“Abandoned Coal Mine Mitigation in High Pressure Artesian Conditions”

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WVTF IMWA 2024

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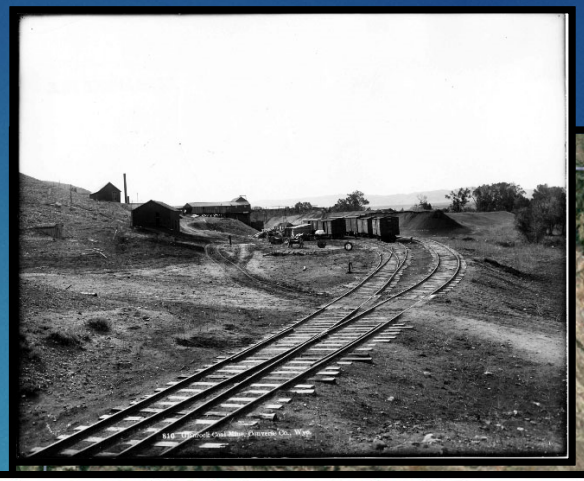
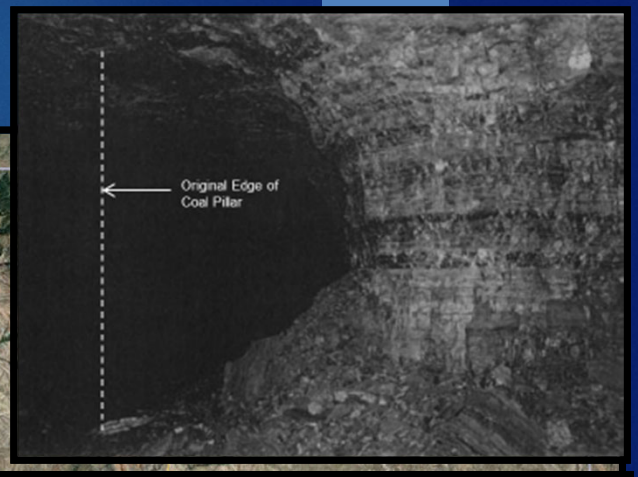
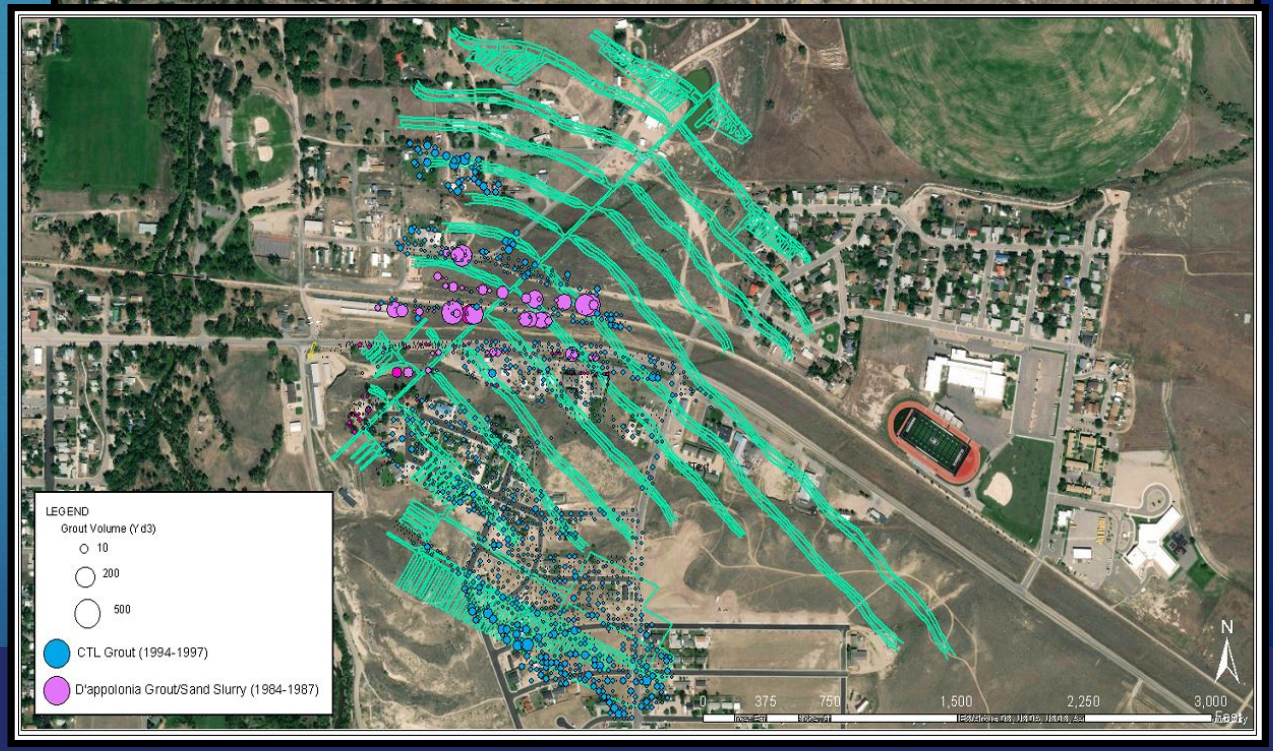
Glenrock Mining History

- 1847: First documented coal production near Glenrock
- 1888: Increase in commercial production. Coal used for domestic purposes
  - Over 855,000 Tons mined
- 1909: Glenrock Mines closed due to poor roof and excessive flooding
- Total undermined area in Glenrock
- No. 1 and No. 2 Mines = 0.88 sq km
- McDonald Mine = .09 sq km
- Two Historic Mitigation Programs Launched
  - D'Appolonia: 1984 – 1987
  - CTL/Thompson: 1994 – 1997
- Decades of Reported Subsidence Events







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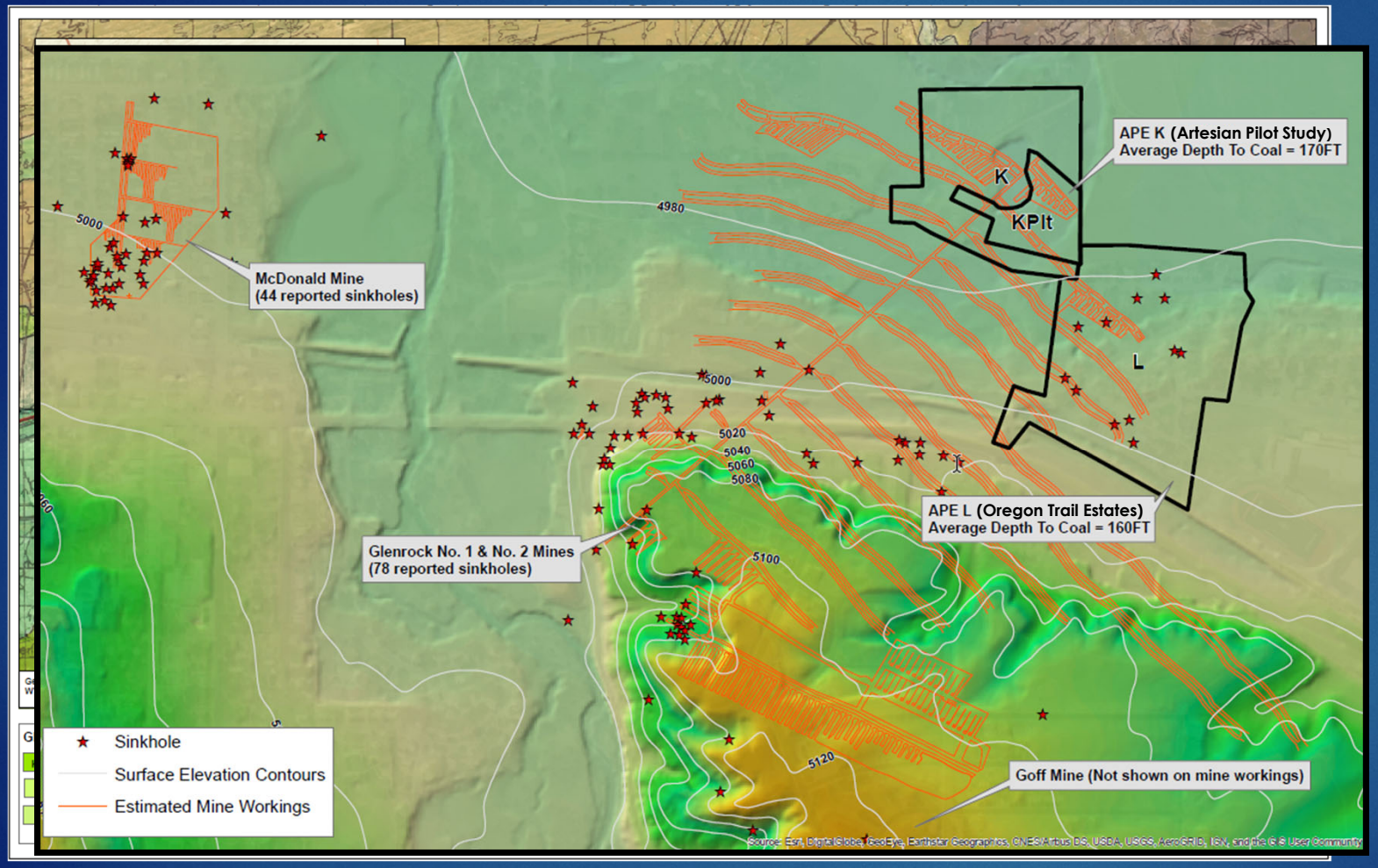
Geology, Physiography, Mitigation Area



Geology & Physiography

- Southwest Margin of the Powder River Basin
- Sub-bituminous Coal within Lance Formation (Kl) at ~2 meters in thickness
- General Strike N300˚W
- General dip trending NE between 8˚ to 15˚
- 112 Years of Water Accumulation within Mine
  - 520 kpa Pressure Head

