Feezor Engineering, Inc.
3377 Hollenberg Drive
Bridgeton, MO 63044
Phone (217) 483-3118

Letter of Transmittal

Date: 10/11/19	Job # BT-142-19
Attention: Chris Nagel	

To:
Missouri Department of Natural Resources
Solid Waste Management Program
1730 East Elm Street
Jefferson City, MO 65101

RE:
Bridgeton Landfill, LLC
Year 3 Heat Extraction Barrier Performance Report

We are sending you attached via: ☐ Regular Mail ☐ UPS ☐ Fed-Ex ☐ Hand Deliver the following items:

☐ Shop Drawings ☐ Plans / Drawings ☒ Report ☐ Samples

☐ Specifications ☐ Proposal ☐ Other ________________________________

Copies	Date	# Pages	Description
1	Oct 2019	94	Report entitled "*Year 3 Heat Extraction Barrier Performance Report*"

☒ For approval ☐ For your use ☐ For review and comment

☐ As requested ☐ For consideration

Remarks:

Copy to:
Erin Fanning – Bridgeton Landfill, LLC
Tom Mahler – EPA

Signed ____________________________________
Daniel Feezor, P.E.

ENGINEERING FOR A BETTER WORLD
FEEZOR
ENGINEERING, INC.

YEAR 3 HEAT EXTRACTION BARRIER PERFORMANCE REPORT

BRIDGETON LANDFILL

BRIDGETON, ST. LOUIS COUNTY, MISSOURI

Prepared For:
Bridgeton Landfill, LLC
13570 St. Charles Rock Road
Bridgeton, MO 63044

October 11, 2019

Project No.: BT-142

STATE OF MISSOURI
DANIEL RICHARD FEEZOR
NUMBER PE-030292
PROFESSIONAL ENGINEER

10/11/19

Prepared By:

P.J. Carey and Associates
5878 Valine Way
Sugar Hill, GA 30518

Feezor Engineering., Inc.
3377 Hollenberg Drive
Bridgeton, MO 63044
Missouri Professional Engineer
Number 030292

Year 3 Heat Extraction Barrier Performance Report

Bridgeton Landfill, LLC

TABLES

APPENDICES

1 INTRODUCTION

Bridgeton Landfill, LLC (Bridgeton Landfill) submitted the *Technical Evaluation of a Heat Extraction Barrier* on November 1st, 2015 to the Missouri Department of Natural Resources (MDNR) which:

- demonstrated the pilot study heat removal system removed heat and could reduce temperatures in temperature monitoring devices near the pilot study wells;
- provided thermal modeling to predict the effectiveness of a Heat Extraction Barrier (HEB);
- provided installation guidance for the HEB; and
- proposed a network of System Performance Monitoring –Temperature Monitoring Probes (SPM-TMP) to monitor temperatures in the neck area.

The MDNR approved the November 1st, 2015 submittal on December 4th, 2015. The approval letter listed ten (10) comments to the submittal. The United States Environmental Protection Agency (USEPA) became the lead regulator on the Bridgeton Landfill North Quarry via an April 28th, 2016 Administrative Settlement Agreement and Order on Consent for Removal Actions (ASAOC). Section VIII.35.c of the April 28th, 2016 North Quarry ASAOC incorporated the November 1st, 2015 submittal and the December 4th, 2015 approval letter except for Comment #1.

In accordance with Section IX.28 of a subsequent June 29th, 2018 Final Consent Judgement, this report provides an analysis of Temperature Monitoring Probe (TMP) data to determine the impact the operation of the Neck Heat Extraction System has on the heat generated by the subsurface reaction.

TMP data have been provided to the MDNR in on-going weekly submittals and are not included in this report. Likewise, heat extraction data have been submitted within monthly reports submitted per Comment #8 of the December 4th, 2015 MDNR comment letter and are not included in this report.

2 HEAT EXTRACTION BARRIER INSTALLATION

The sixteen (16) HEB elements – called Heat Extraction Wells (HEW) – were installed during July 11th, 2016 through September 17th, 2016. The piping and manual instrumentation were installed by September 25th, 2016. Operations of the HEB commenced on October 11th, 2016 once the grout cured and background SPM-TMP readings were obtained. As-built record drawings detailing the installation of the HEB were submitted to the USEPA and MDNR on November 23rd, 2016.

The Gas Inceptor Wells (GIW) pilot system (GIW-2, GIW-3, GIW-4, GIW-5, GIW-6, GIW-7, GIW-8, GIW-9, GIW-10, GIW-11, GIW-12, and GIW-13) has been removing heat since November 2014 and remained in operation during the installation of the HEWs. The GIW system was then incorporated into the entire HEB system.

During 2018, a backup generator was installed for system operation in the event of a power failure. Also, in 2018, a secondary cooling tower was installed, and was connected to the system in July 2019. The twenty-eight (28) heat extraction units, cooling towers, cooling liquid storage tank, pump, backup generator, and instrumentation system comprise the Neck Heat Extraction System. An as-built diagram of the Neck Heat Extraction System is provided in **Appendix A**.

Automated Barrier System Data Collection

At the time of system startup on October 11th, 2016, heat extractor units were outfitted with inlet and outlet temperature sensors and flow meters that required manual recording of temperature and flow. Those sensors and flow rate meters were read and recorded once per day during the initial startup period then once every other day after the startup period. During November 2016, the heat extraction system was outfitted with an automated data collection system to allow for the amounts of removed thermal energy to be calculated directly from a database of temperature and flow rate measurement records.

The heat extractors are each outfitted with a flow rate meter and wireless Resistance Temperature Detectors (RTDs) that provide measurement results for inlet and outlet temperature. The measurement results are transmitted (via wired connections for the flow meters and via wireless transmission for the inlet and outlet RTDs) to a centralized data collection system. The data collection system records measurement results at ten (10) minute intervals. The exception to this is GIW-5, which is outfitted with wireless RTDs for inlet and outlet temperature data collection but does not have an automated flow rate meter data collector due to the limited number of data input channels available on the wired connection chart recorder. Flow rate measurements for GIW-5 are recorded manually once per week.

Temperature and flow rate measurement results have been provided in previous Neck Heat Extraction System Monthly Reports.

3 HEAT EXTRACTION BARRIER PERFORMANCE

The Neck Heat Extraction System has been in operation since October 11th, 2016. The yearly report contained herein analyzes data collected since the October 11th, 2018 Year 2 Heat Extraction Barrier Report submittal (from September 2018 through the end of August 2019). Based upon the empirical data collected, the Neck Heat Extraction System is effectively removing thermal energy, as described in the following bullet points:

- The amount of thermal energy removed by the HEB since initiation of operation has been measured at greater than 8.02 billion BTUs (**Table 1**);
- The SPM-TMPs 3 and 4 (the units north of the HEB line) continue to trend downward in temperature (**Appendix B**). These temperatures are evidently affected by the Neck Heat Extraction System.; and
- The 220 °F isotherm line has been stationary near GIW-10 since the HEB was installed (**Appendix E**).

<u>Calculation of Amount of Thermal Energy Removed</u>

The thermal energy removed from the landfill via the extraction points (both the HEW and GIW units) occurs through passing liquid through each extractor that emerges warmer than it was when it entered the extractor. The rate of energy removal is equal to the mass of the fluid mixture passing through the extractor per given time, times the heat capacity of the fluid mixture, times the change in temperature that occurred as it passed through the extractor, and is expressed by Equation 1:

$$HRR = C_p(T)\ x\ Q\ x\ \delta(T)\ x\ (T_o - T_i) \qquad (1)$$

Where:

HRR = Heat Removal Rate (kilowatts);
$C_p(T)$= Heat Capacity of Fluid Mixture as a function of Temperature;
Q = Flow Rate (gpm, corrected from the recorded reading for viscosity variation);
$\delta(T)$= Mass Density of Fluid Mixture as a function of temperature;
T_o = Outflow Temperature (°F); and
T_i = Inflow Temperature (°F)

While calculation of the amount of thermal energy removed is not a HEB performance criterion, this information (and the supporting data) are submitted to the USEPA and MDNR via Neck Heat Extraction System Monthly Reports. A summary of the calculated removed thermal energy from initiation of operations through August 2019 is provided in

Table 1. During this time, more than 8.02 billion BTUs of thermal energy have been removed by the system.

Review of Northern SPM-TMPs

SPM-TMP3 is located approximately 14 feet north of the HEB line, and SPM-TMP-4 is located approximately 19 feet north of the HEB line. Both TMPs continue to show reductions in temperature. The temperature versus depth graphs for the four (4) System Performance Monitoring TMPs are provided in **Appendix B.** These graphs show the starting temperature, gray shaded historical temperatures, and the most recent five (5) weeks of temperature data collected. Please note TMP-SPM-1 and TMP-SPM-2 are south of the HEB, which is closer to the reaction area.

Review of 220 °F Isotherm

An additional gauge of Neck Heat Extraction System performance can be observed by a comparison of the current 220 °F subsurface isotherm to the isotherm provided in the November 2015 *Technical Evaluation of a Heat Extraction Barrier* and the isotherm provided in the previous (Year 1) Annual Report. A 220 °F subsurface isotherm has been used historically as a measure of the limit of the maximum northern extent of the possible reaction, if significant settlement was also measured.

The current 220 °F subsurface isotherm was prepared by interpolation of current (July – August 2019) maximum temperature measurement results observed at TMPs near the heat extraction system. July – August 2019 temperature measurement results were previously provided to MDNR in weekly reports. Temperature versus depth graphs for the neck area and North Quarry TMPs are provided in **Appendix C** and temperature versus depth graphs for pilot study TMPs are provided in **Appendix D**.

The figure provided in **Appendix E** illustrates 2015, 2017, 2018, and current (2019) subsurface conditions. As depicted in the figure, the location of the 220 °F subsurface isotherm is stationary, suggesting the heat extraction system continues to have a stabilizing effect on subsurface temperatures near the system. As stated above, this metric is not a HEB performance criteria, but is used as a visual indicator of system performance.

4 PREDICTED AMOUNTS OF REMOVED THERMAL ENERGY

A memorandum evaluating the predicted versus actual amounts of removed thermal energy has been prepared by P.J. Carey & Associates, P.C. (Carey) and is provided in

Appendix F. The evaluation indicates that the Neck Heat Extraction System is generally removing thermal energy from the subsurface as predicted by past thermal modeling.

5 SYSTEM PERFORMANCE MONITORING

System performance monitoring is intended to verify that the heat removal system is achieving a target temperature in the neck area north of the HEB and to assess the presence and trend of heat input from south of the HEB. As discussed in Section 3, the northern two (2) SPM-TMPs show temperature reductions. Past thermal modeling predicted that temperatures north of the HEB line should not exceed 170 °F and the following was developed as the criterion for no additional thermal modeling:

- Thermocouples within TMP 1, 2R, 3R, and 4R are less than or equal to 185 °F.

The 185 °F threshold value is well below the historical 200 °F "trigger criteria" within TMPs 1, 2R, 3R, and 4R. If a thermocouple exceeds this 185 °F threshold, then the existing thermal model will be reassessed to determine if additional heat extraction points are needed. Monitoring of conditions south of the HEB will continue which will allow determination of when heat extraction may be slowed, terminated, or even—if necessary—supplemented with additional points to achieve performance goals.

6 HEAT EXTRACTION BARRIER OPERATIONAL PERFORMANCE

On March 11, 2019, it was observed that HEW-4 was not able to accommodate a six (6) gallon per minute flow that was deemed optimal. Flow continued to decrease until it ceased on July 22, 2019. Two separate field investigations (on July 31, 2019 and August 13, 2019) have determined that a constriction in HEW-4 exists between 90-95 feet below ground level.

Temperature measurement results for adjacent SPM-TMPs were evaluated to determine if there is evidence of thermal rebound. TMP-SPM-3 is the closest TMP to HEW-4 (approximately 25 feet away). Time series per TMP thermocouple graphs are provided in **Appendix G** for TMP-SMP-2 and TMP-SPM-3. The TMP-SPM-3 graph depicts stable subsurface temperatures north of the HEB despite the zero-flow condition beginning July 2019 at HEW-4. The graph for TMP-SPM-2 (approximately 45 ft south of HEW-4) also depicts generally downward trends since July 2019 for most of the individual probes.

On October 1st, 2019 representatives from Bridgeton Landfill met with the MDNR to discuss the above-referenced investigations of HEW-4 and present a preliminary analysis. It was agreed that for individual units which fail, a separate analysis will be submitted for each unit which will study the need for replacement of the unit and / or augmentation of the system. Additionally, a discussion of temperature trends will be provided going forward as part of the monthly heat extraction reports. Per the October 1st, 2019 meeting, replacement of individual heat extraction units will only occur if:

- Significant trends in thermal "downgradient" TMPs suggest temperatures are increasing; and / or
- Thermal modeling suggests that over time, the loss of a heat extraction unit would violate the performance criteria discussed in Section 5 of this report.

Thermal modeling will be conducted for the inoperable HEW-4 unit. The report of the thermal modeling analysis is expected to be submitted to the USEPA and MDNR by January 31st, 2020.

7 HEAT EXTRACTION BARRIER AUGMENTATION

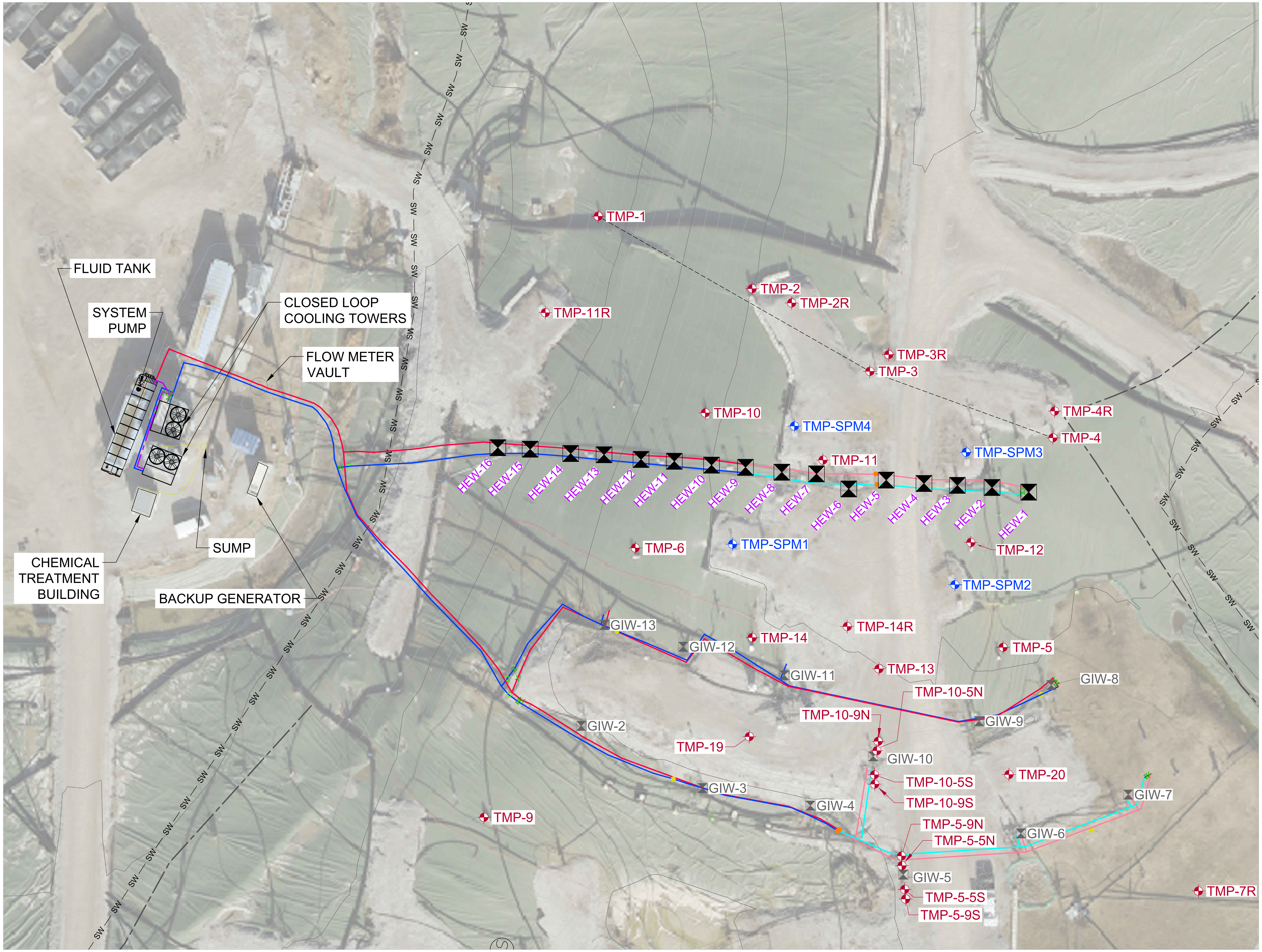
Because the northern SPM-TMPs (3 and 4) exhibit temperatures (**Appendix B**) below the 185 °F threshold described in Section 5, no augmentation of the heat extraction barrier is believed to be needed.

TABLE 1 Calculated Removed Thermal Energy Period 10-16-2016 to 08-31-2019		
Unit	kW-hr	BTU
October 2016	69,424	236,875,785
November 2016	99,680	340,108,964
December 2016*	94,914	323,846,224
January 2017	73,187	249,715,748
February 2017	50,326	171,710,730
March 2017*	81,953	279,623,793
April 2017	68,140	232,493,844
May 2017*	69,138	235,897,728
June 2017	68,067	232,242,976
July 2017	65,728	224,262,959
August 2017*	68,424	233,464,140
September 2017	71,091	242,562,818
October 2017	78,242	266,960,853
November 2017	64,301	219,396,358
December 2017	83,078	283,461,621
January 2018	79,664	271,814,776
February 2018	69,126	235,856,424
March 2018	78,664	268,400,318
April 2018	70,648	241,051,008
May 2018	52,457	178,984,018
June 2018	53,007	180,860,661
July 2018	55,368	188,916,575
August 2018	54,199	184,927,165
September 2018	58,769	200,518,402
October 2018	71,189	242,896,390
November 2018	80,207	273,665,952
December 2018	78,344	267,310,494
January 2019	76,642	261,501,015
February 2019	53,082	181,115,676
March 2019	53,583	182,824,531
April 2019	56,089	191,374,325
May 2019	53,204	181,531,226
June 2019	46,069	157,188,236
July 2019	51,601	176,063,226
August 2019	55,374	188,936,521
Total October 2016 - August 2019	**2,352,978**	**8,028,361,479**

* Note - These months energy removed were recalculated and different from the monthly reports.

APPENDIX A

NECK HEAT EXTRACTION SYSTEM AS-BUILT PLAN VIEW DRAWING



LEGEND

(light line)	EXISTING TOPOGRAPHY (2' CONTOUR)
—500—	EXISTING TOPOGRAPHY (10' CONTOUR)
(red line)	COOLING LOOP EFFLUENT PIPING 4"
(blue line)	COOLING LOOP INFLUENT PIPING 4"
(pink line)	COOLING LOOP EFFLUENT PIPING 2"
(cyan line)	COOLING LOOP INFLUENT PIPING 2"
●	TEMPERATURE MONITORING LOCATION
×	CHECK VALVE
⋈	FLOW CONTROL VALVE
○	FLOWMETERS
— SW — SW — SW —	SOLID WASTE PERMIT BOUNDARY
(dash line)	QUARRY HIGHWALL
TMP-6	TEMPERATURE MONITORING PROBE
TMP-SPM3	TEMPERATURE MONITORING PROBE - SYSTEM PERFORMANCE MONITORING
⧗	HEAT EXTRACTION POINT

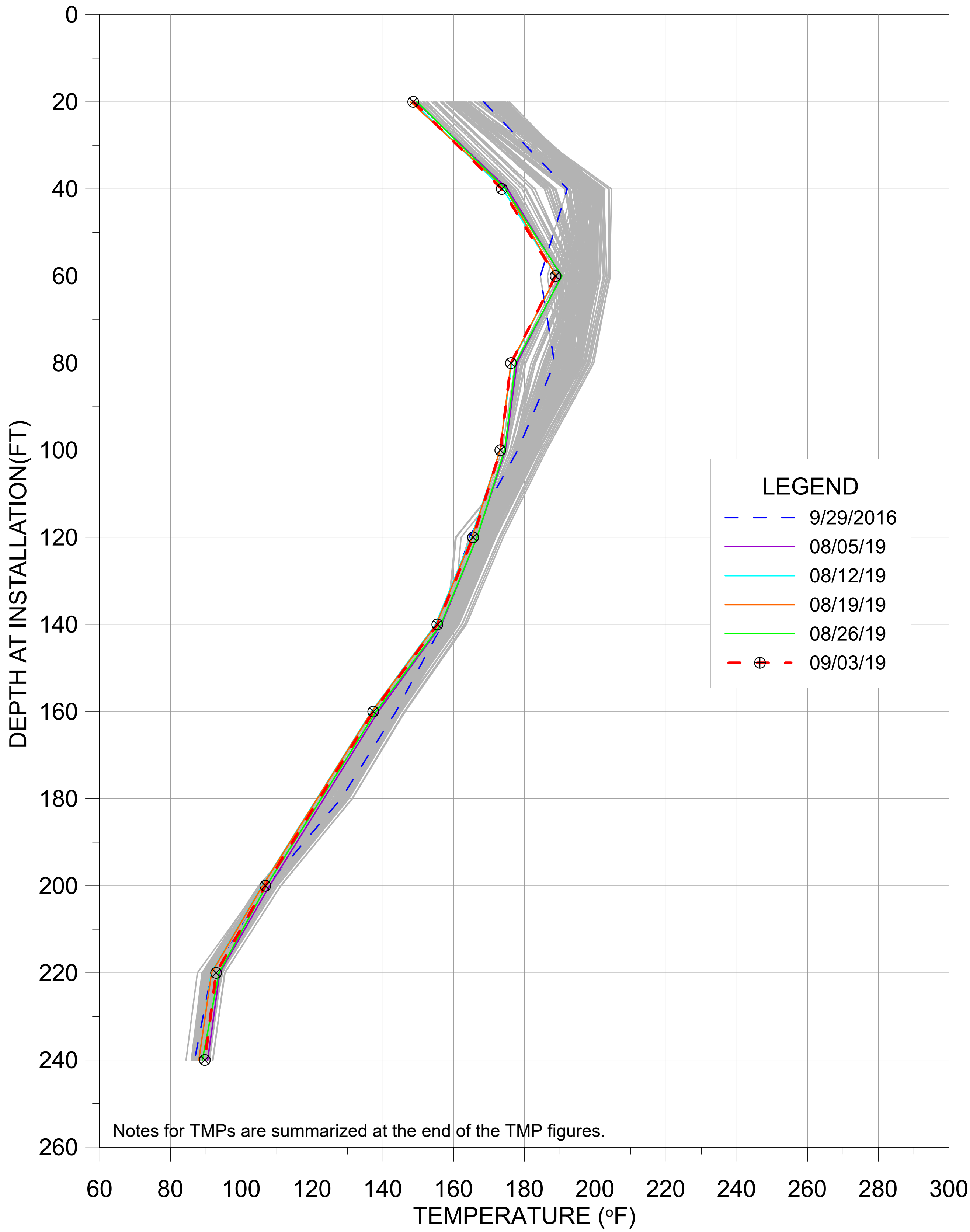
NOTE:
AERIAL TOPOGRAPHY PROVIDED BY COOPER AERIAL SURVEYS, INC. AND IS DATED DECEMBER 12, 2018

JONATHAN E. WILKINSON PE-2006029714 (Seal: STATE OF MISSOURI, JONATHAN E. WILKINSON, NUMBER PE-2006029714, PROFESSIONAL ENGINEER; signed 9/20/2019)	PREPARED BY FEEZOR ENGINEERING, INC. Engineering for a Better World. 3377 Hollenberg Dr, Bridgeton, MO 63044, Ph: 217-483-3118. Missouri State Certificate Of Authority #: E-200912211	PROJECT BRIDGETON LANDFILL HEAT EXTRACTION SYSTEM BRIDGETON, ST. LOUIS COUNTY, MISSOURI	PREPARED FOR BRIDGETON LANDFILL LLC 13570 ST. CHARLES ROCK ROAD BRIDGETON, MO 63044	SEPTEMBER 2019 DESIGNED BY: PML APPROVED BY: JEW	DRAWING A
		DRAWING TITLE PLAN SYSTEM VIEW		REVISIONS:	DATE / DSN. / APV.
		PROJECT NUMBER: BT-142	FILE PATH: C:\Users\plins\Dropbox (Feezor Engineering)\Bridgeton\100-149\BT-142 (2017 Heat Extraction Reporting)\2019\2019 Annual Report\Drawings\BT-142 A Plan System View		

