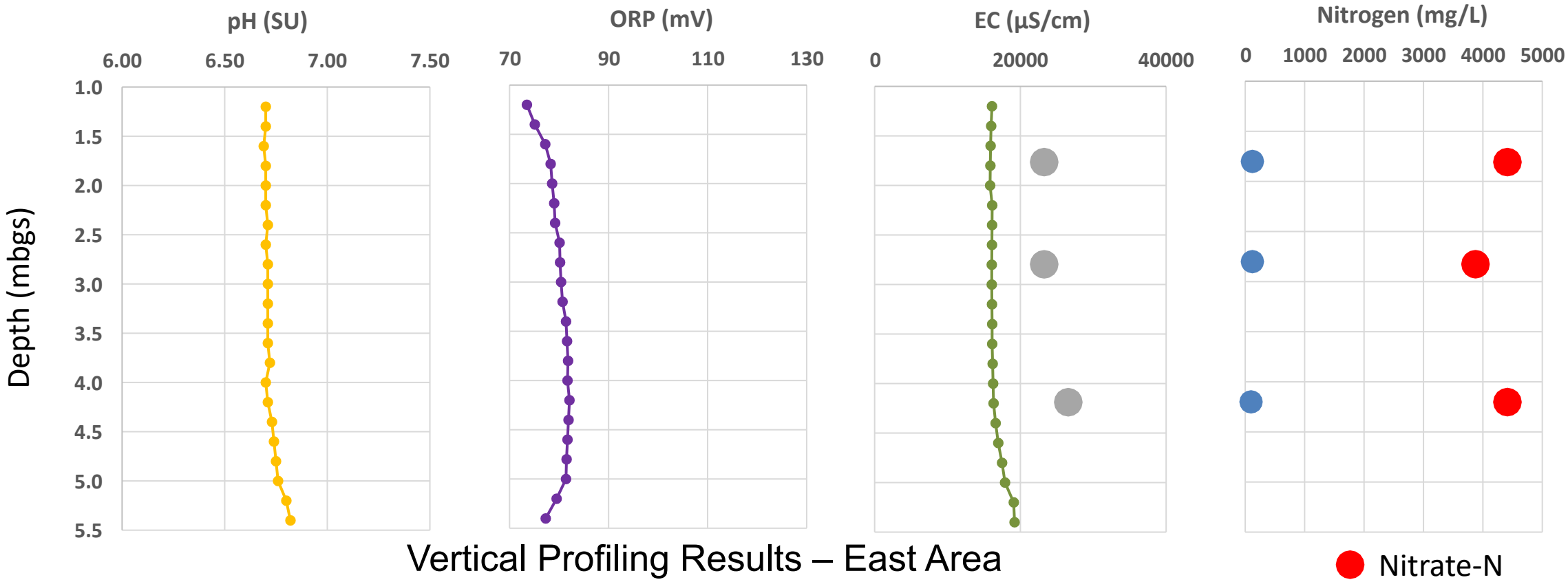


Vertical profile (south)



- Increases in chloride, ammonia-N, nitrate-N with depth
- Chloride 980 mg/L (shallow) to 5,300 mg/L (deep)

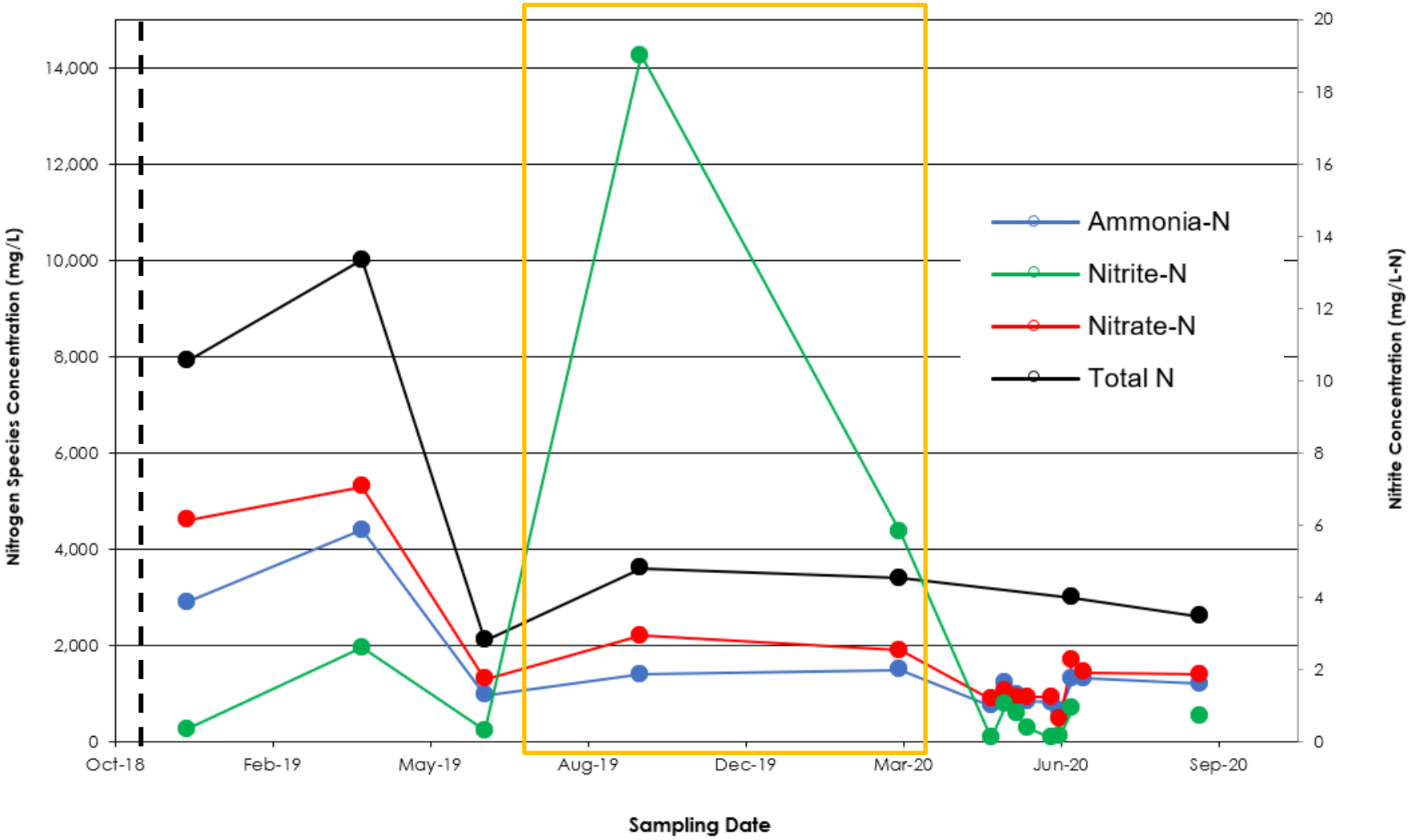
Vertical profile (east)