Target Pilot & Mitigation Area

- Area K Artesian Pilot Location
  - Conducted in 2019
  - 0.01 sq km
  - Feasibility Study to for inherent risks mitigating in artesian conditions
- Oregon Trail Estates (Area L)
  - Conducted 2021 to Present
  - 0.06 sq km

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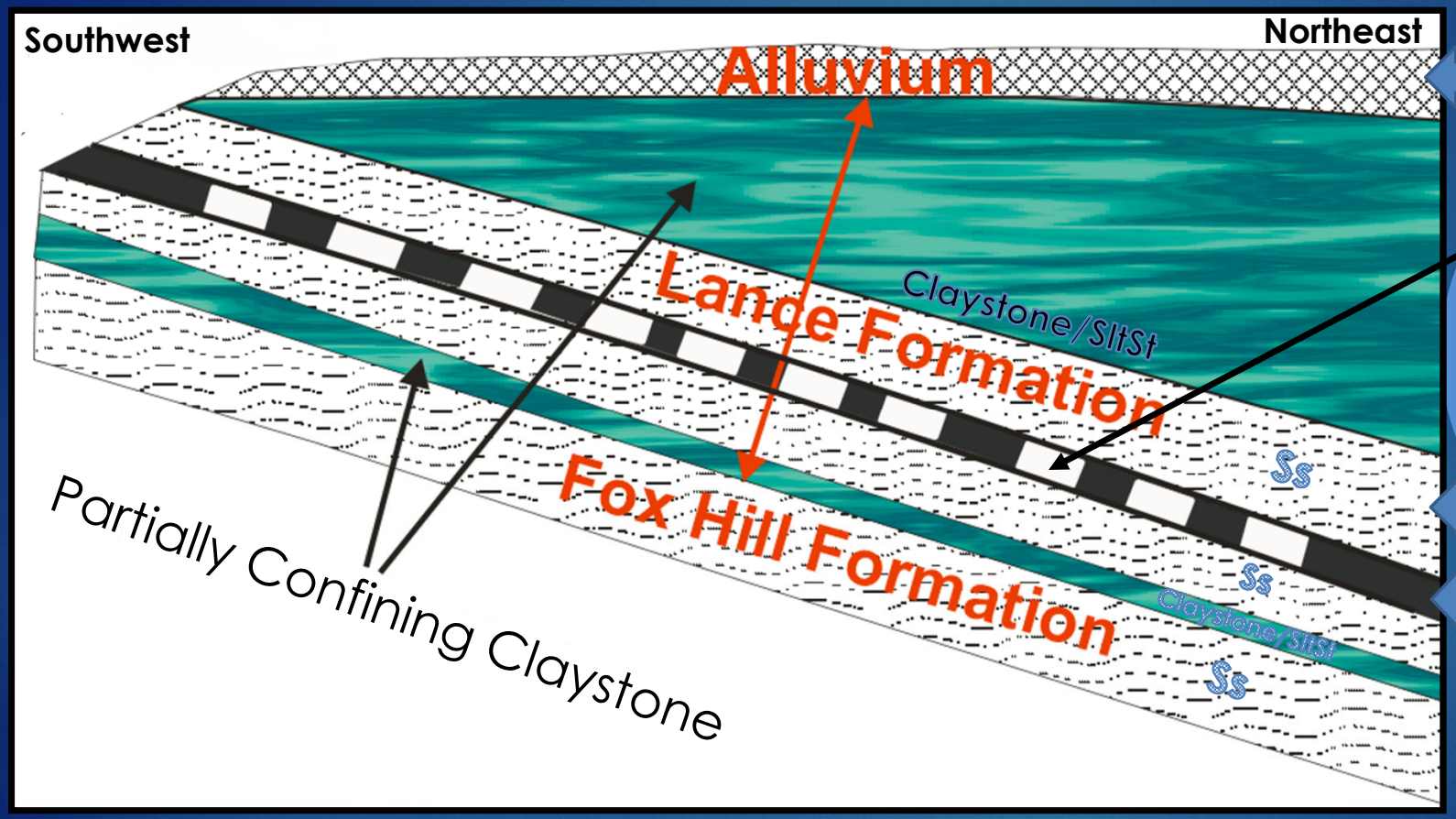
Localized Aquifer System in Target Mitigation Area



Unconfined (Aquifer 1)

Mined Coal Interval (Room/Void)
- Acting as underground storage for groundwater

Partially Confined (Aquifer 2)

Partially Confined (Artificial Aquifer 3)
- Artesian Conditions; artificial groundwater reservoir

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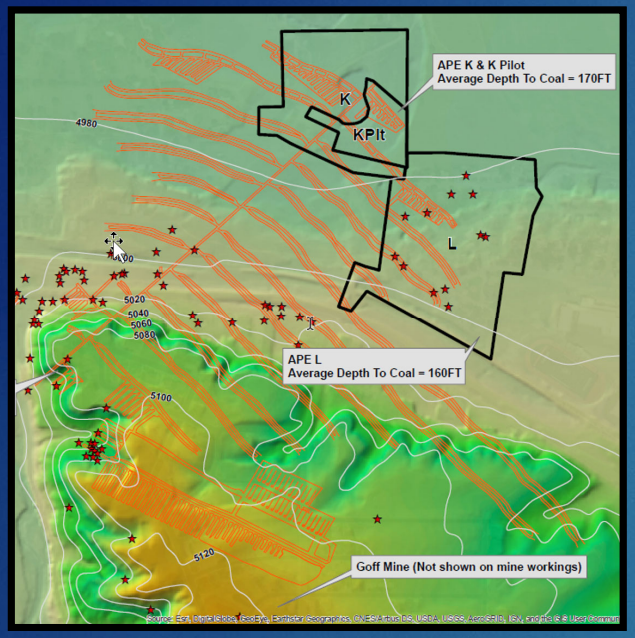
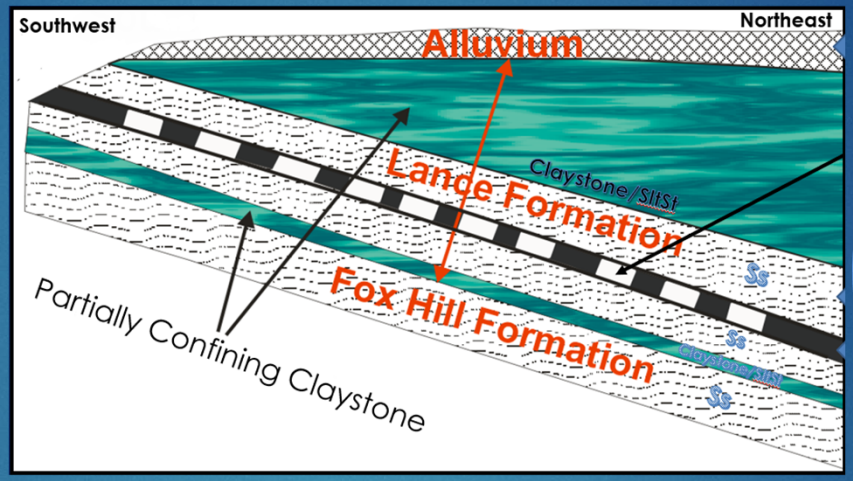
Mining Impact on Local Hydrology



