Battelle
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Estimates of Engineered and Natural Source Zone Depletion by Wireline Temperature Measurement

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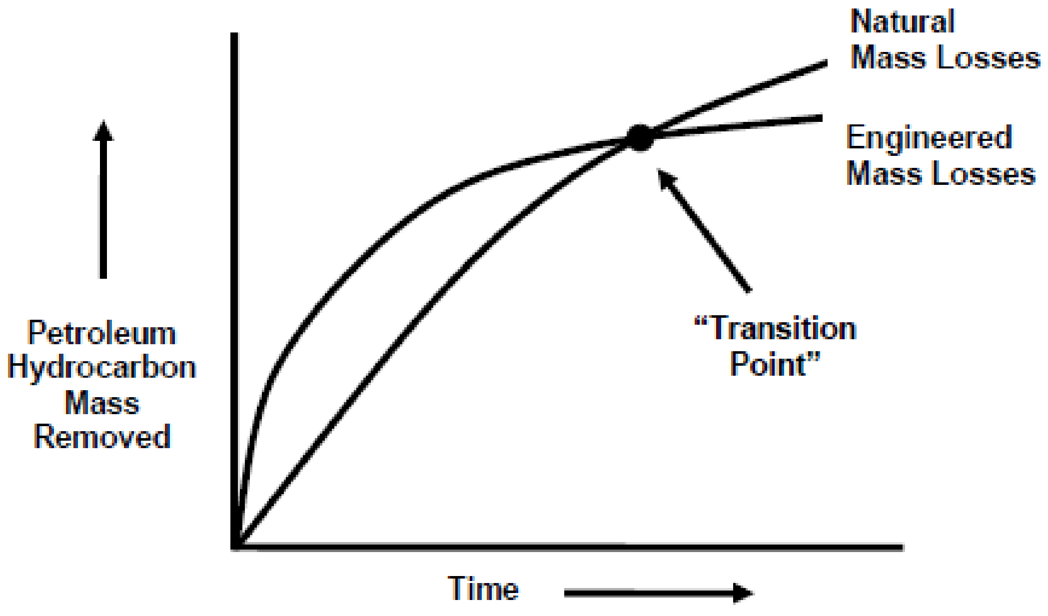
Objective

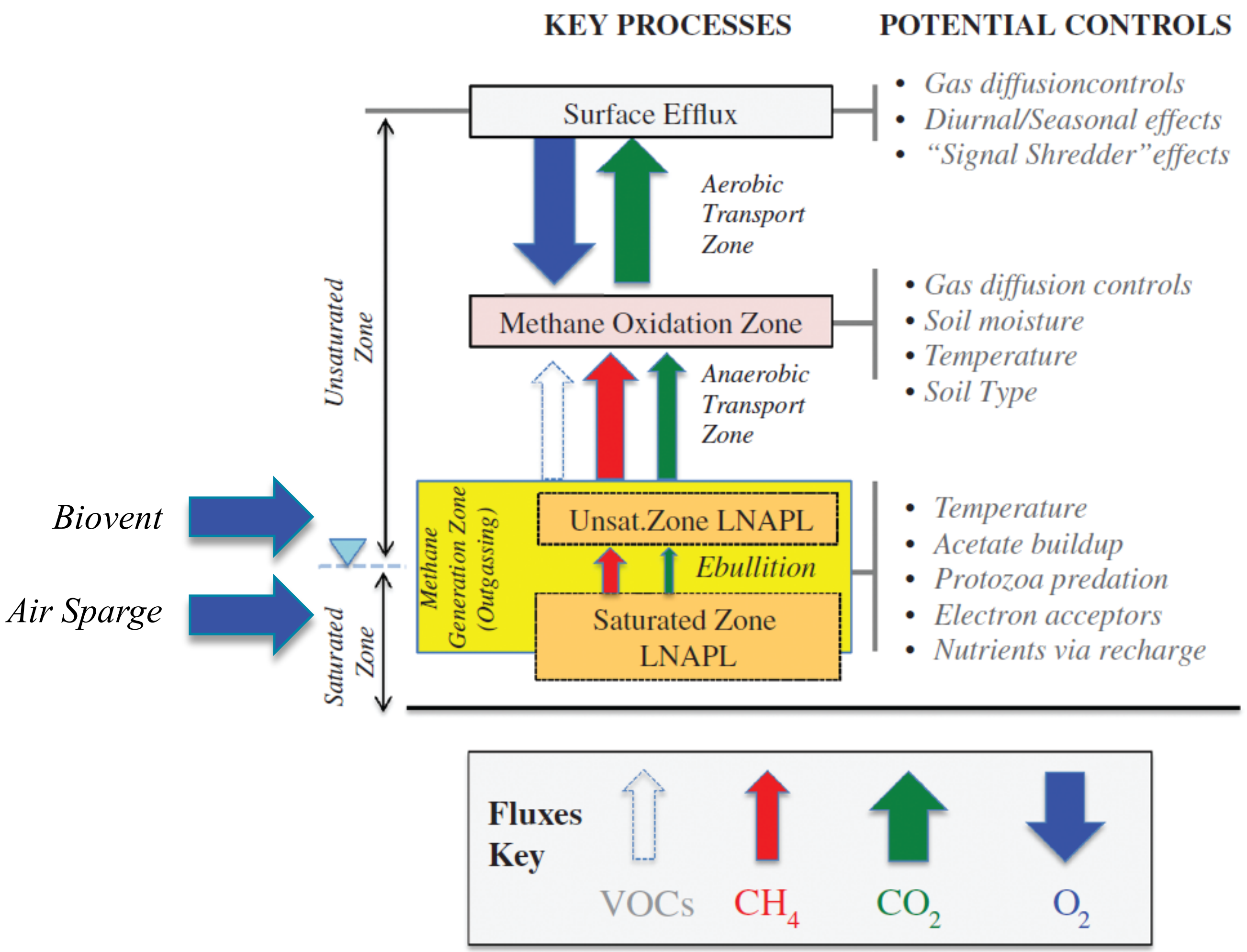
– Compare Engineered and Natural Source Zone Depletion Rates using thermal gradients



Natural Source Zone Depletion (NSZD)

Engineered Source Zone Depletion (ESZD)

NSZD Theory



Adapted from Garg et al. (2017)

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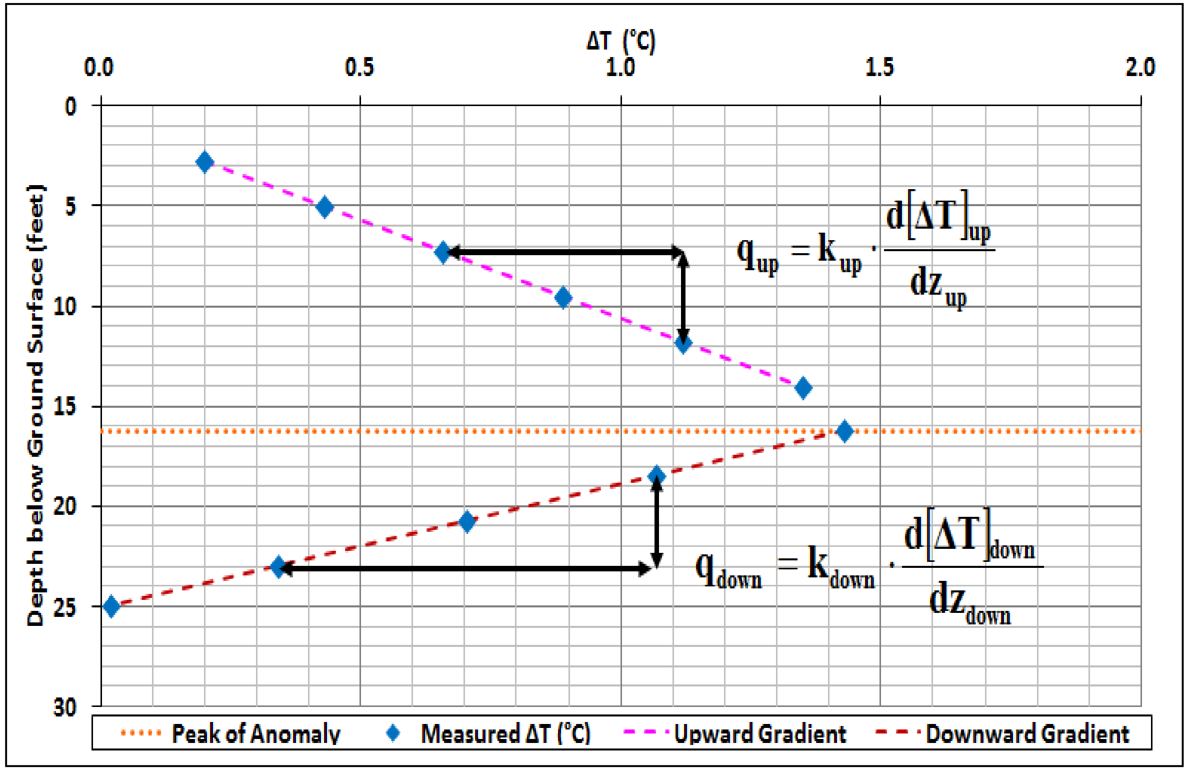
NSZD Theory