APPENDIX B

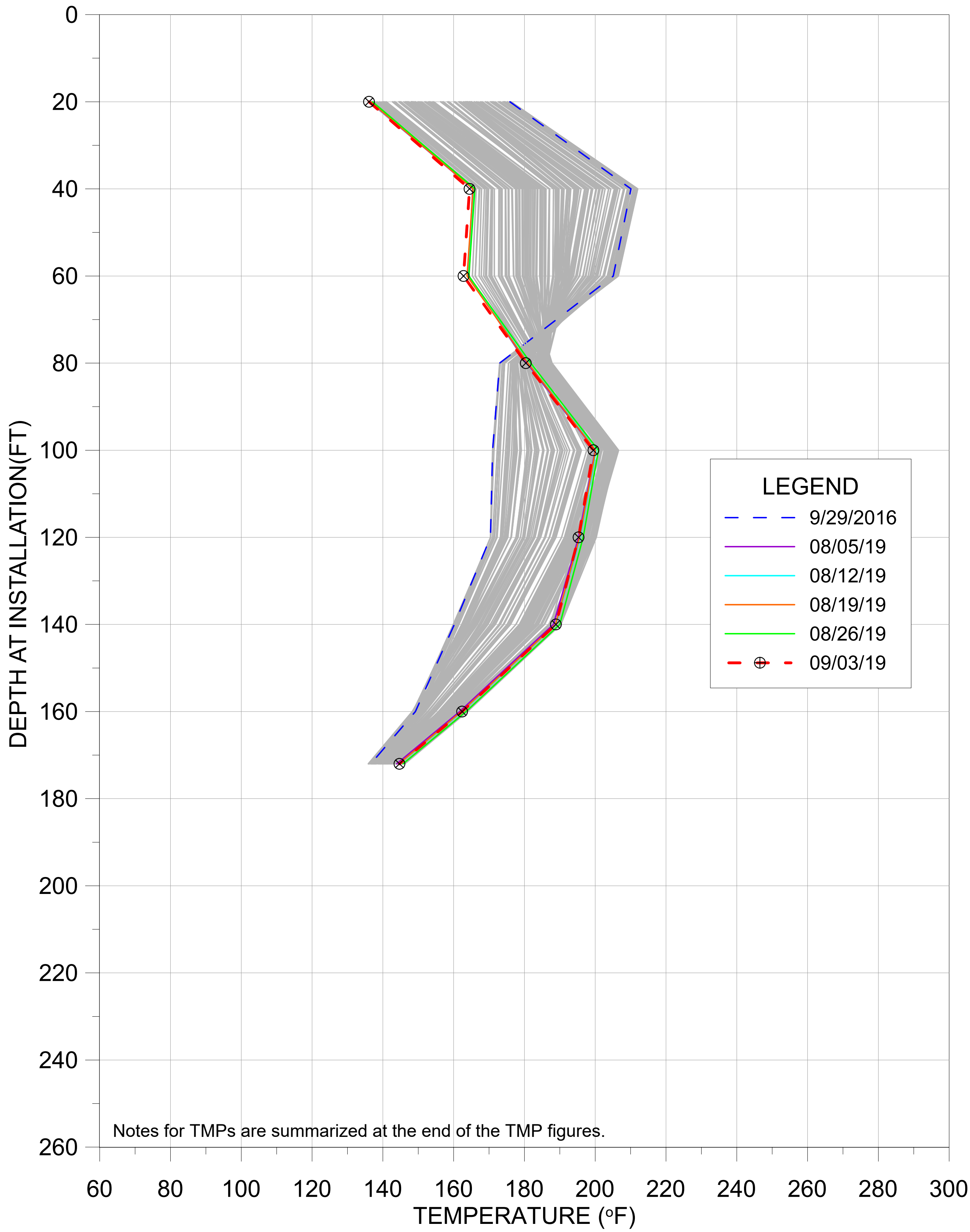
SYSTEM PERFORMANCE MONITORING (SPM) TMP GRAPHS AS OF 9/3/2019

TMP-SPM1



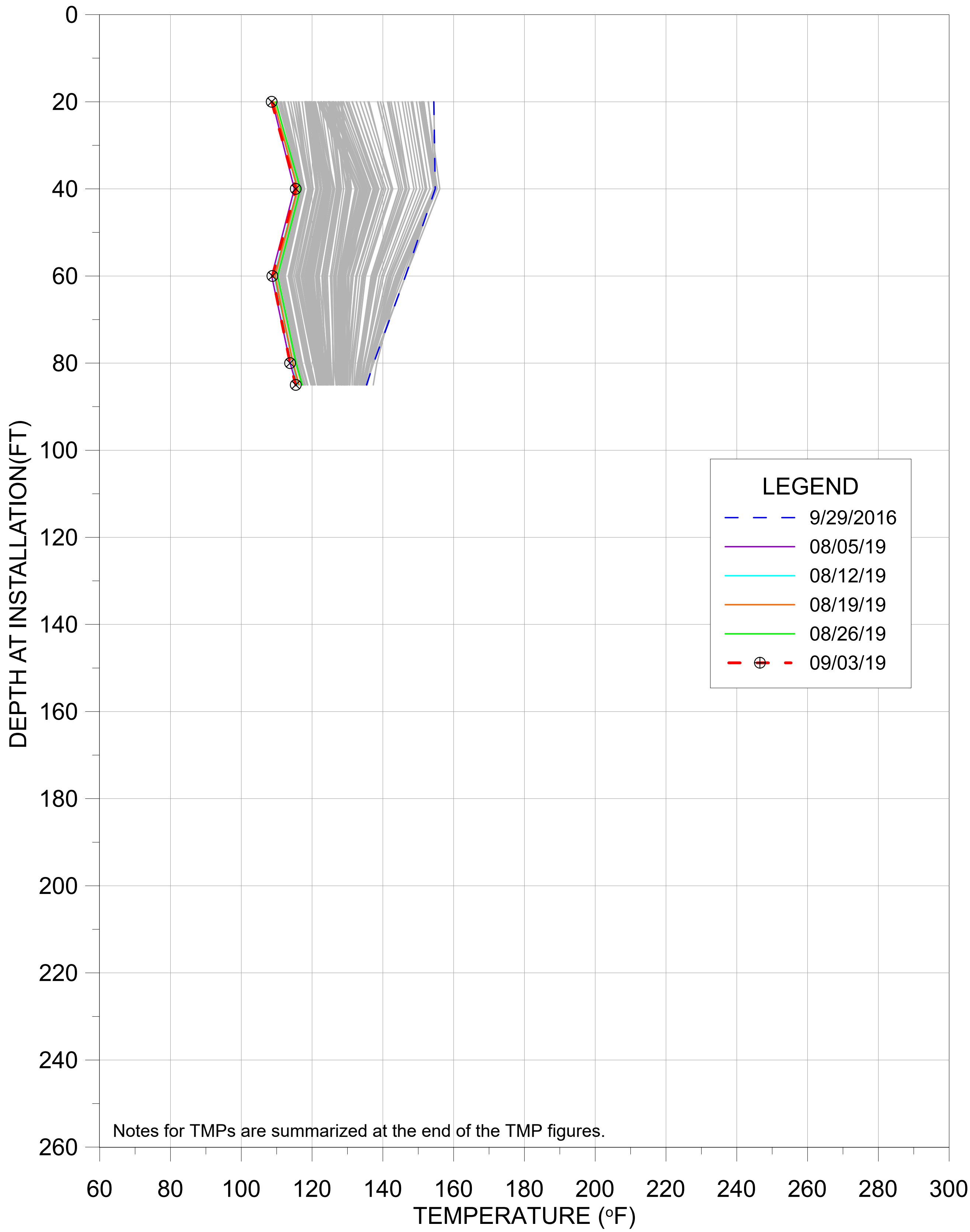
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-SPM2



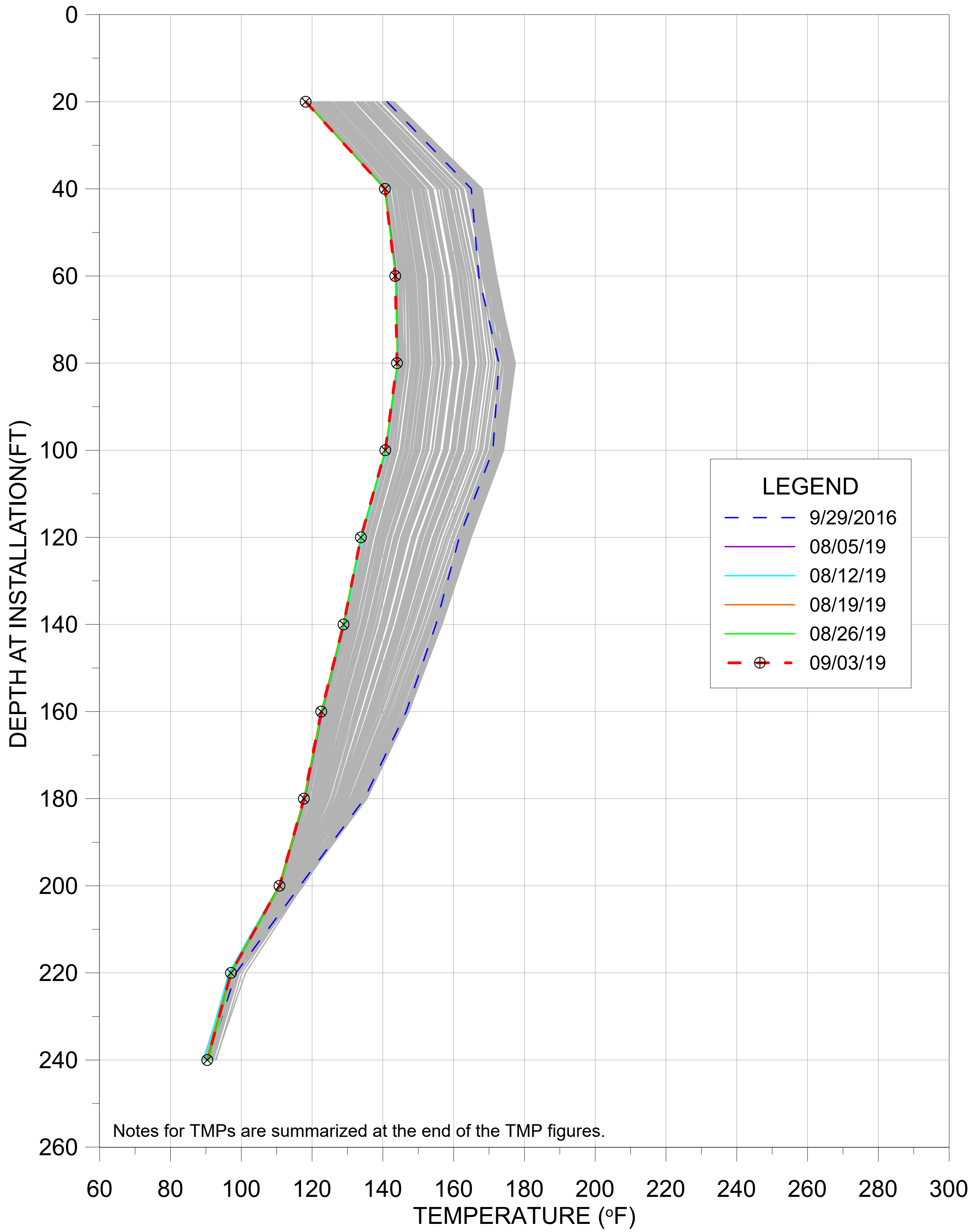
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-SPM3



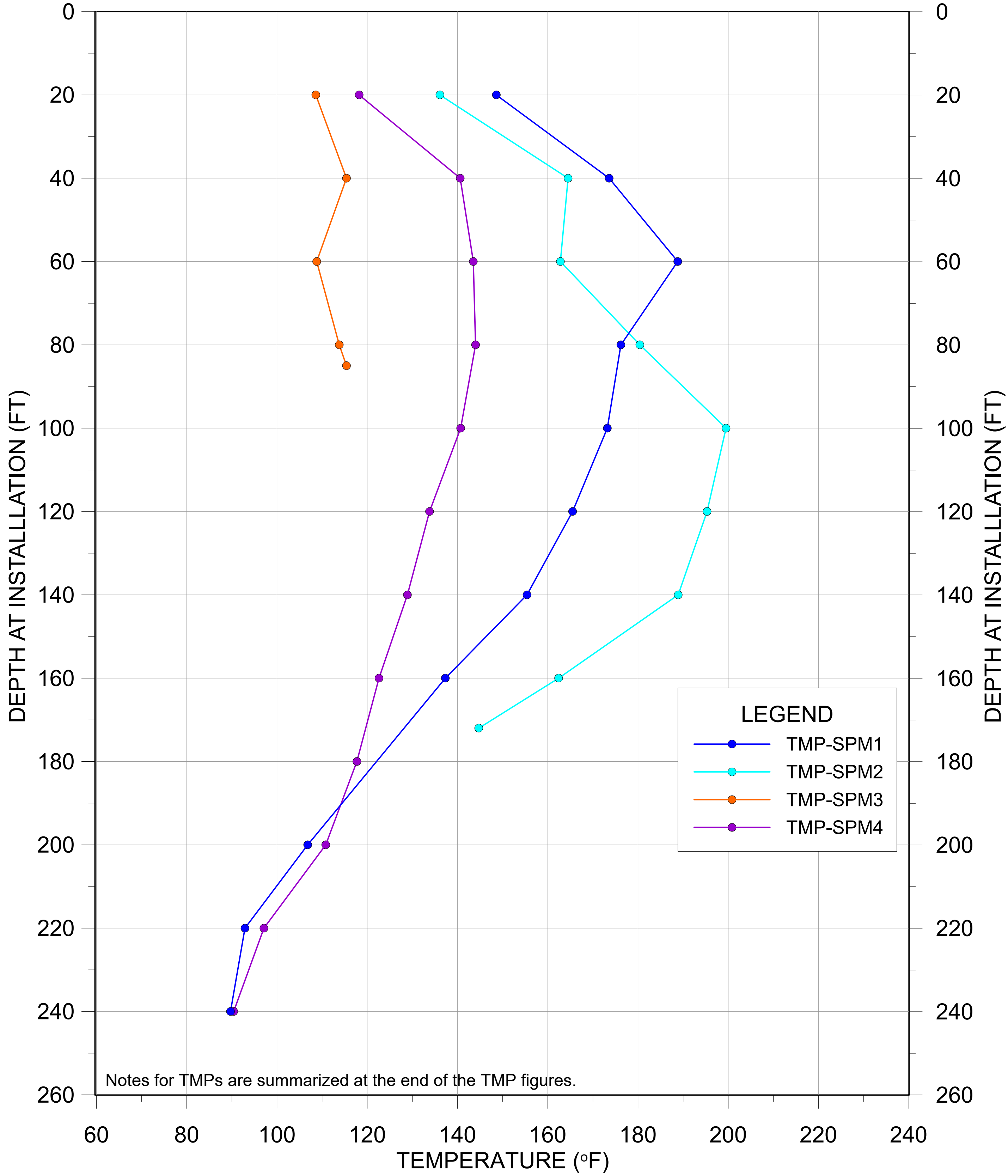
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-SPM4



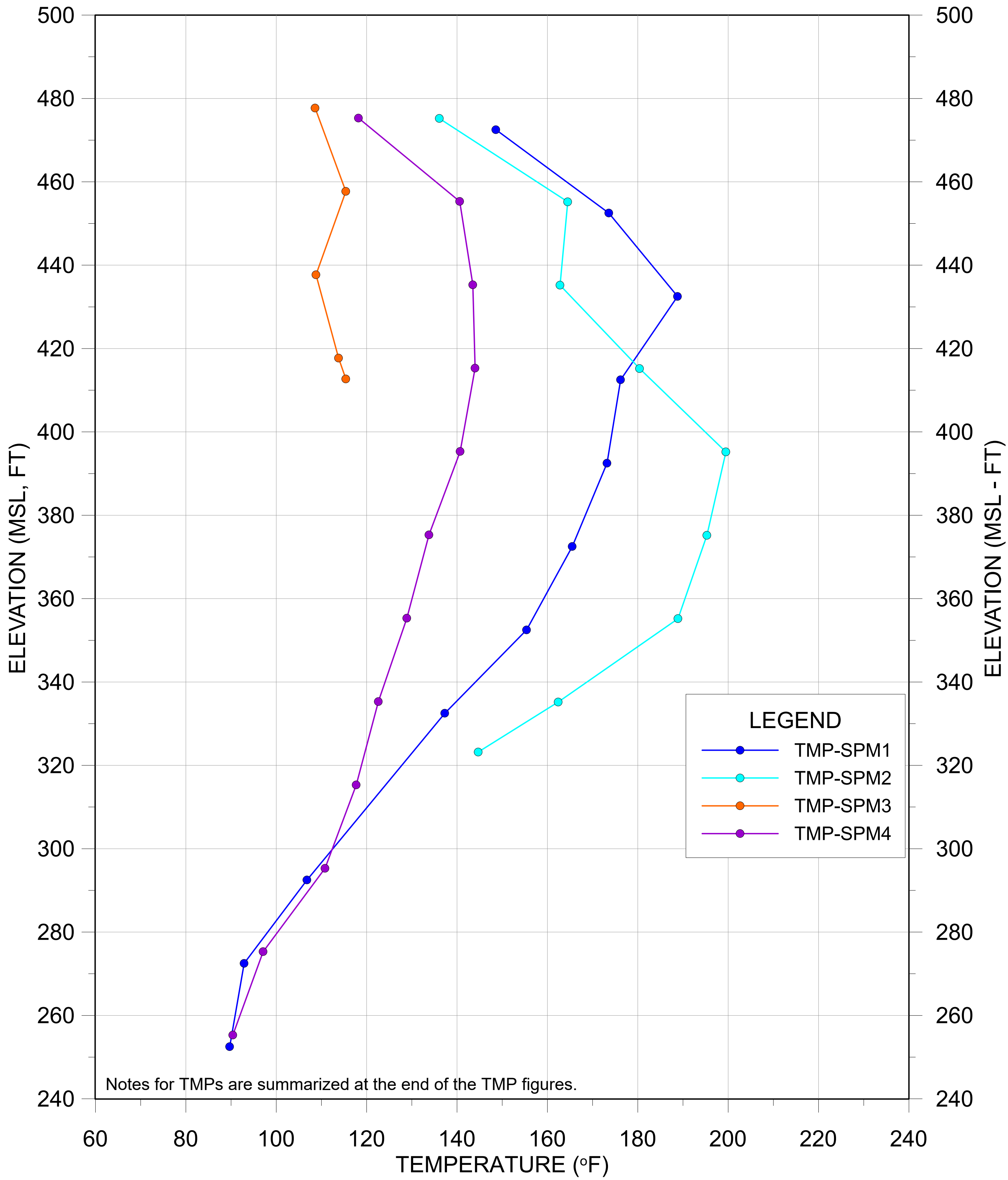
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

9/3/2019 - SPM



TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

9/3/2019 - SPM



TEMPERATURE VS ELEVATION
BRIDGETON LANDFILL

SPM BRIDGETON LANDFILL NOTES

Notes that are new for the reporting week are in **bold**.

SPM-1:

1. No temperature reading could be obtained and resistivity was fluctuating at the unit at 180 ft depth since 4/2/2018.

SPM-2: NONE

SPM-3: NONE

SPM-4: NONE

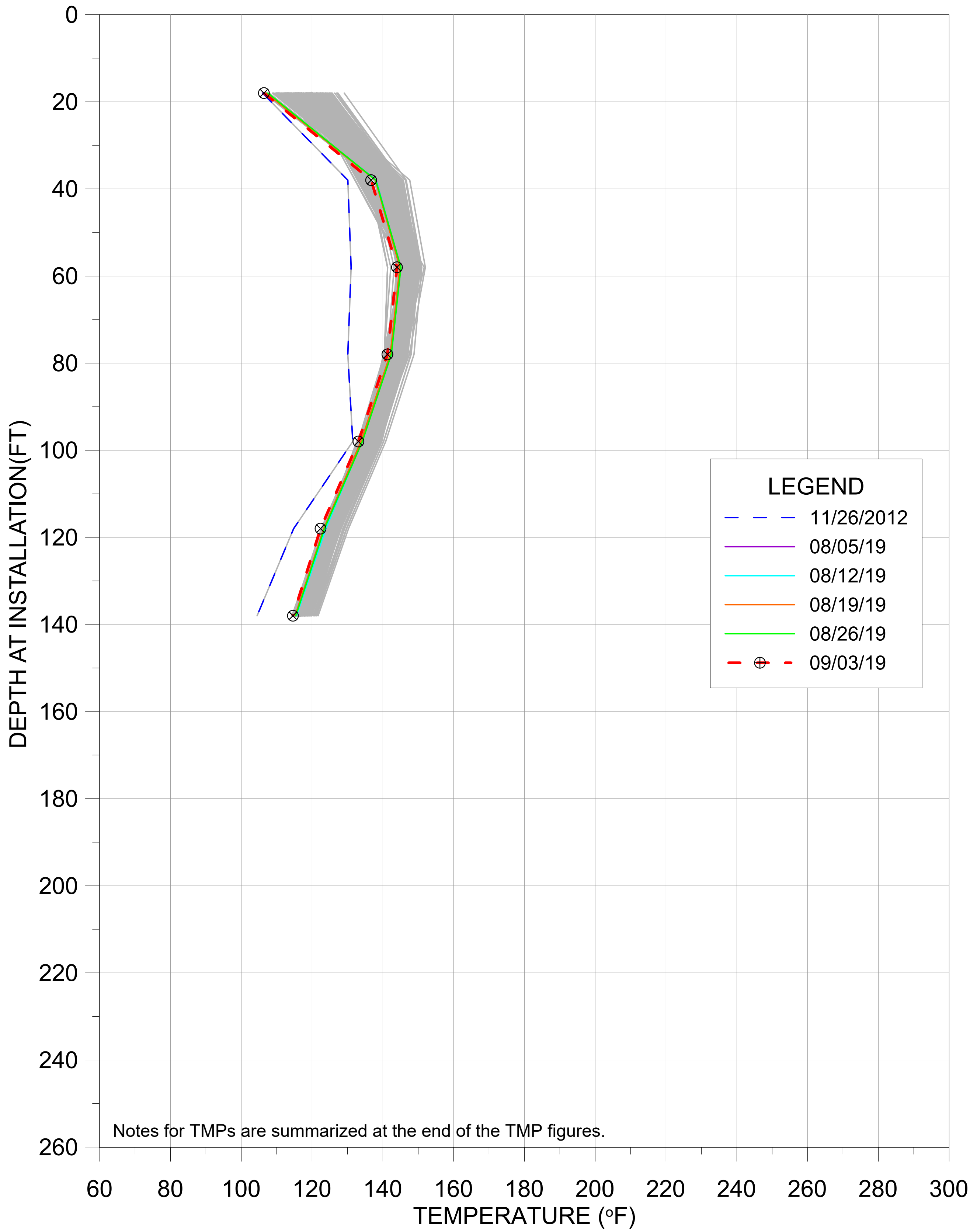
SPM TEMP VS DEPTH & DEPTH VS ELEVATION (**09/03/19**):

NONE

APPENDIX C

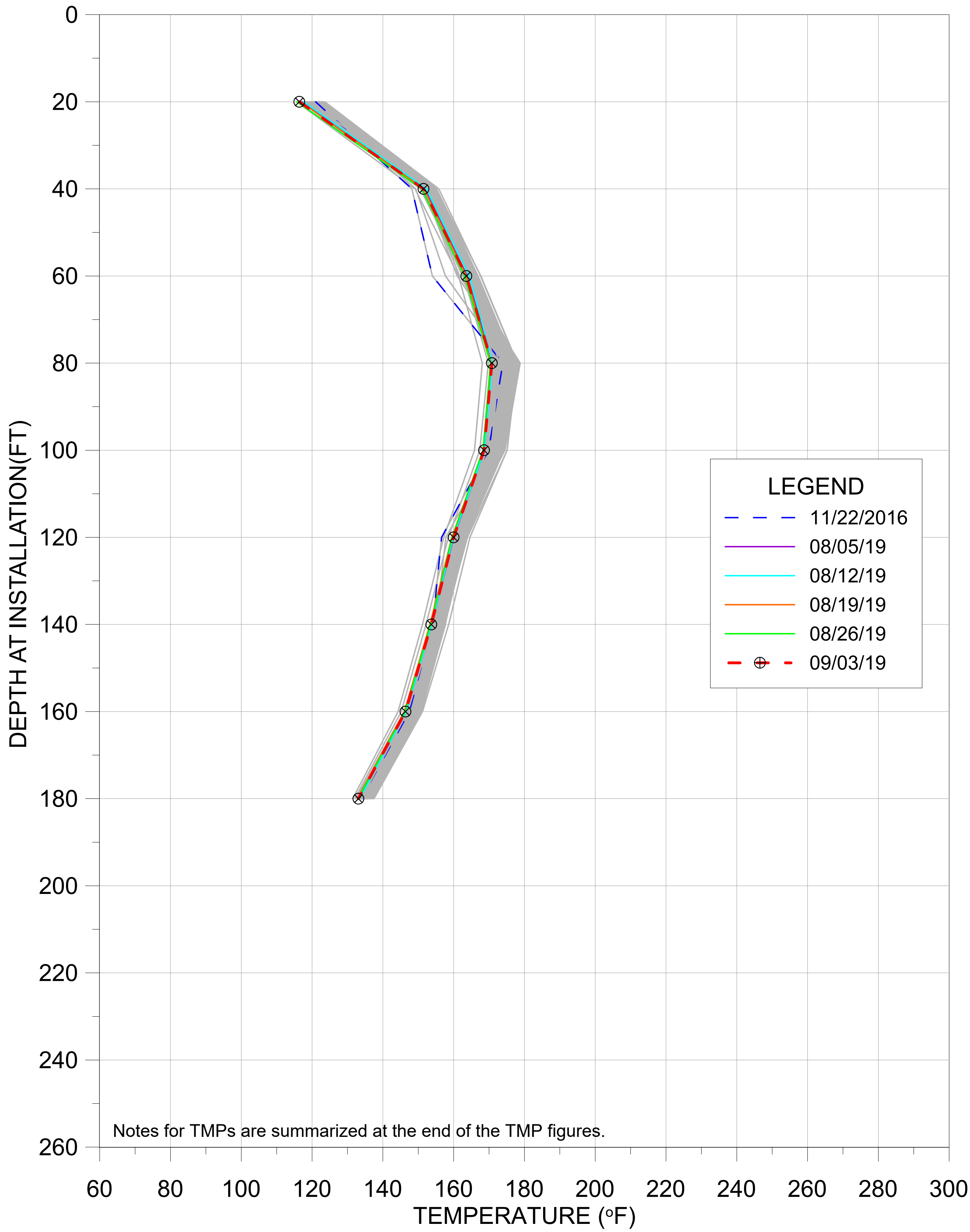
NECK AREA AND NORTH QUARRY TMP GRAPHS AS OF 9/3/2019