Vertical Profiling Results – East Area

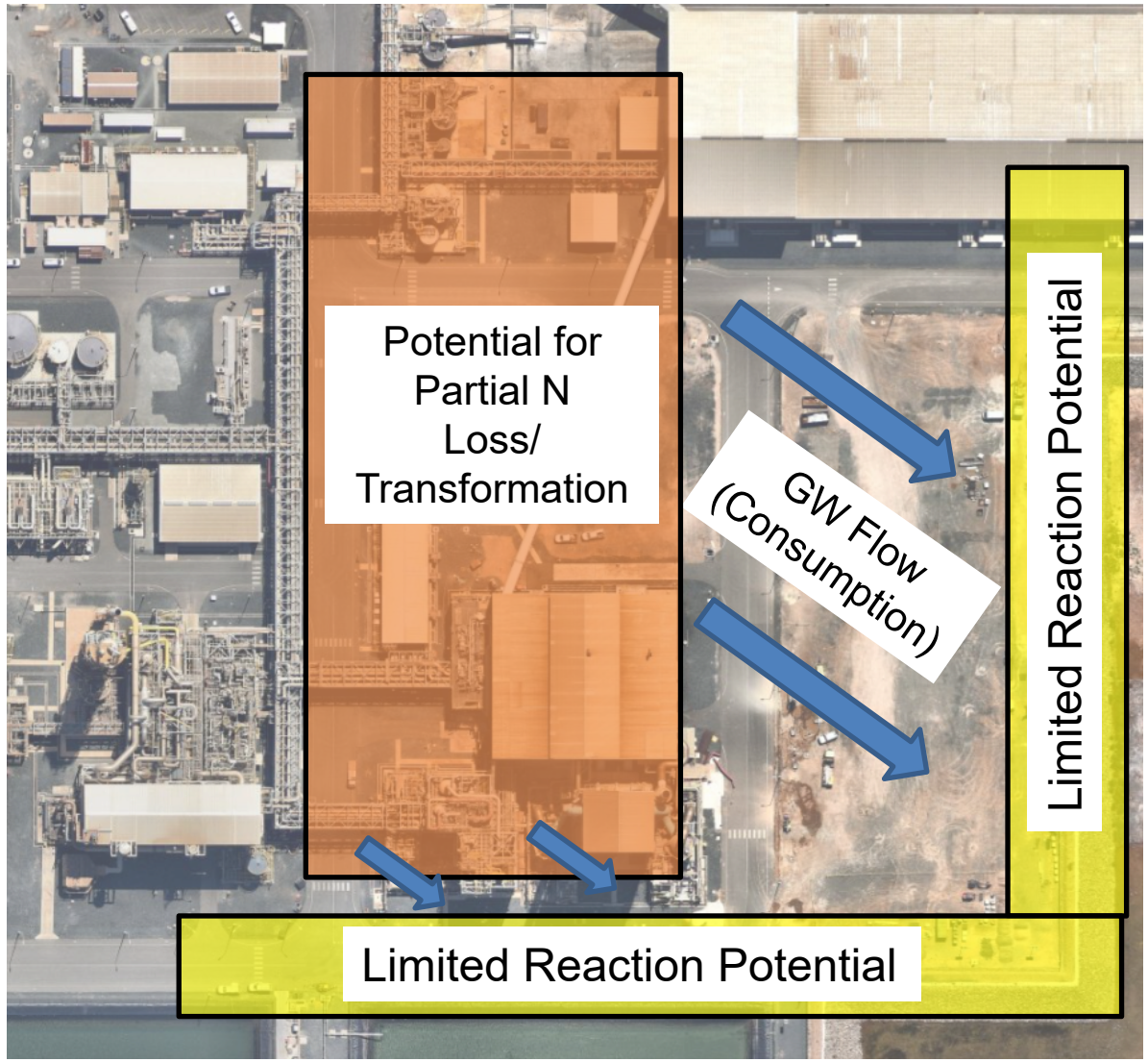
- Consistent chloride, ammonia-N, nitrate-N with depth
- Chloride ~ 6,000 mg/L