- Heat flux calculated from temperature gradient
- Oxidation of hydrocarbons releases heat, flux is proportional to reaction rate



(Adapted from Sweeney and Ririe, 2014)

$$q_d = k_d \frac{d[\Delta T]}{dz}$$

Where:

$q_d =$ Heat flux (up/down)

$k_d =$ Thermal conductivity (up/down)

$\Delta T =$ Change in temperature anomaly

Methanogenesis (0.06 kJ/g)
$C_{16}H_{34}$ + 7.5 H_2O → 12.25 CH_4 + 3.75 CO_2

Methane Oxidation (56 kJ/g)
CH_4 + 2 O_2 → CO_2 + 2 H_2O

Gasoline Oxidation (48 kJ/g)
C_xH_y + (x+¼y) O_2 → x CO_2 + (½y) H_2O

(Warren and Bekins, 2015; Sweeney and Ririe, 2014)

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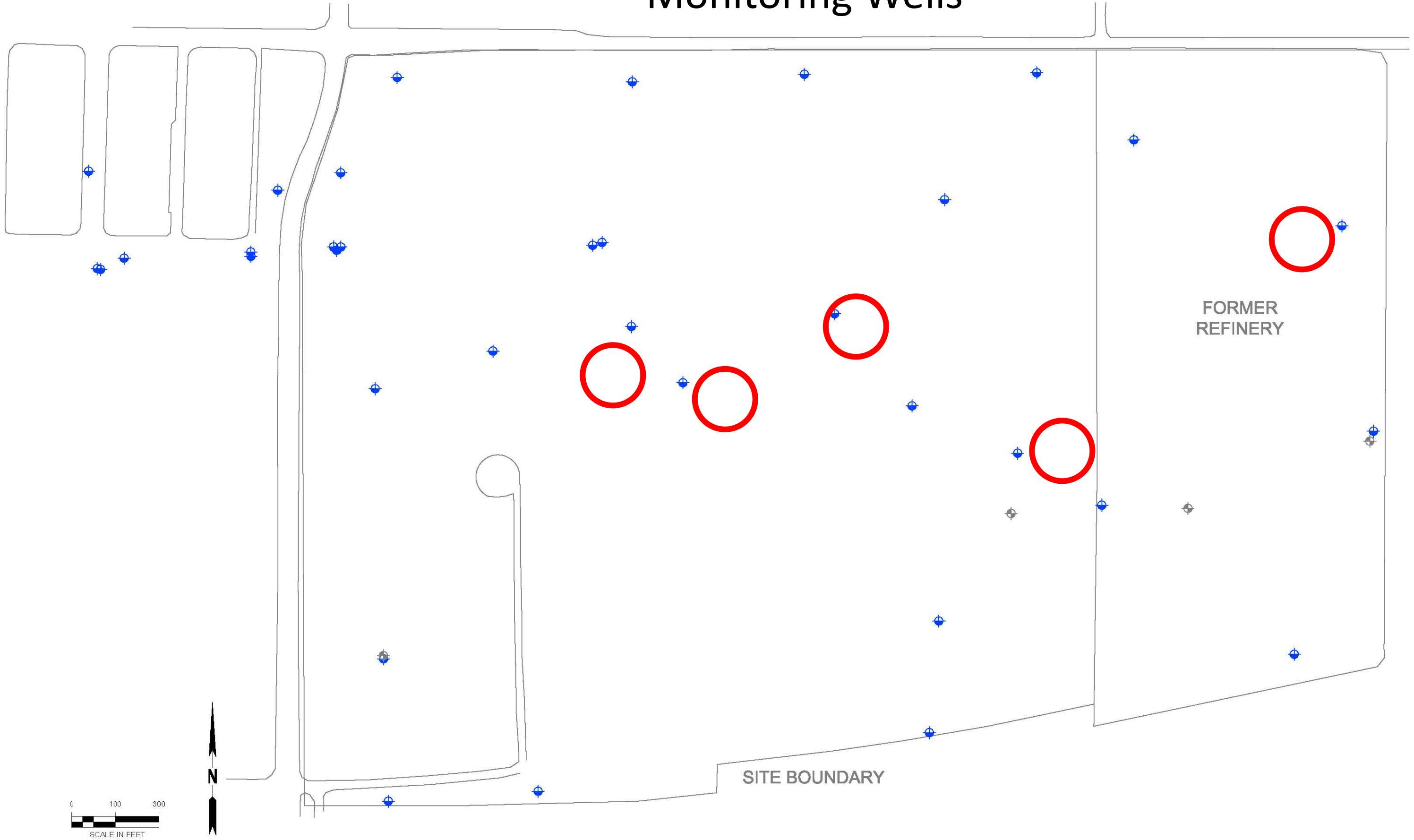
Site Background

- Former California Central Valley Refinery, operated from early 1900s to 1986
- Demolition and initial remediation completed in early 1990s
- Minimal mobile LNAPL remaining
- Groundwater at 250 ft bgs
- Benzene plume historically migrating northwesterly

Methodology

- Active air sparge and biovent systems
- Estimate NSZD/ESZD with systems in operation and after shutdown
- Temperature profiles from the wells circled in red

