Combined *In Situ* Sulfate-Enhanced Bioremediation and Bioventing for Soil and Groundwater Treatment of Petroleum Contamination

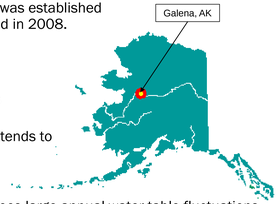
Group 2

Kylah Wyatt and Bruce Henry (Parsons, Denver, CO) | Edward Heyse (Parsons, Huntsville, AL) | Brian Blicker (Parsons, Bozeman, MT)

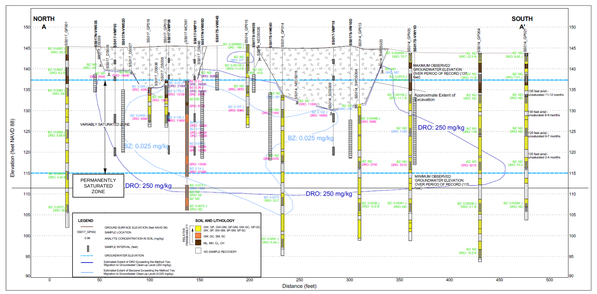
Overview

Site Description / Background

- Former Galena Forward Operation Location, Alaska was established as an airfield during World War II and officially closed in 2008.
- Impacts to Site SS014/SS017 are dominated by diesel-range organics (DRO) and benzene.
- A DRO groundwater plume extends approximately 560 feet (ft) along the plume axis at concentrations exceeding cleanup levels (CULs).
- Impacts are present to over two acres of soil and extends to 40 ft below ground surface (bgs), including the vadose zone, variably saturated zone (VSZ), and permanently saturated zone (PSZ).
- Due to proximity to the Yukon River, the site undergoes large annual water table fluctuations controlled by the freeze/thaw cycle of the river (up to 30 ft), creating a seasonal VSZ.
- Predominantly interbedded sand and silt with underlying gravel. Groundwater flows north to south, except during the flow reversal observed following ice break up on the Yukon River.
- Site has low groundwater temperatures (4-6 degrees Celsius), low to moderate sulfate (20 to 40 milligrams per liter [mg/L]), and elevated dissolved iron (average 80 mg/L).
- The selected remedy includes a three-pronged, sustainable bioremediation approach:
  - Excavation of shallow soil hot spots with on-site treatment (landfarming of petroleum- impacted soil);
  - Bioventing treatment of soil within the vadose zone and VSZ;
  - *In situ* treatment of non-aqueous phase liquid (NAPL)-contaminated source area soil in the PSZ and lower VSZ by sulfate-enhanced anaerobic bioremediation (SEB) (Parsons patent US Patent 8,679,340 B1 – March 25 2014).
- The combined remedy, along with performance monitoring, is intended to address contamination to meet Alaska state human health criteria for unrestricted land use.



Bioventing System Design and Excavation Cross Section

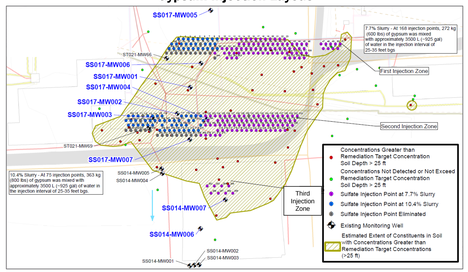


Cleanup Plan Implementation

Objectives and General Approach

- Bioventing provides an electron acceptor source (oxygen from air), which enhances bioremediation of soil at <25 ft bgs.
- SEB provides an electron acceptor source (sulfate from gypsum), which enhances bioremediation of soil and groundwater at >25 ft bgs.

Gypsum Injection Layout



Field Work

- 8,550 cubic yards of contaminated soil above 15 ft bgs was removed in 2011, 2017, and 2018 to be treated at the Galena landfarm for hydrocarbon-impacted soil.

- In 2016 the bioventing system was installed to treat remaining contaminated soil in vadose zone and VSZ that was not excavated. The system became operational in April 2017.
- In summer 2017, a gypsum slurry was injected in temporary borings in the PSZ.
- Performance monitoring sampling events occur annually to document remedy performance. Two monitoring events have occurred (2017 and 2018).