Hydraulic Head; northeast down dip

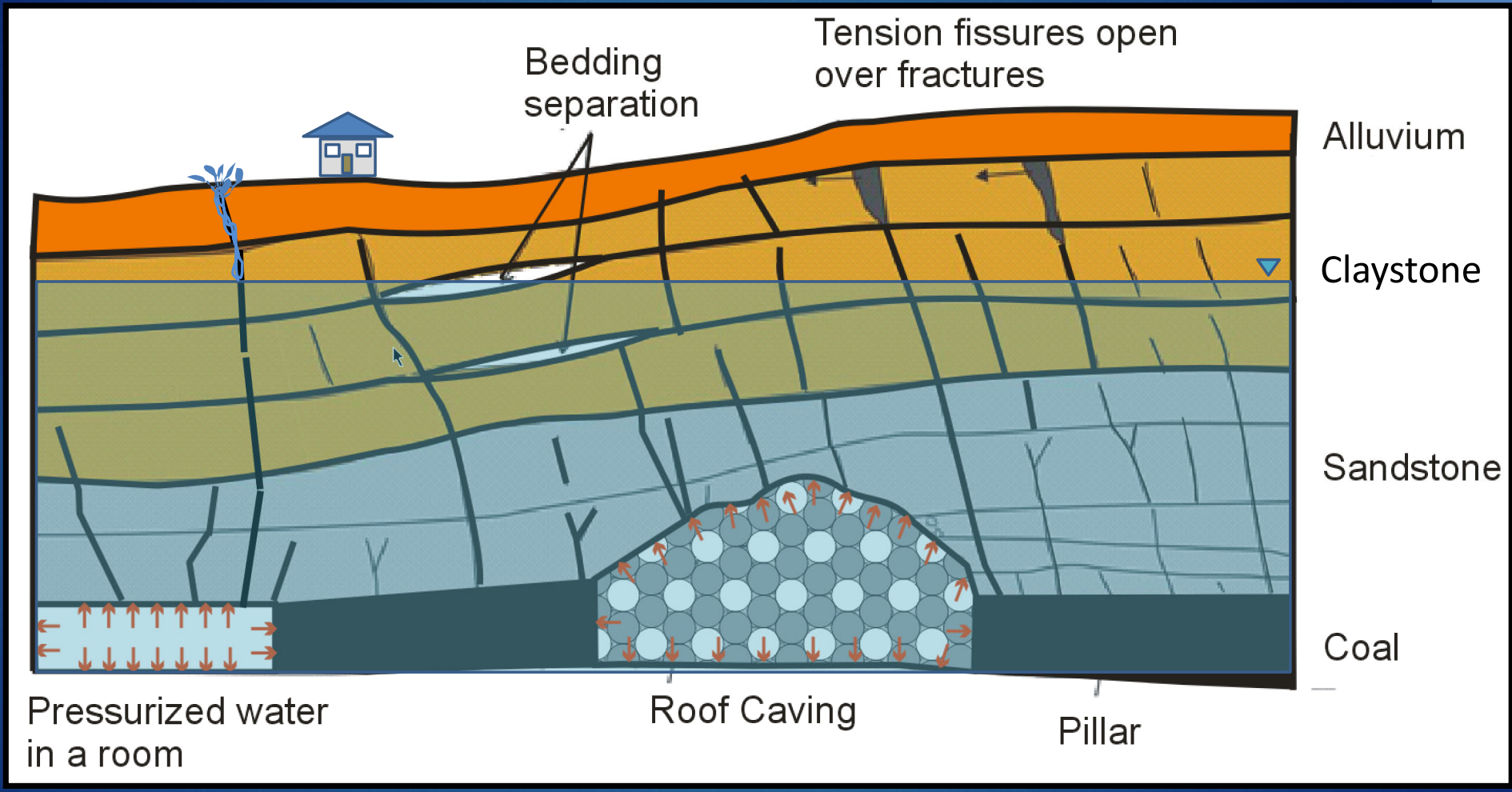


Localized confining layers. Three hydraulic systems created

Artesian Conditions; Mined interval

Formation of Artesian Condition

Mining Impact on Local Hydrology

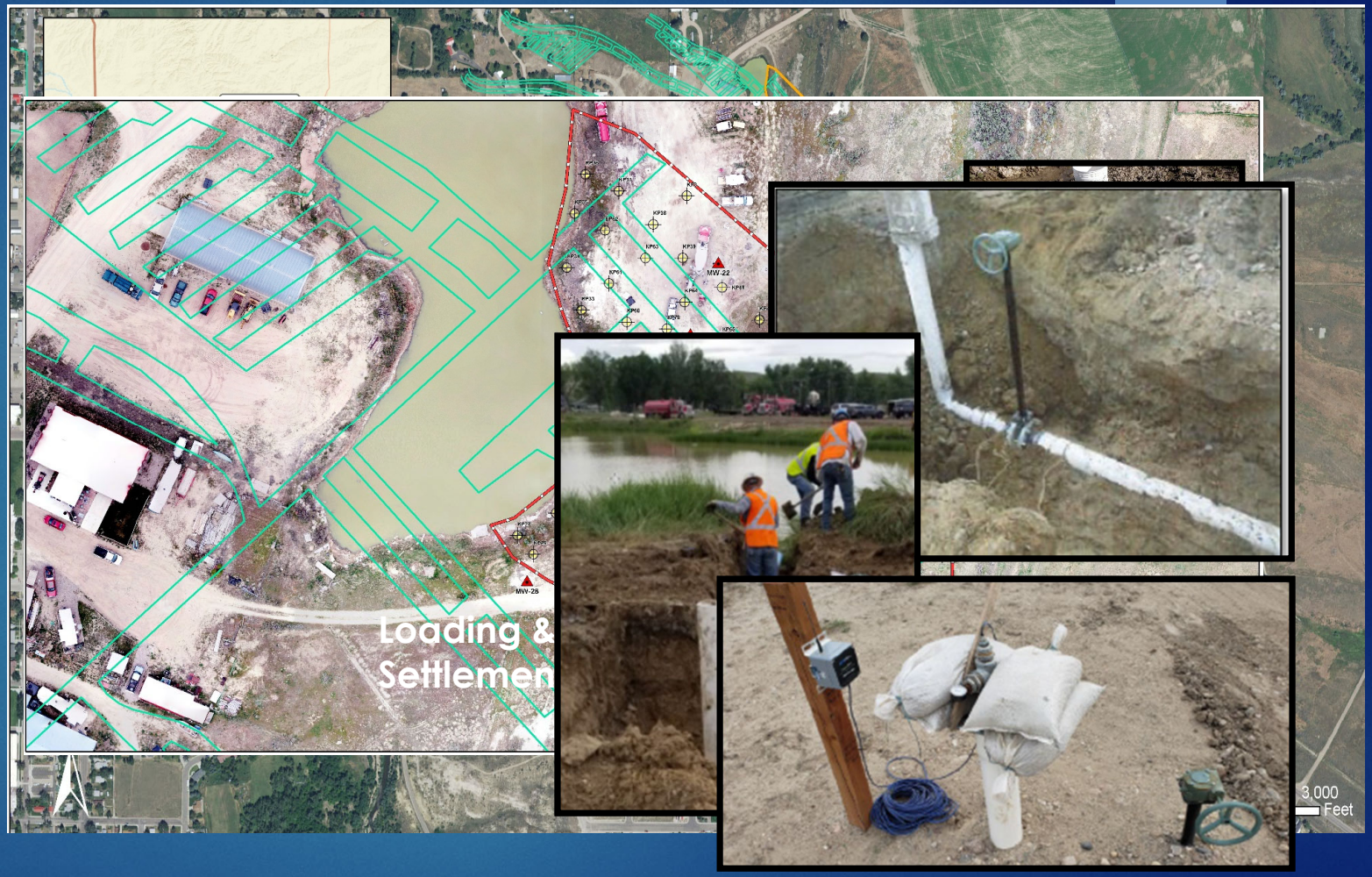


Risks of Condition?

- Mine subsidence
- Extended periods of drought increase subsidence risk due to loss of confinement and increase of effective stress on overburden rock
- Communication of mine water within the overlaying strata
  - Flooded basements and crawl spaces
  - Impact local infrastructure
  - Potential sulphate attack to concrete elements
  - Communication of water in mine with overlaying strata
- Infilling could increase the potential for localized flooding through groundwater displacement within overburden rock
- Settlement could be triggered through large scale dewatering leading to (destabilization and loss of existing rock buoyancy)
- Trapped groundwater leading to high localized groundwater pressure

Pilot Program

- Purpose: To test the feasibility of mitigation under artesian conditions within a heavily developed suburb
- 7 monitoring wells in Pilot area (shallow/deep).
- Approximately 100 proposed injection borings for grouting.
- Grout barrier towards sub-development to prohibit groundwater flow.
- Surcharge load cells to simulate footing weights and measurement of differential Settlement
- One discharge well equipped with ball valve to relief pressure if above 'baseline' pressure readings
- Total Grout Injected: 3,800 m^3 (4,975CY) over .01 sq km (2 acres)



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Alternative Grouting Approach

Design Criteria

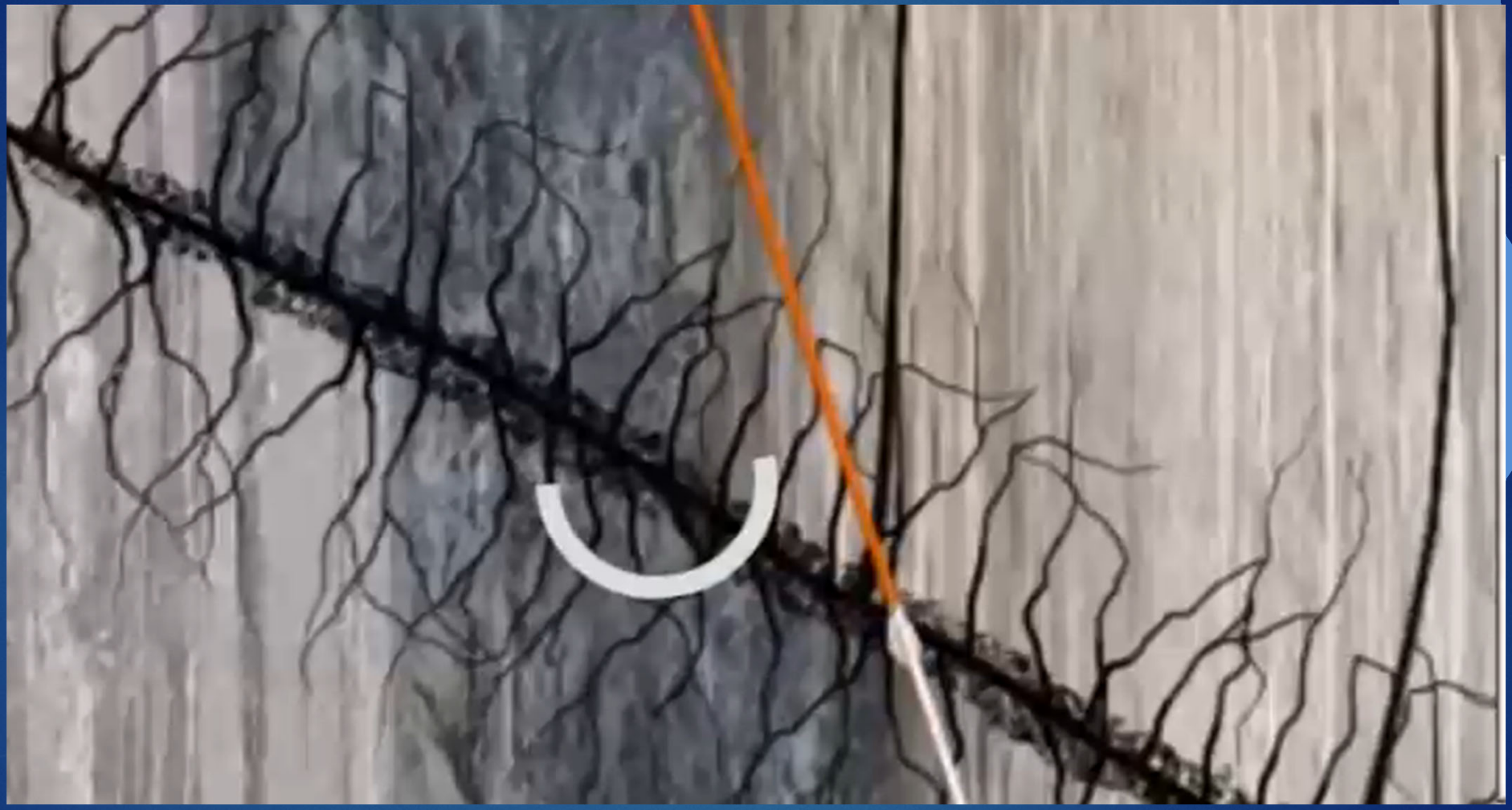
- Focus on filling voids, not on strength of grout (confinement)
- Compression Strength 200 psi (1.4 MPa) (sample coring showed 1,200 to 8,000 psi in-situ) (8 to 55 Mpa)
- Heavier than water, consolidates and cures within mine
- Fills mine voids, joints and fractures in rock overburden and rubbleized material with pressure

Traditional Approach

Modern Approach

DH [2]1

Alternative Grouting Approach – Cont.