TMP-1



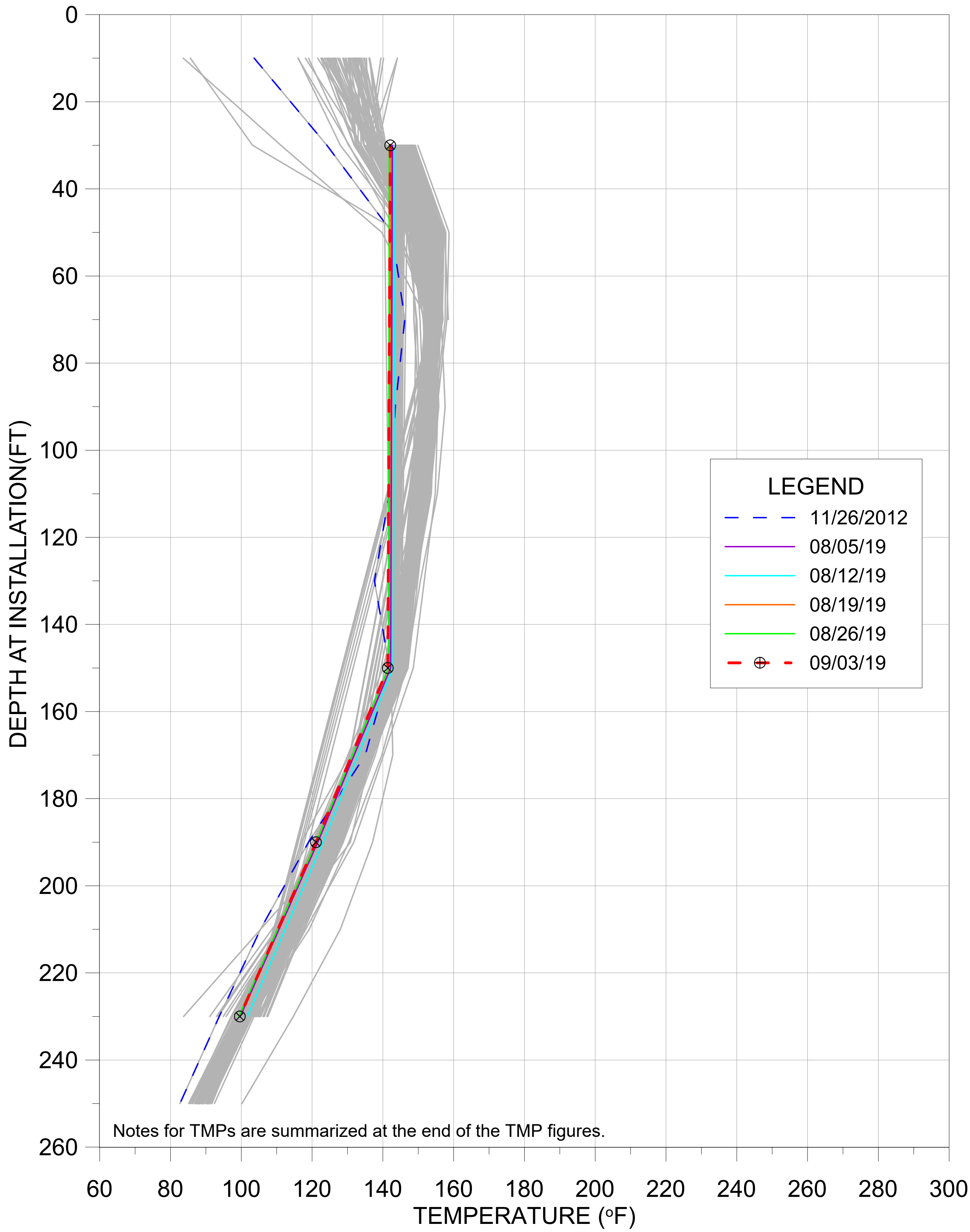
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-2R



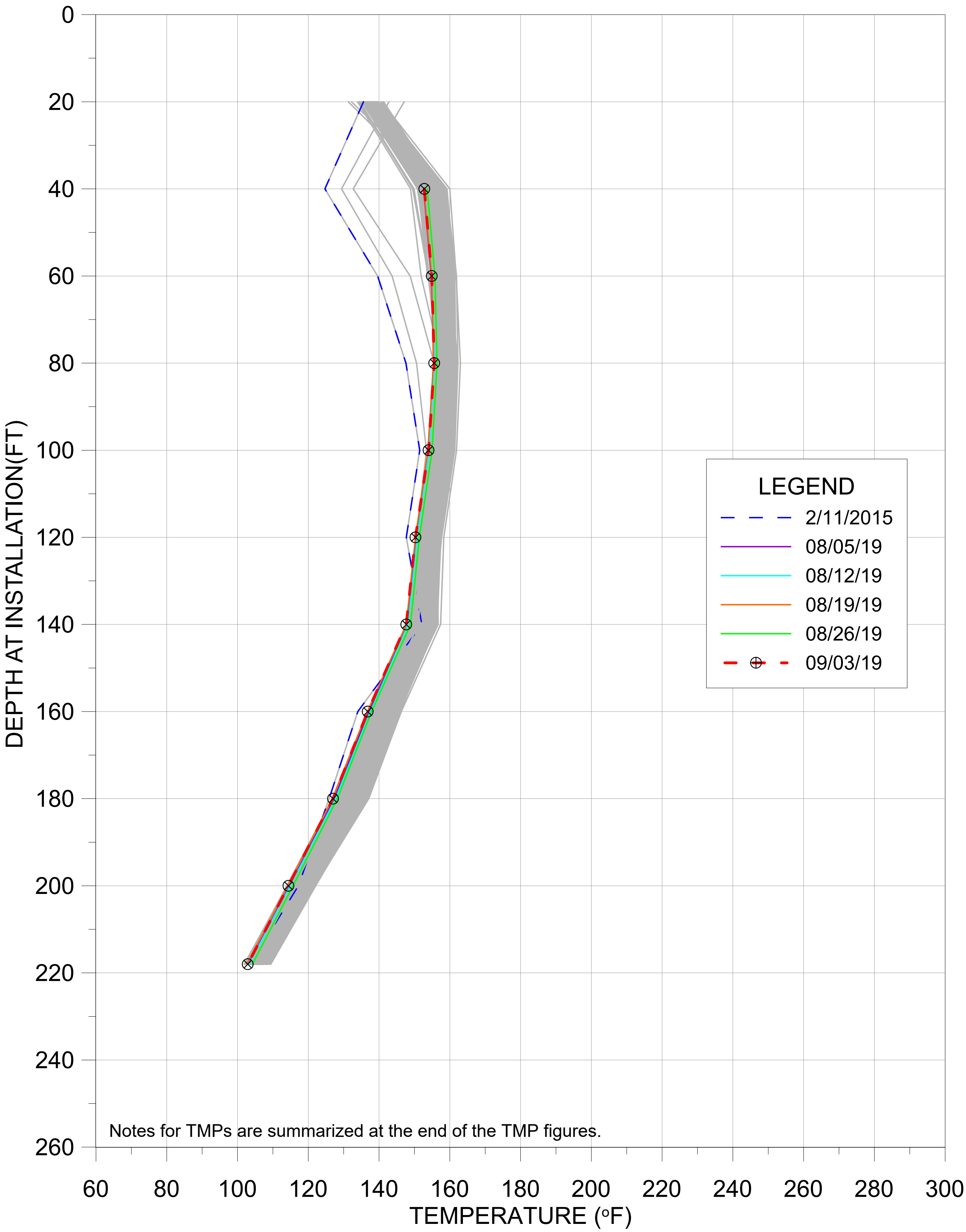
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-3



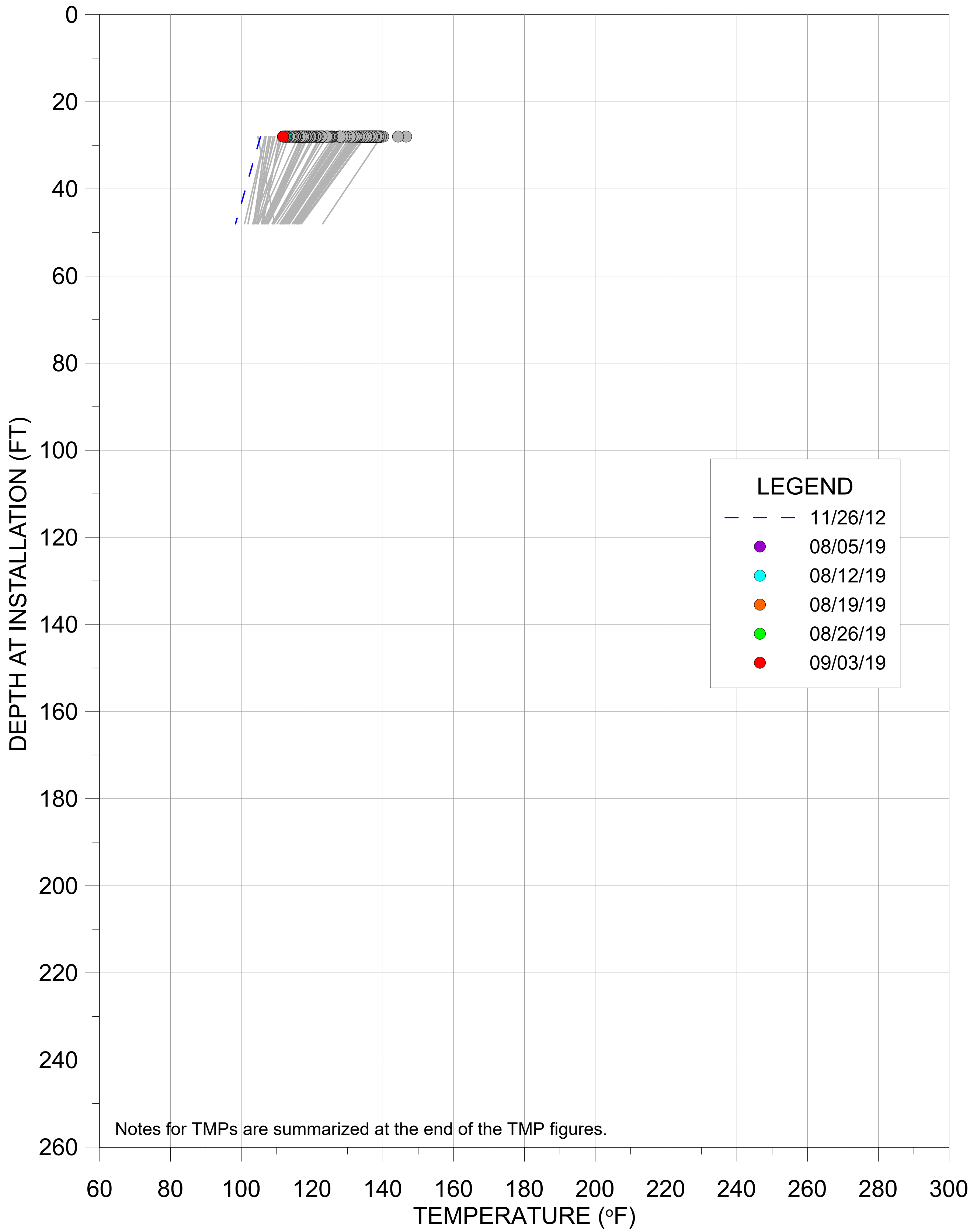
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-3R



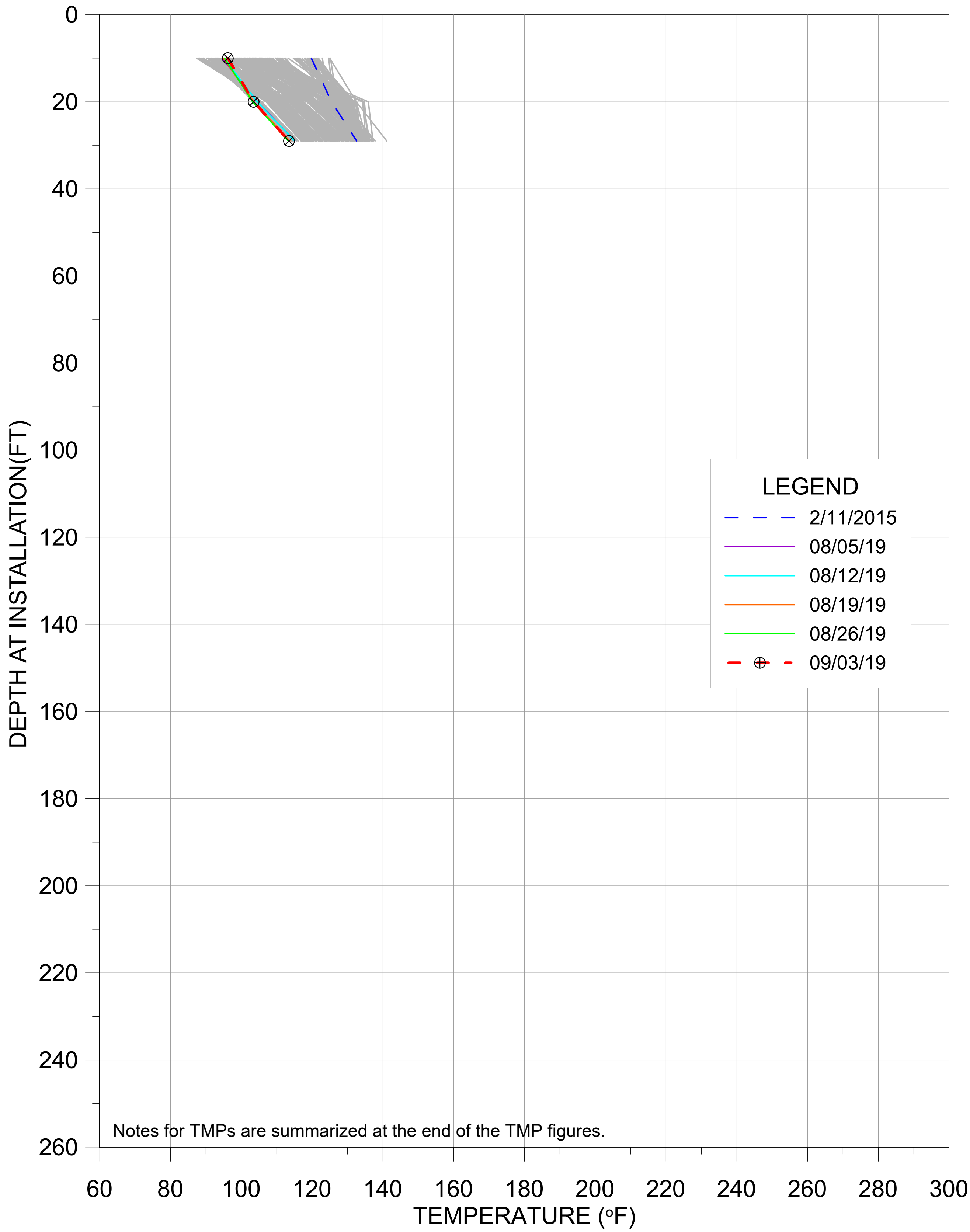
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-4



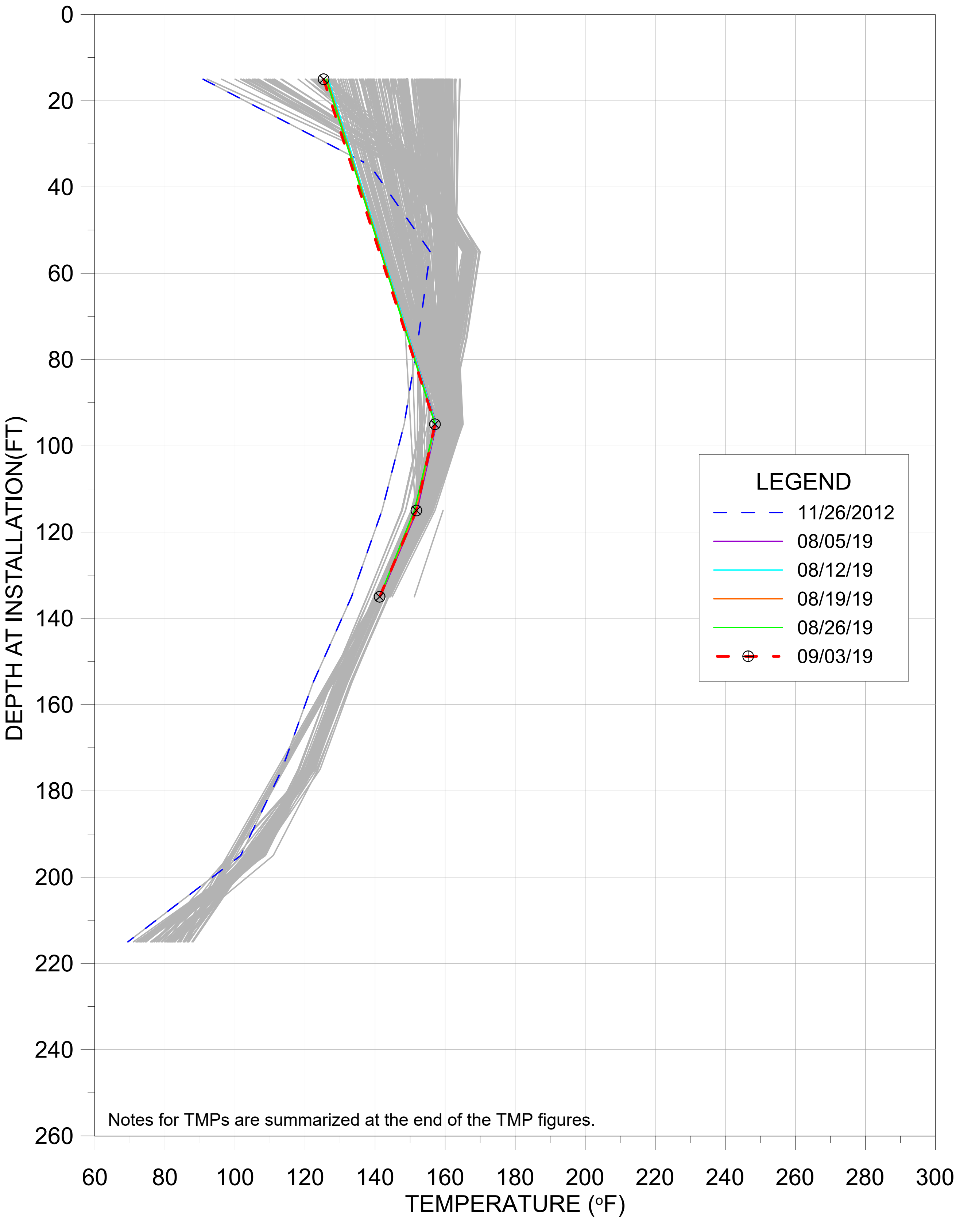
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-4R



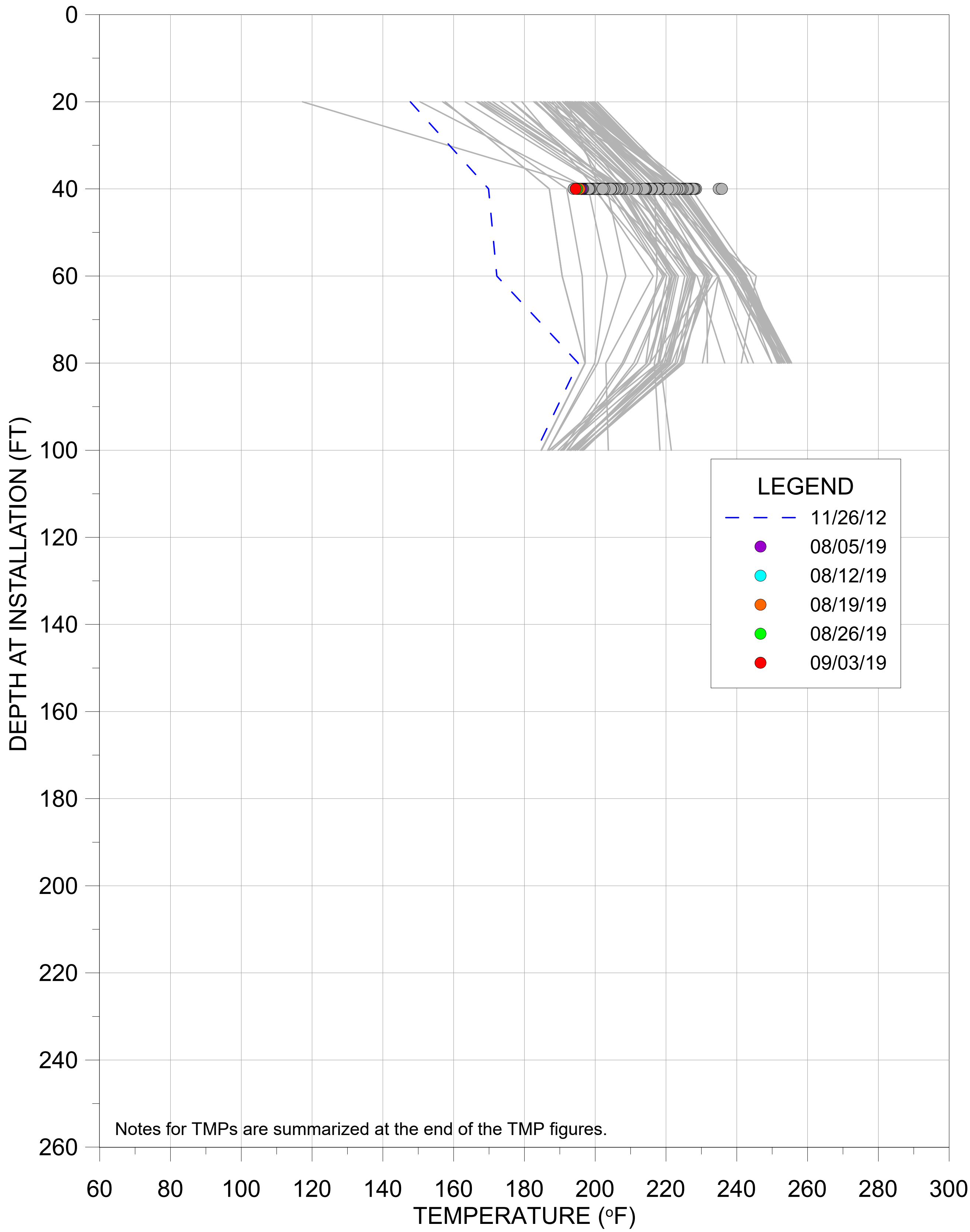
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-6



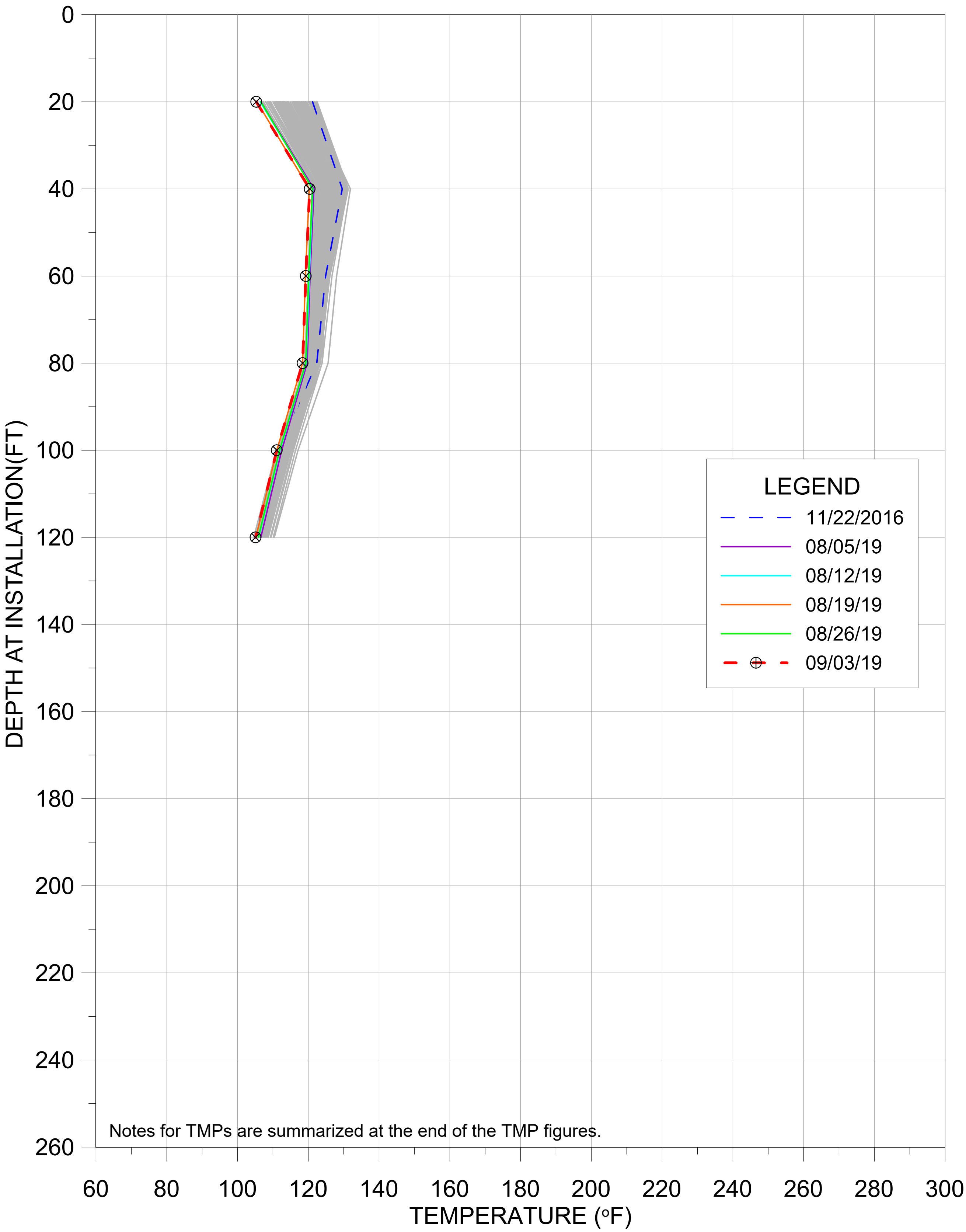
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-9