Nitrogen attenuation – near release area



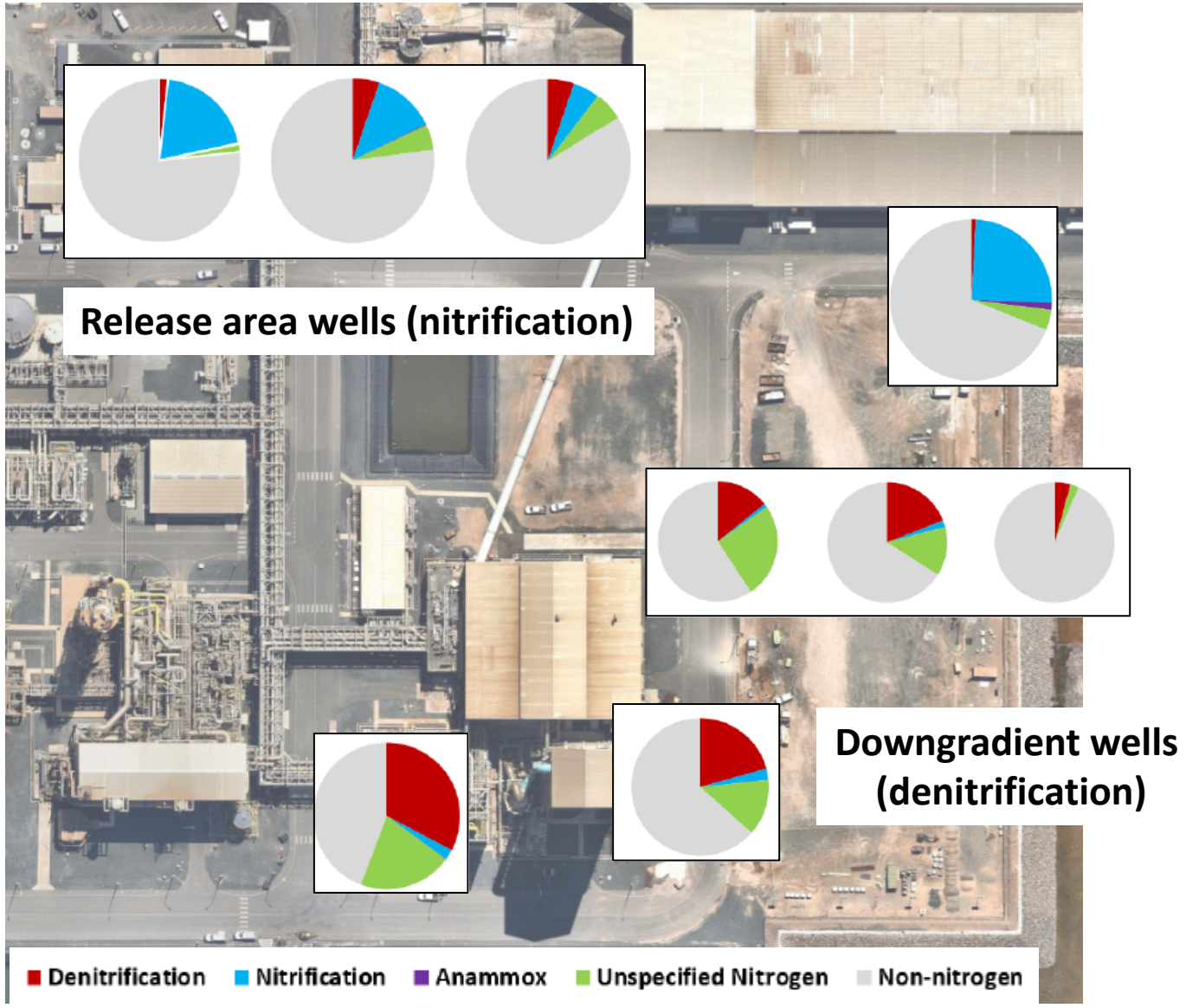
- Concurrent loss of N species
- Accumulation of nitrite (evidence for biological activity)
- Less evident in downgradient areas

Nitrogen and geochemical summary



- Source areas show potential for variable N reactions
  - Mixed NO_3^- and NH_4^+
  - Oxygen availability
  - Changes in ORP
  - Overall concurrent loss of NO_3^- and NH_4^+, appearance of NO_2^-
- Oxygen consumed along flow path
  - Shift to primarily NO_3^-
- Limited potential for reaction downgradient without enhanced bio
  - Electron donor limited for denitrification