Monitoring Wells



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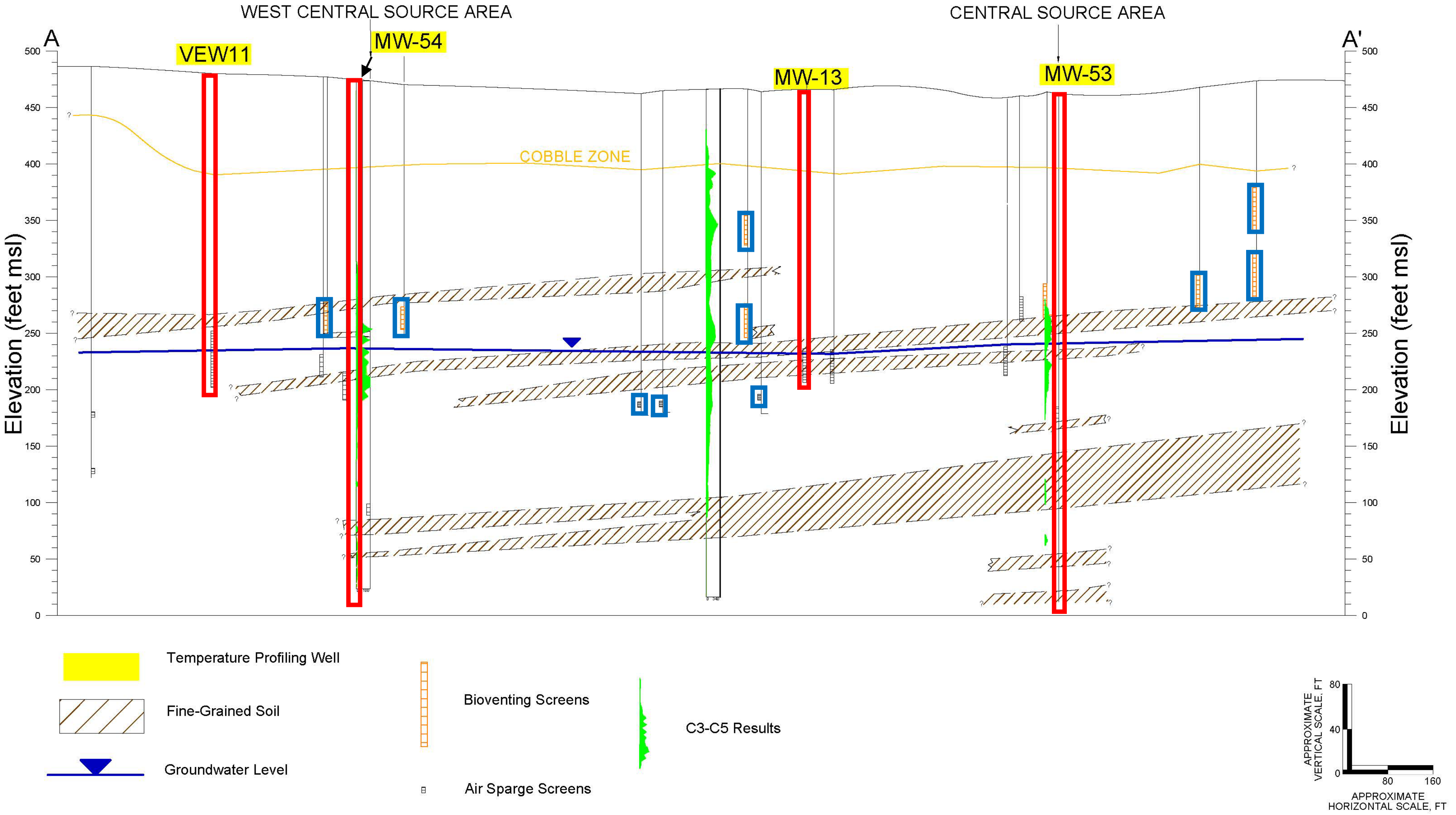
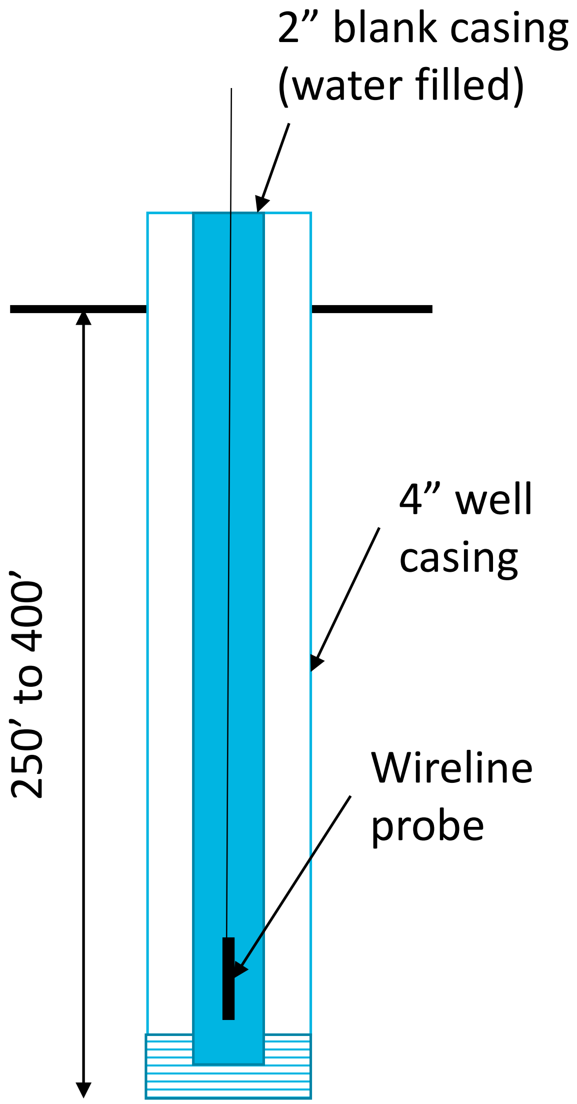
Cross Section



Wireline Temperature Measurement

- Used in the petroleum industry to log boreholes for physical properties
- Smaller diameter PVC casing with no screen installed within well and filled with water
- Internal casing allowed to equilibrate
- Temperature probe lowered down internal casing at 20 ft/min



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Wireline – Comparison to Thermocouples

- Advantages
  - Uses existing wells
  - Continuous measurement in space
  - Cost effective for deep wells
    - Wireline
      - $10/foot for installation in 4” wells
      - ~$250/well measuring event
    - Thermocouples
      - $21/foot installation (10’ spacing)
      - $18/foot/month monitoring and analysis
  - Allows wells to be reused after the test
- Disadvantages
  - Requires repeated wireline measurements to get data over time
  - Requires installation of internal casing or blocking the well screen

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Results

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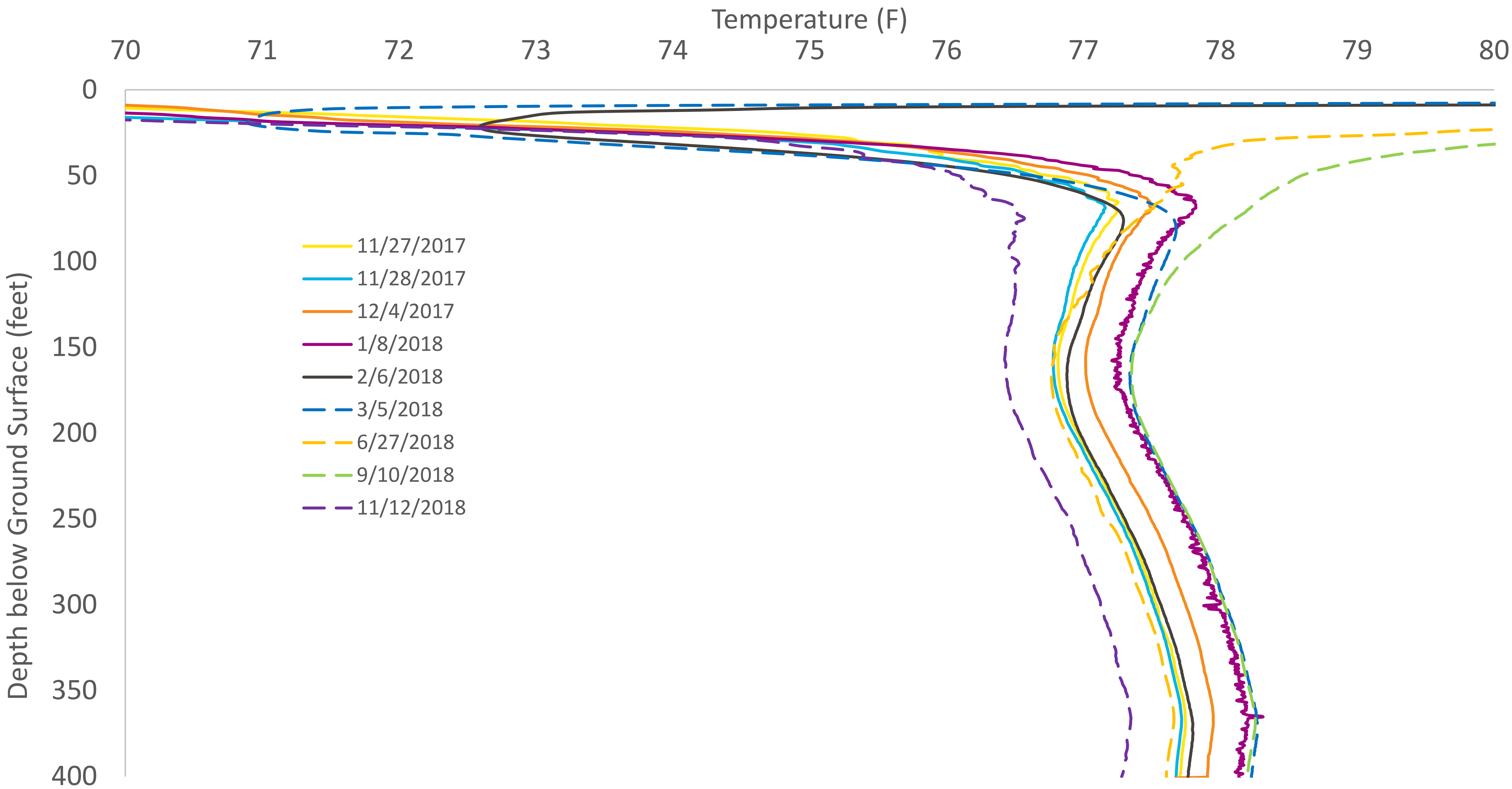
Background Temperature – REF-TO1