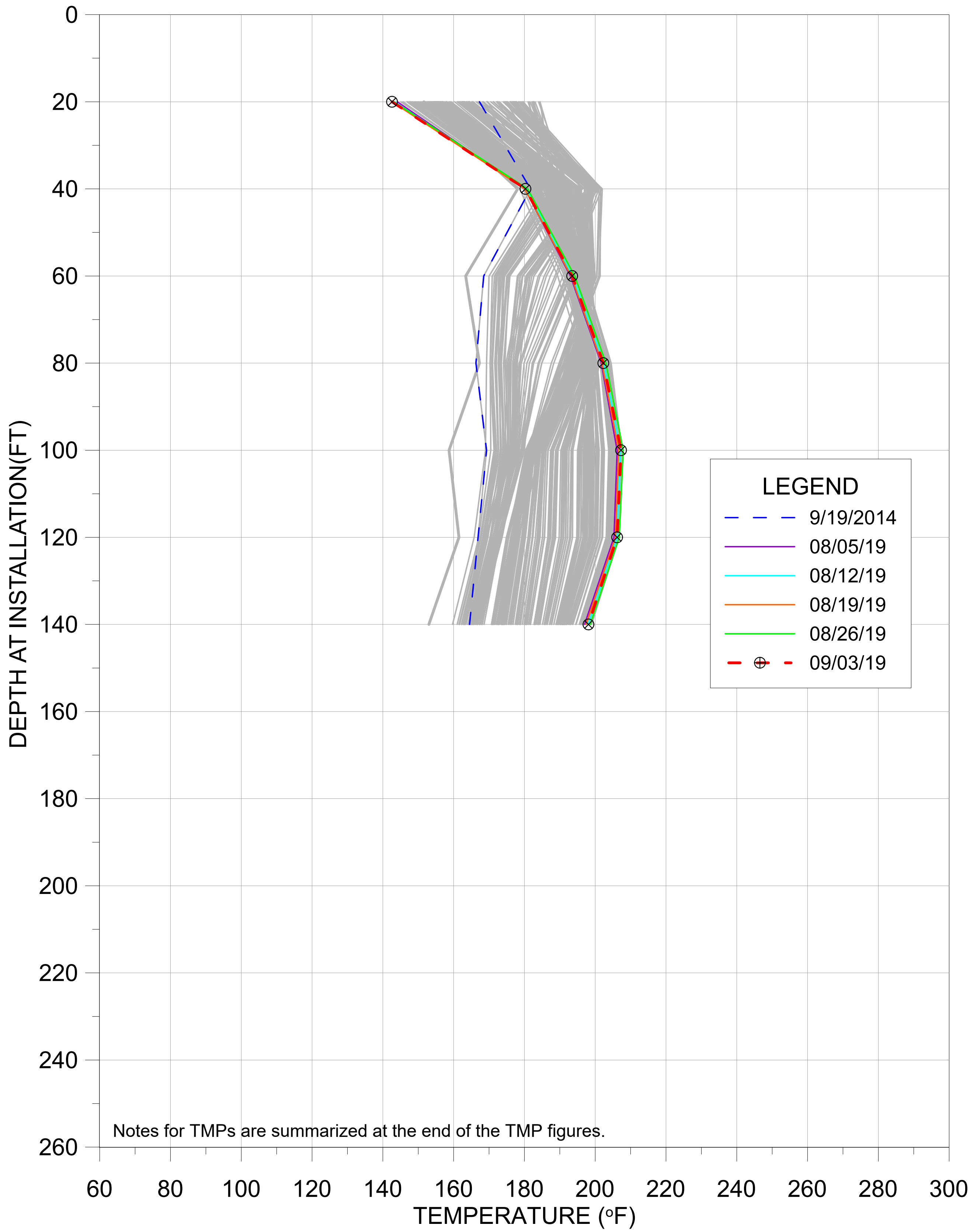
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-11R



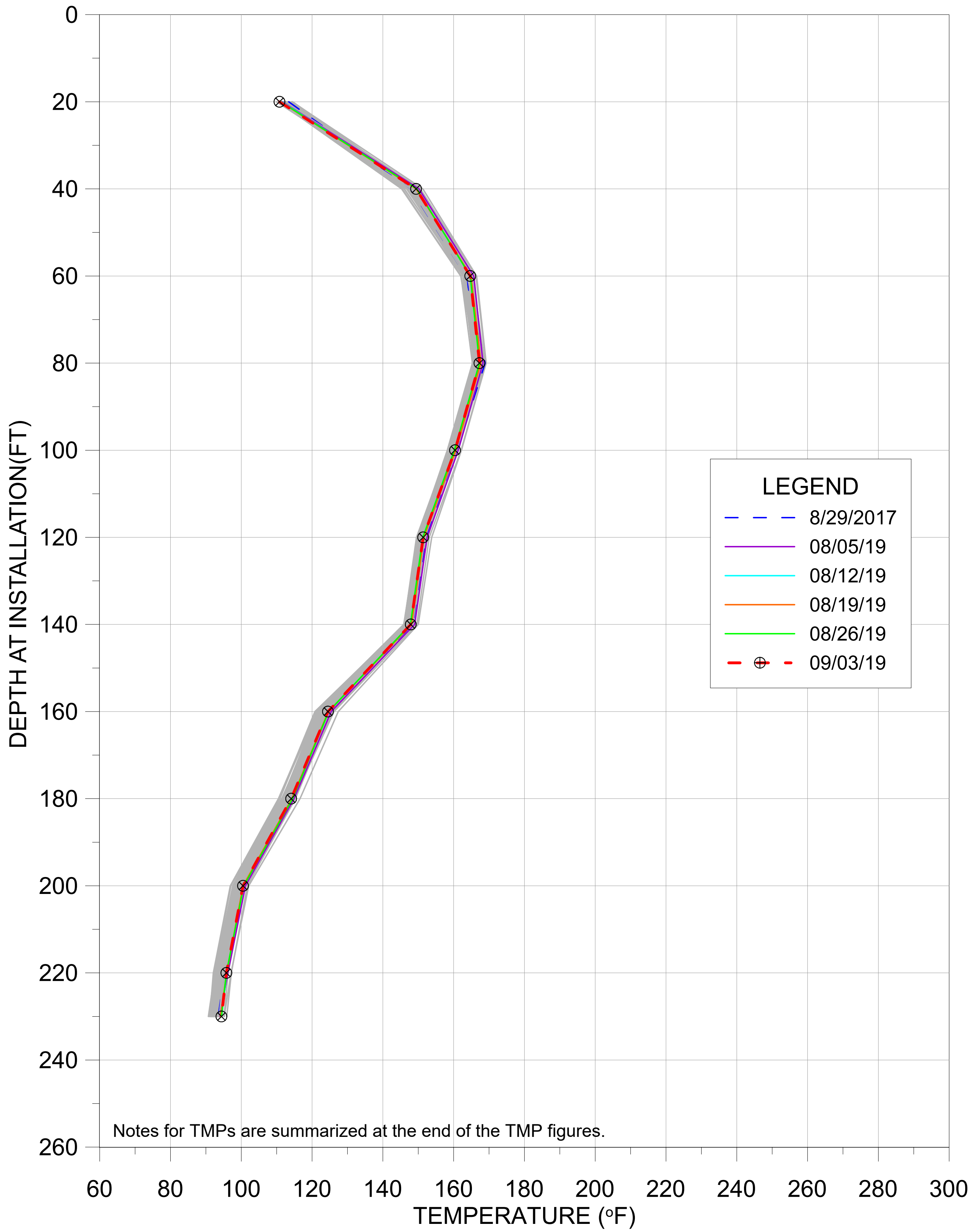
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-14R



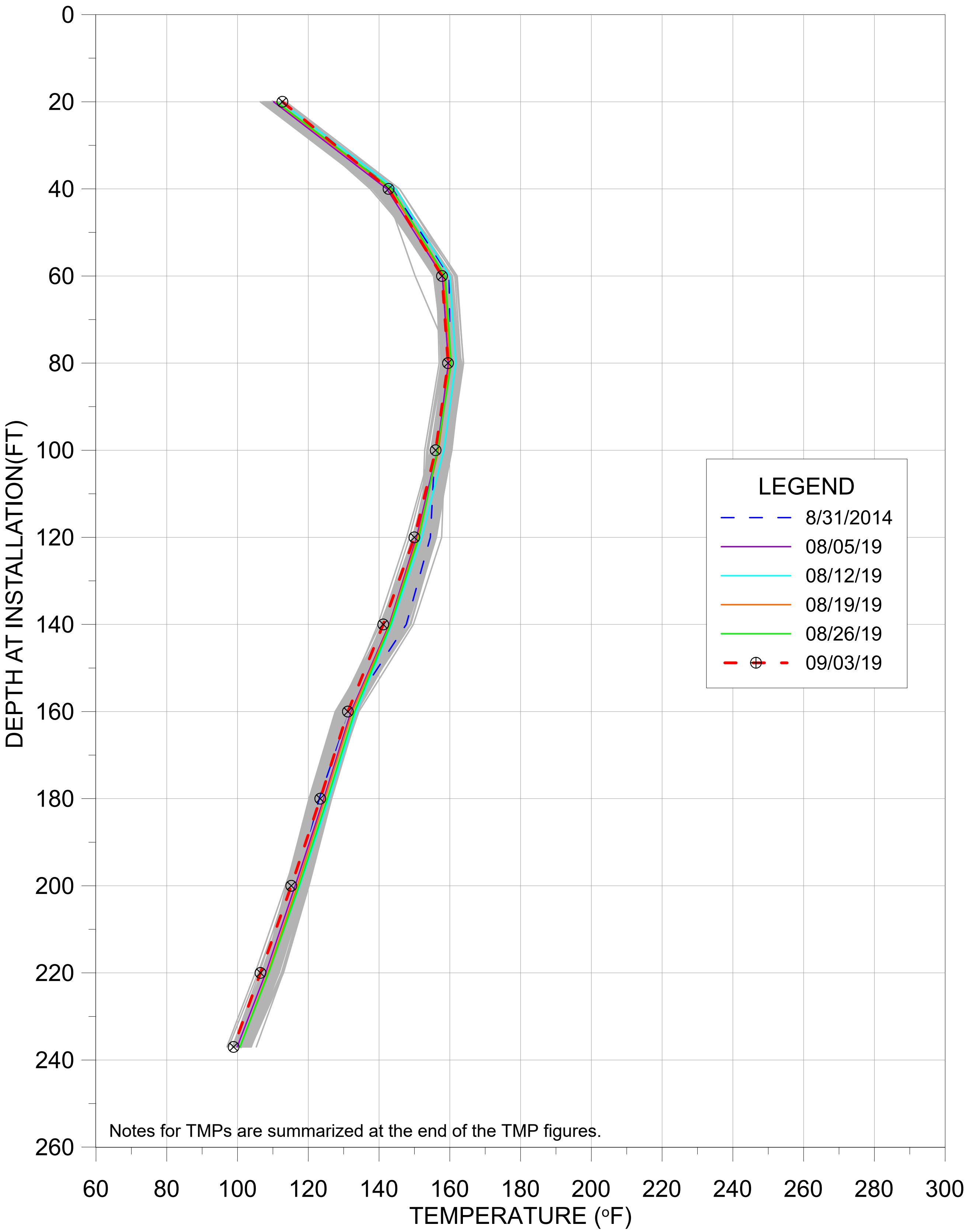
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-16R



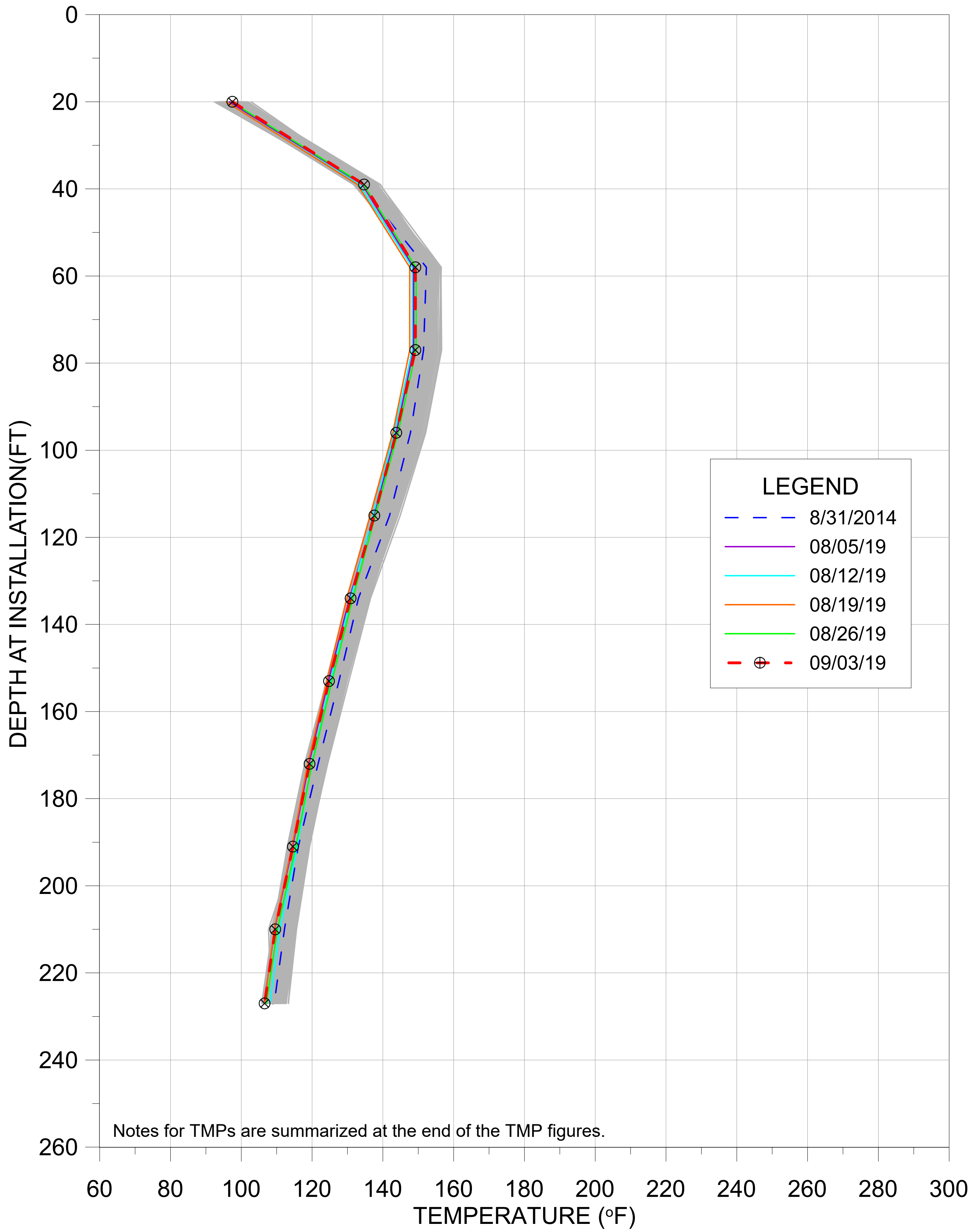
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-17



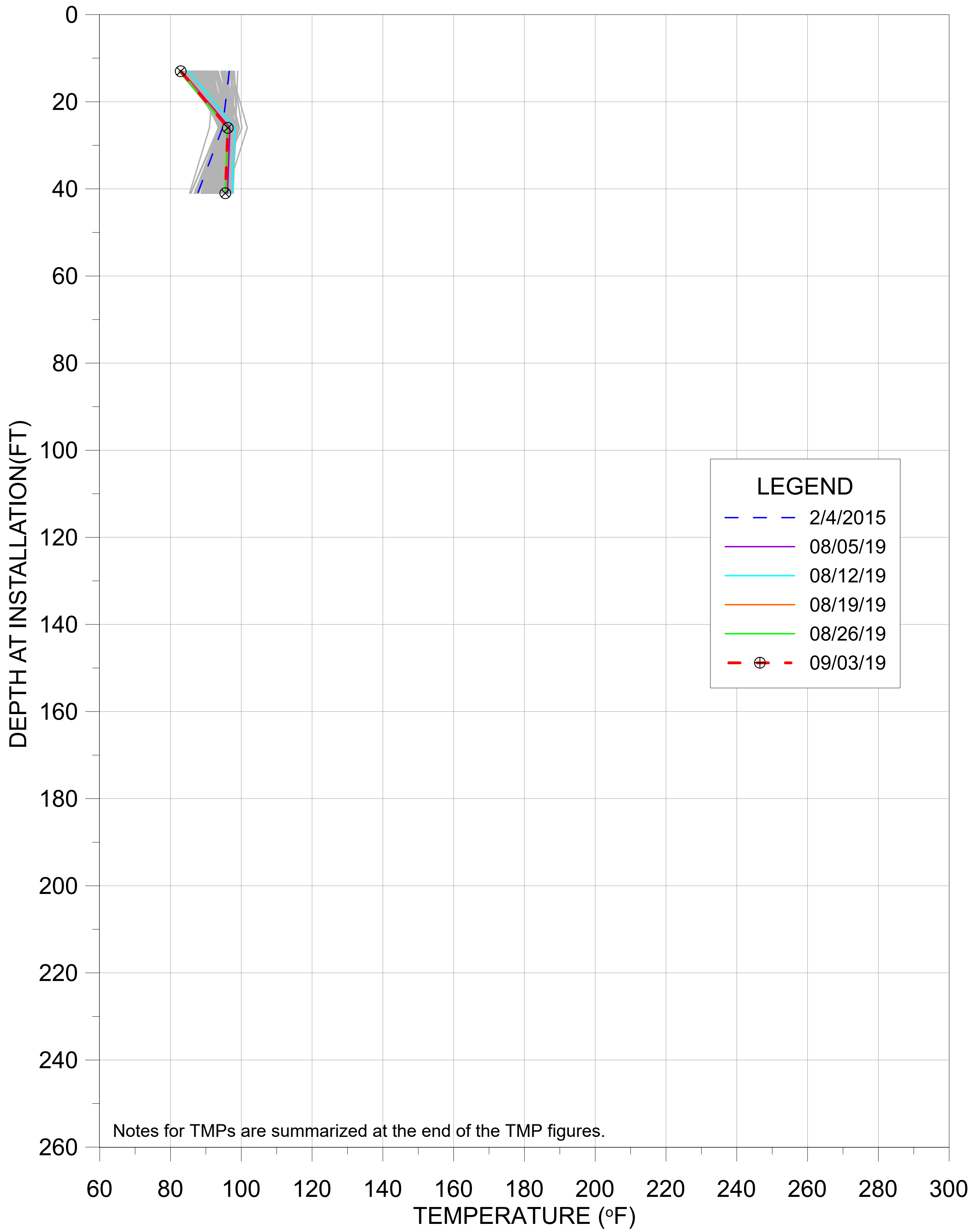
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-18



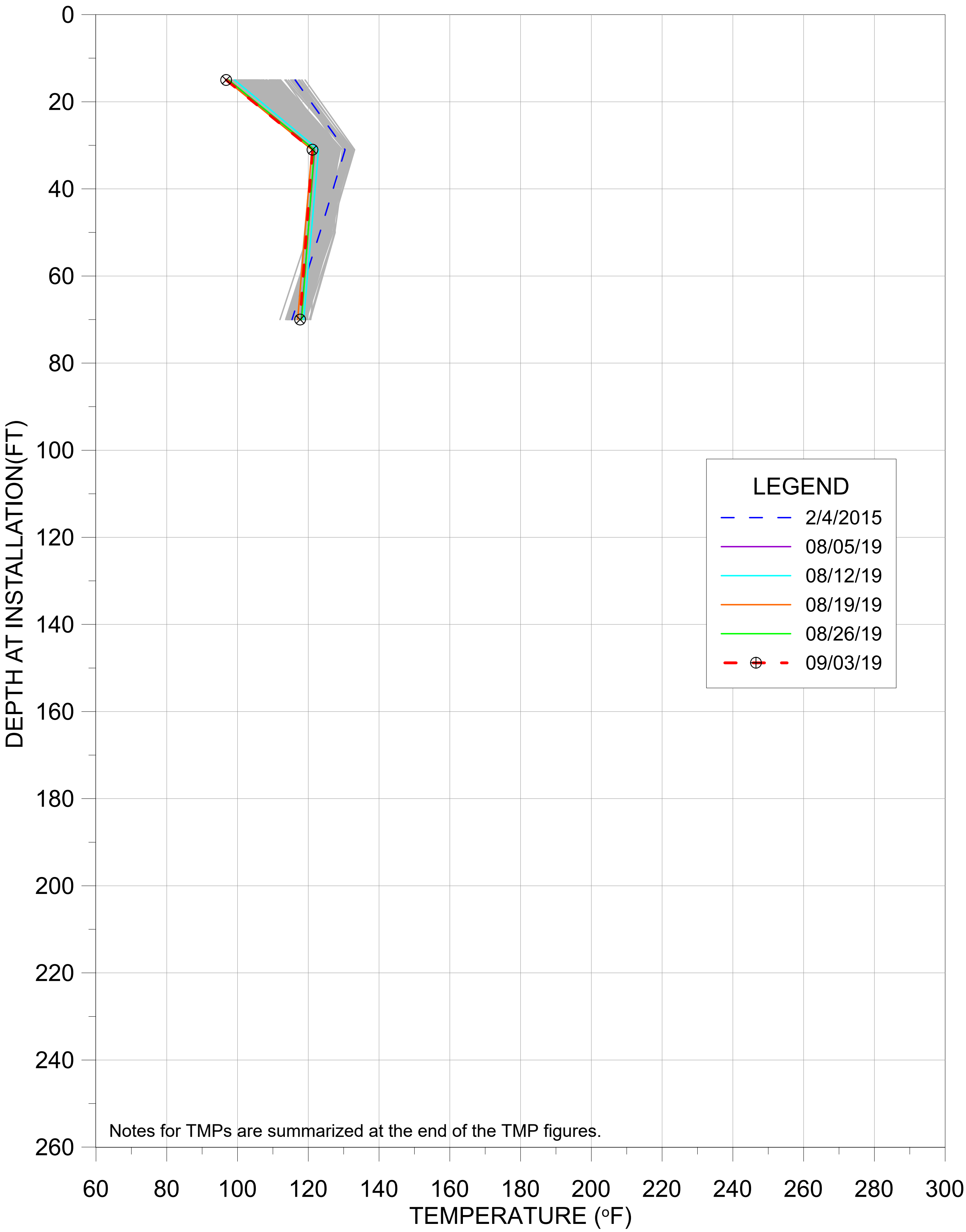
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-21



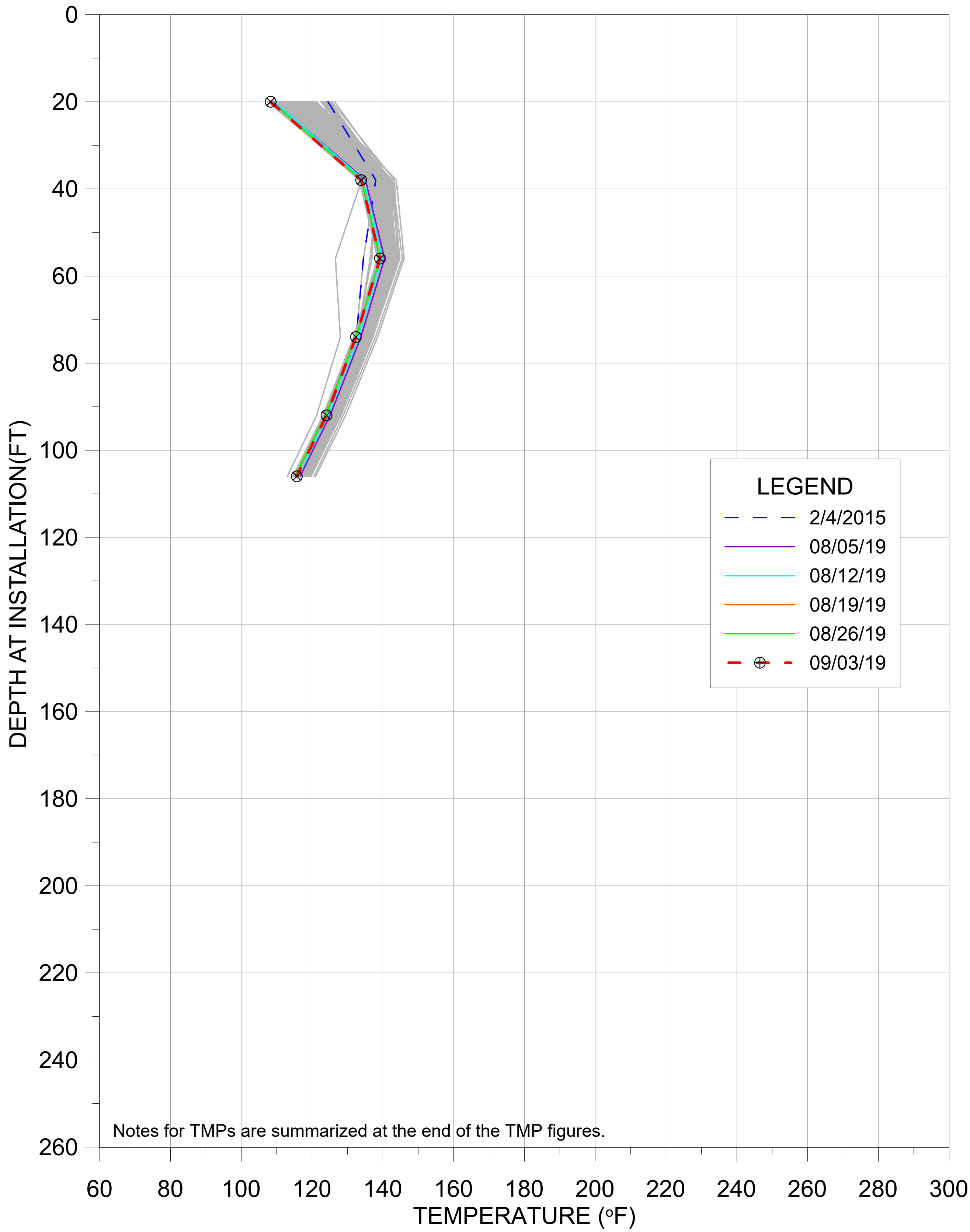
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-22