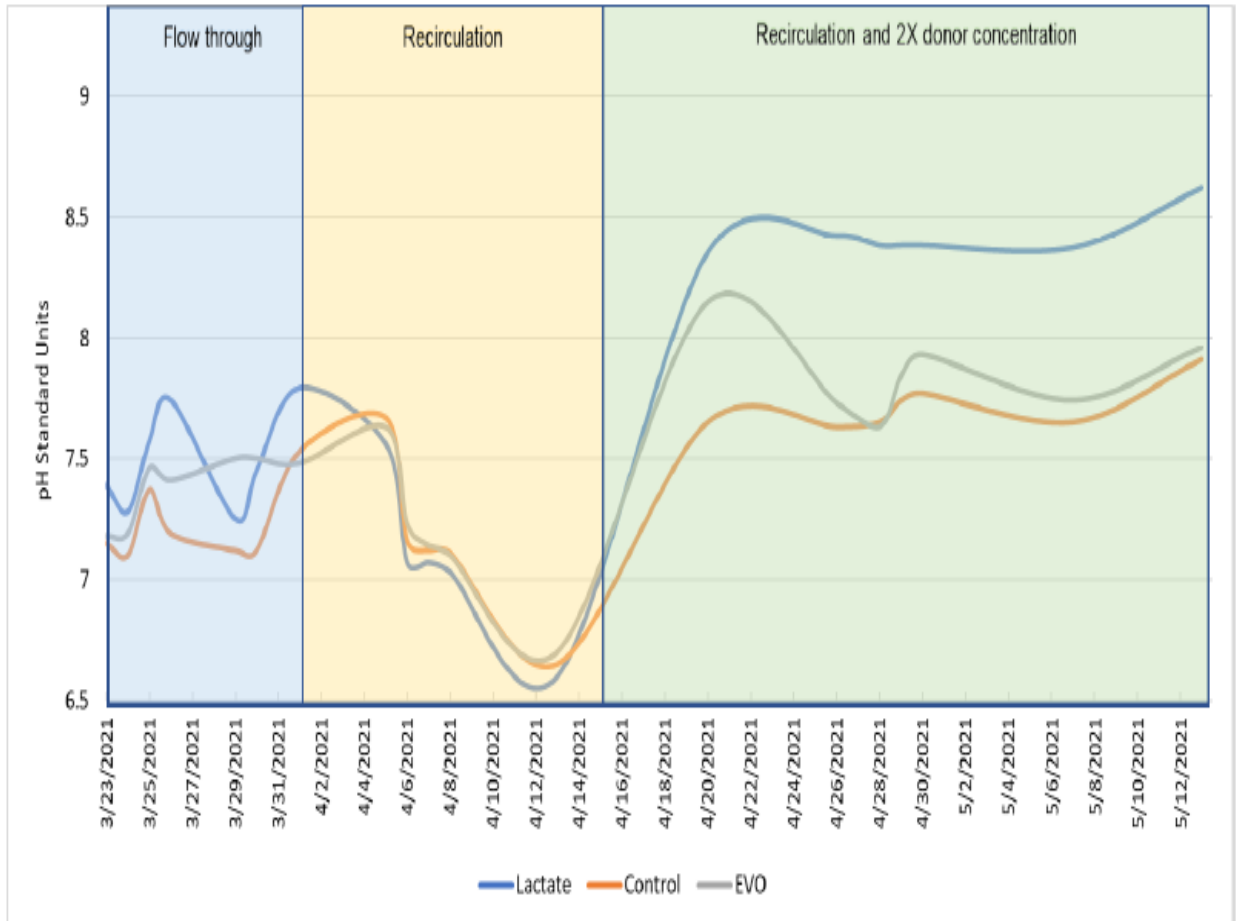
Bacteria community – NGS



- Bacteria communities vary in composition and number throughout the site
- Driven by geochemical conditions
  - Nitrifiers in source area (oxygen available)
  - Denitrifiers downgradient
  - Anammox populations present in most sampling locations (qPCR)
- Bacteria diversity allows for biostimulation options rather than bioaugmentation