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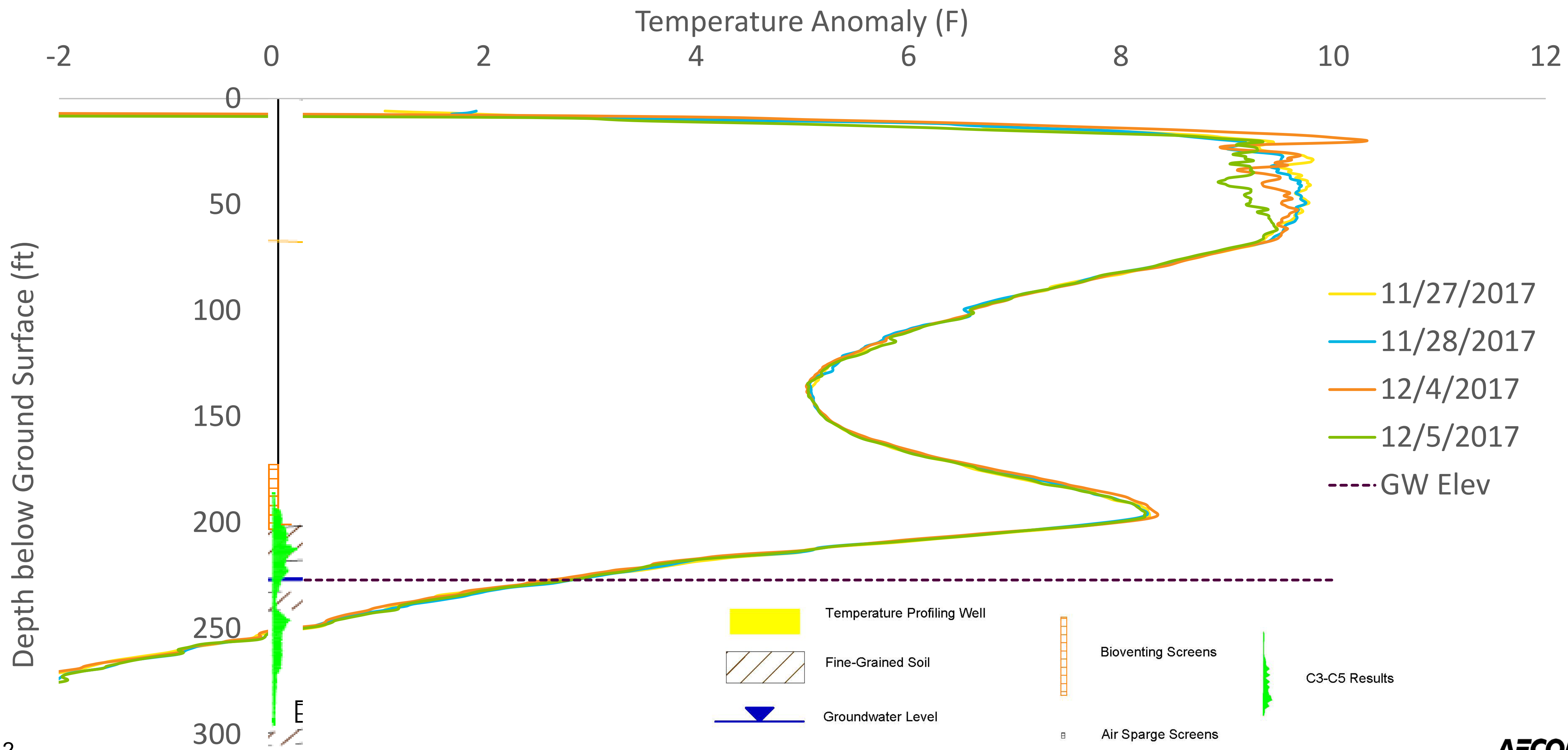
Baseline Temperature Measurement – MW-53



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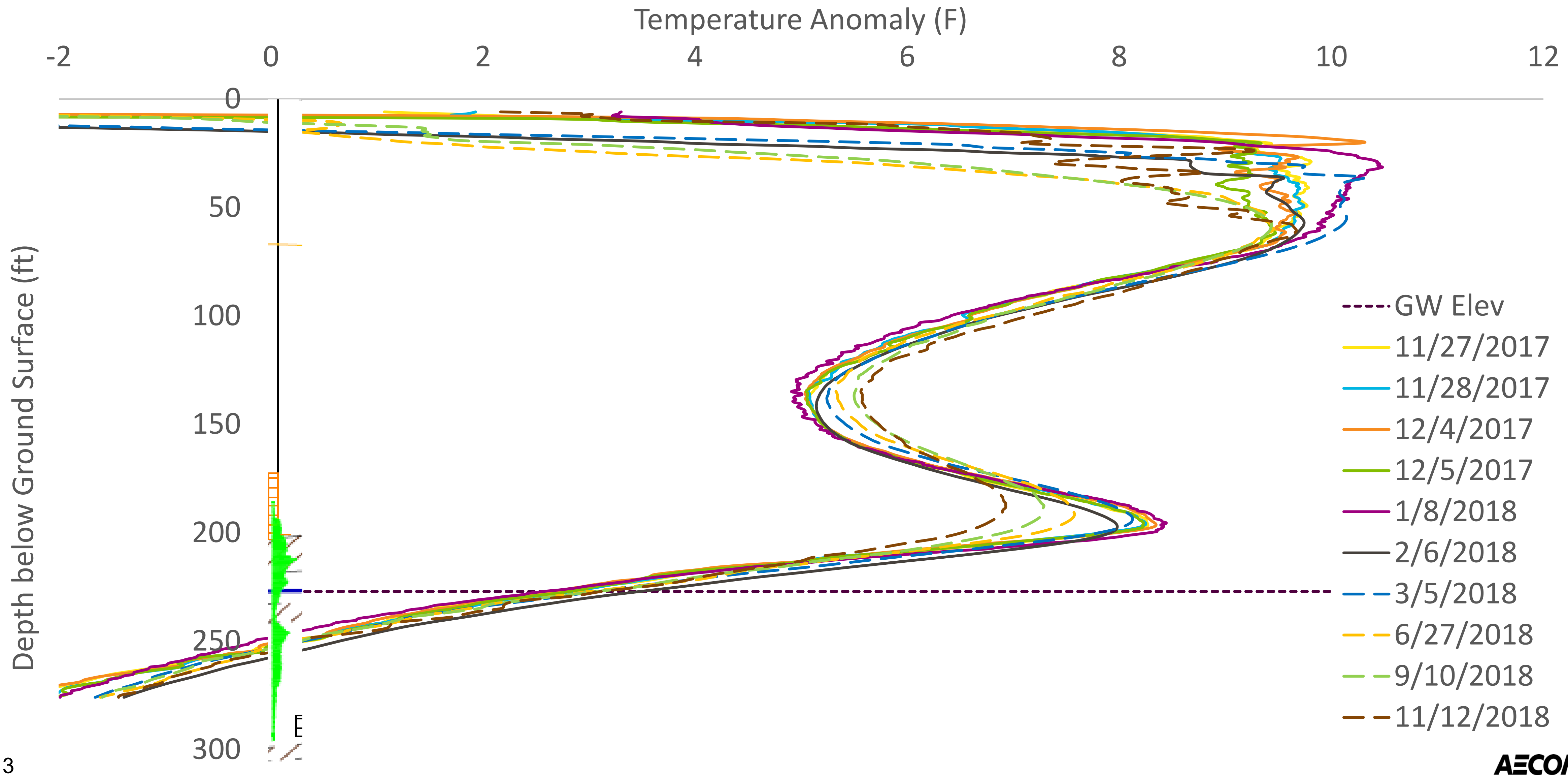
MW-53



Temperature Anomaly (F)
-2
0
2
4
6
8
10
12
0
50
100
150
200
250
300
Depth below Ground Surface (ft)
GW Elev
11/27/2017
11/28/2017
12/4/2017
12/5/2017
1/8/2018
2/6/2018
3/5/2018
6/27/2018
9/10/2018
11/12/2018