Slide 11

DH [2]1 Potentially Delete Slide

Dave Hibbard; 10.09.2021

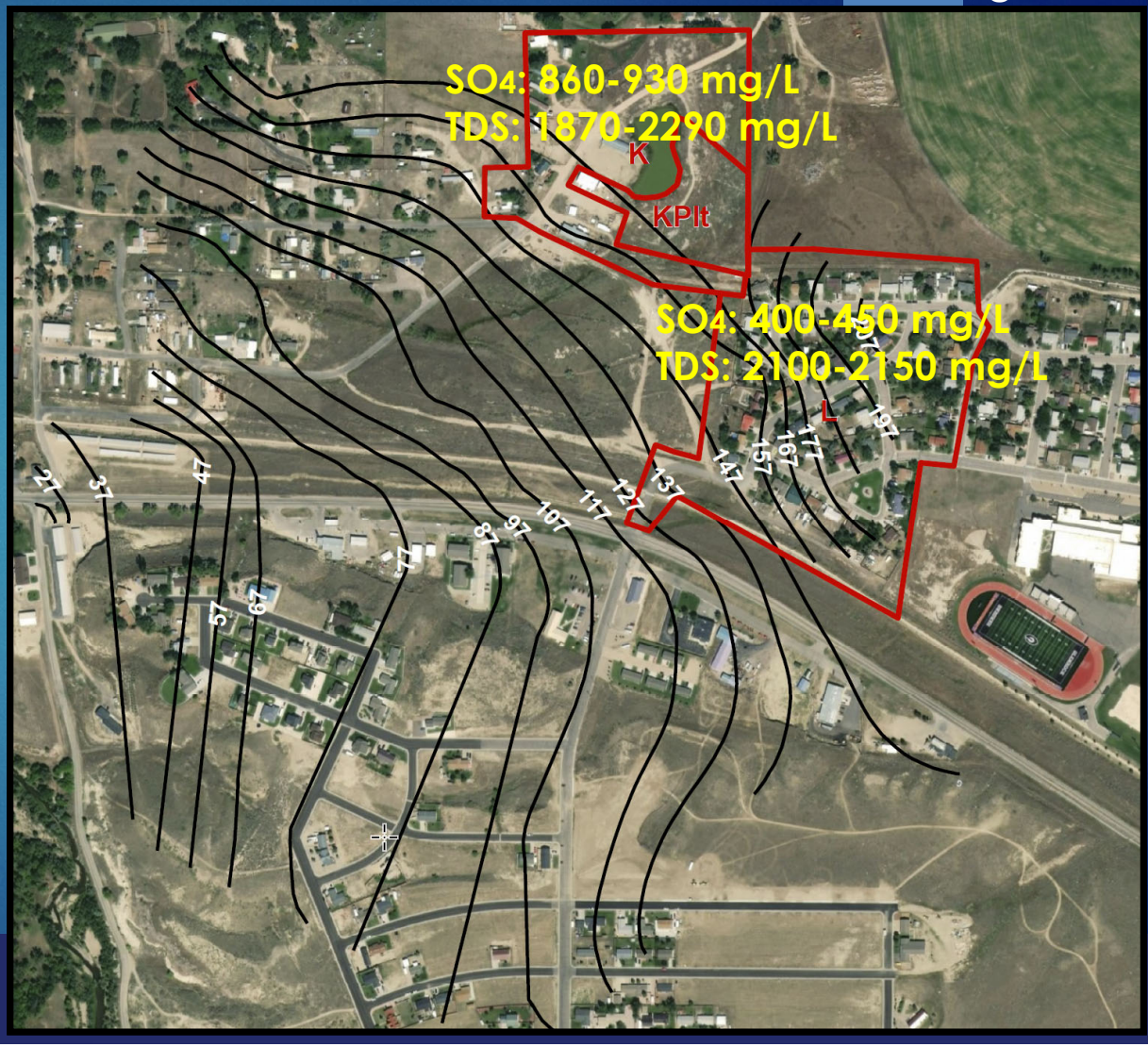
Prelim. Chemical Analyses Findings

Adjacent North Platte River: SO_4: 803 mg/L, TDS: 1840 mg/L

- Water quality in Lance Formation, Mine, Coal, Pond and Platte River is very similar
- Water quality standard within WDEQ Class 2 (agriculture)

Glenrock Area K Field Parameter Readings

Well ID	Sample Date	pH	Temperature (°C)	Specific Conductivity (µS/cm)
BA-GM12-MW-20	4/10/19	8.10	11.9	3280
BA-GM12-MW-21	4/4/19	9.58	11.2	1721
BA-GM12-MW-22	4/4/19	9.26	11.7	1562
	4/9/19	9.76	13.1	1525
BA-GM12-MW-23	4/5/19	9.30	13.3	2370
BA-GM12-MW-24	4/8/19	8.77	12.1	3480
	4/9/19	7.80	12.3	3450



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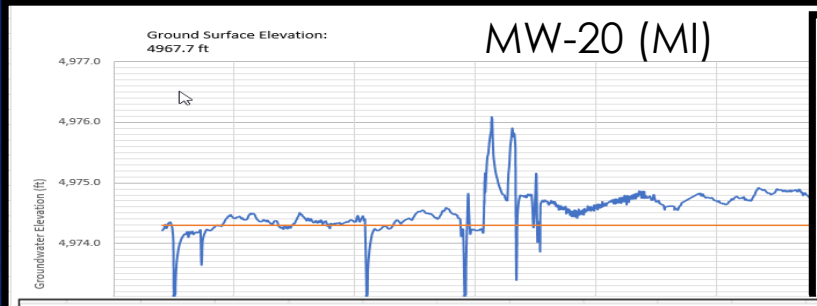
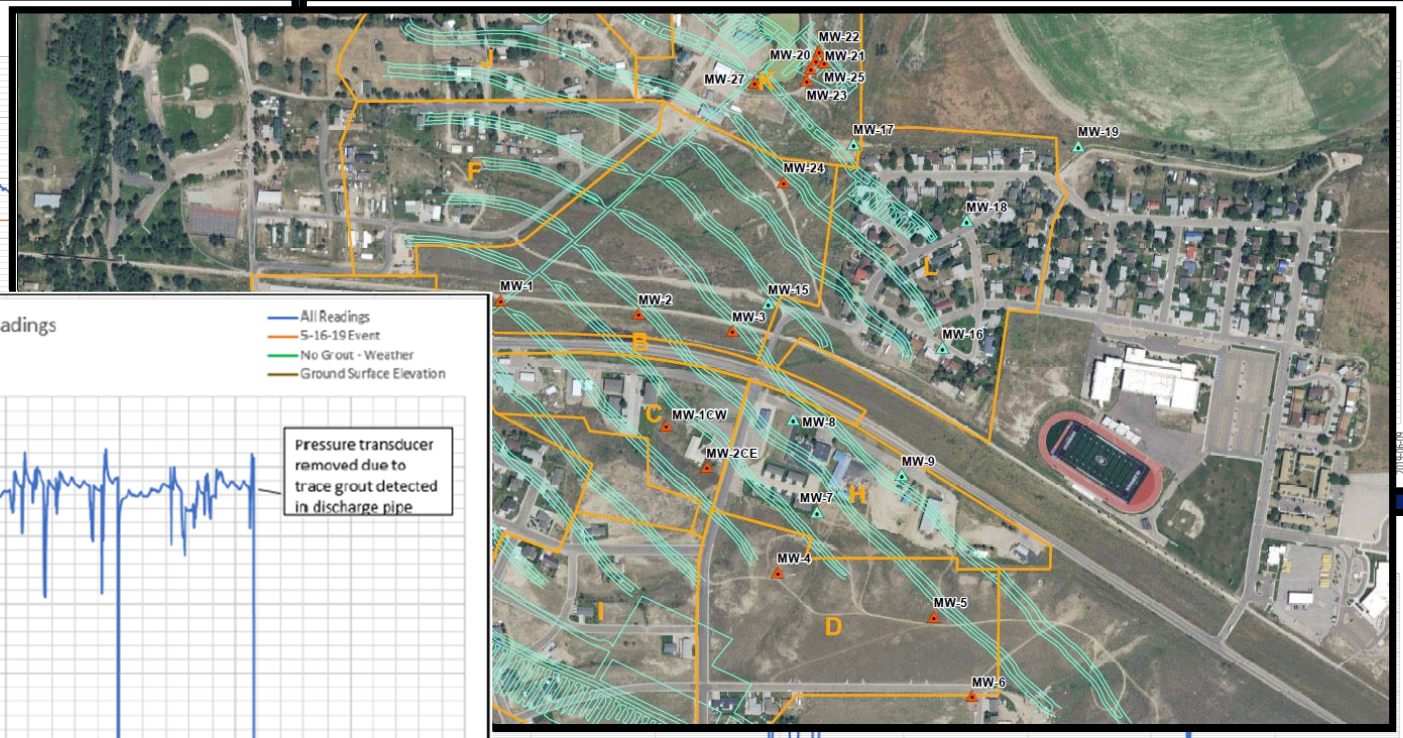
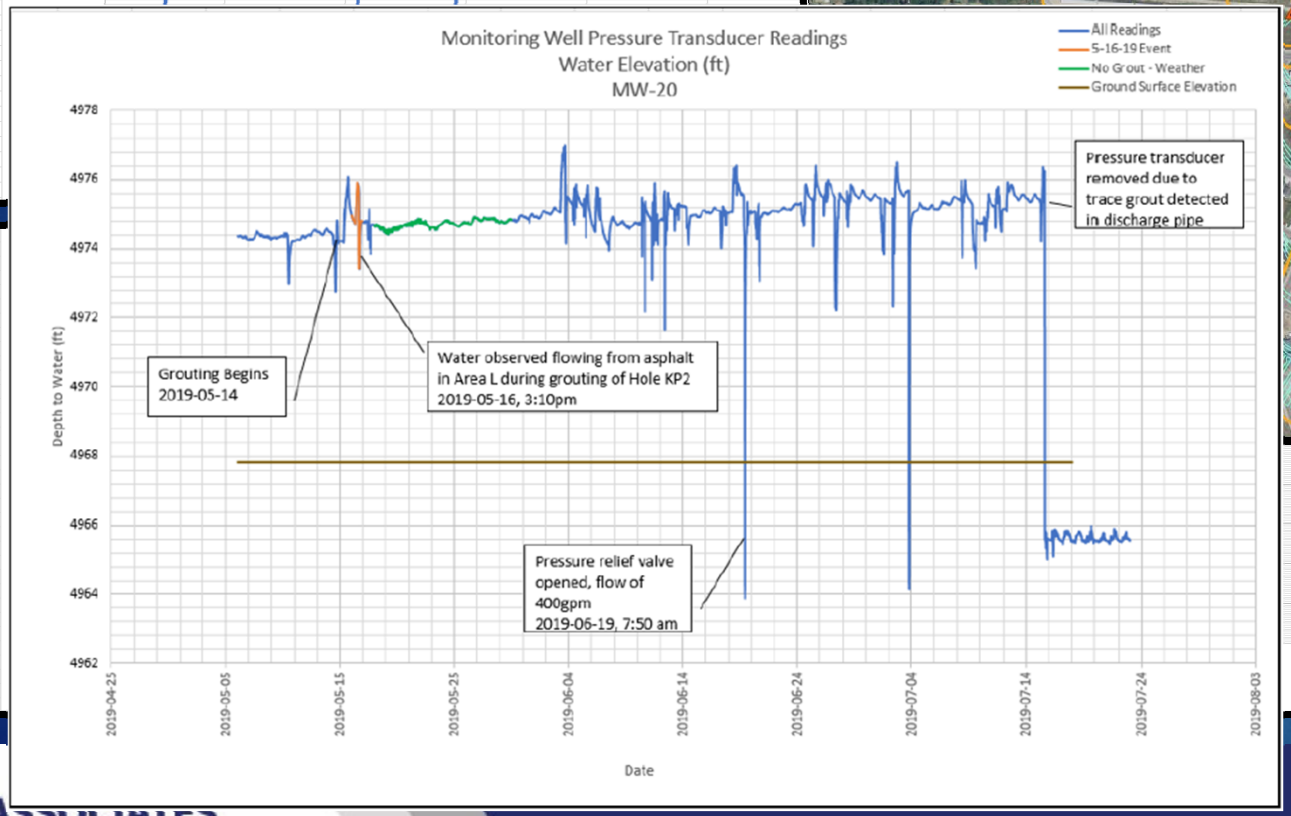
Groundwater Response While Grouting