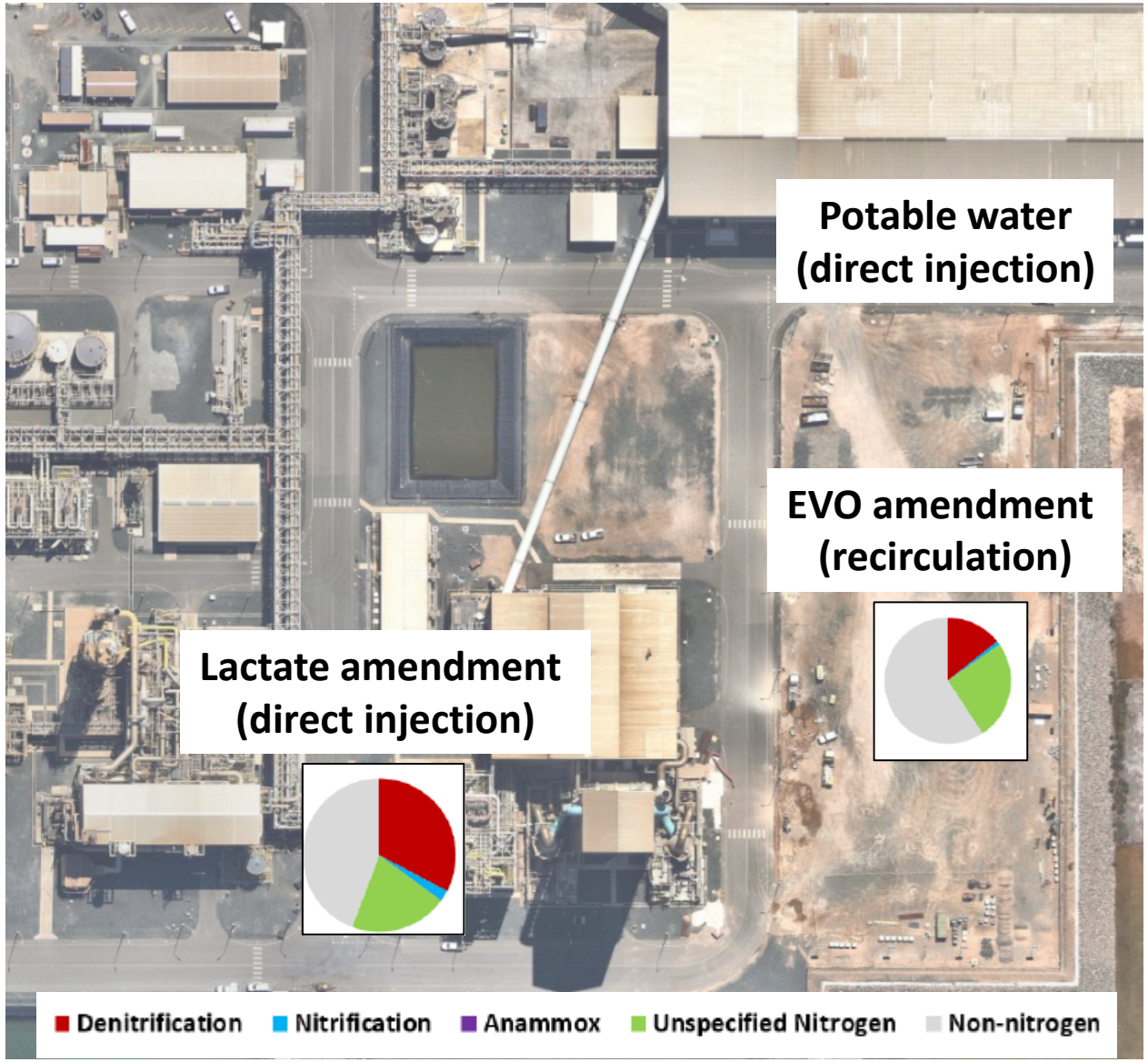
Biostimulation evaluation

Treatability testing



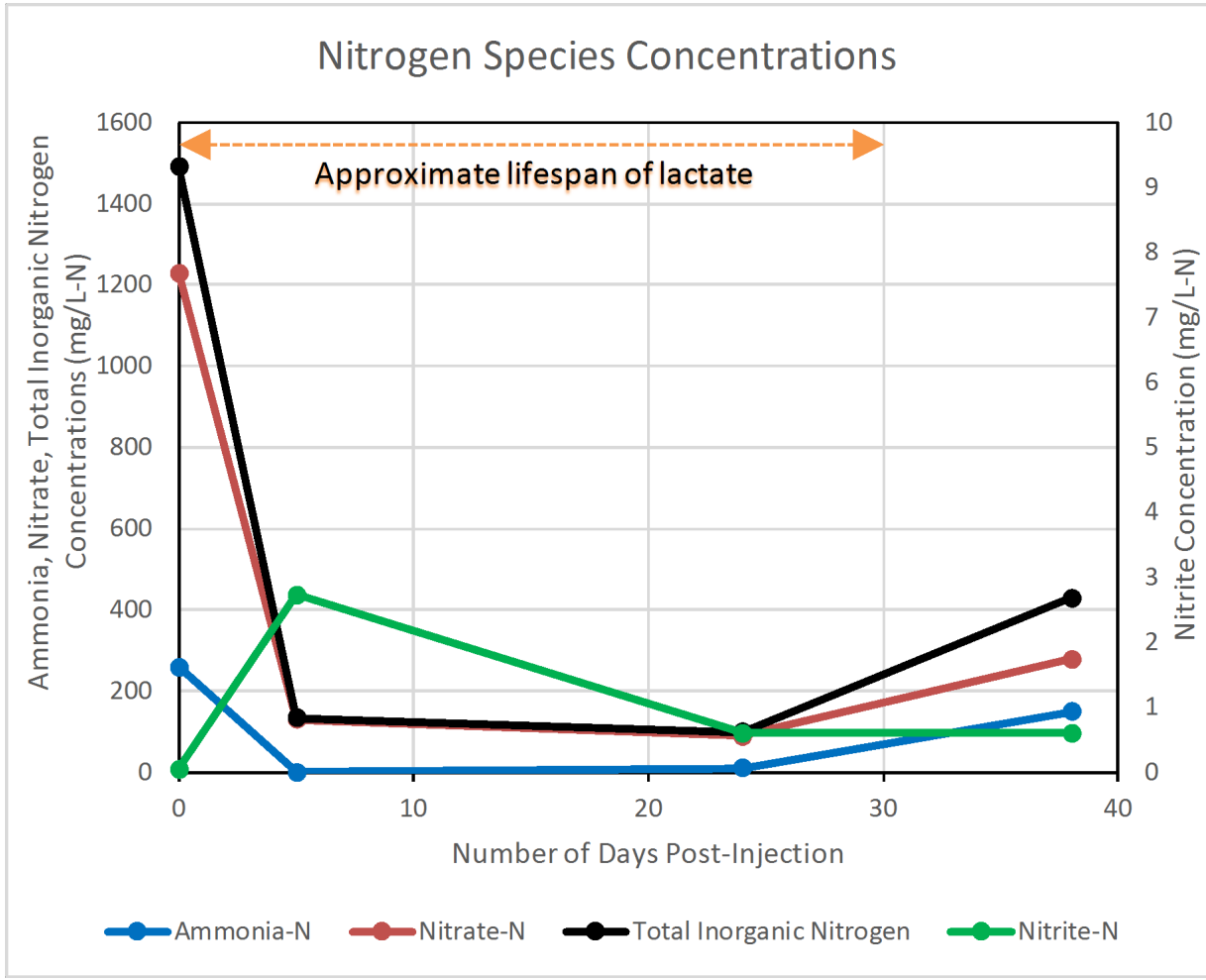
- Natural attenuation limited by carbon availability
  - Direct effect on denitrification
  - Limited anammox potential in oxidizing conditions
- Significant sorption of N species to soil
  - Secondary source
  - Prolong attenuation/affect dosing
- Electron donor source
  - Emulsified vegetable oil vs. sodium lactate: both viable
  - Variable dosing: balance denitrification/anammox
- pH changes – potentially inhibitory conditions possible
- Flow through vs. recirculation