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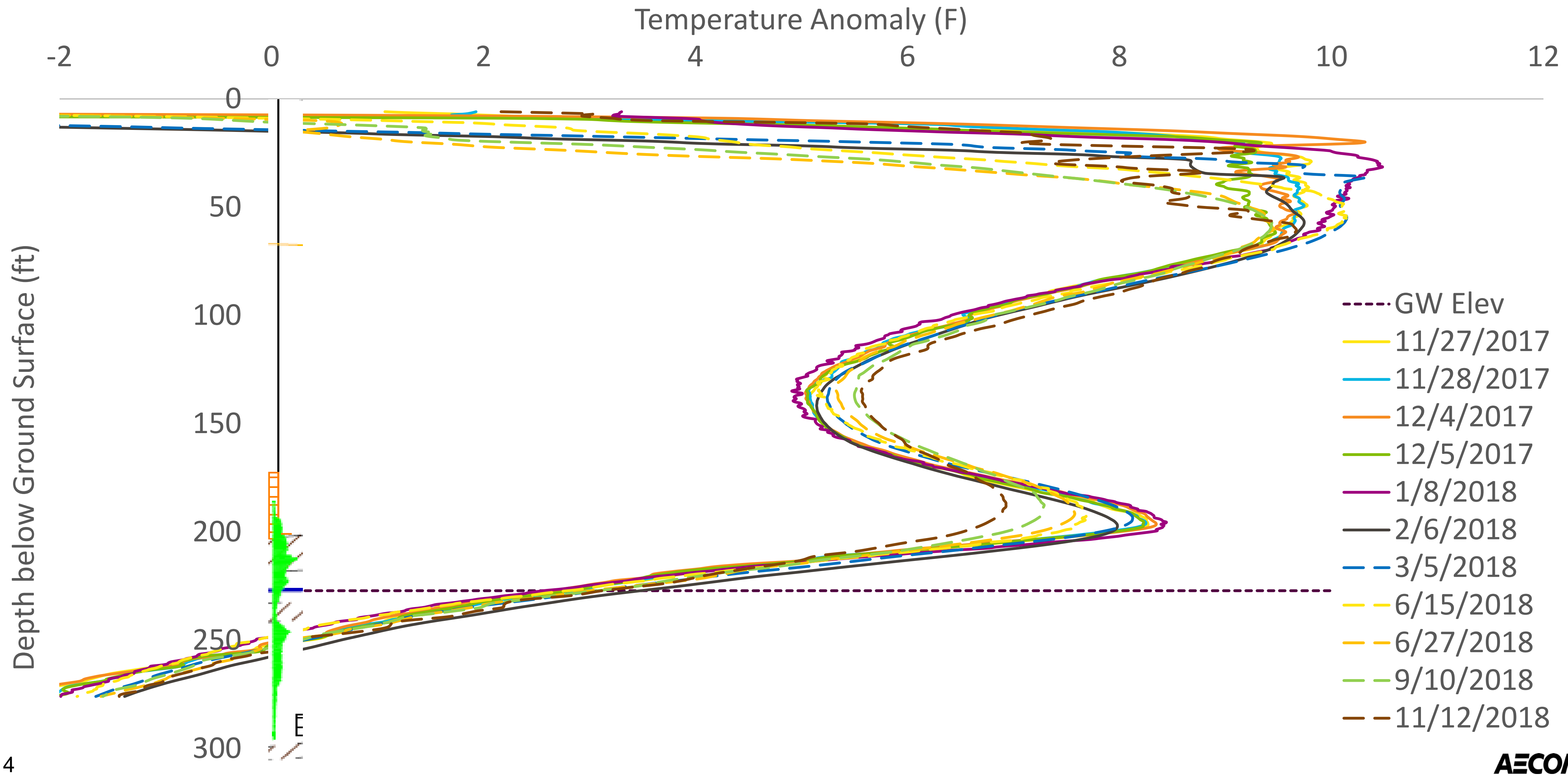
MW-53



Temperature Anomaly (F)
-2
0
2
4
6
8
10
12
Depth below Ground Surface (ft)
0
50
100
150
200
250
300
GW Elev
11/27/2017
11/28/2017
12/4/2017
12/5/2017
1/8/2018
2/6/2018
3/5/2018
6/15/2018
6/27/2018
9/10/2018
11/12/2018

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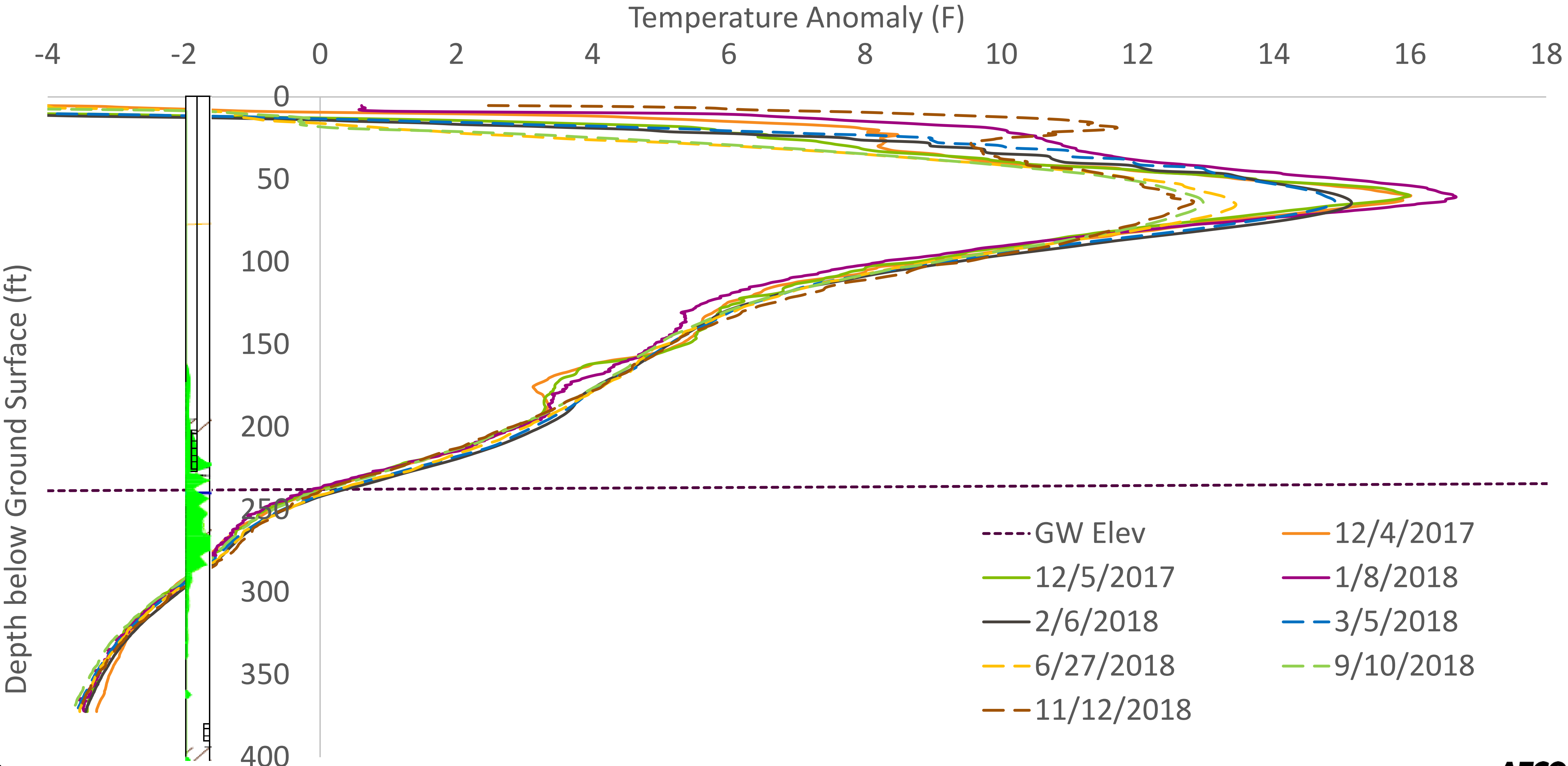
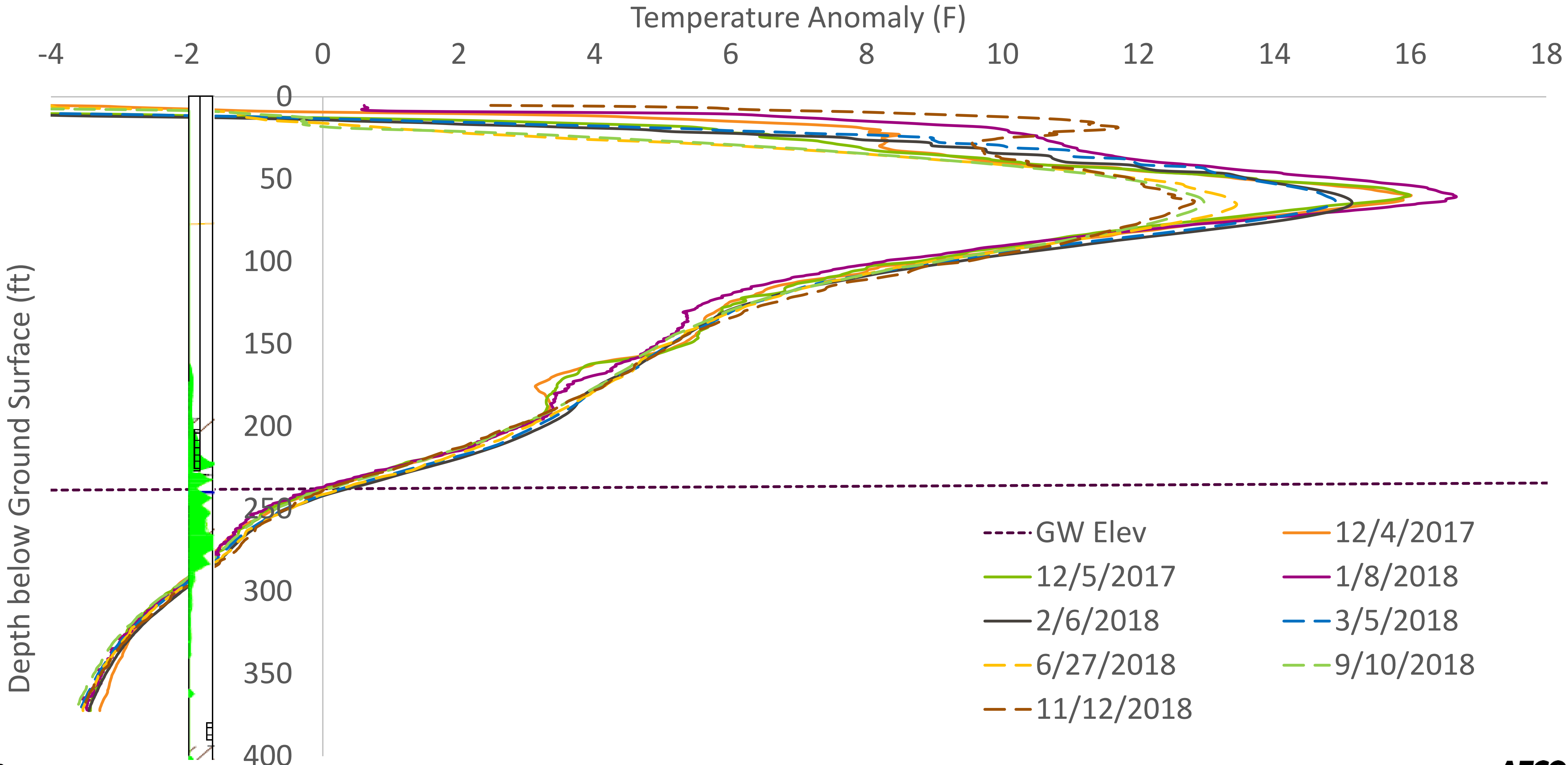
MW-54