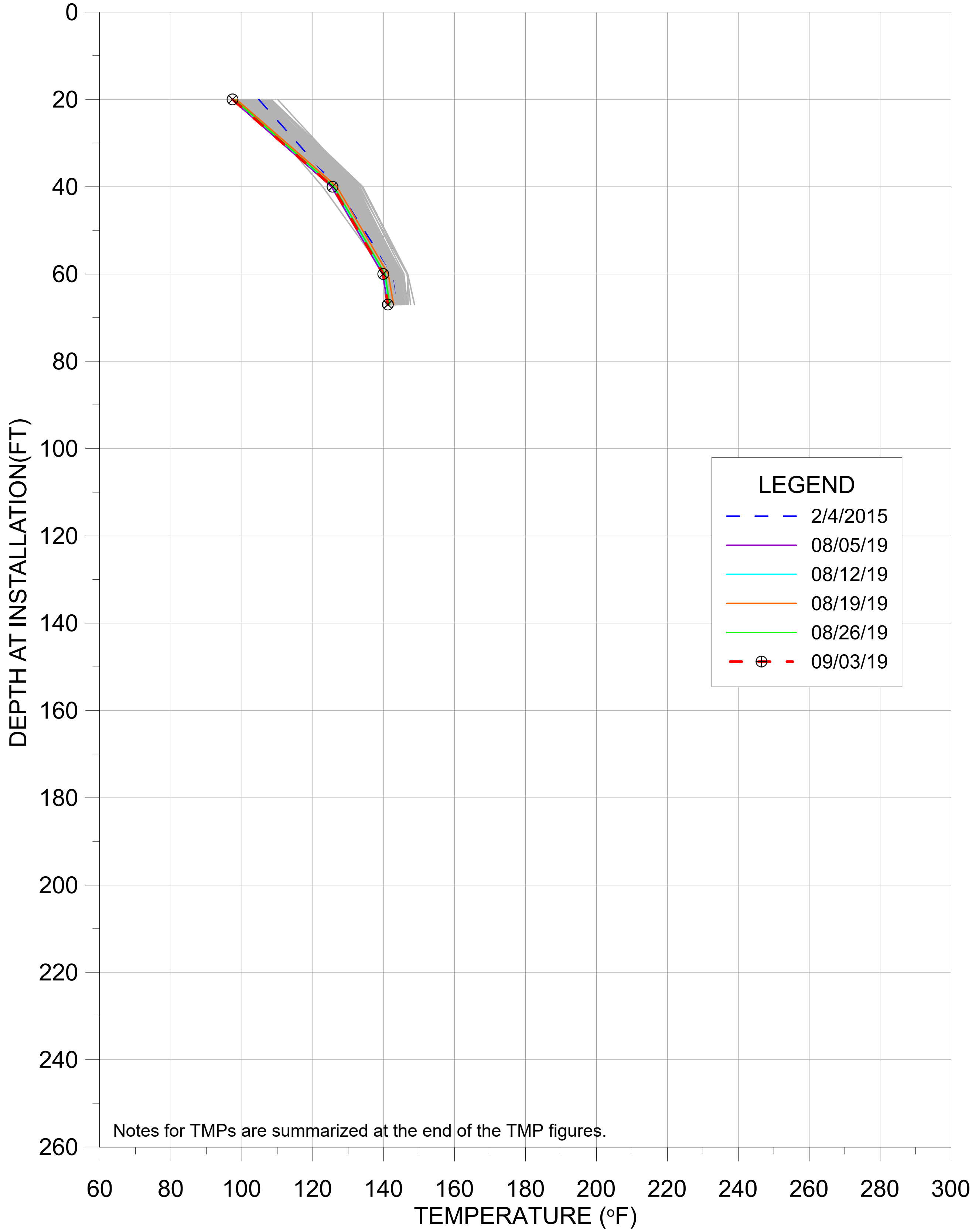
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-23



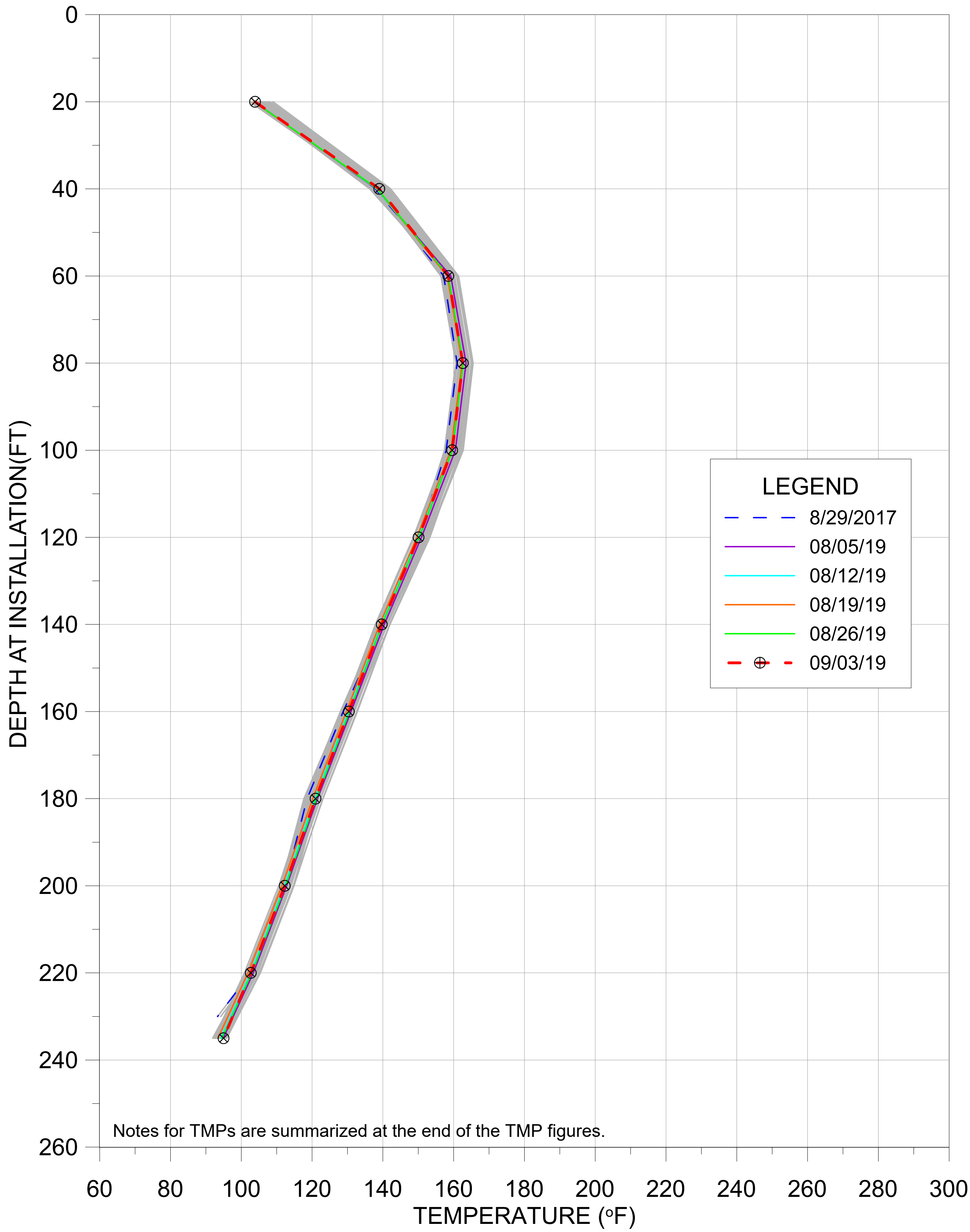
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-24



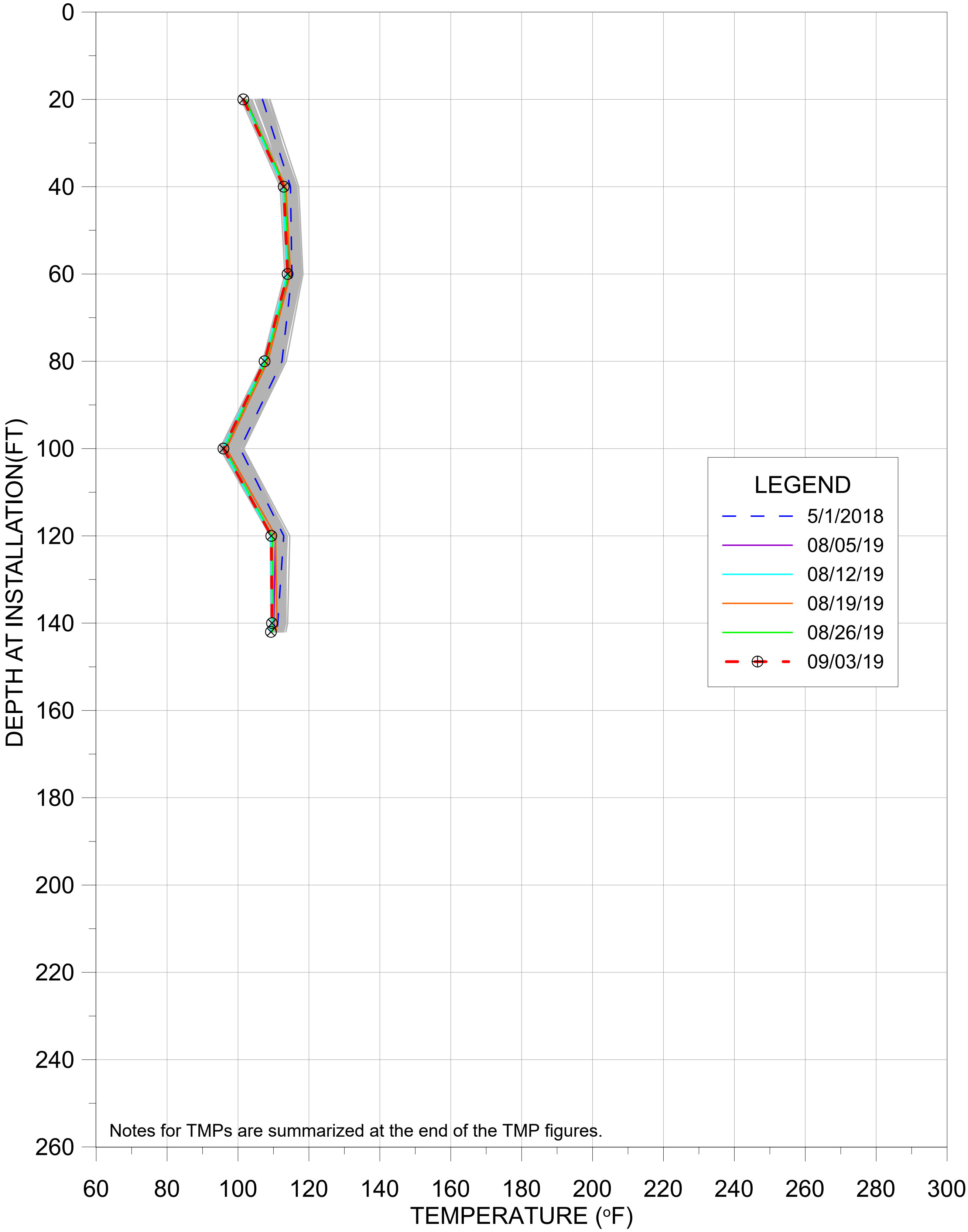
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-25R



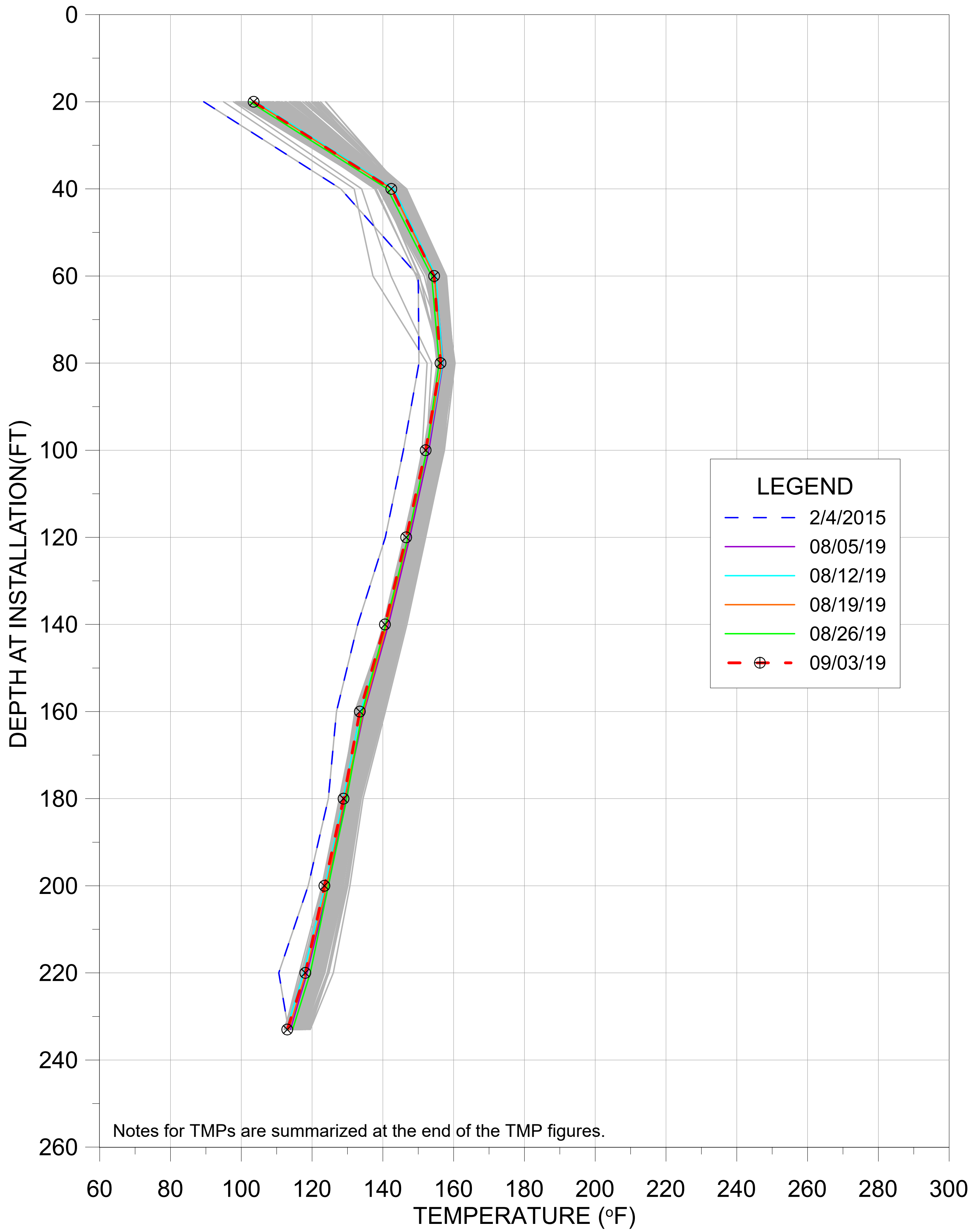
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-26R



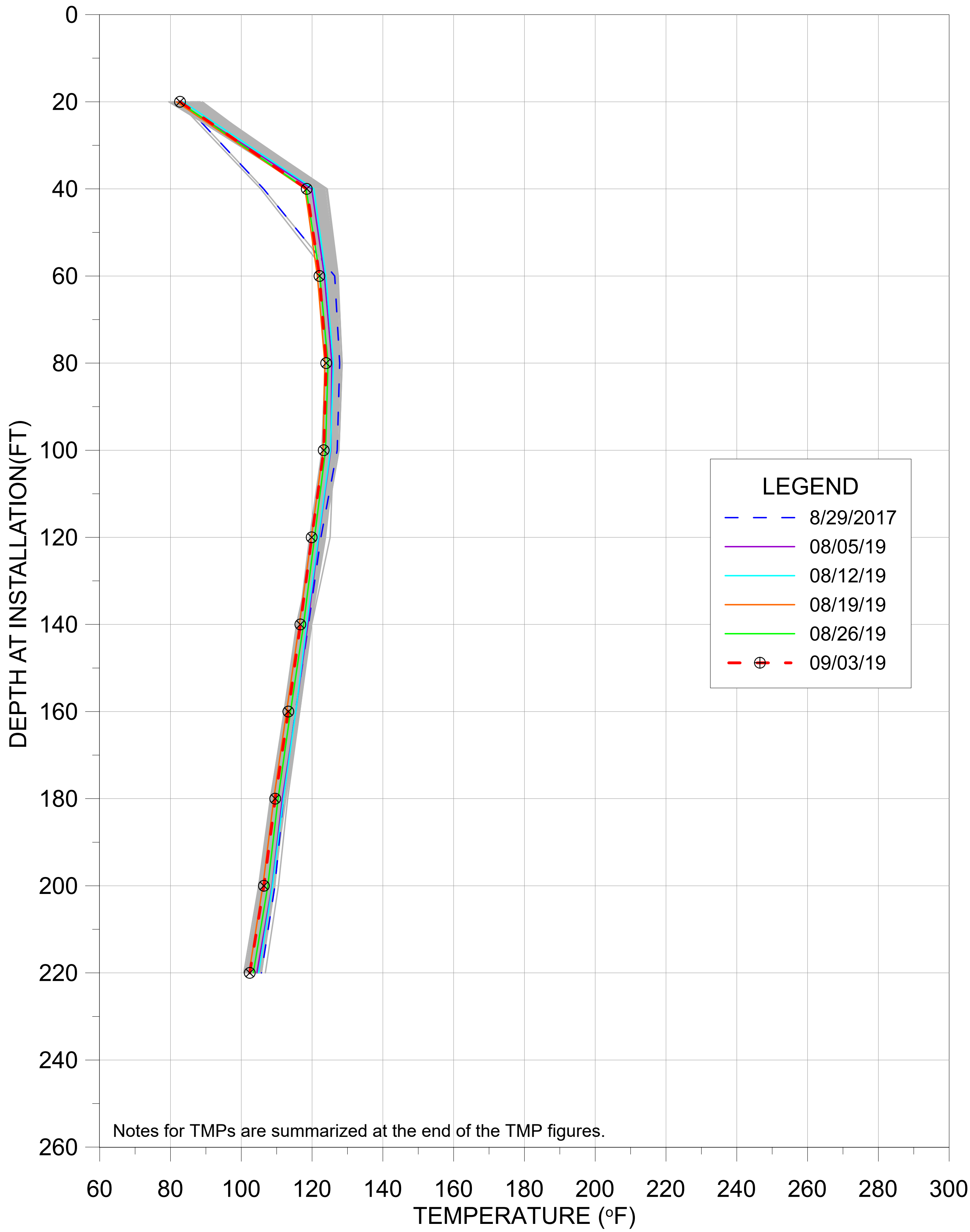
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-27



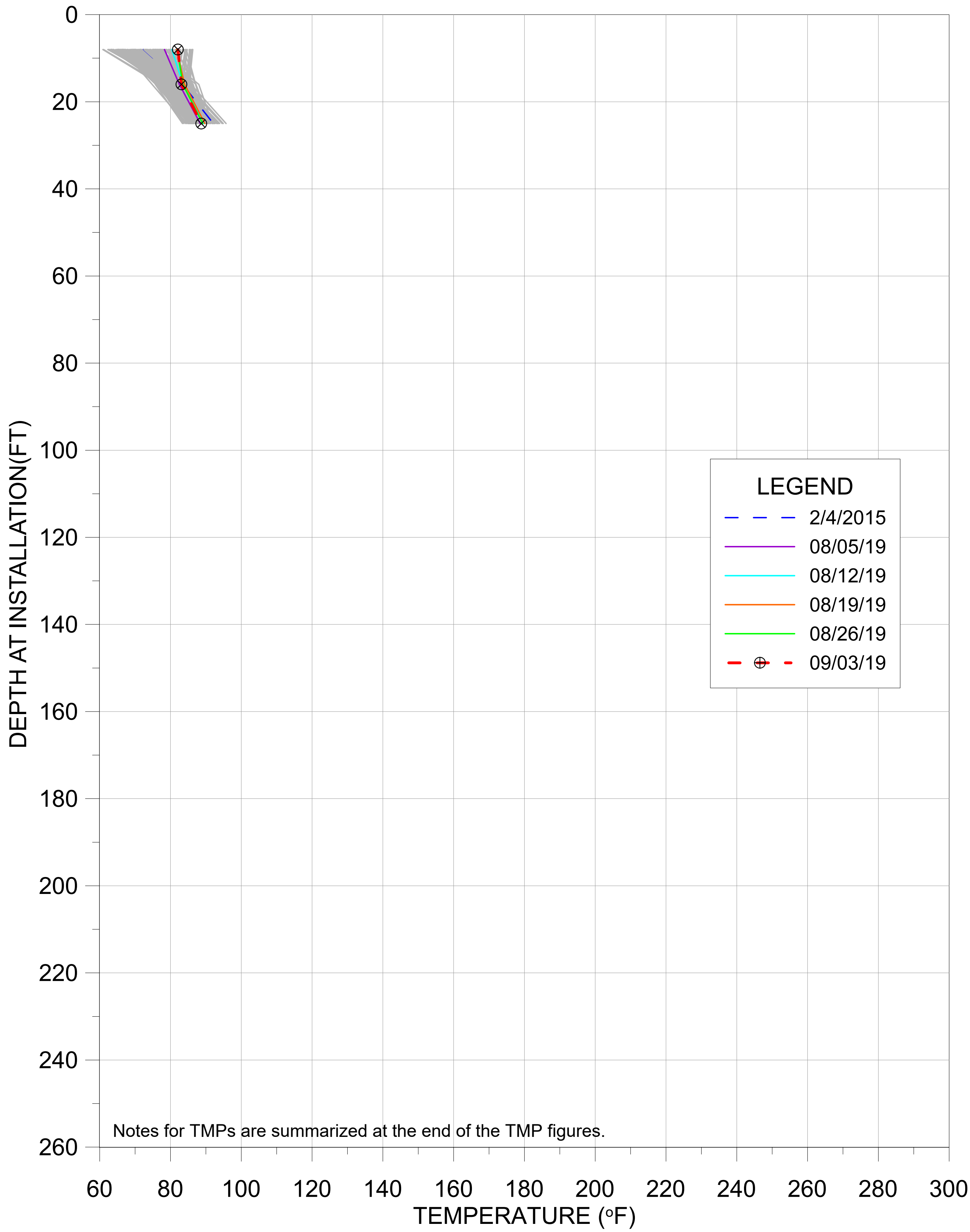
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-28R



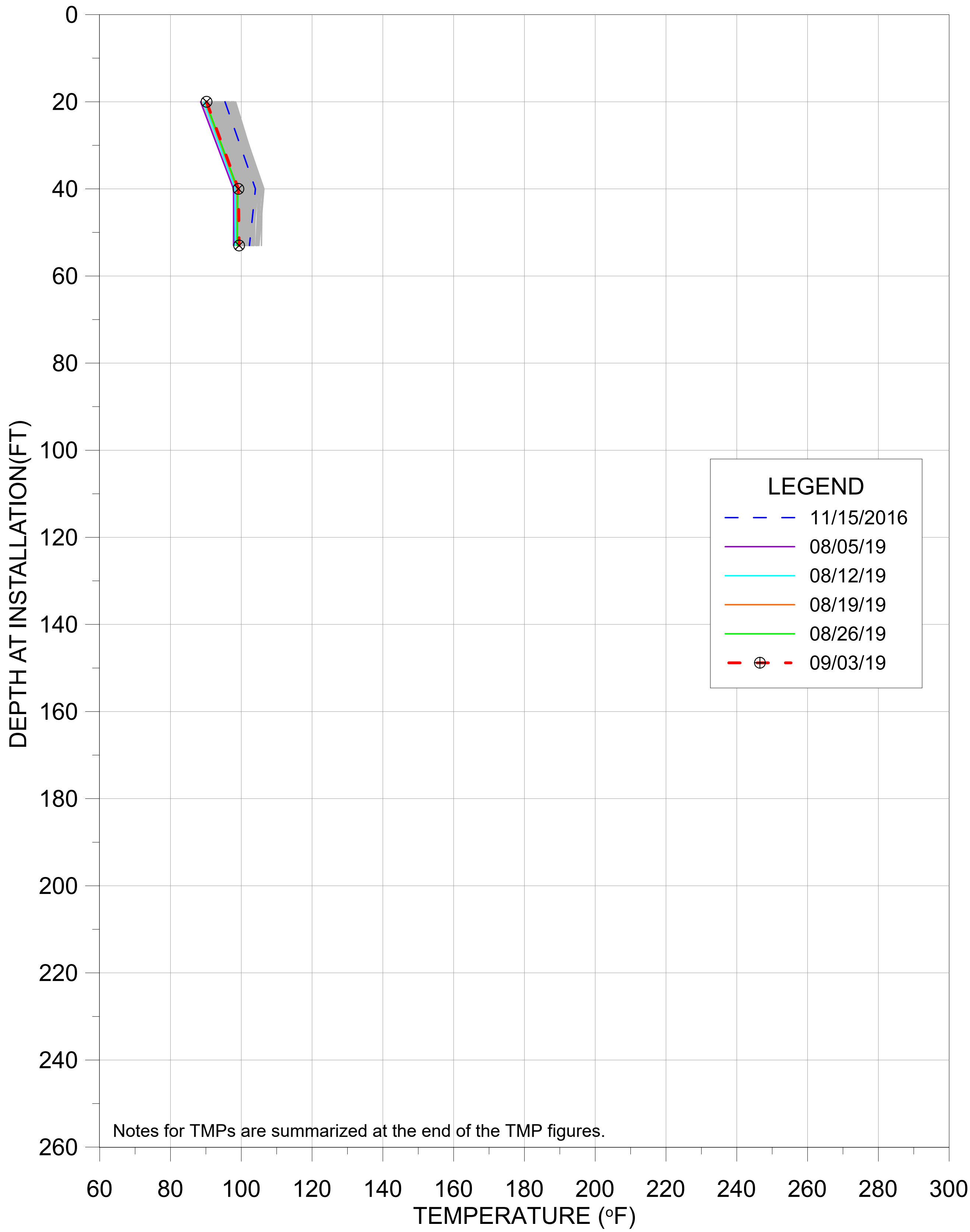
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-29