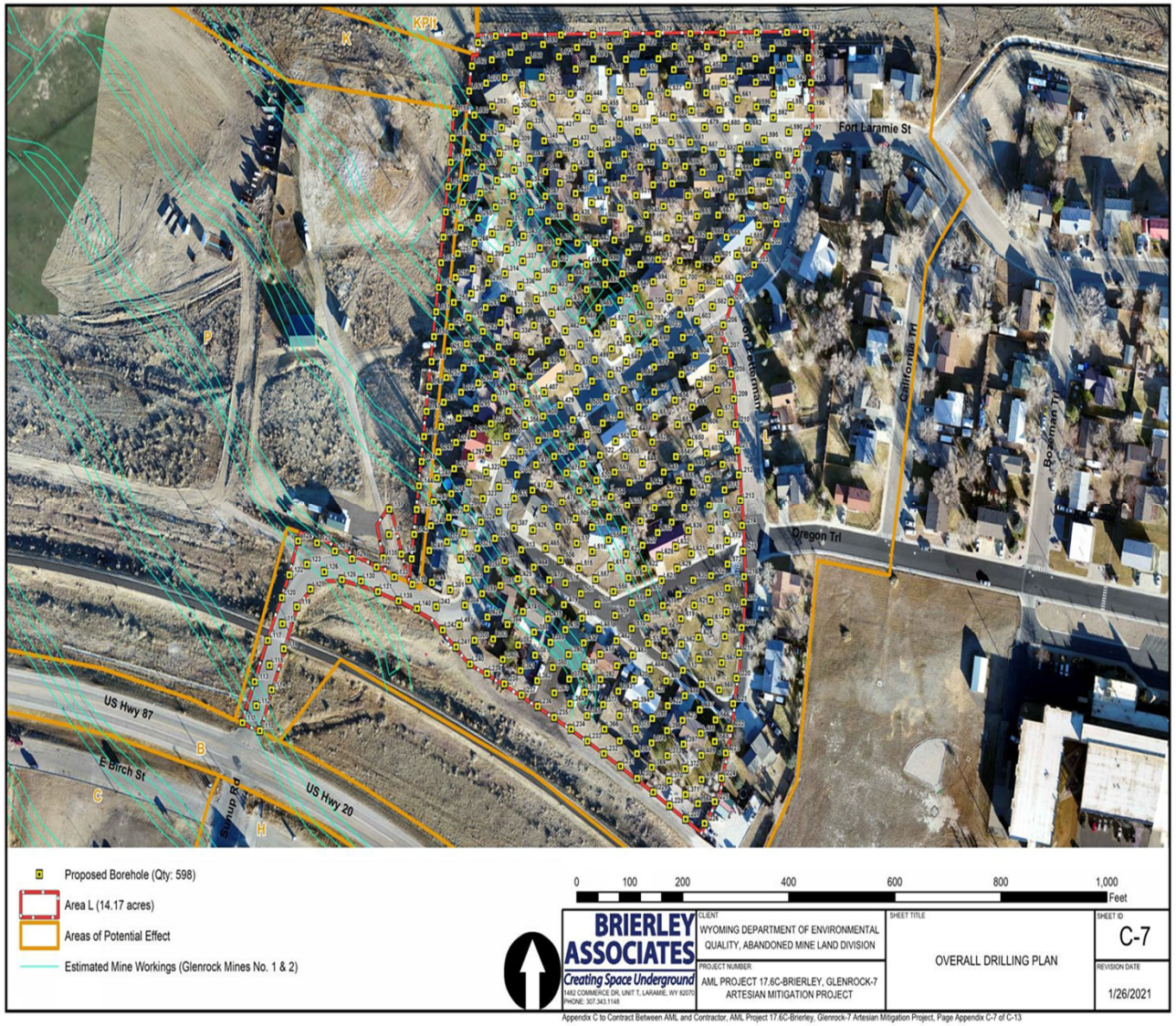


Lessons Learned From 2019 Pilot Program

- Mitigation under artesian conditions is possible without inducing settlement or heave in local structures
  - No load cells were recorded to have moved more than 1-2 mm during the pilot program (movement could be attributed to natural settlement)
- Monitoring of the shallow and deep groundwater levels during mitigation is critical
- Need to have a way of releasing groundwater pressure during grouting operations from the mined interval to prevent surface releases of water

2021 Project: Oregon Trail Estates Mitigation Area

- 598 boreholes
  - Average Depth ~150 ft BGS
  - Range from 130-200 ft BGS
  - Grout Injected, 25,256 CY
- Water discharged from 6 permitted wells on the NW corner of sub-development
  - Set in voids/rubble in mine interval
- Baseline surveys were conducted prior to project start. Including; thermal, orthomosaic mapping, LiDAR scans, and placement of cloud-based piezometers for groundwater monitoring



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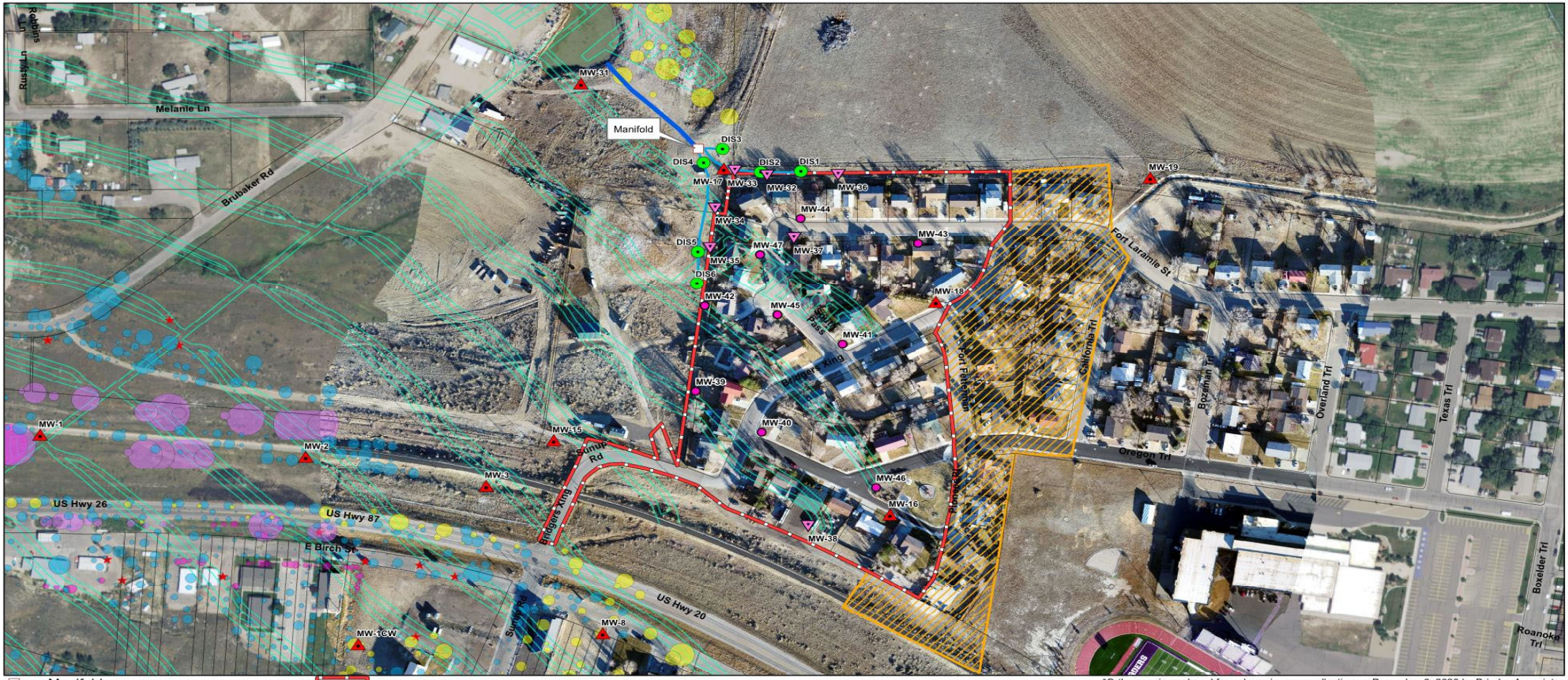