Temperature Anomaly (F)
-4
-2
0
2
4
6
8
10
12
14
16
18
Depth below Ground Surface (ft)
0
50
100
150
200
250
300
350
400
GW Elev
12/4/2017
12/5/2017
1/8/2018
2/6/2018
3/5/2018
6/27/2018
9/10/2018
11/12/2018

MW-54


Temperature Anomaly (F)
-4
-2
0
2
4
6
8
10
12
14
16
18
0
50
100
150
200
250
300
350
400
Depth below Ground Surface (ft)
GW Elev
12/4/2017
12/5/2017
1/8/2018
2/6/2018
3/5/2018
6/27/2018
9/10/2018
11/12/2018

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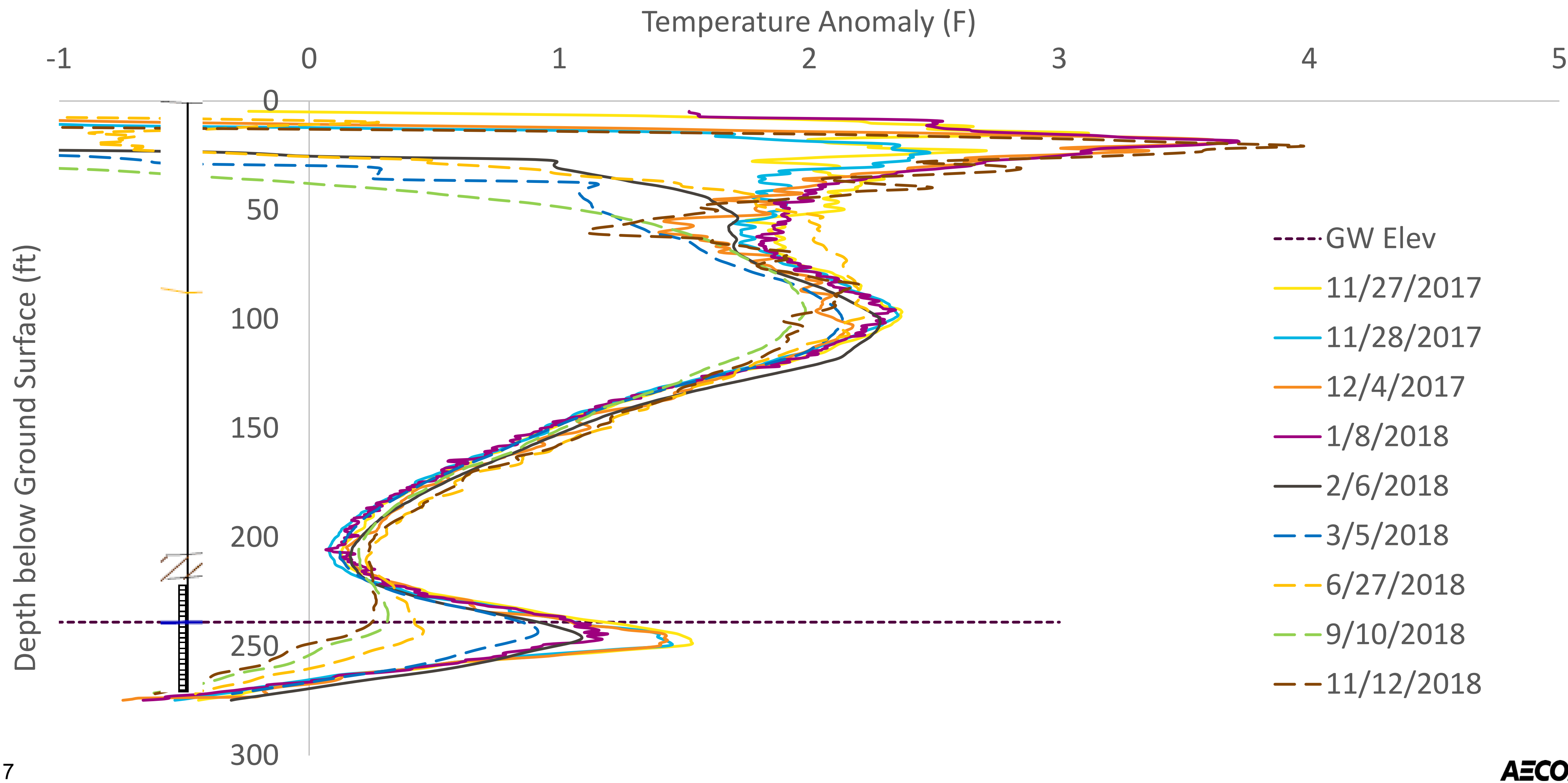
VEW-11


Temperature Anomaly (F)
-1
0
1
2
3
4
5
Depth below Ground Surface (ft)
0
50
100
150
200
250
300
GW Elev
11/27/2017
11/28/2017
12/4/2017
1/8/2018
2/6/2018
3/5/2018
6/27/2018
9/10/2018
11/12/2018