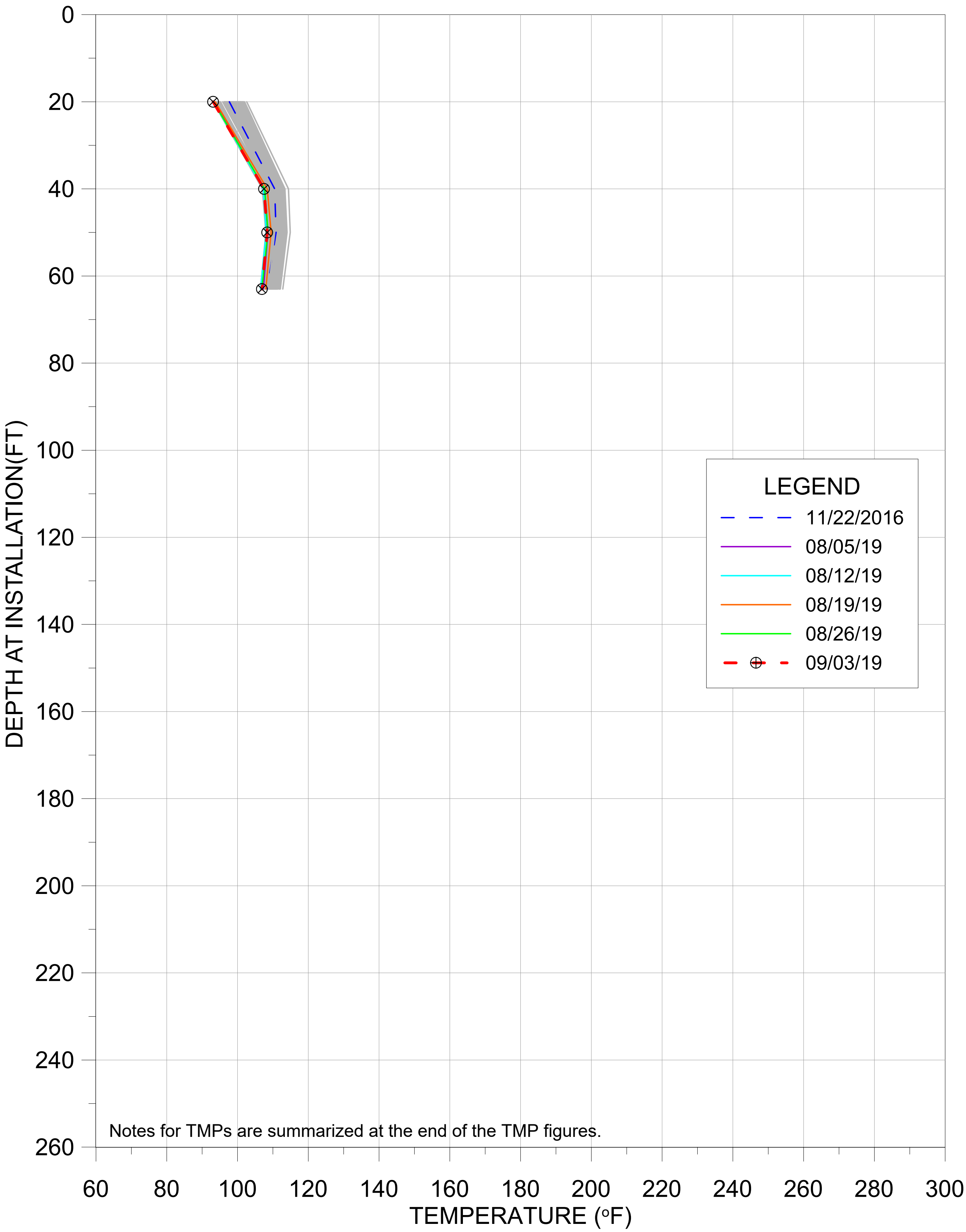
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-33



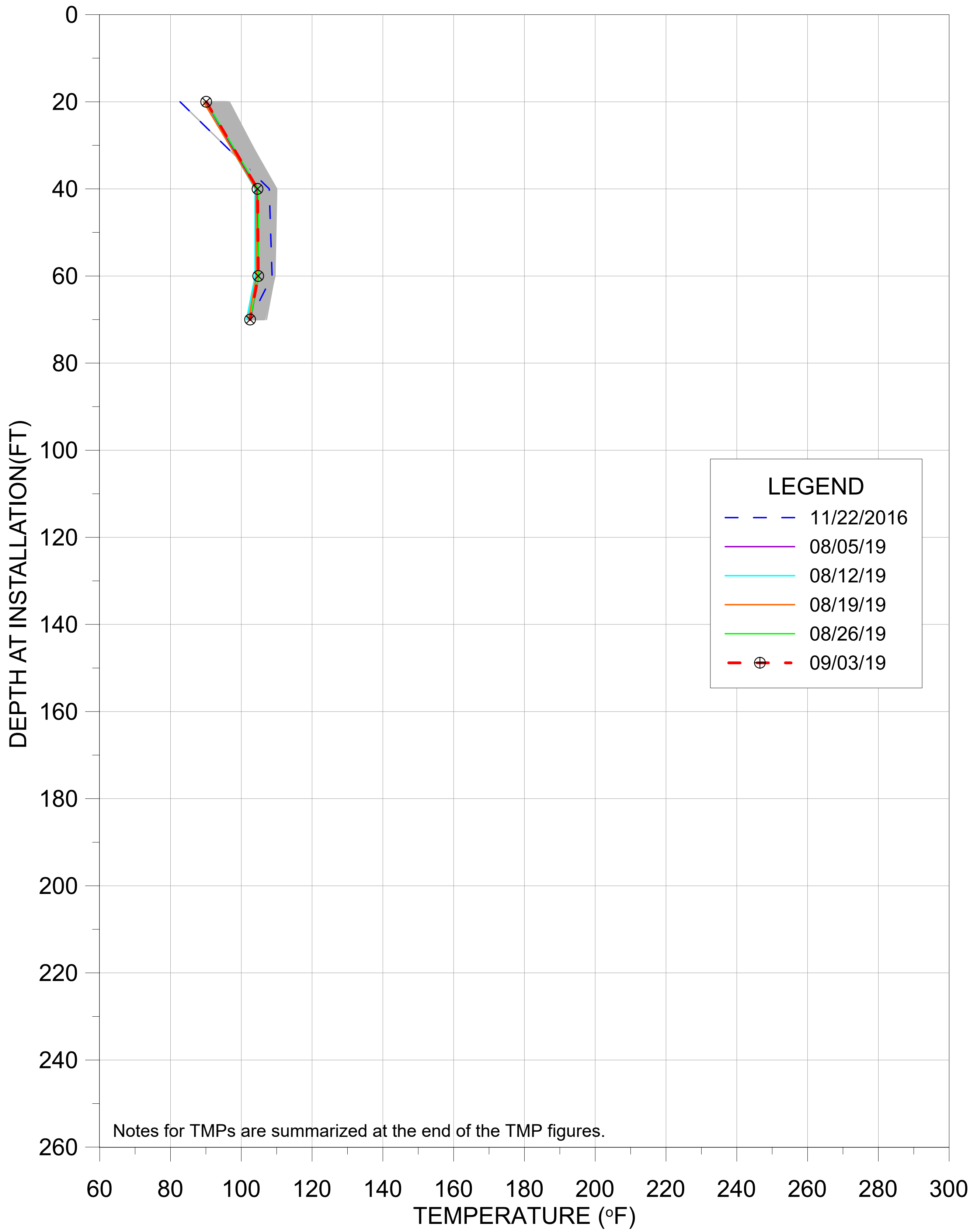
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-34



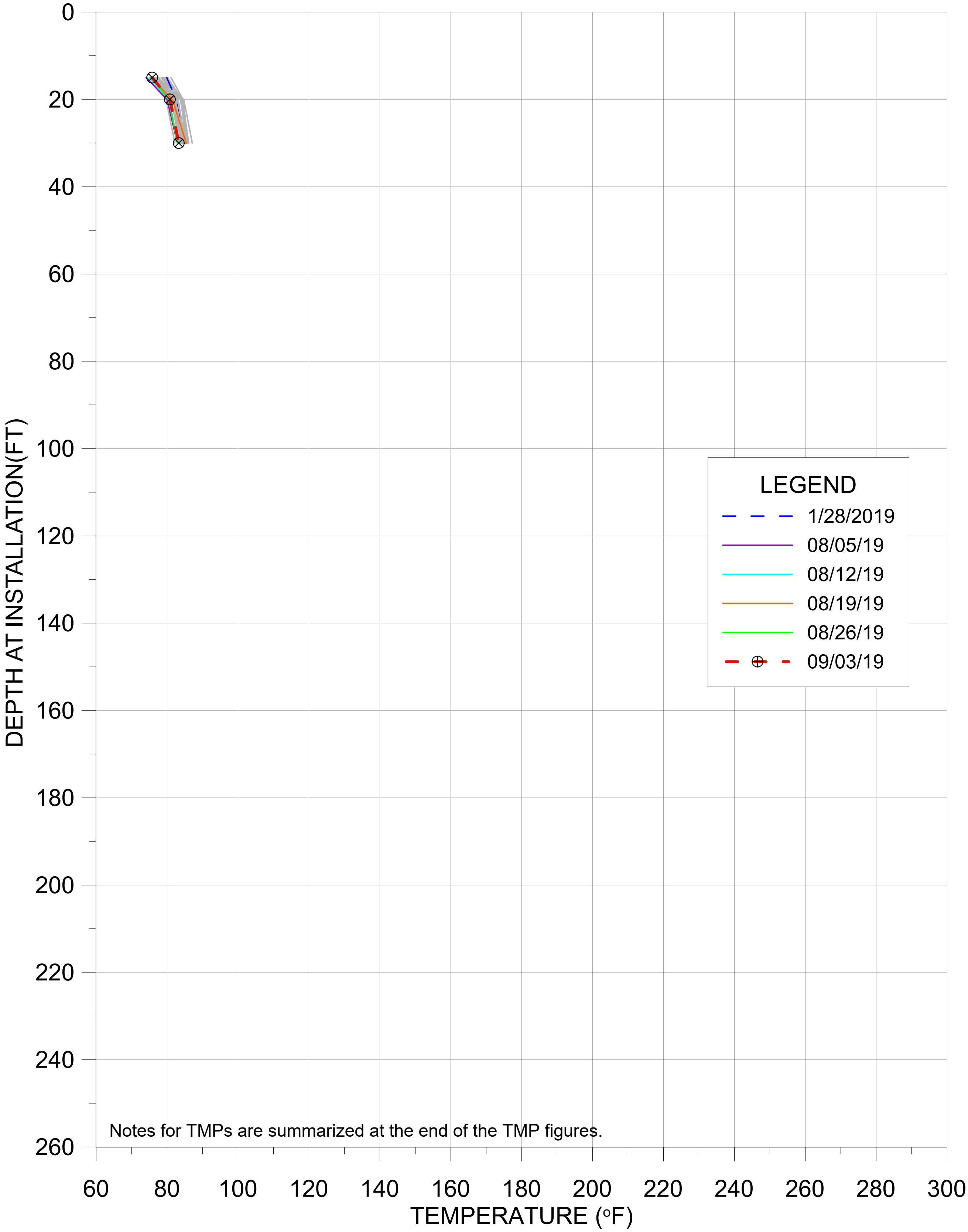
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-35



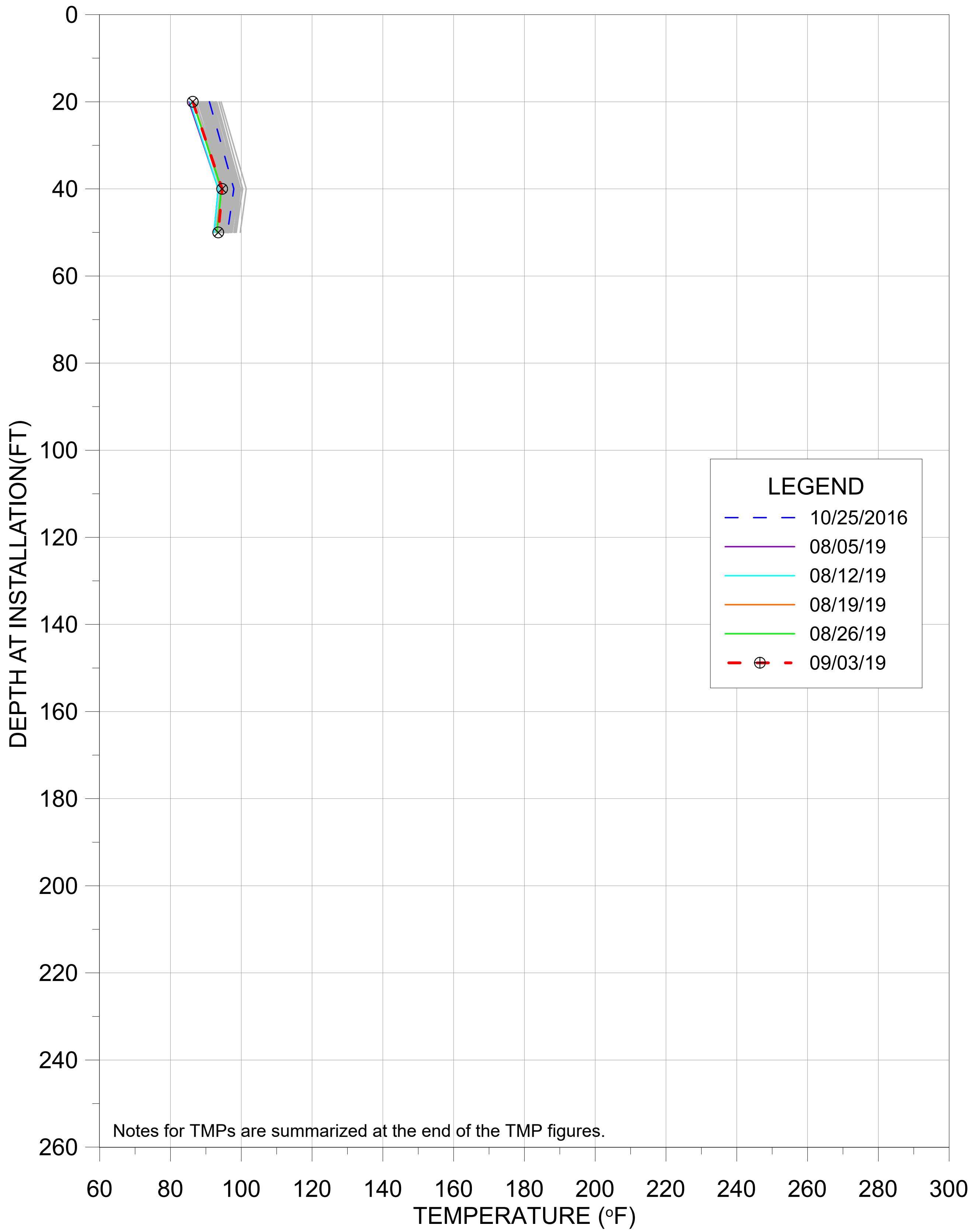
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-36R



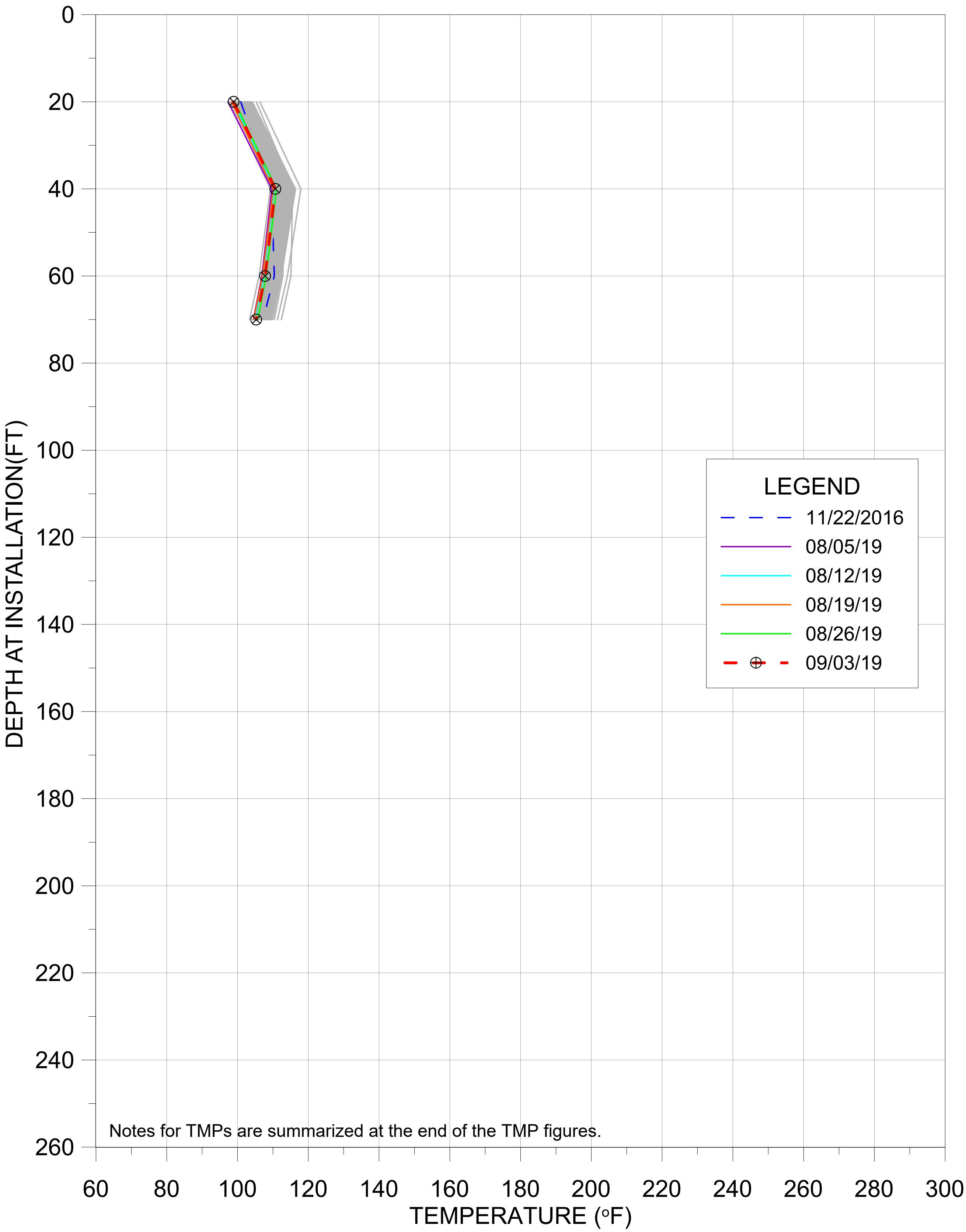
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-37



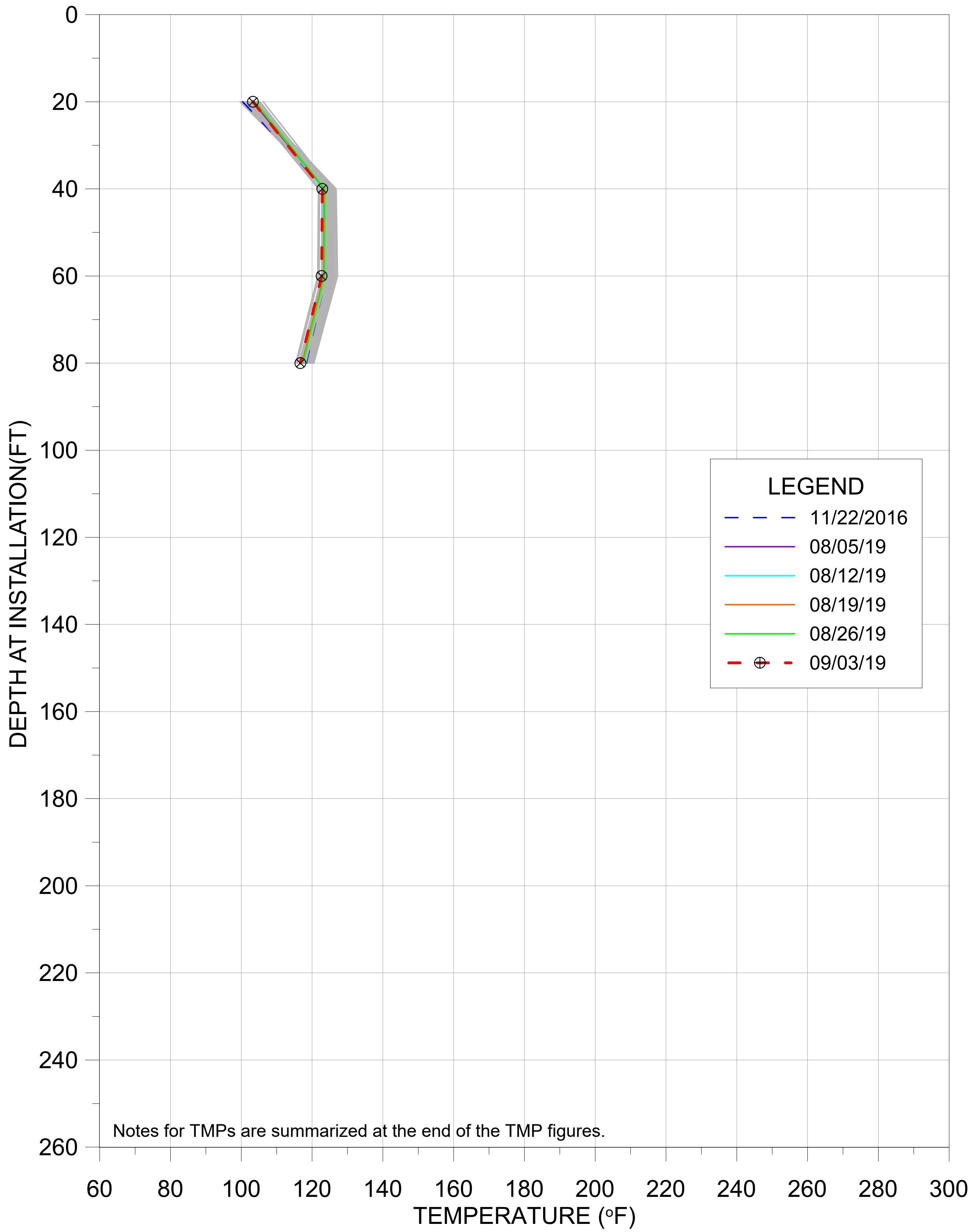
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-38



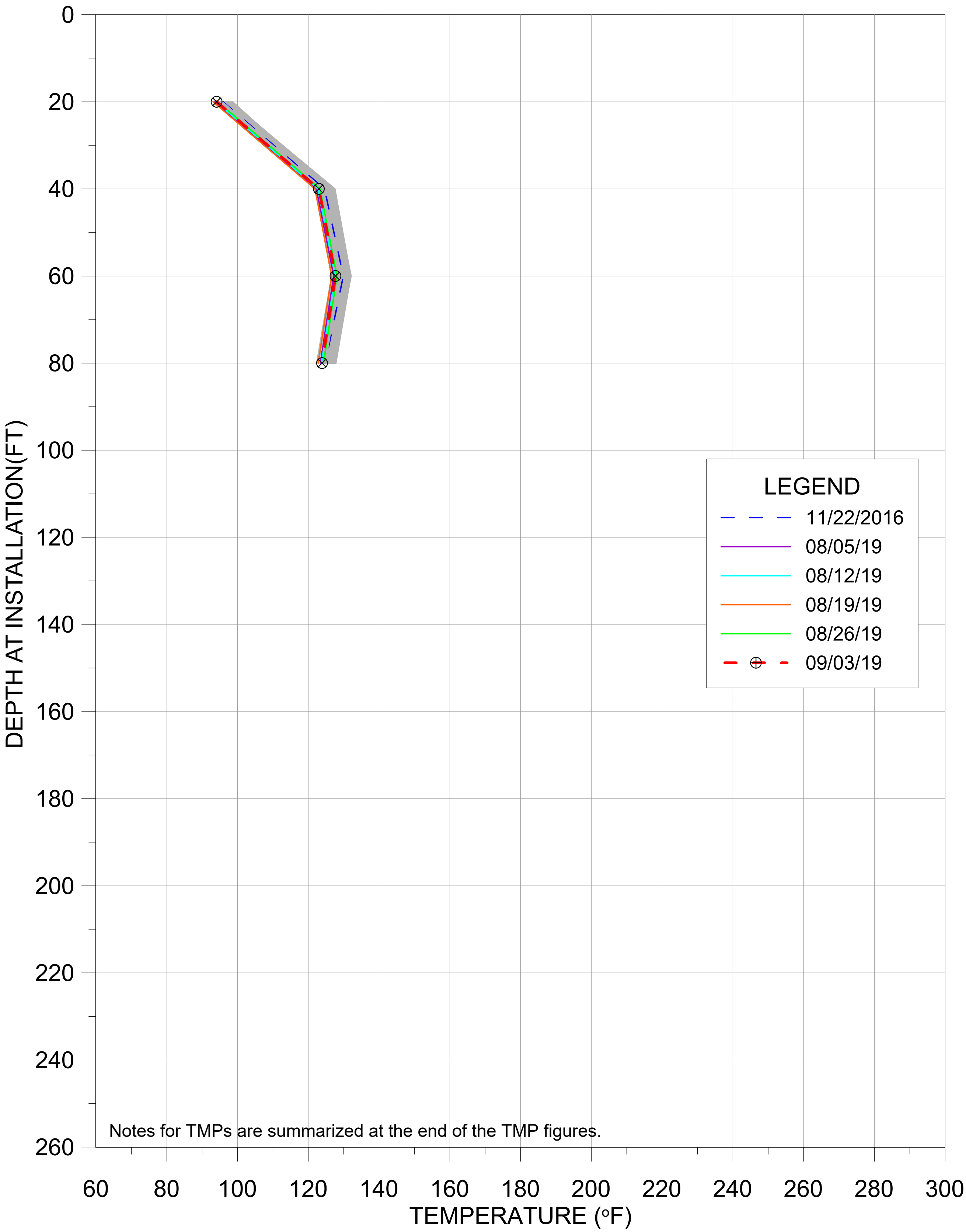
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-39