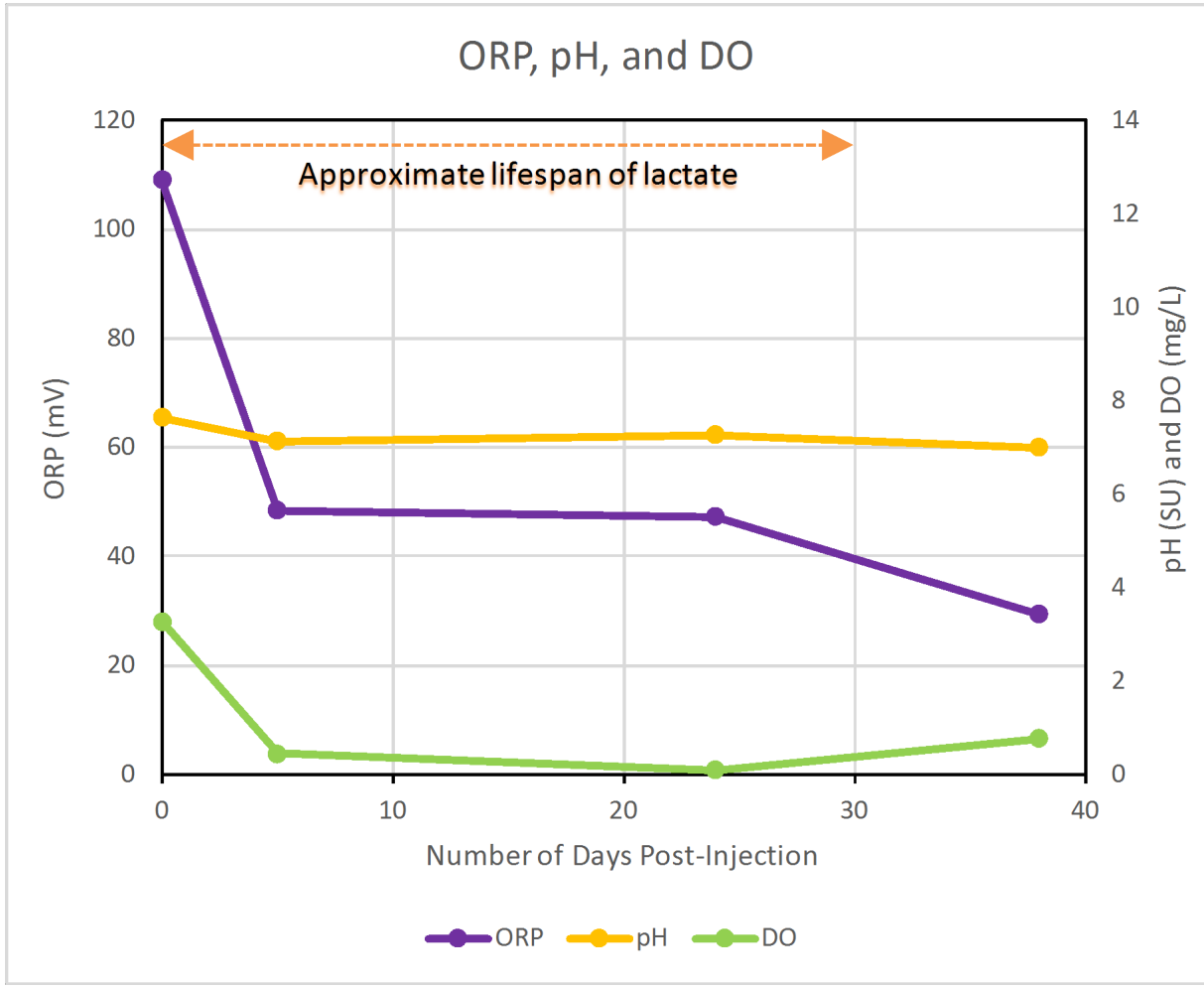
Injectability testing



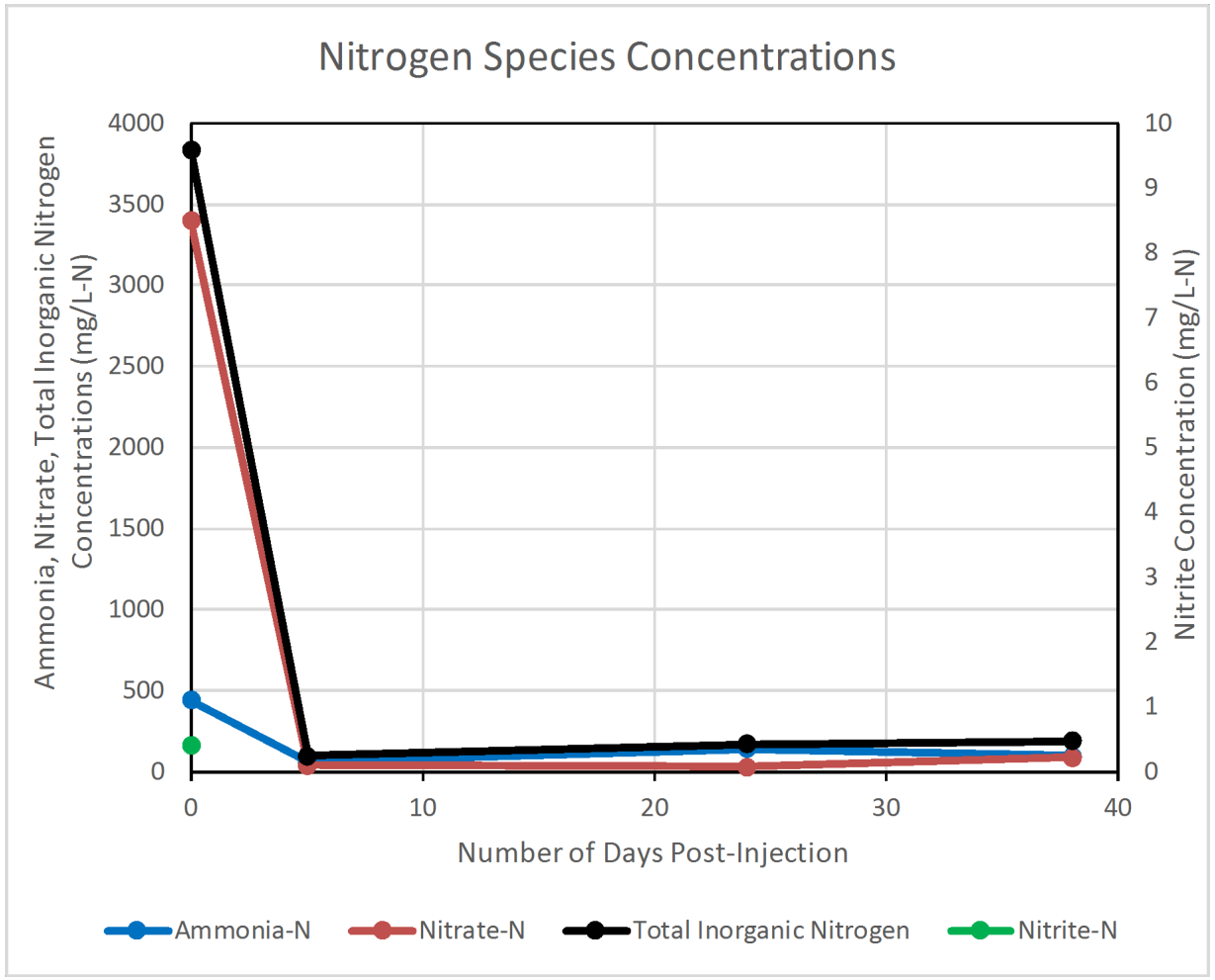
- Three test areas
  - Evaluate injection rates
  - Amendment distribution
  - Effectiveness/longevity of electron donors (EVO/lactate)
- Variable injection rates
  - Driven by geology
- Monitored for amendment migration/downgradient effects