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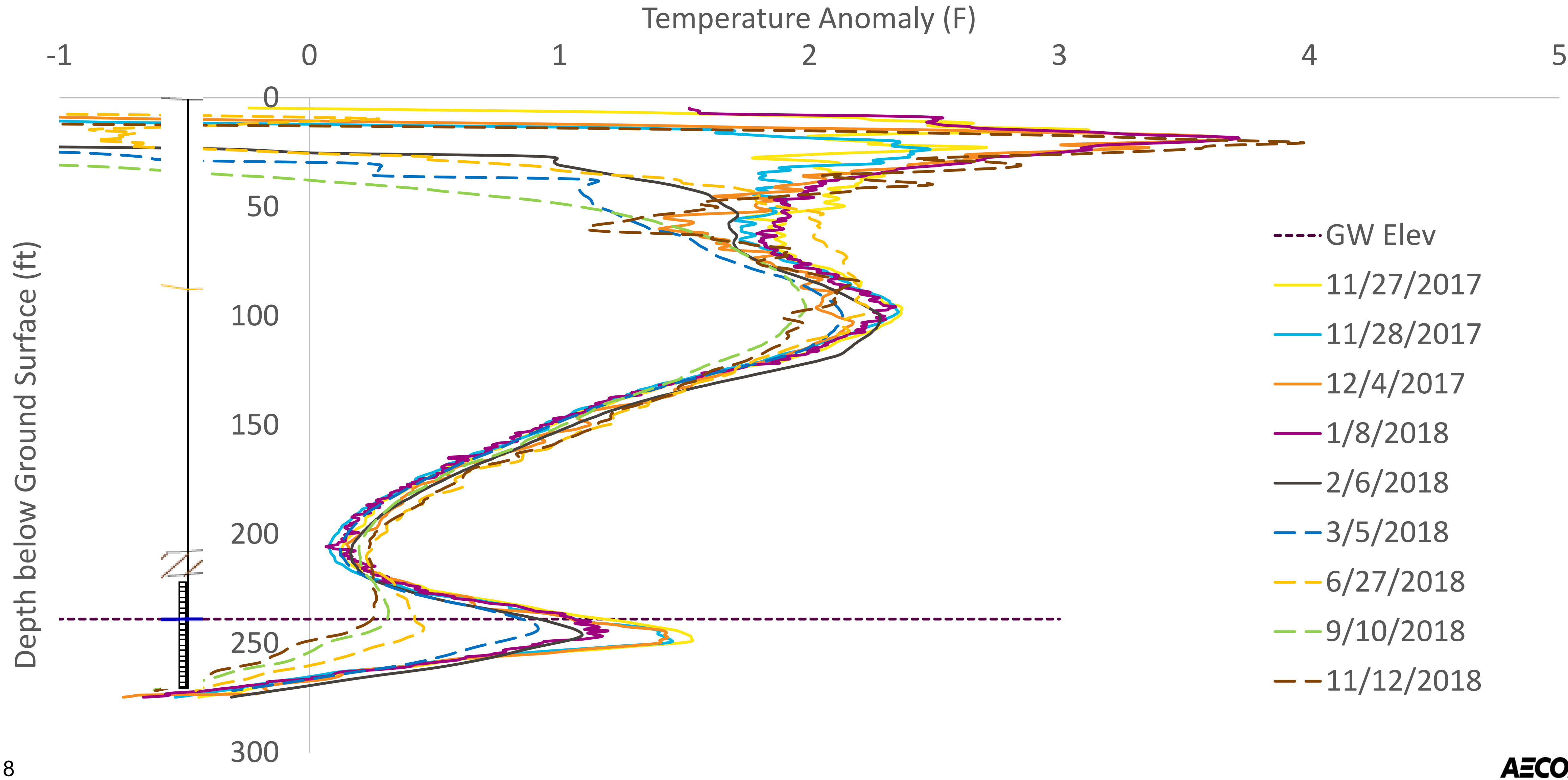
VEW-11



Temperature Anomaly (F)
-1
0
1
2
3
4
5
0
50
100
150
200
250
300
Depth below Ground Surface (ft)
GW Elev
11/27/2017
11/28/2017
12/4/2017
1/8/2018
2/6/2018
3/5/2018
6/27/2018
9/10/2018
11/12/2018

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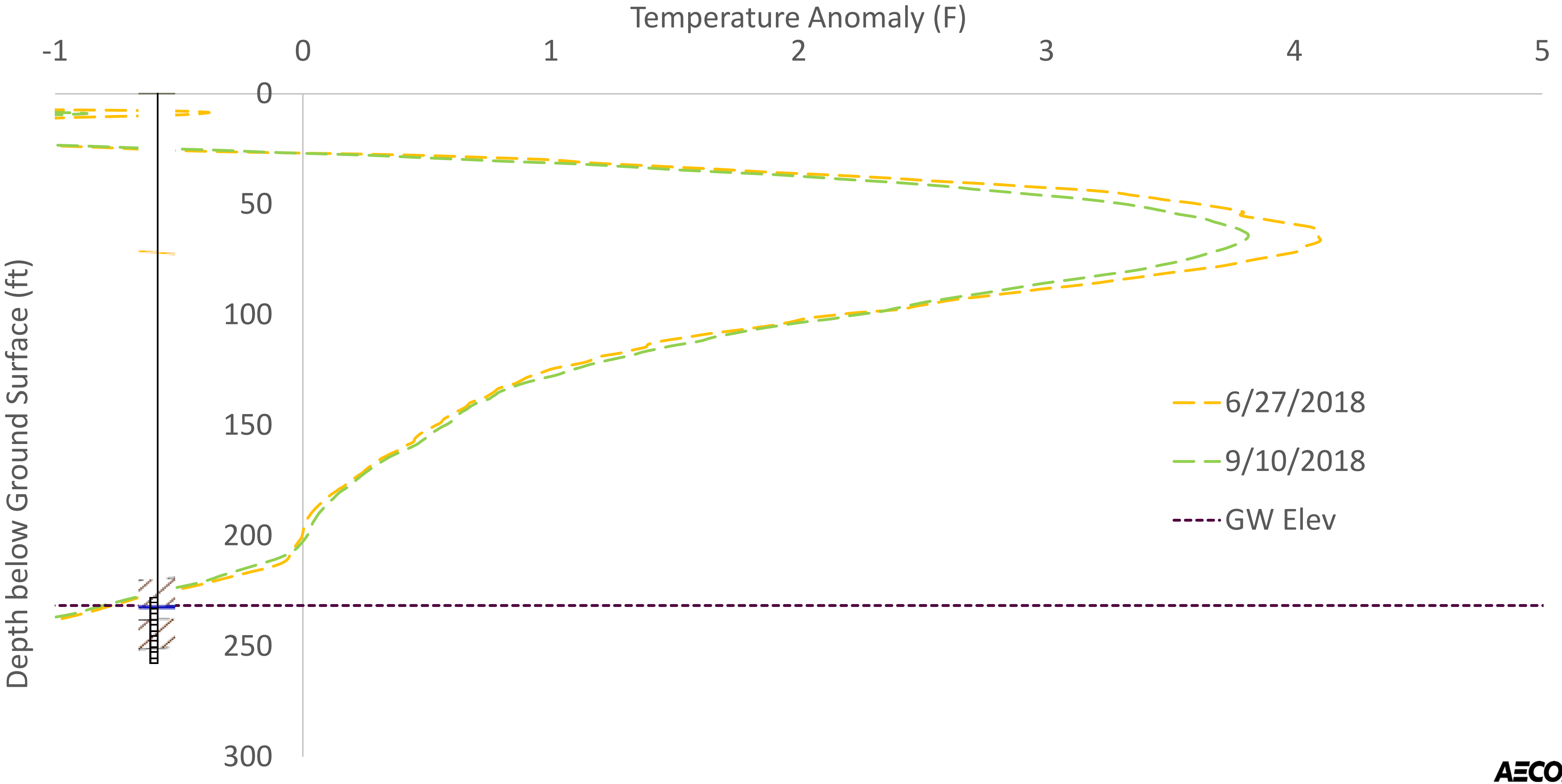
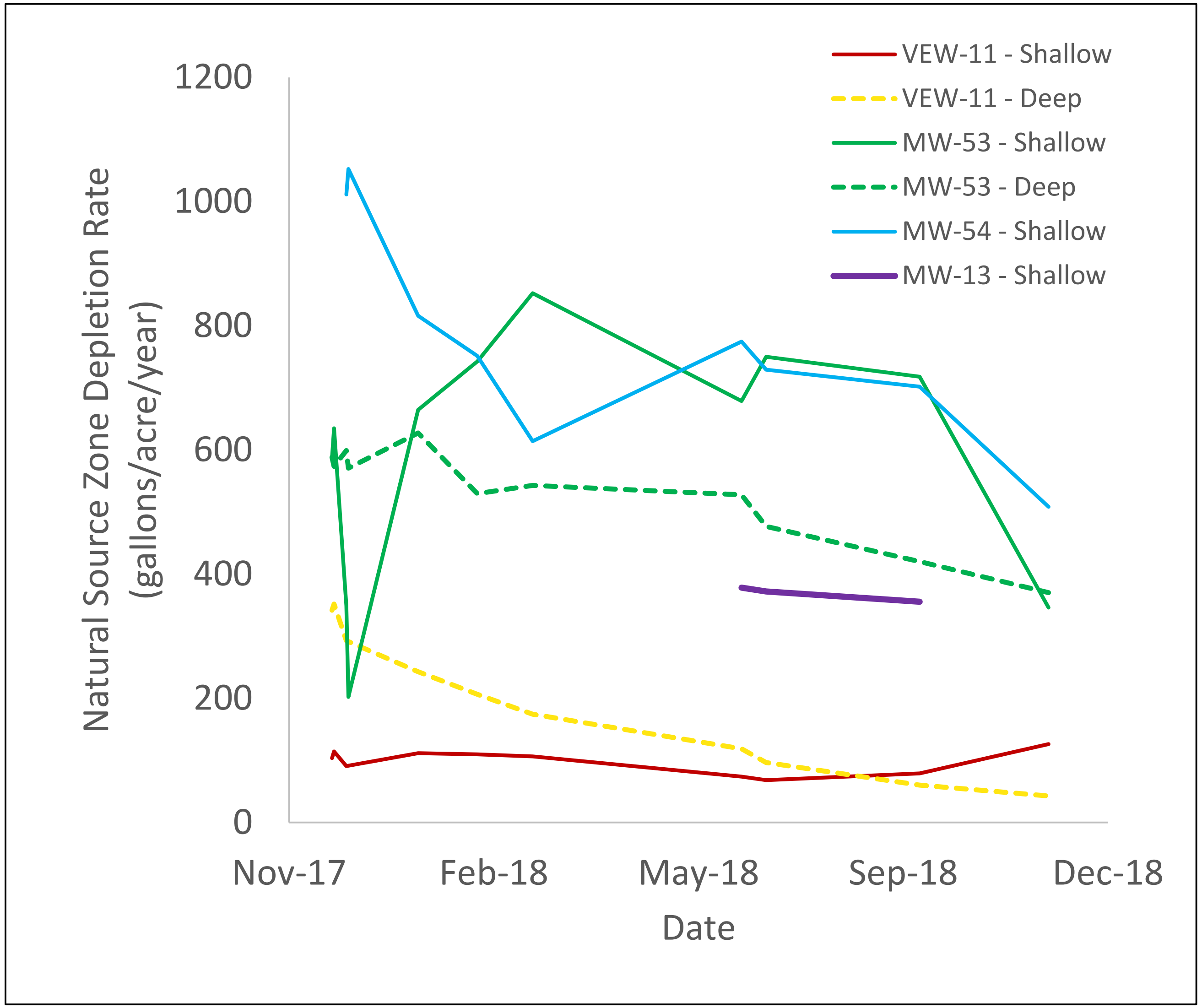
MW-13 (no sparge/biovent influence)