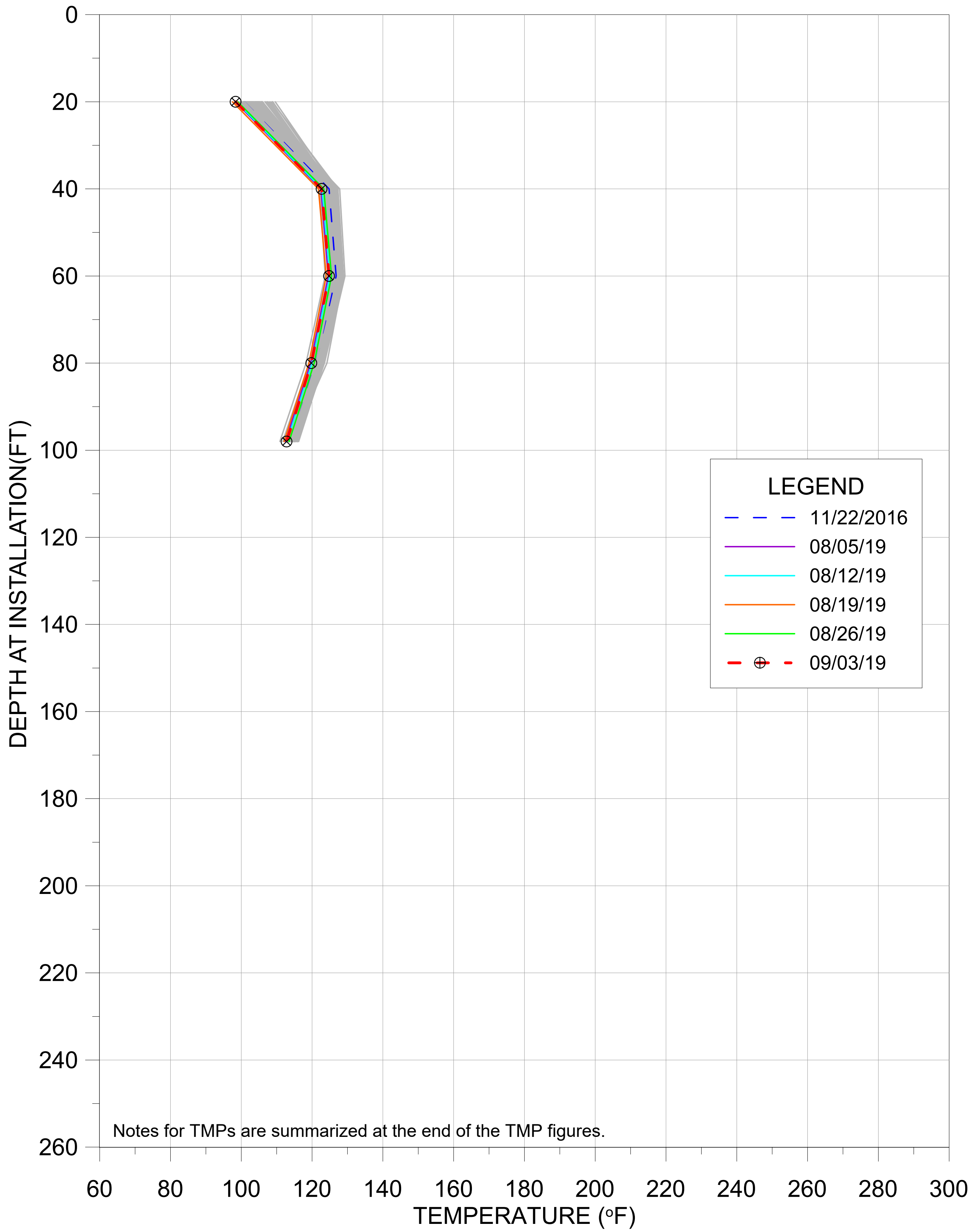
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-40



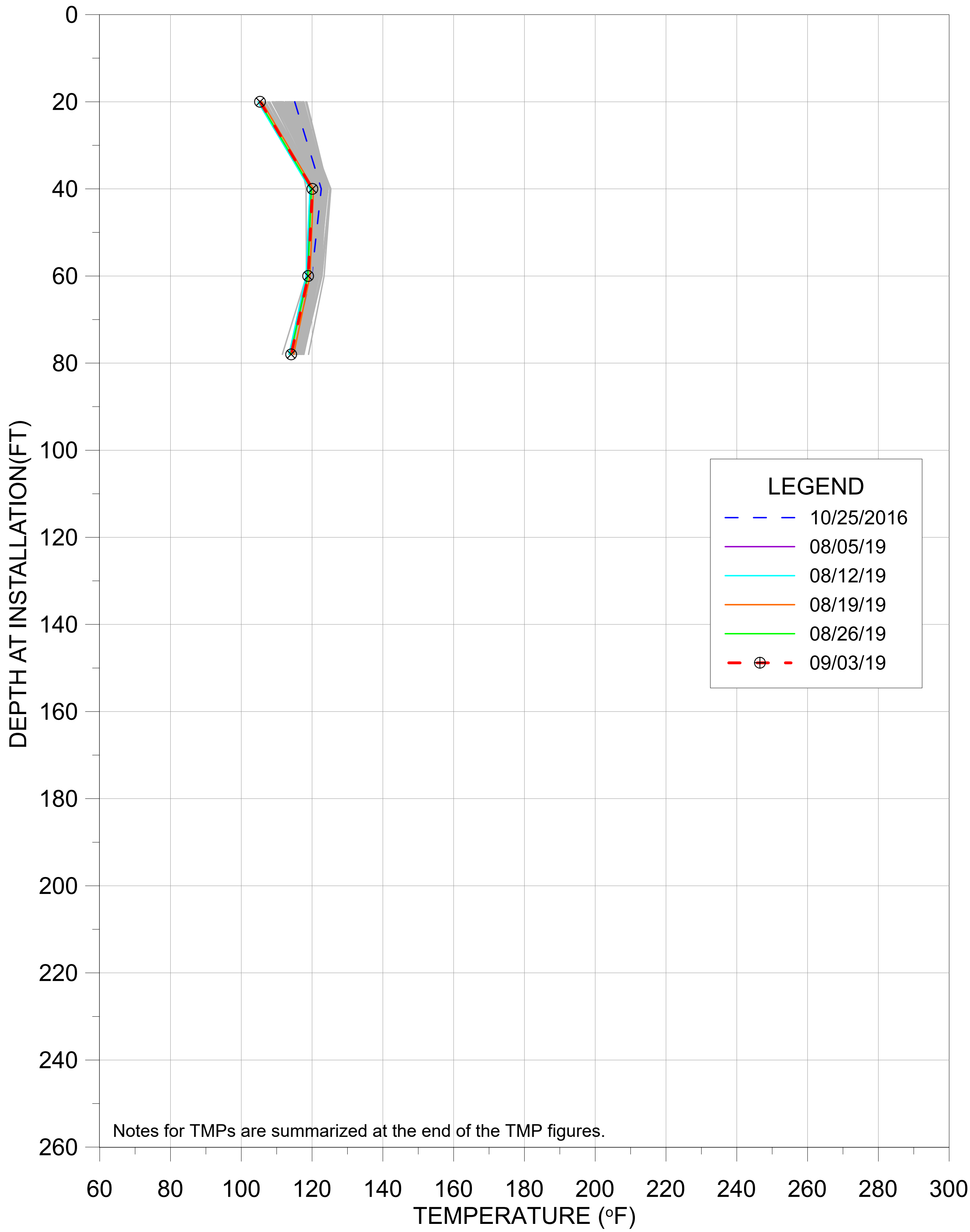
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-41



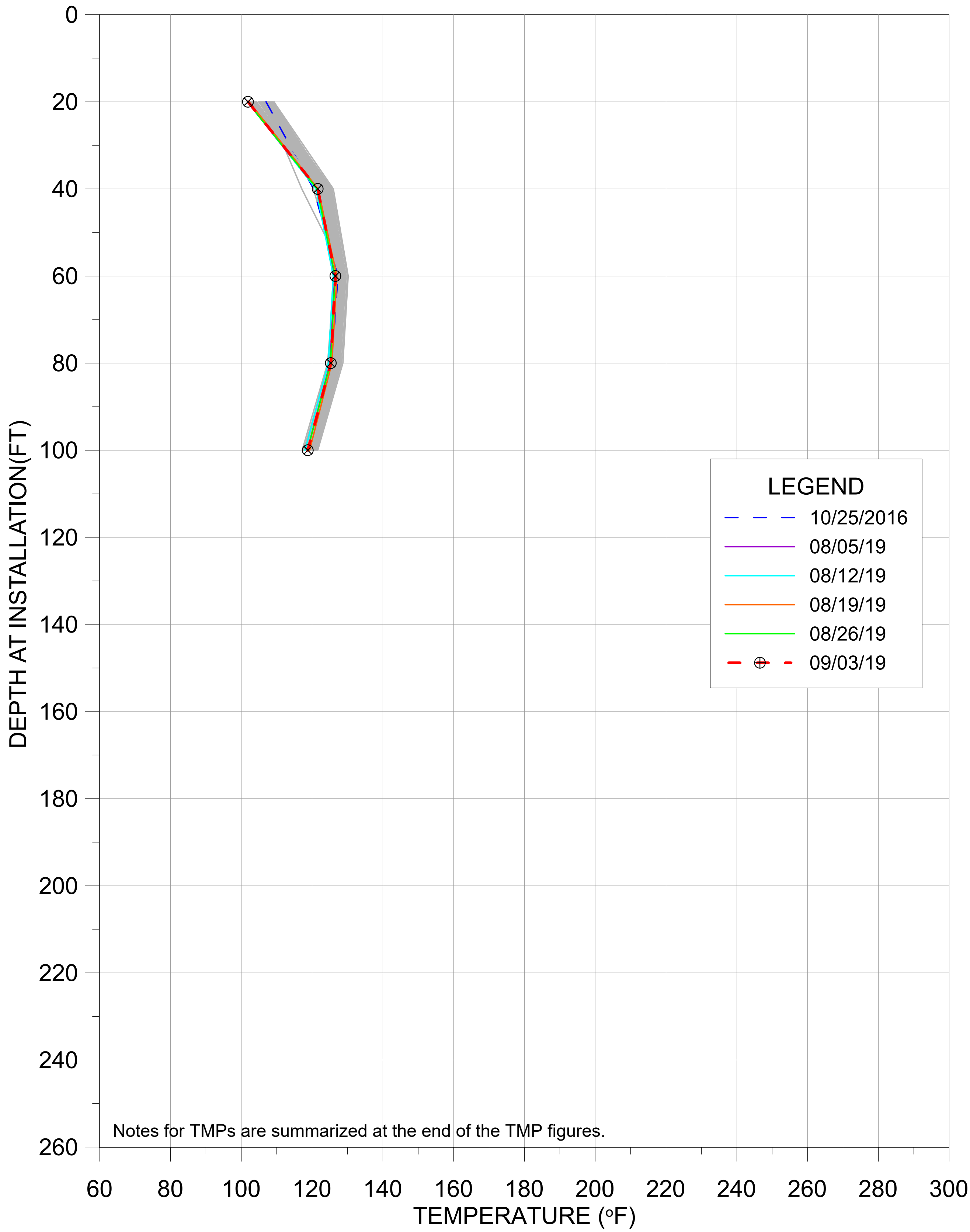
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-42



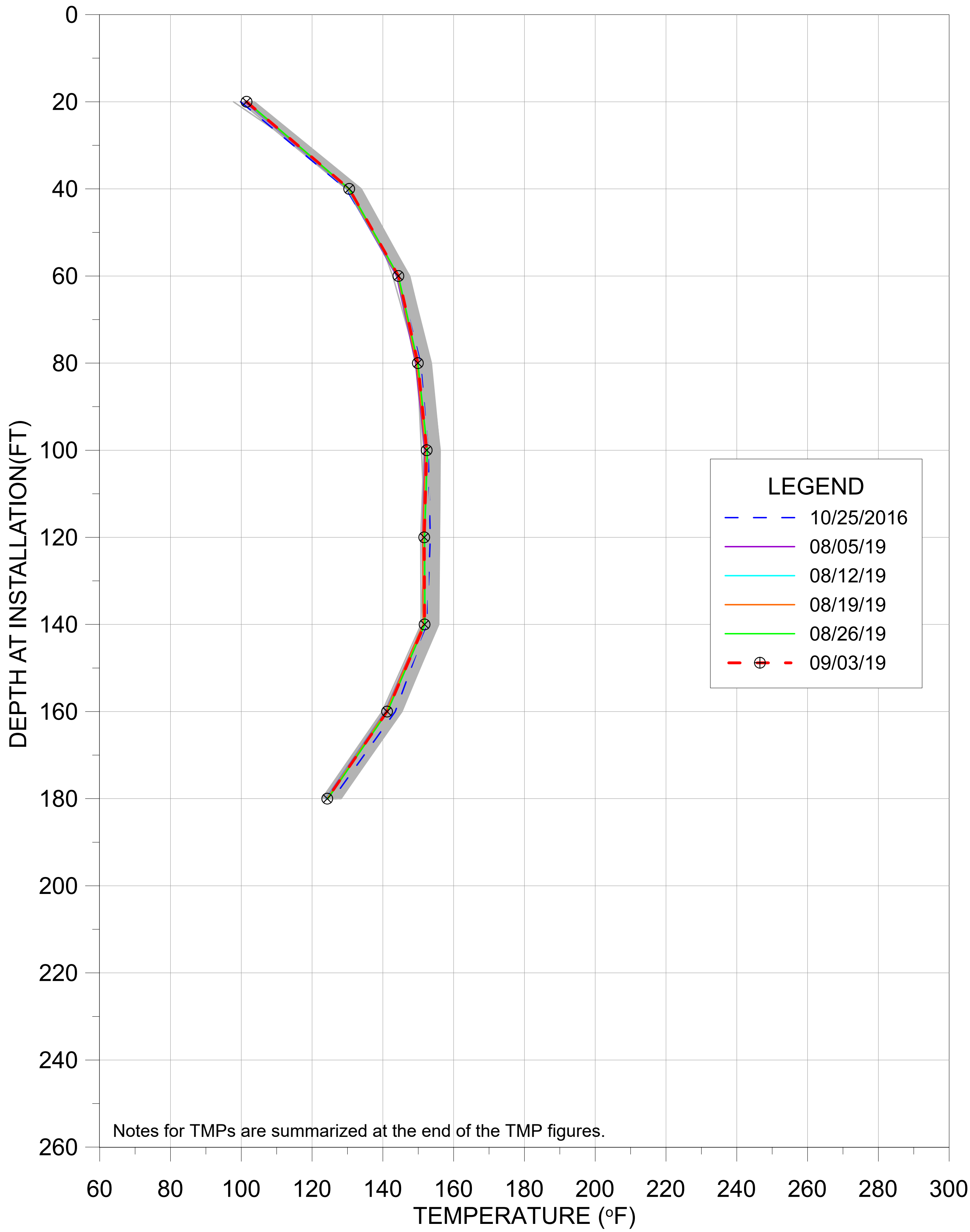
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-43



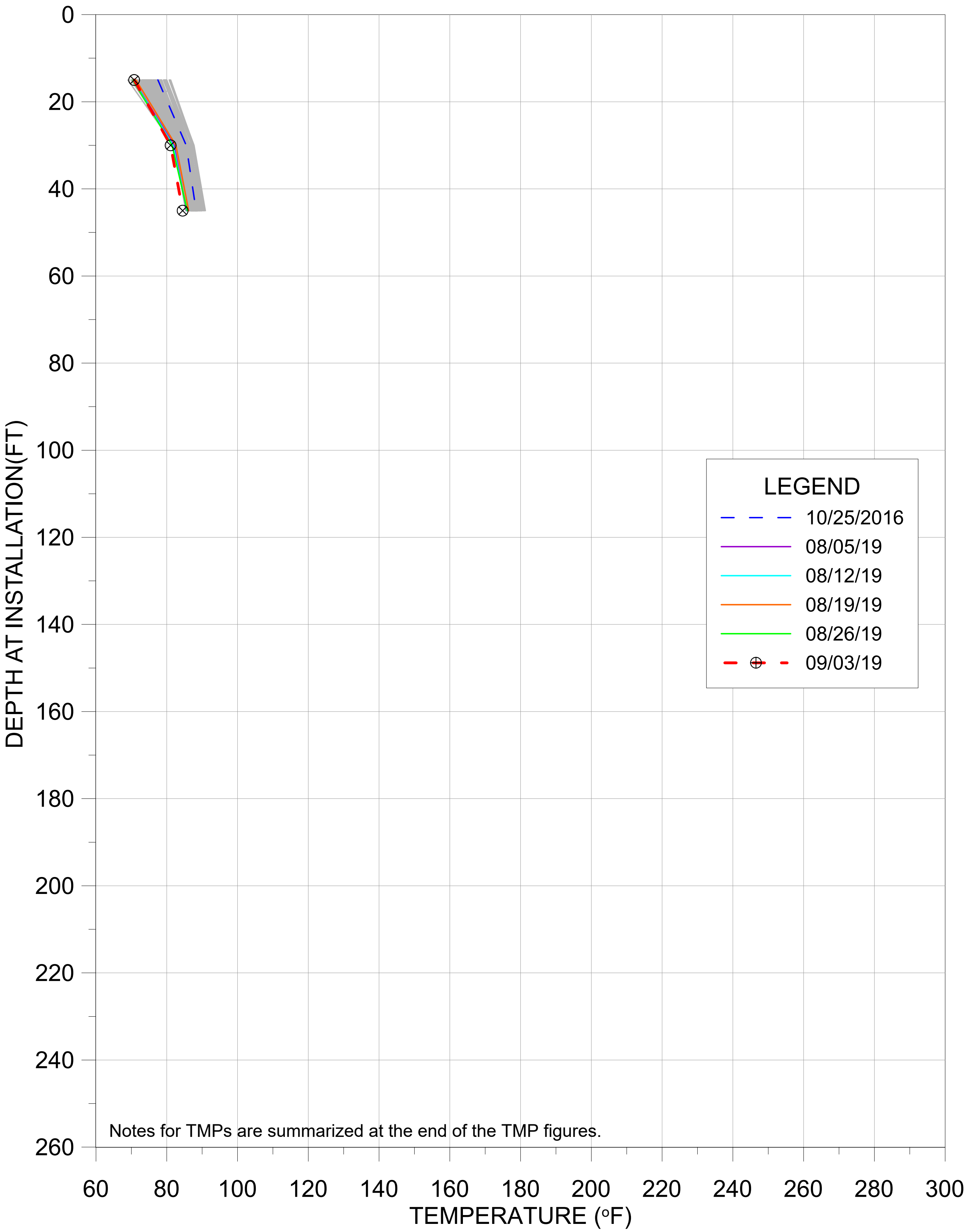
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-44



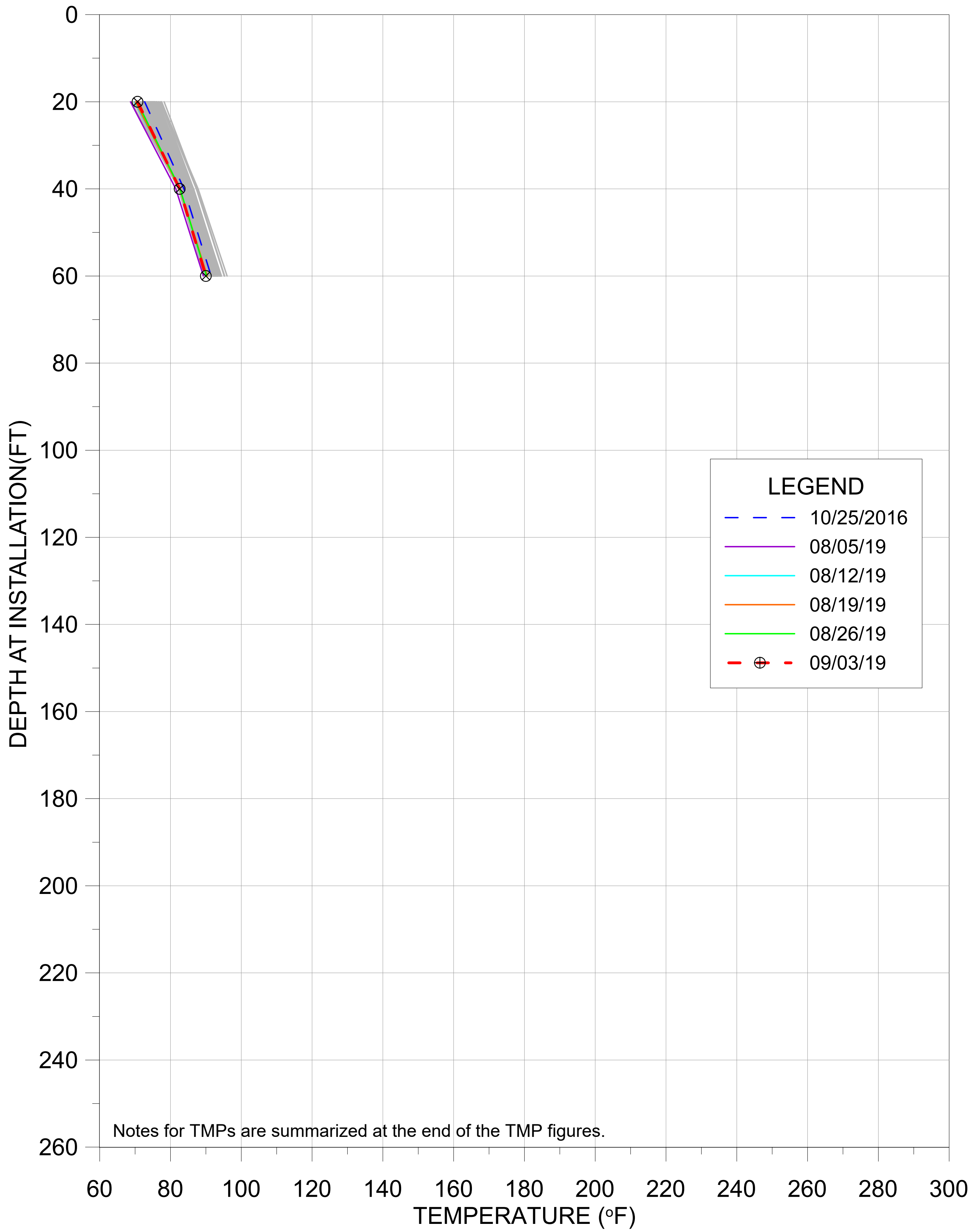
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-45



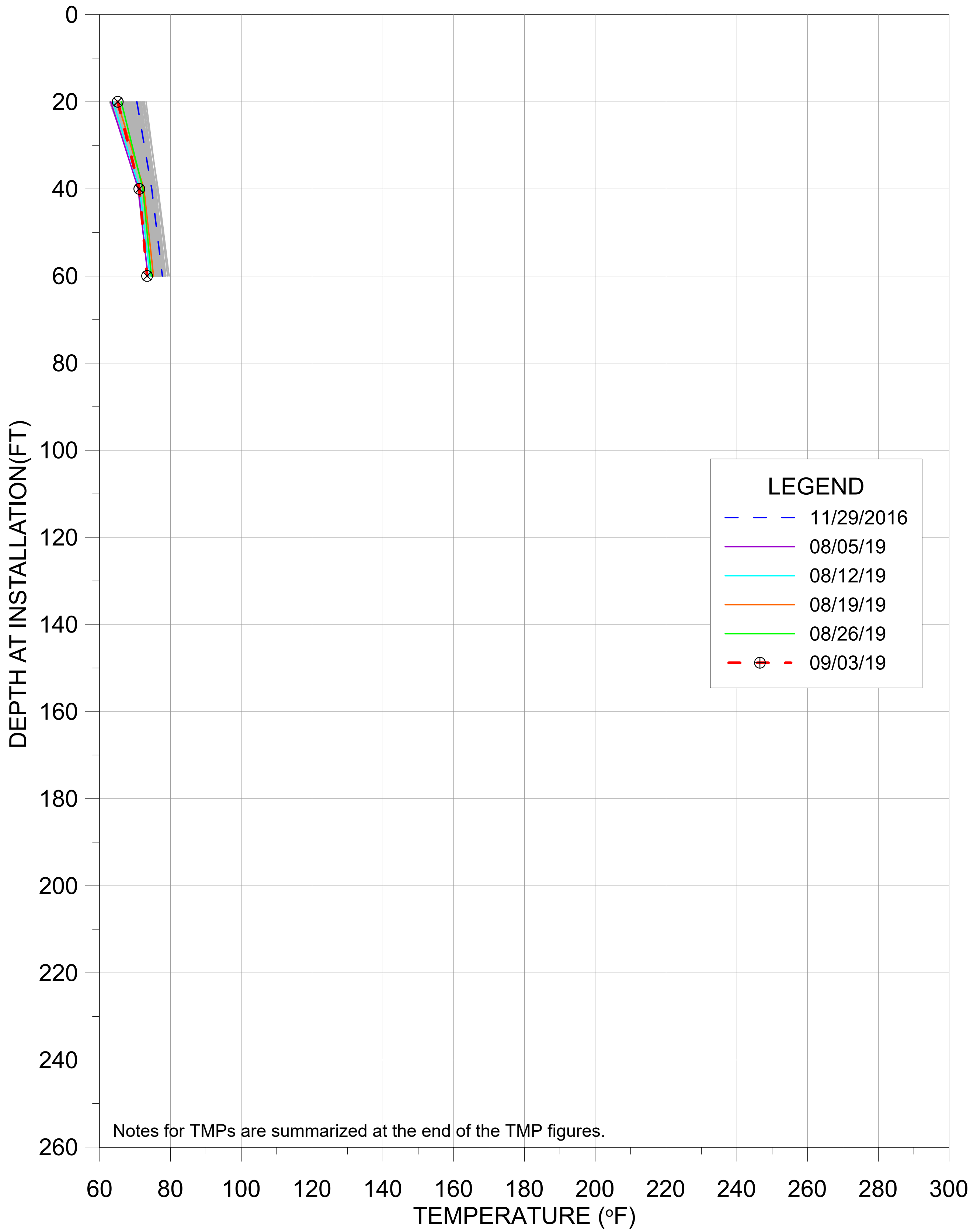
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-46