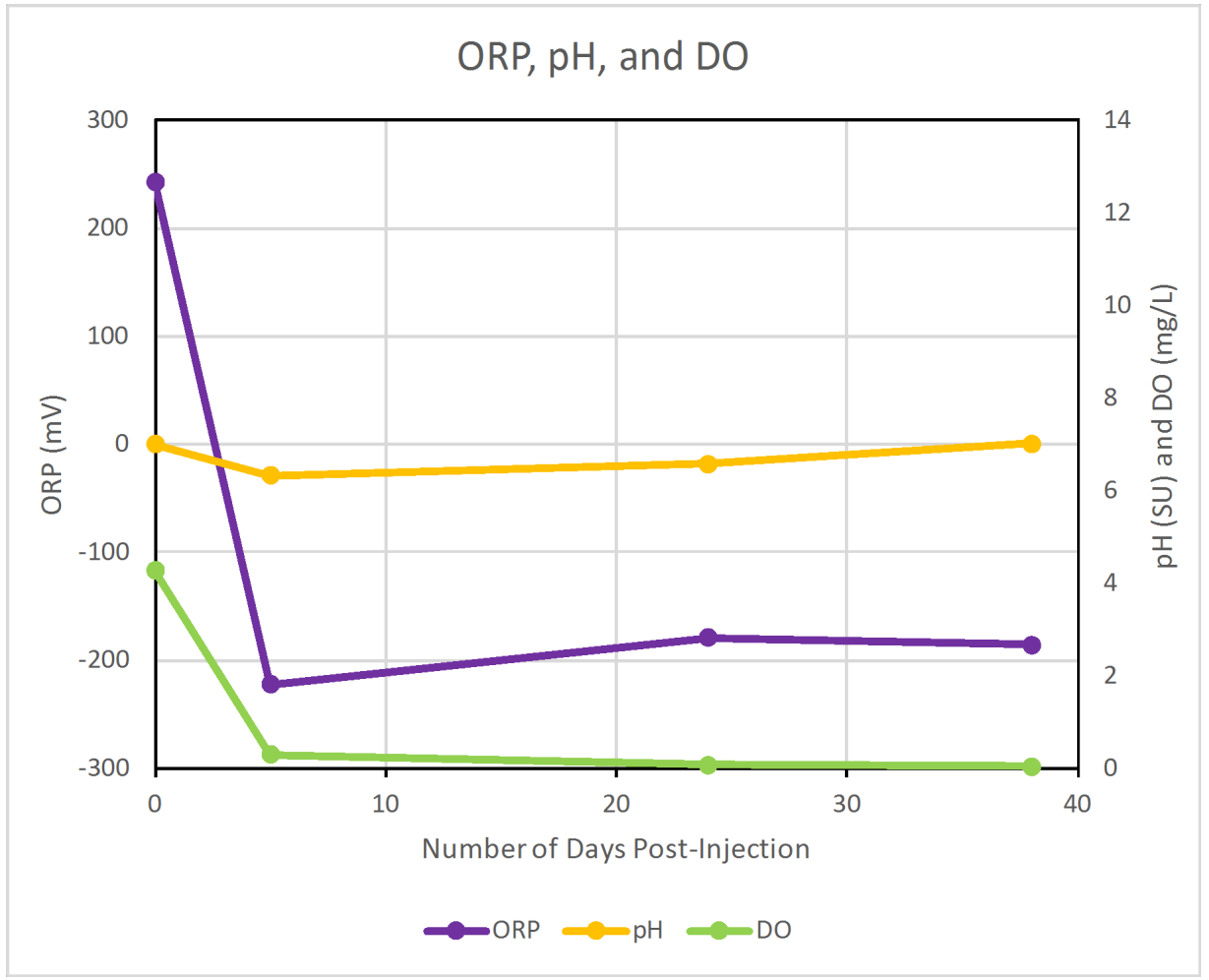
Injectability evaluation: lactate



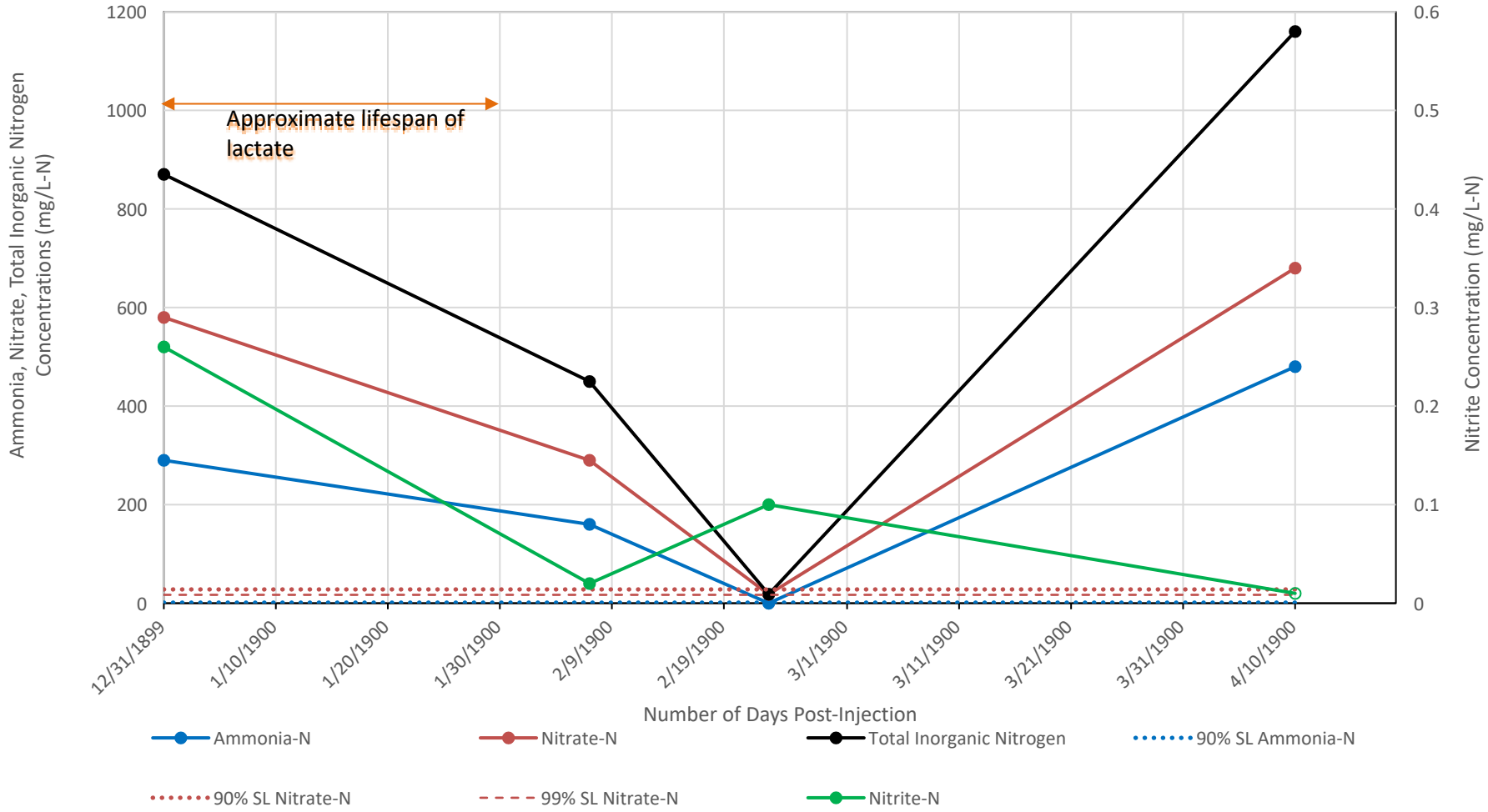


Injectability evaluation: EVO

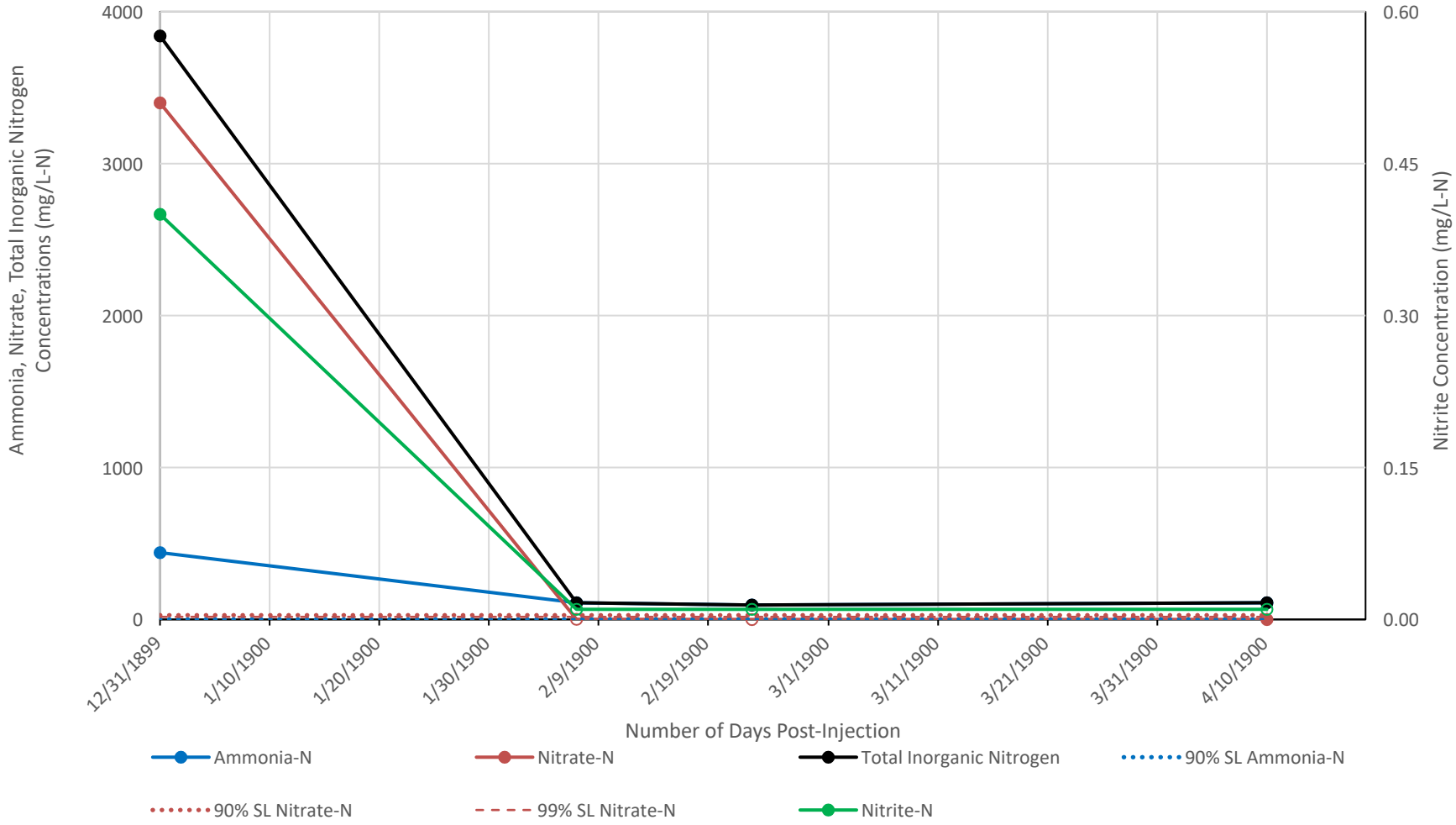




Lactate injection – 100 days



EVO injection – 100 days



Summary/Lessons Learned

- In-situ bioremediation of nitrogen demonstrated in complex geologic/geochemical setting (up to 90% degradation of total inorganic nitrogen)
- Nitrogen loss via combined denitrification/anammox processes under mild reducing conditions with addition of electron donor
- Understanding current conditions is critical: nitrogen species, geochemistry, microbiology, geology
- As always, amendment distribution is key; implications for full-scale design

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Q&A