*Orthomosaic produced from drone imagery collection on December 8, 2020 by Brierley Associates

- Manifold
- Shallow Monitoring Well
- Area L Discharge Well (Installed 2020)
- Area L Proposed Shallow Wells
- Active Monitoring Well
- Historic Subsidence Event
- Area L Trenching (12" PVC)
- Area L Trenching (24" Corrugated HDPE)

- Area L (14.17 acres)
- Converse County Parcel Boundary
- Area L (Mitigation Not Needed)
- Estimated Mine Workings (Glenrock No. 1 and 2 Mines)

GROUT SOURCE

- CTL
- Brierley Associates
- D'appolonia
- D'appolonia Sand Slurry

0 100 200 400 600 800 1,000 Feet

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CLIENT: WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY, ABANDONED MINE LAND DIVISION

PROJECT NUMBER: AML PROJECT 17.6C-BRIERLEY, GLENROCK-7 ARTESIAN MITIGATION PROJECT

SHEET TITLE: DISCHARGE & MONITORING WELLS

SHEET ID: C-6

REVISION DATE: 5/11/2021

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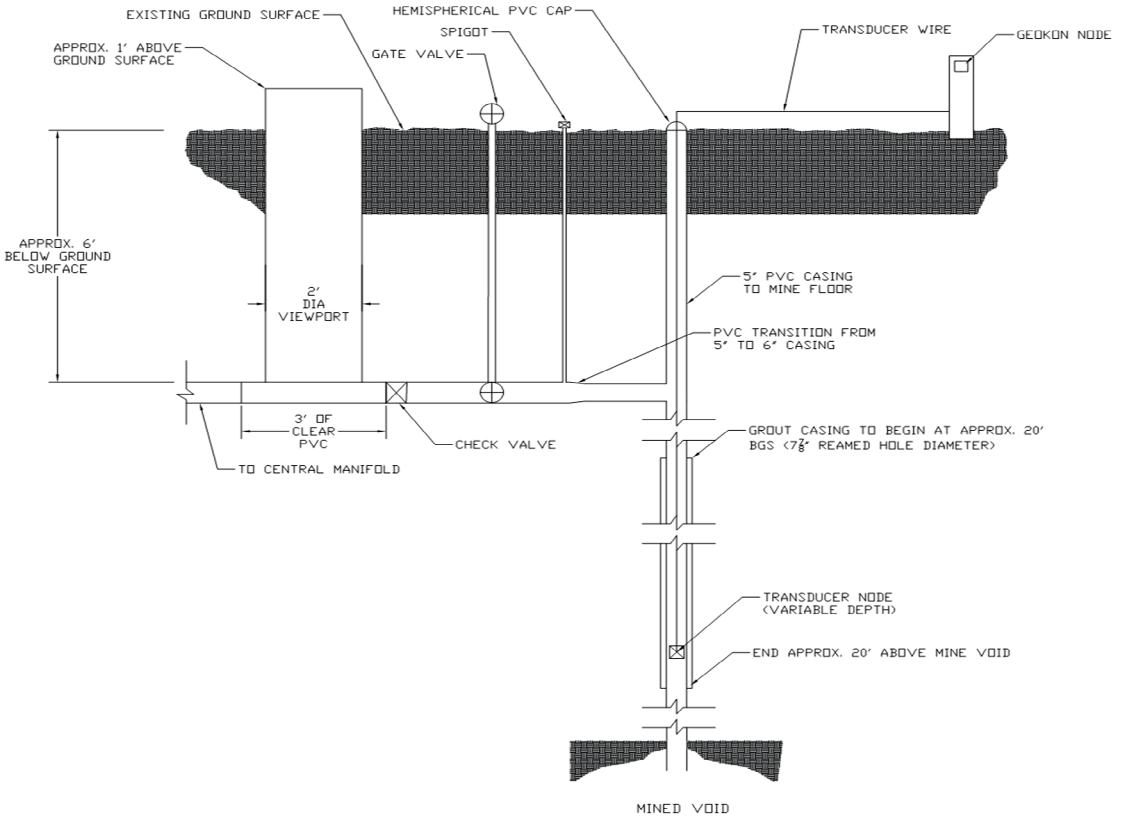

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CLIENT: WYOMING DEPARTMENT OF ENVIRONMENTAL QUALITY, ABANDONED MINE LAND DIVISION

PROJECT NUMBER: AML Project 17.6.B-Glenrock-6

SHEET TITLE: Typical Discharge Well Cross Section

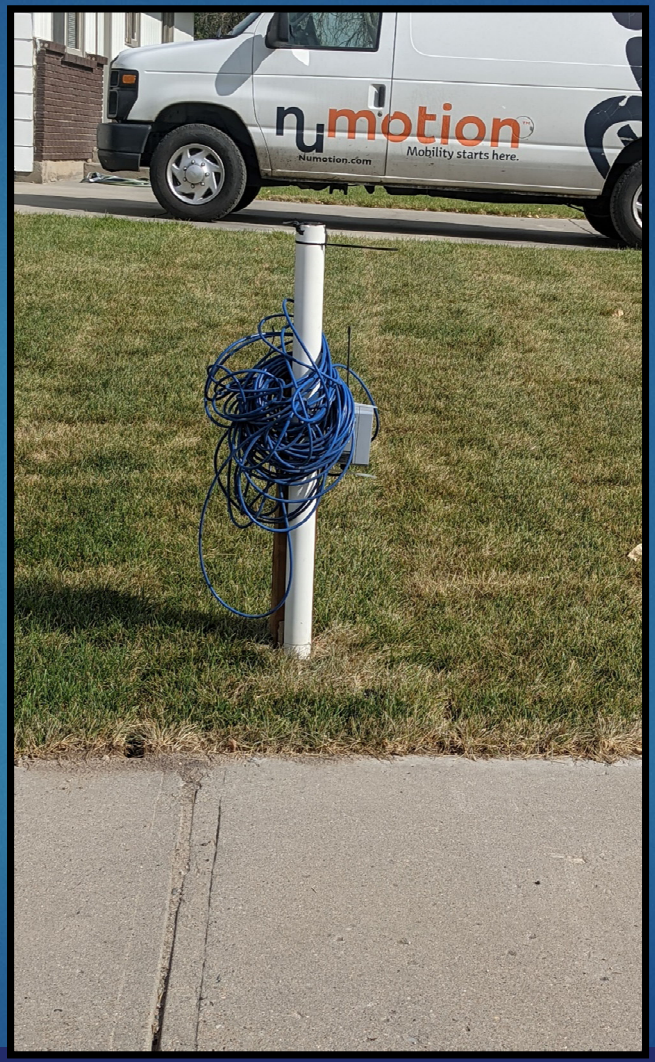
SHEET ID: SH-19

REVISION DATE: 03/26/2021

AML Project 17.6B-Brierley-Glenrock-6, Diagram 1

Monitoring Wells

- Installed across the APE to monitor shallow groundwater response to construction operations
- 20 total monitoring wells: 16 shallow wells (20 feet or 6 meters in depth or less) and 4 deep wells set in the mine interval
- Each set with a vibrating wire piezometer and wireless node for remote data monitoring on regular intervals
- Wells installed in multiple stages before project