NSZD/ESZD Rates

- Overall rates range from 450 to 1,300 gal/ac/yr in each well
- Deep ESZD rates decreased 90% (VEW-11) and 50% (MW-53) after the systems were off for one year
- Shallow NSZD rates were greater than Deep ESZD



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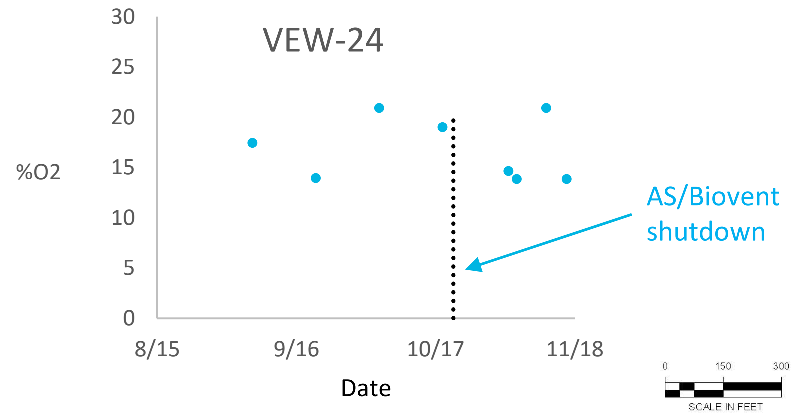
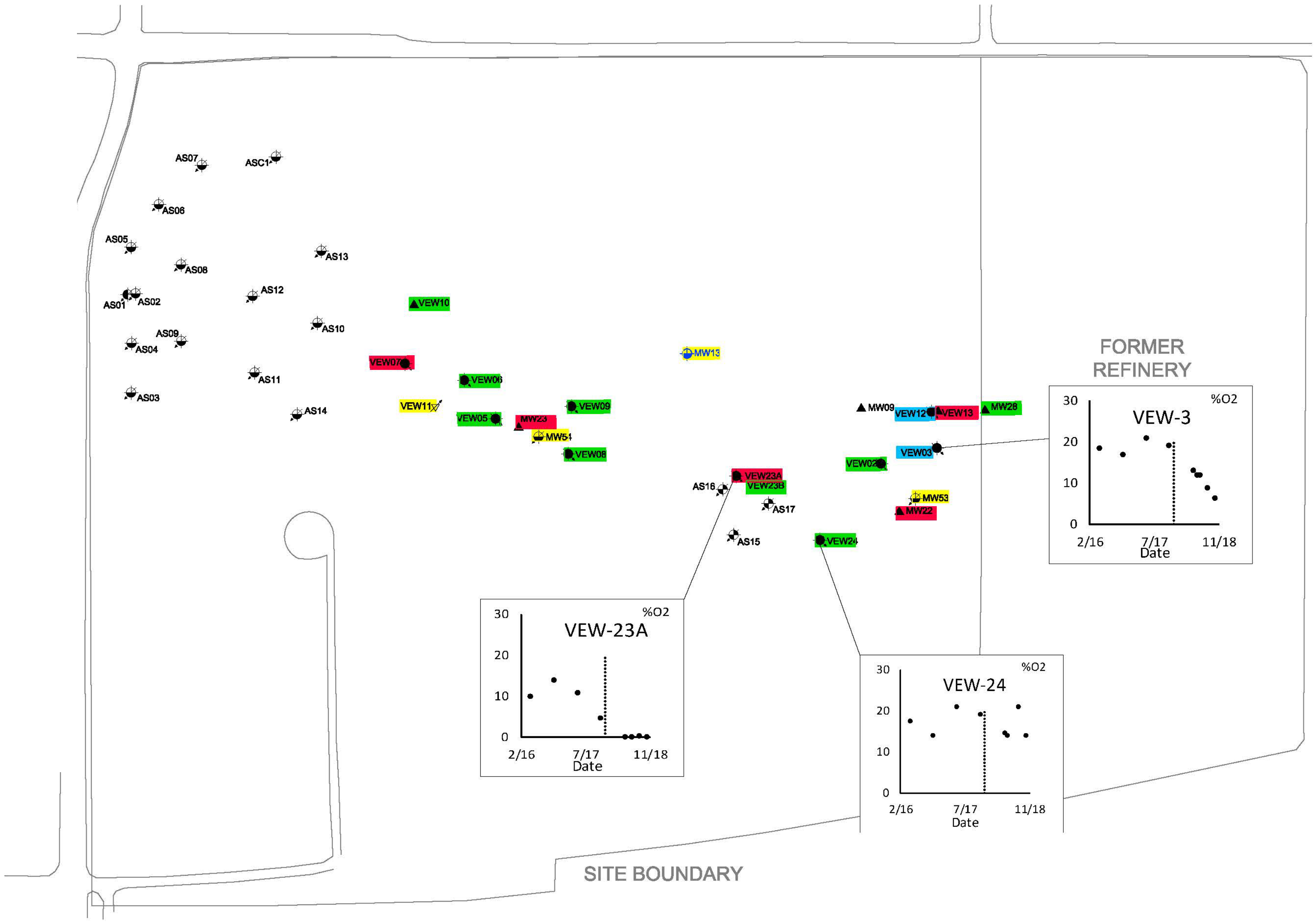
Oxygen Concentrations

- Five wells show rapid decrease in oxygen concentration
- Two wells show a slow decrease in oxygen concentration
- Ten wells showed no consistent decrease in oxygen even without air addition





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Issues

- Oxygen persisted in some wells after system shutdown
  - Hydrocarbons in the subsurface are discontinuous
    - Sampling from a long screen
  - Potential limits on degradation
    - Moisture

- Accounting for energy storage $$q_{down} - q_{up} + q_{NSZD} = \frac{dq_{storage}}{dt}$$
  - NSZD slope does not account change in stored energy in soil
  - Energy storage calculation is sensitive to integration method

- Benzene in groundwater is the driver at the site; NSZD/ESZD is not compound specific

Conclusions

- Wireline Temperature measurement can be used with existing monitoring wells to estimate ESZD/NSZD without sacrificing the well
- Distinct temperature peaks related to engineered air injection and natural oxygen diffusion were observed
- Shows ESZD effectiveness
- ESZD measurements decreased 50-90% when systems were shutdown
- NSZD greater than ESZD at this site
- Oxygen decreased after sparge/biovent shutdown in some, but not all wells

Thank You!

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