Injection Point Testing

Sulfate Mixing Hopper

Injection Rig

Groundwater Performance Monitoring

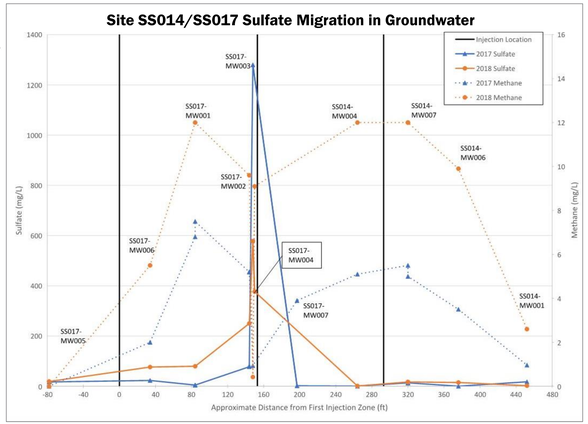
Indicator Contaminants of Concern (COCs)

- DRO, benzene, and naphthalene are used to track the performance of remedies on groundwater and, indirectly, remedies on soil in VSZ and PSZ.

Groundwater Results

- In 2018, decreasing sulfate concentrations, with increasing methane concentrations, were observed with increasing distance from all injections.
- Increasing methane concentrations downgradient of injection zones indicate that sulfate consumption is occurring in the treatment area as intended.
- Methane concentrations were elevated through most of the plume but decreased dramatically at SS017-MW003, located within the secondary injection zone, which had the greatest sulfate concentrations in both 2017 and 2018.

Site SS014/SS017 Sulfate Migration in Groundwater



- Naphthalene exceeded Alaska's human health CUL by the greatest amount (153 to 259 times the CUL). Benzene and naphthalene decreased in 2018 results for wells in the first and second injection zones with reductions of up to 46% and 42%, respectively, compared to 2017 values.
- Sulfate-reducing conditions were observed throughout the site, with many wells exhibiting methanogenic conditions.

Additional Remedy Details

- The sulfate slurry was designed considering the limited solubility of gypsum (calcium sulfate), with an anticipated five years until it is fully dissolved, providing a source of passive *in situ* dosing in the treatment area.
- 72,824 kilograms of calcium sulfate was emplaced using a total of 243 injection points. Injection materials were emplaced in five 2-ft vertical intervals at each injection location to promote vertical and lateral distribution.
- The length of the treatment area is approximately 330 ft (parallel to groundwater flow) and 350 ft wide (perpendicular to groundwater flow) in the northern part of the site but narrows toward the southern end.
- High dissolved iron concentrations in groundwater will likely precipitate sulfide, which is produced by sulfate-reducing bacteria.

Bioventing Performance Monitoring

Bioventing System Details

- The 35 vent well (VW) system is equipped with two URAI DSL 36 rotary lobe positive displacement blowers with a combined capacity of 400 standard cubic feet per minute (scfm).
- Target flow rates of 6 scfm for shallow VWs, and 10 scfm for deep VWs.
- 20 vapor monitoring point (VMP) locations, each with 4 monitoring intervals.

Soil Vapor Results

- Static soil vapor data documented reductions in total petroleum hydrocarbon-gasoline (TPH-g) up to 97%, and reductions of benzene, toluene, ethylbenzene, and xylene (BTEX) concentrations ranging from 62.5 to 99.9% compared to baseline concentrations.
  - Results from fine-grained soil, between 3 and 8 ft bgs, showed the greatest TPH-g reductions, indicating the effectiveness of bioventing for areas of low permeability.
- Aerobic conditions persisted at 62 of the 66 sampled VMPs for over a week following system shut down.
- *In situ* respiration oxygen utilization rates ranged from 0.52 to 2.1 %/day, which translates to biodegradation rates ranging from approximately 0.36 to 1.45 mg TPH/kg soil-day. All locations showed a decrease in biodegradation rates compared to 2017.

Conclusions

- Sulfate concentrations in groundwater have increased from background levels to an average of 85 mg/L, with a maximum observed concentration of 1,280 mg/L, indicating that sulfate was successfully delivered to groundwater in the treatment area.
- Modest increases of sulfate were observed up to 85 ft downgradient of injection zones. Geochemical conditions indicate sulfate-enhanced bioremediation.
- Biodegradation rates calculated from *in situ* respiration tests indicate the presence of biological activity in the unsaturated zone, and accelerated petroleum hydrocarbon biodegradation in the subsurface during the initial phase of the bioventing operation.
- Soil gas analytical data trends indicate a decrease in total volatile organic compounds concentrations of up to 97%, and benzene concentrations of up to 99.9% (average of 91%), showing the degradation of fuel-related contaminants is taking place.
- The performance monitoring results indicate active degradation of contaminants is occurring, and soil gas VOC concentrations are anticipated to continue to decline.
- Reduction of COCs observed in groundwater and soil vapor.