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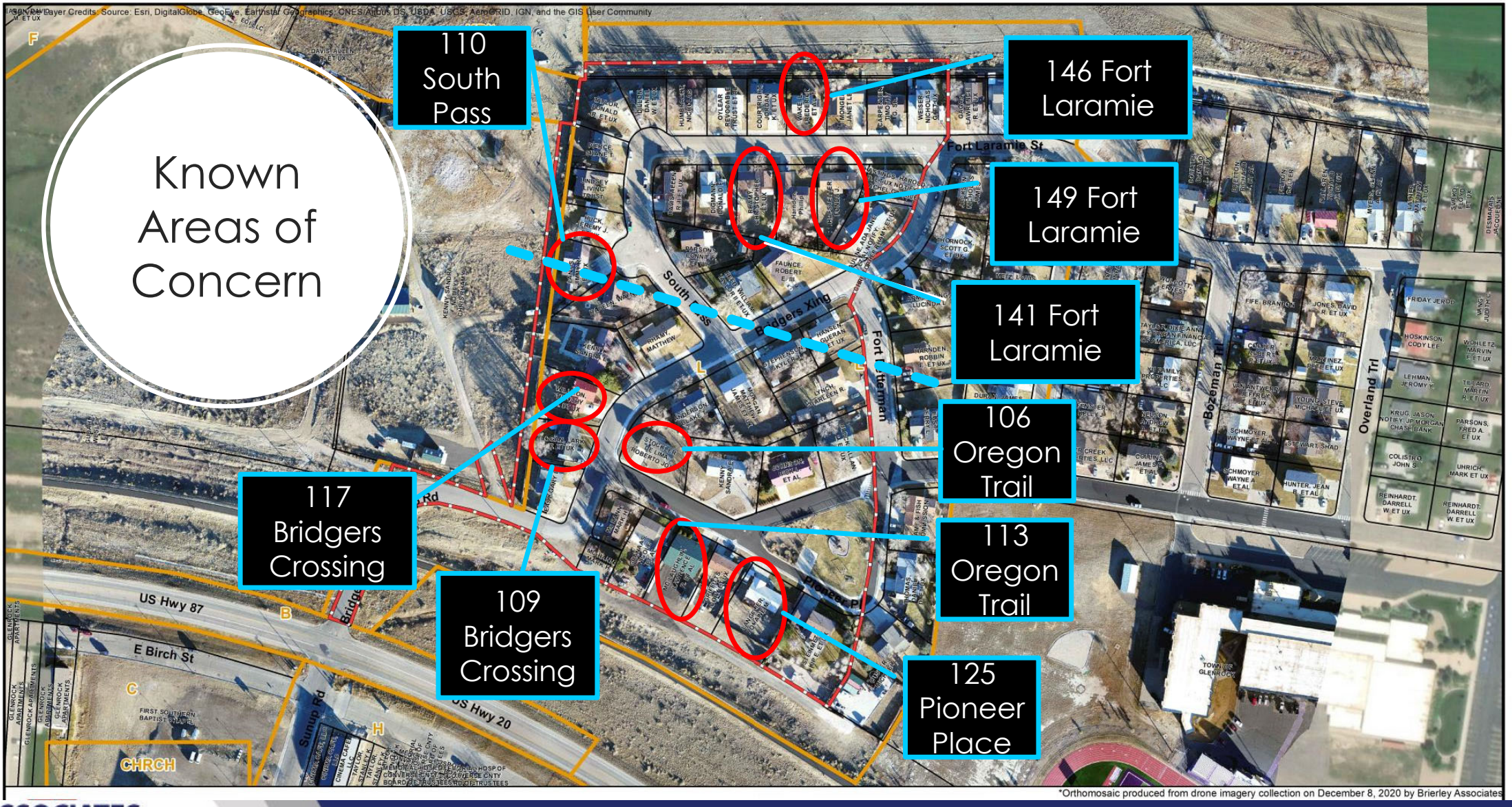
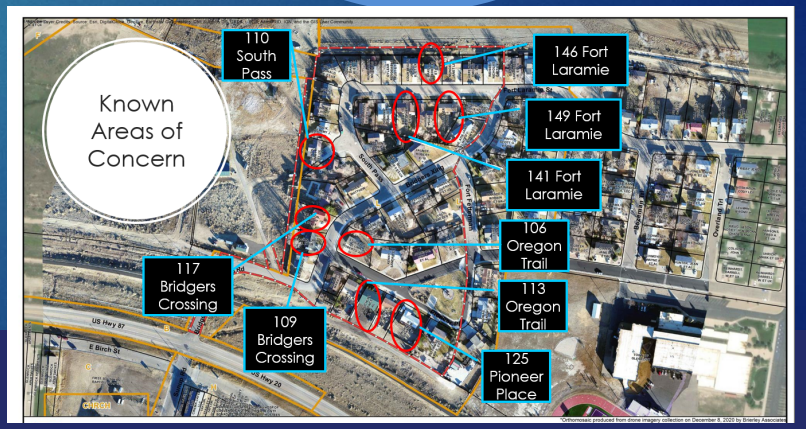


*Orthomosaic produced from drone imagery collection on December 8, 2020 by Brierley Associates

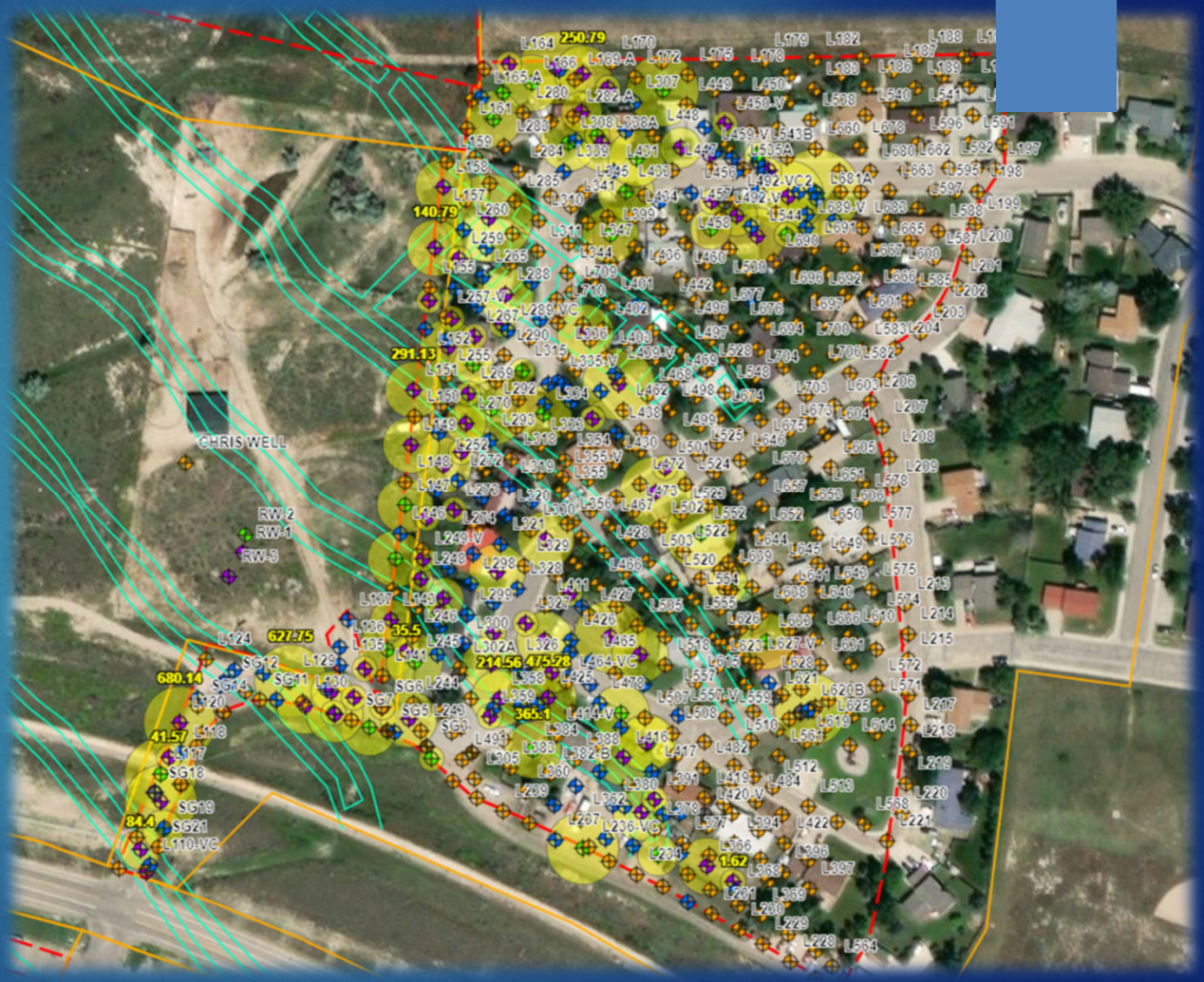
110 South Pass

- Crawlspace always flooded with at least 6 inches (15 cm) of water (42 years).
- Water level directly responds to the opening of discharge wells.
- Property is confirmed to be undermined by 2018 exploratory borings.



Project Summary

- Upon completion in November 2021, ~24,538 cubic yards (19,000 cubic meters) of grout has been injected into the Area. This equates to ~4,956,038 gallons of water (18.7 million liters).
  - Orange = Coal
  - Purple = Rubble
  - Green = Void
  - Blue = Grout
  - Yellow Circles = Representative volumes of grout injected at location
- ~5,650,922 gallons (21.3 million liters) of water has been discharged through the well system.
  - Approx. 8 Olympic Sized Swimming Pools



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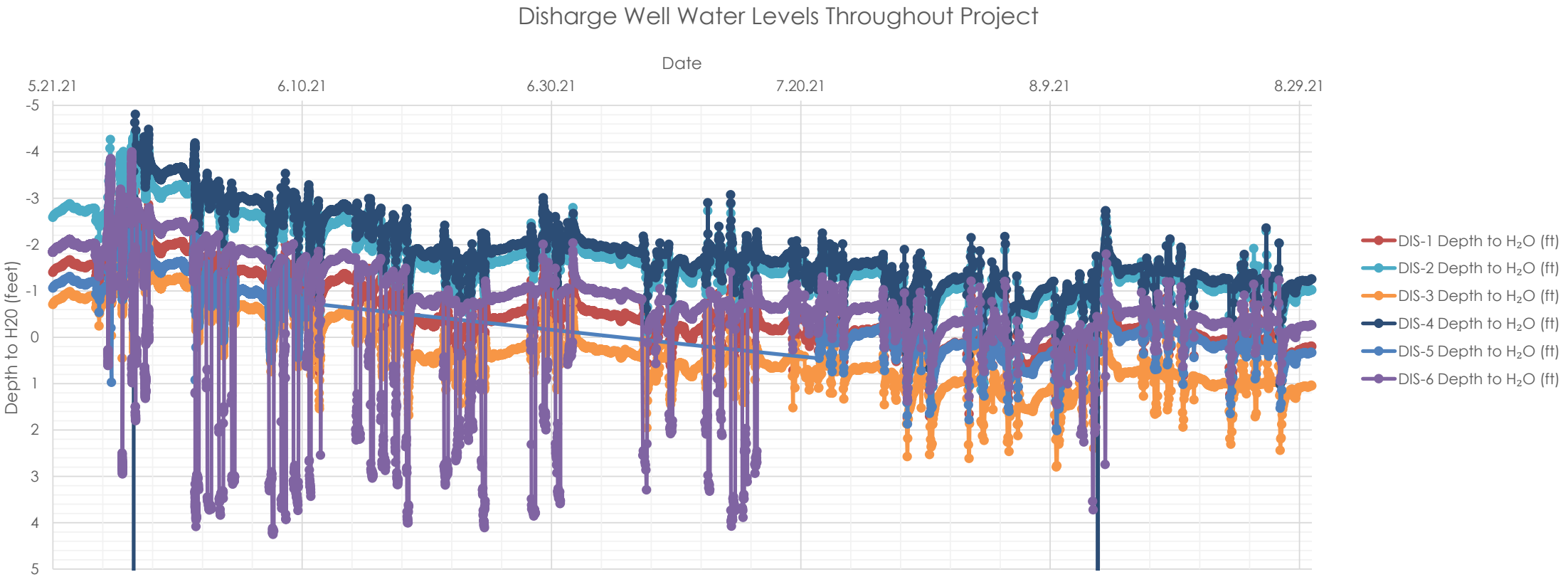
Groundwater Response

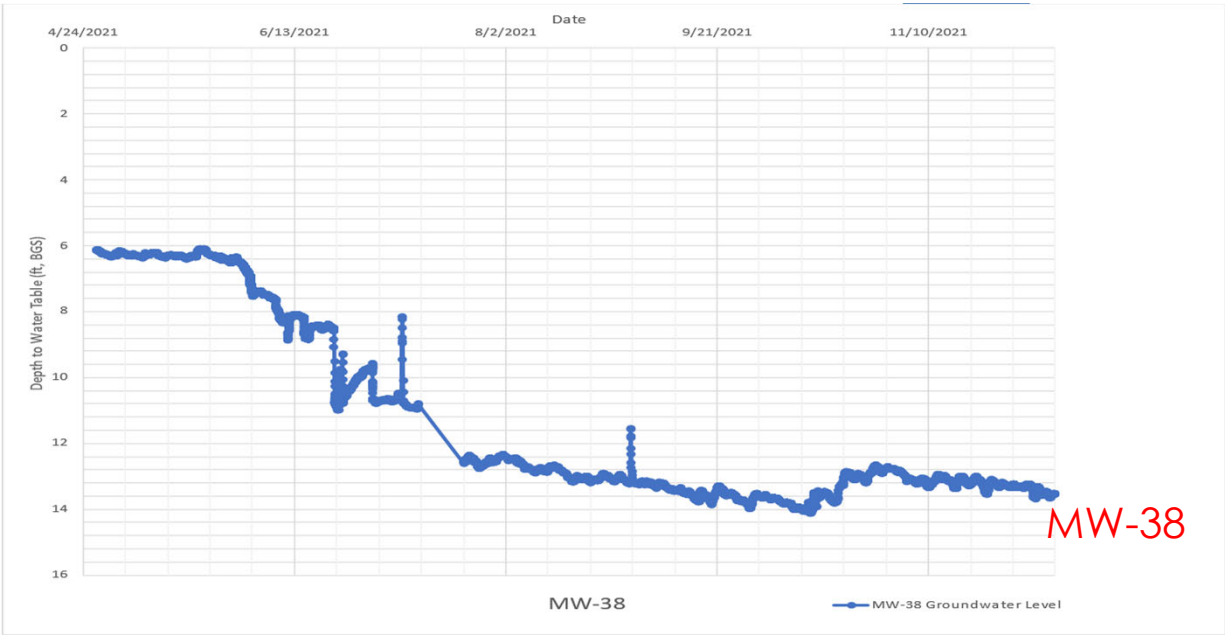
- Mitigation began in late-May 2021
  - Work began at the southern end of the APE to push water to discharge wells located to the North
  - Immediate response notated in discharge and monitoring wells across the site.
  - Distance from grouting to discharge well ~ 700+ feet (200 meters)

Discharge Well Water Depth



Shallow Groundwater Response

- Large decrease in groundwater level in shallow wells across job site
  - MW-38: GW decreased a net ~8 feet from the baseline at the beginning of the project (from ~6 feet BGS to ~14 feet BGS) (2.4 meter drop)
  - MW-40: GW decreased a net ~6 feet from the baseline at the beginning of the project (from ~12 feet BGS to 18 feet BGS) (3.6 meter drop)
- Decrease in GW level has been consistent and maintained at these decreased levels



MW-38

MW-40

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DH [2]6

Chemical Analysis: pH, TDS, TSS

Sample #	Date Sample Collected	Discharge Well	TDS (mg/L)	TSS (mg/L)	pH
1	6/1/2021	DIS-6	2230	ND	7.32
2	6/8/2021	DIS-6	2230	2	7.49
3	6/15/2021	DIS-6	2140	ND	7.30
4	6/22/2021	DIS-6	2130	ND	7.50
5	6/29/2021	DIS-6	2110	ND	7.65
6	7/7/2021	DIS-6	2120	ND	7.49
7	7/13/2021	DIS-4	2110	ND	7.53
8	7/20/2021	DIS-4	2120	ND	7.27
9	7/27/2021	DIS-2	2220	1	6.98
10	8/3/2021	DIS-4	1800	ND	7.37
11	8/11/2021	DIS-6	2200	1	7.36
12	8/18/2021	DIS-4	1970	ND	7.24
13	8/24/2021	DIS-4	1870	1	7.25

Slide 25

DH [2]6 Add pH column

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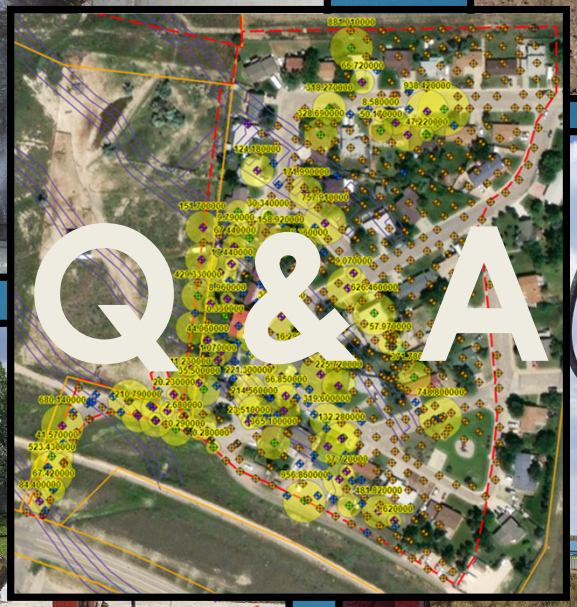
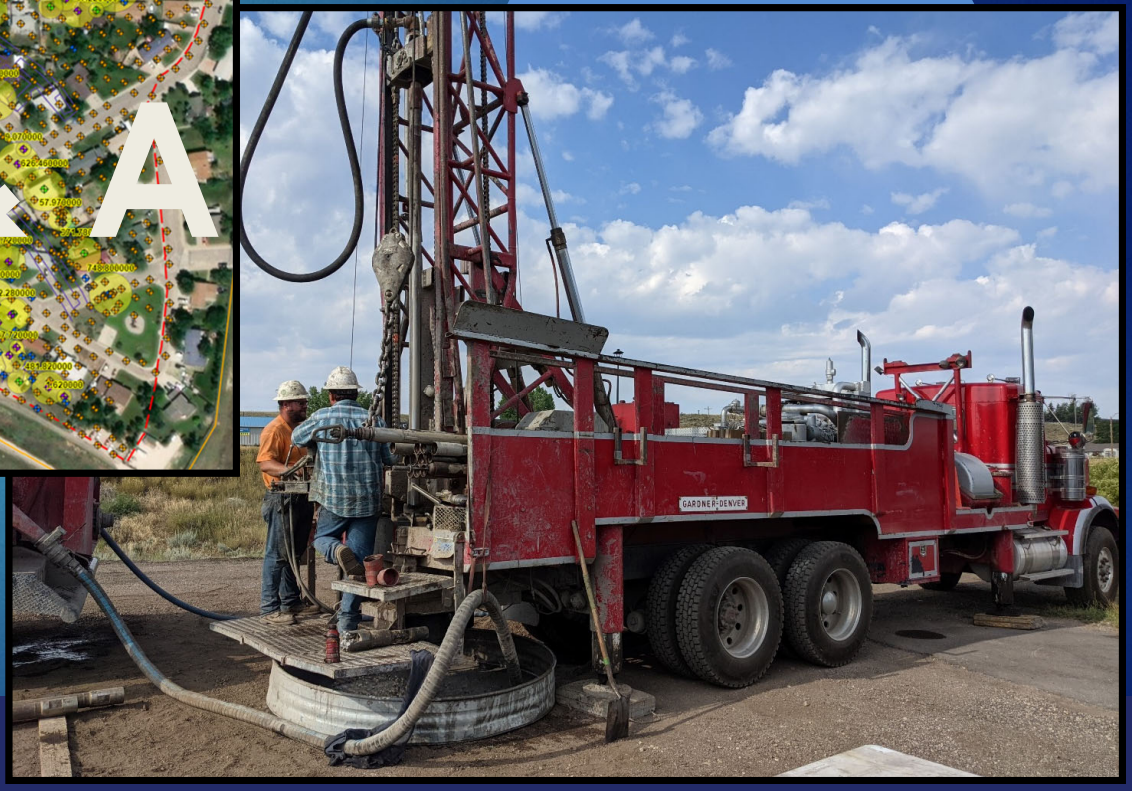


Q & A



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