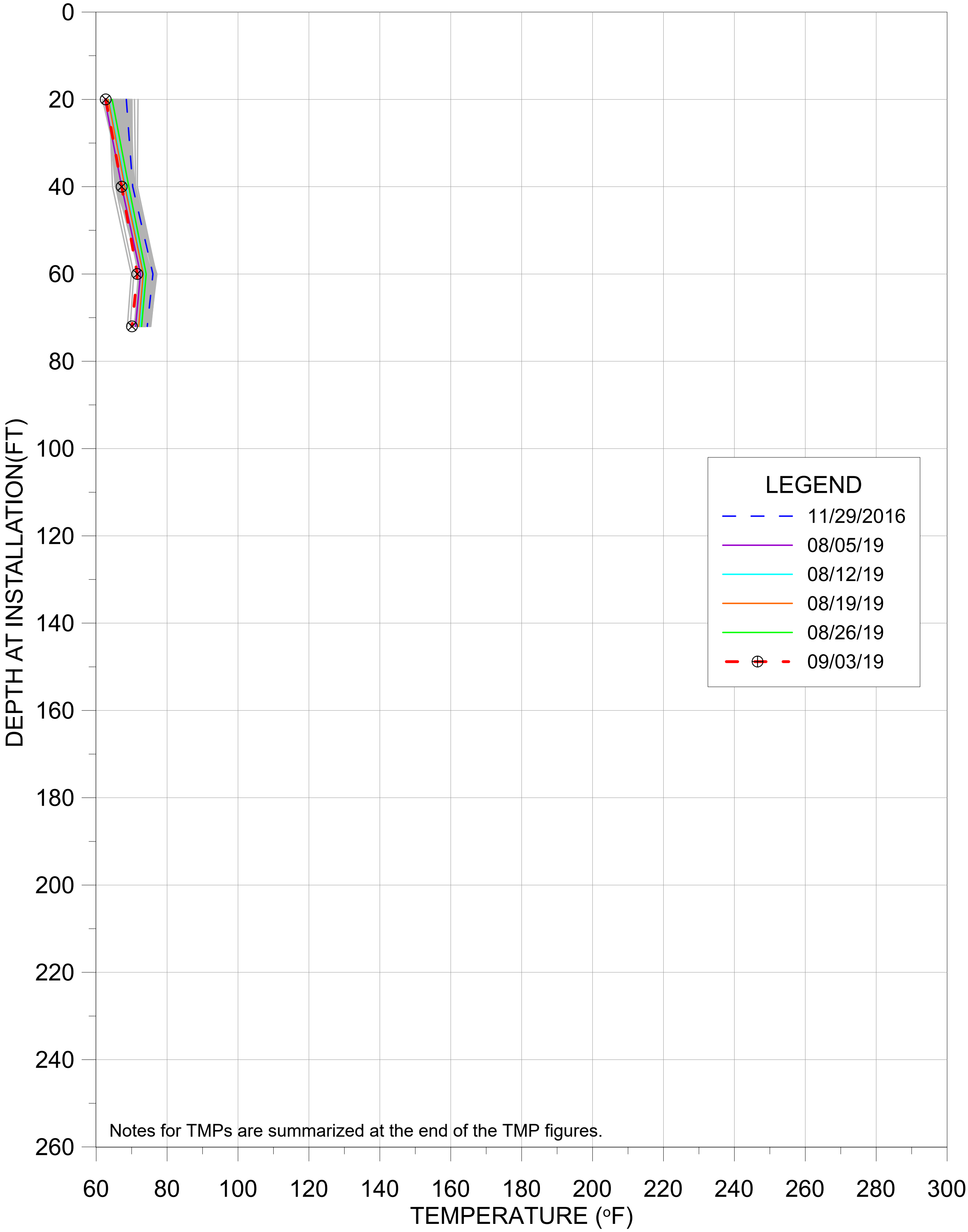
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-47



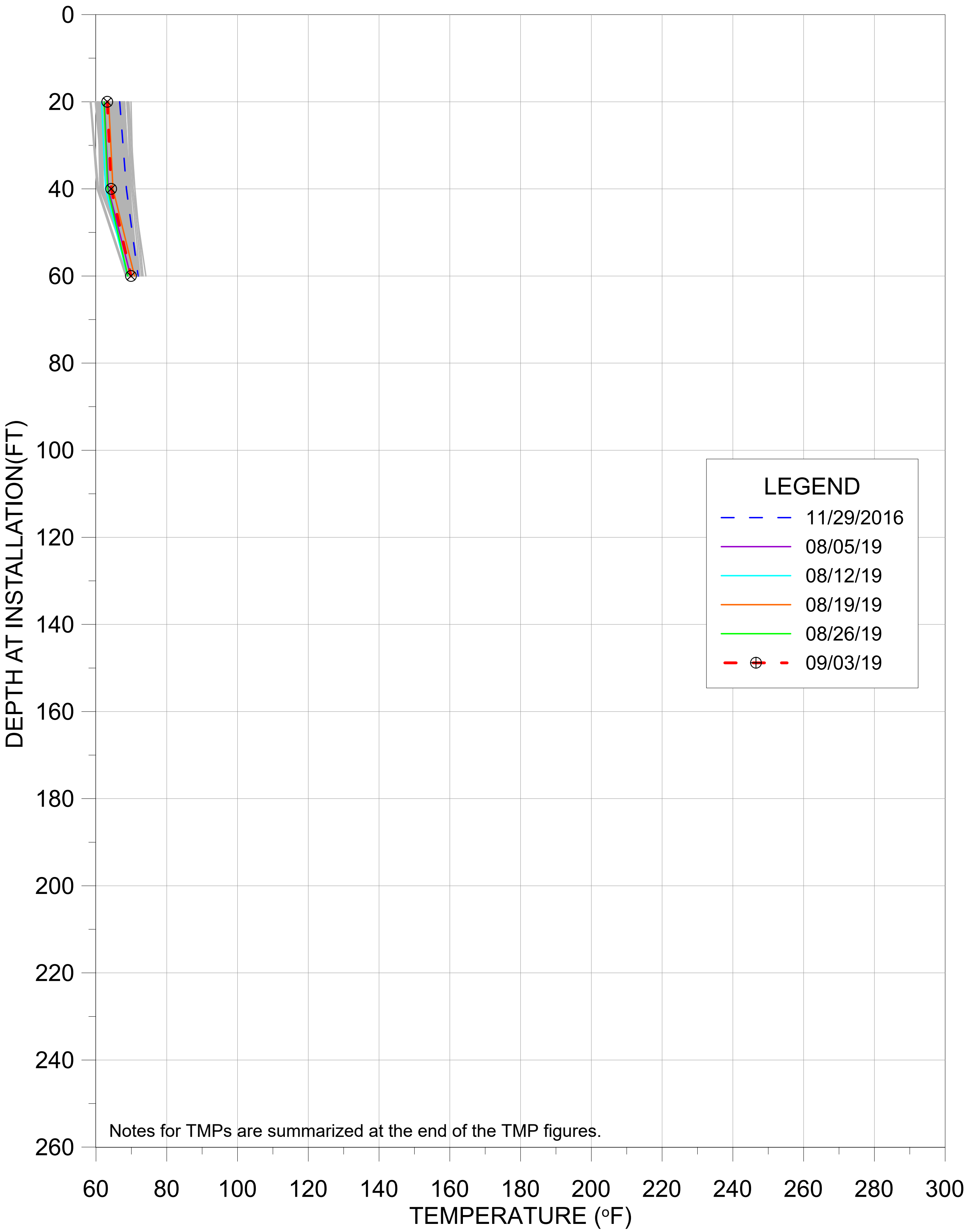
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-48



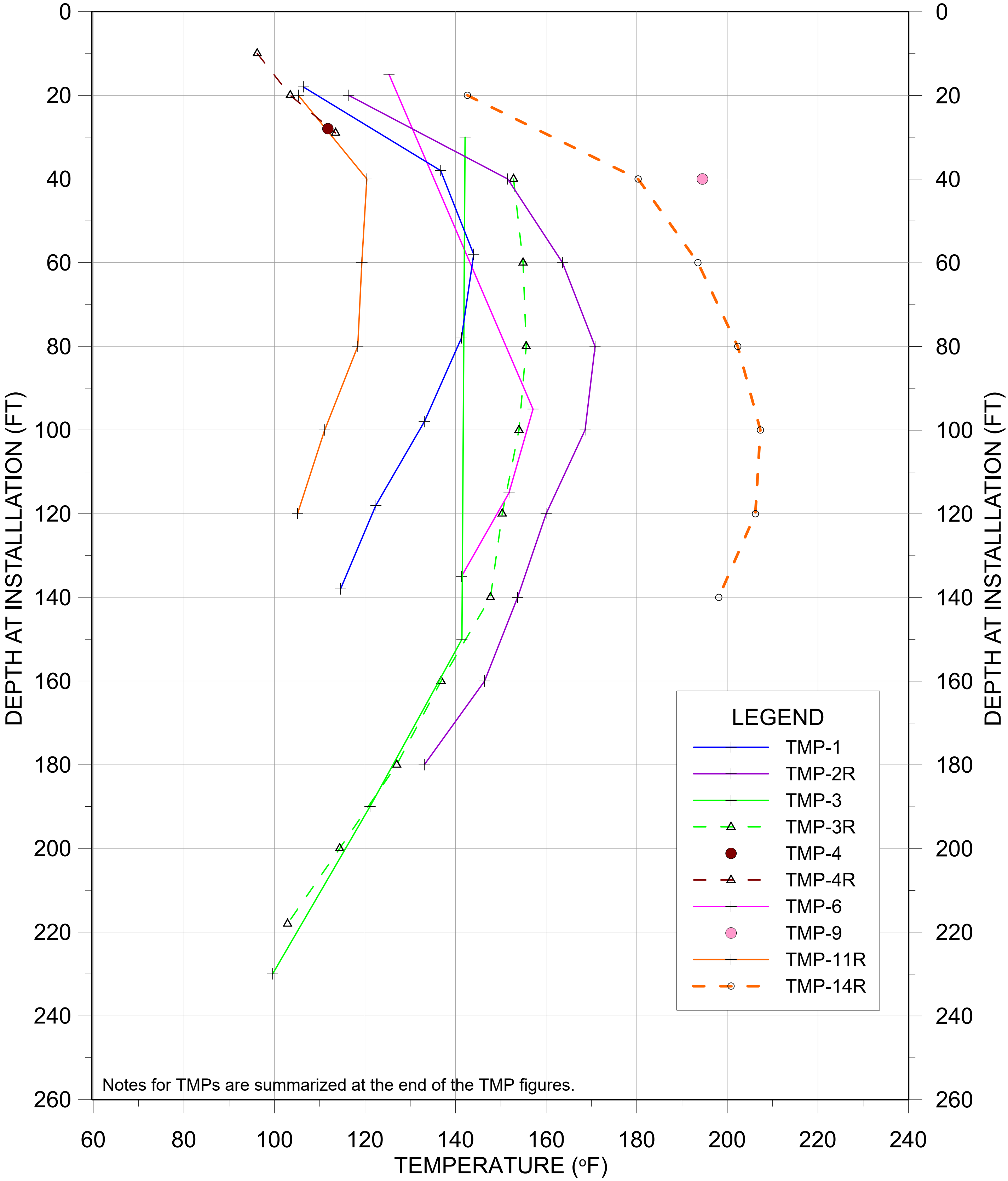
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-49



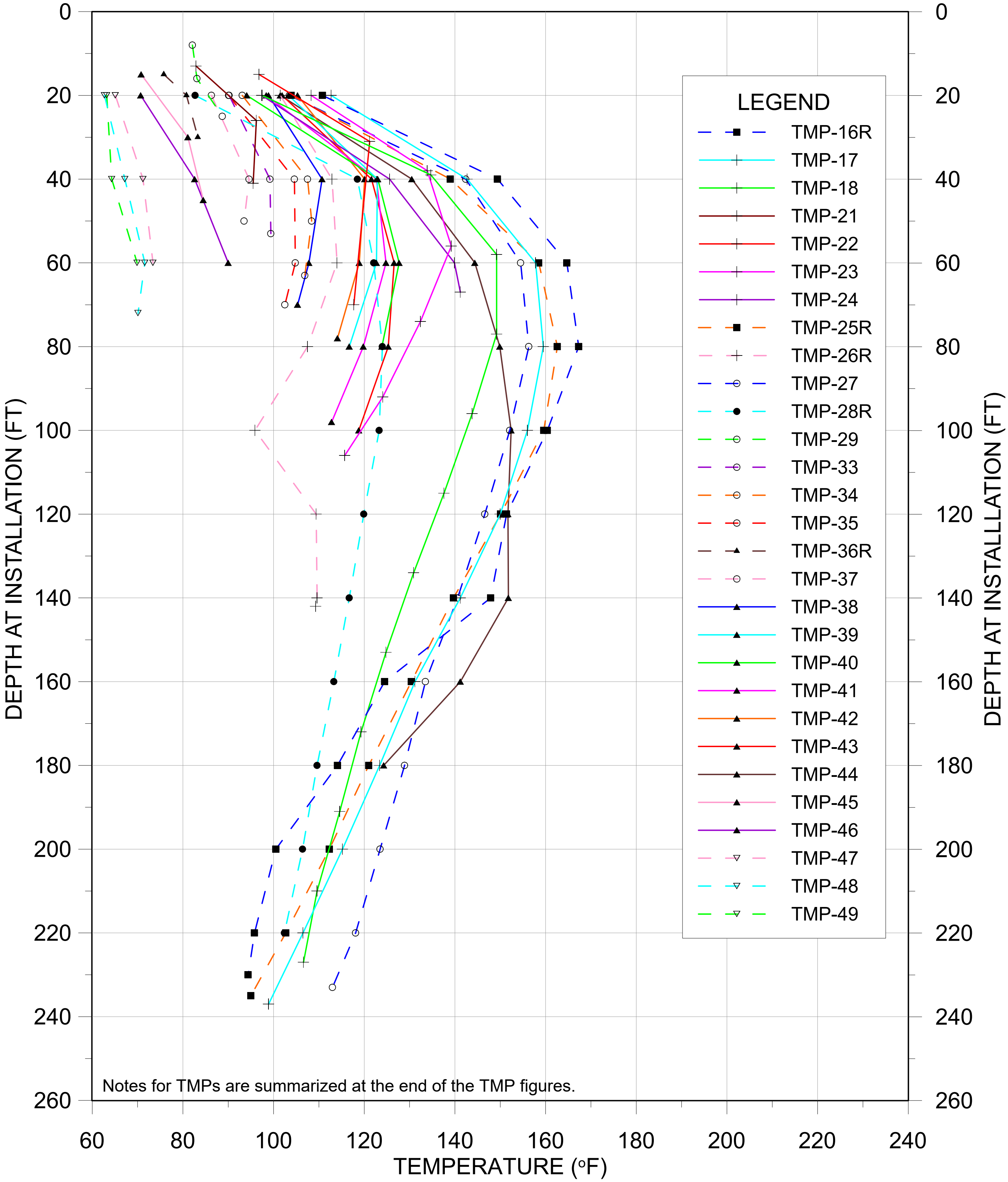
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

9/3/2019



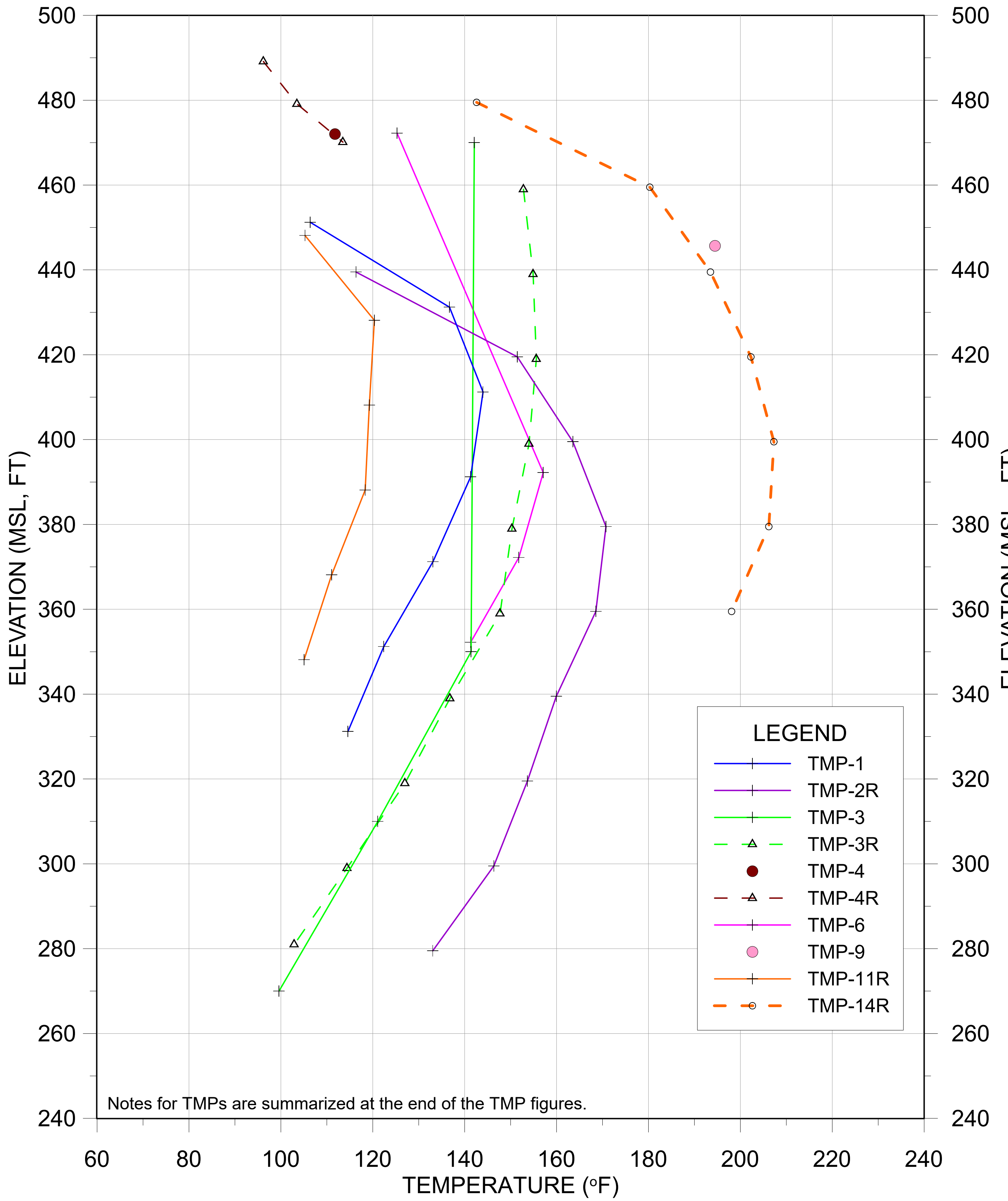
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

9/3/2019 - NORTH QUARRY



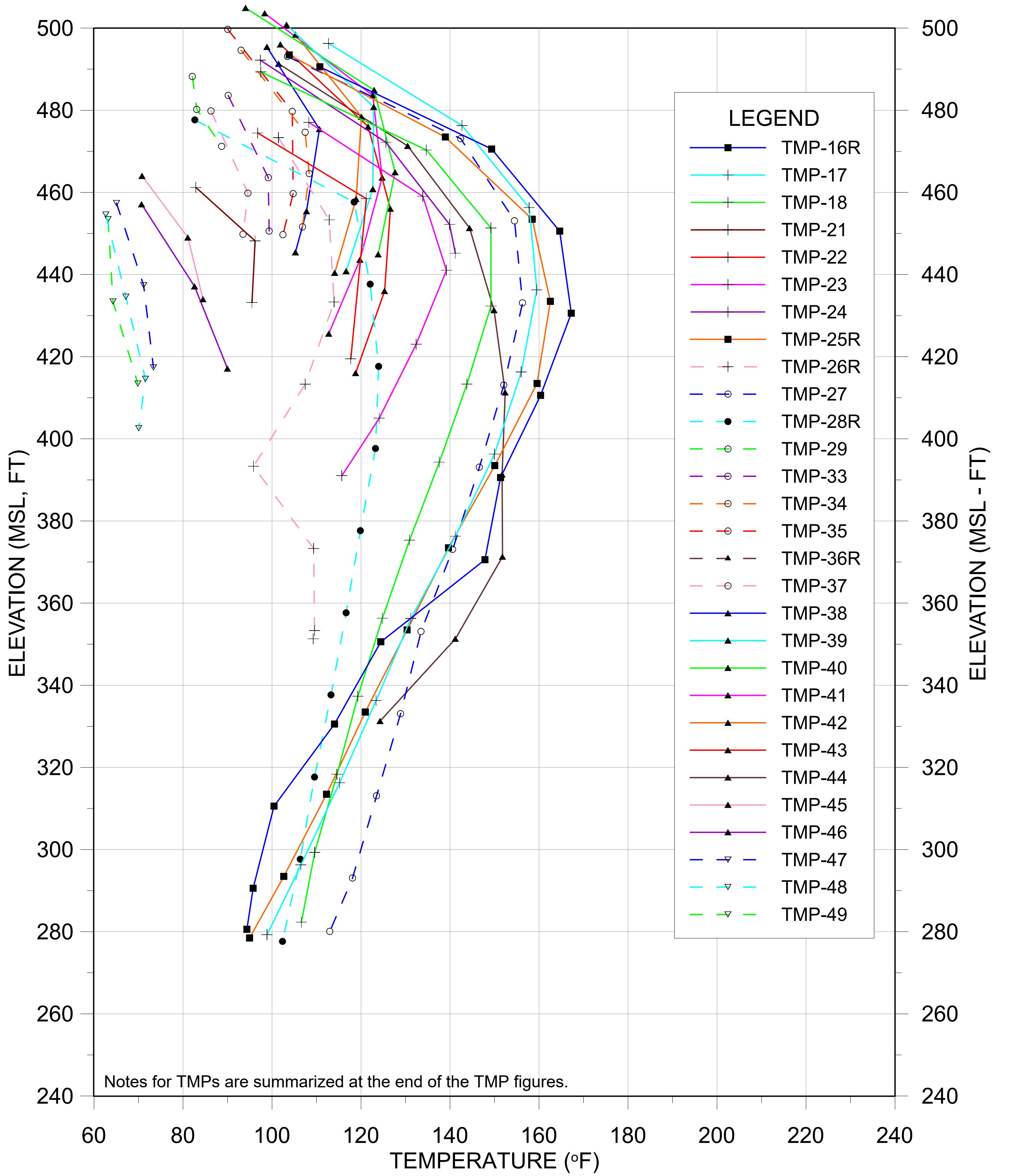
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

9/3/2019



TEMPERATURE VS ELEVATION
BRIDGETON LANDFILL

9/3/2019 - NORTH QUARRY



TEMPERATURE VS ELEVATION
BRIDGETON LANDFILL

TMP BRIDGETON LANDFILL NOTES
TMP notes that are new for the reporting week are in **bold.**

TMP-1: NONE

TMP-2:

1. TMP-2 has been replaced by TMP-2R and will no longer be monitored or included in the presentation.

TMP-2R:

1. Data reported on 11/29/2016 was inadvertently left as the 11/22/2016 data. This was corrected on 12/5/2016 reading submittal.

TMP-3:

1. No reliable temperature readings have been obtained at 170 ft depth since 1/29/2014, except on 3/13/2014.
2. The connectivity tests on 4/11/2014 conducted by CEC showed that units at 10, 90, 130, 210 and 250 ft depths are no longer reliable.
3. The connectivity tests on 10/28/2014 conducted by Feezor Engineering showed that units at 10, 90, 110, 130, 210 and 250 ft depths are not reliable.
4. The unit at 50 ft depth was fluctuating resistance since 10/1/2018. Therefore the temperature is determined to be unreliable.
5. No temperature reading could be obtained at 70 ft depth since 10/22/2018.

TMP-3R:

1. The unit at 20 ft depth had a fluctuating resistance since 9/25/2017. Therefore the temperature is determined to be unreliable.

TMP-4:

1. The connectivity tests on 4/11/2014 conducted by CEC showed that the unit at 48 ft depth is no longer reliable.

TMP-4R: NONE

TMP-5: TMP NO LONGER IN SERVICE– Verified by Connectivity testing by Feezor Engineering in March 2015.

TMP-6:

1. The connectivity tests on 4/11/2014 conducted by CEC showed that units at 35, 55, 75, 155, 175, and 195 ft depths are no longer reliable.
2. No reliable temperature readings have been obtained at the unit at 215 ft depth since 6/13/2014.

TMP-7R: TMP NO LONGER IN SERVICE

TMP-8: TMP NO LONGER IN SERVICE

TMP-9:

1. Unit at 100 ft depth had an inaccurate temperature reading on 8/1/2013 and no reading since 8/6/2013.
2. The connectivity tests on 4/11/2014 conducted by CEC showed that units at 20, 60, 80, and 100 ft depths are no longer reliable.

TMP-10:

1. All units were verified by connectivity testing by Feezor Engineering on 6/1/2017 to be unreliable.

TMP-11:

1. All units were verified by connectivity testing by Feezor Engineering on 11/23/2016 to be unreliable.
2. TMP-11 is no longer in service and will not be included in the presentation.

TMP-11R: NONE

TMP-12:

2. All units were verified by connectivity testing by Feezor Engineering in October 2015 to be unreliable.

TMP-13: TMP NO LONGER IN SERVICE

TMP-14:

1. All units were verified by connectivity testing by Feezor Engineering in March 2016 to be unreliable.

TMP-14R:

1. Due to the connectivity test results by Feezor Engineering on TMP-14 (see note above), TMP-14R is added to this reporting data set as of 3/7/2016.

TMP-15: TMP WAS NEVER IN SERVICE

TMP-16:

1. TMP-16 has been replaced by TMP-16R and will no longer be included in the presentation.

TMP-16R: NONE

TMP-17: NONE

TMP-18: NONE

TMP-19: NOT PART OF THIS SUBMITTAL (HEAT EXTRACTION TMP)

TMP-20: NOT PART OF THIS SUBMITTAL (HEAT EXTRACTION TMP)

TMP-21: NONE

TMP-22:

1. No temperature reading could be obtained and resistivity was fluctuating at the unit at 50 ft depth since 4/2/2018.

TMP-23: NONE

TMP-24: NONE

TMP-25:

1. TMP-25 has been replaced by TMP-25R and will no longer be included in the presentation.

TMP-25R: NONE

TMP-26:

1. TMP-26 has been replaced by TMP-26R and will no longer be included in the presentation.

TMP-26R: NONE

TMP-27: NONE

TMP-28:

1. TMP-28 has been replaced by TMP-28R and will no longer be included in the presentation.

TMP-28R: NONE

TMP-29: NONE

TMP-33: NONE

TMP-34: NONE

TMP-35: NONE

TMP-36: TMP-36 has been replaced by TMP-36R and will no longer be included in the presentation.

TMP-36R: NONE

TMP-37: NONE

TMP-38: NONE

TMP-39: NONE

TMP-40: NONE

TMP-41: NONE

TMP-42: NONE

TMP-43: NONE

TMP-44: NONE

TMP-45: NONE

TMP-46: NONE

TMP-47: NONE

TMP-48: NONE

TMP-49: NONE

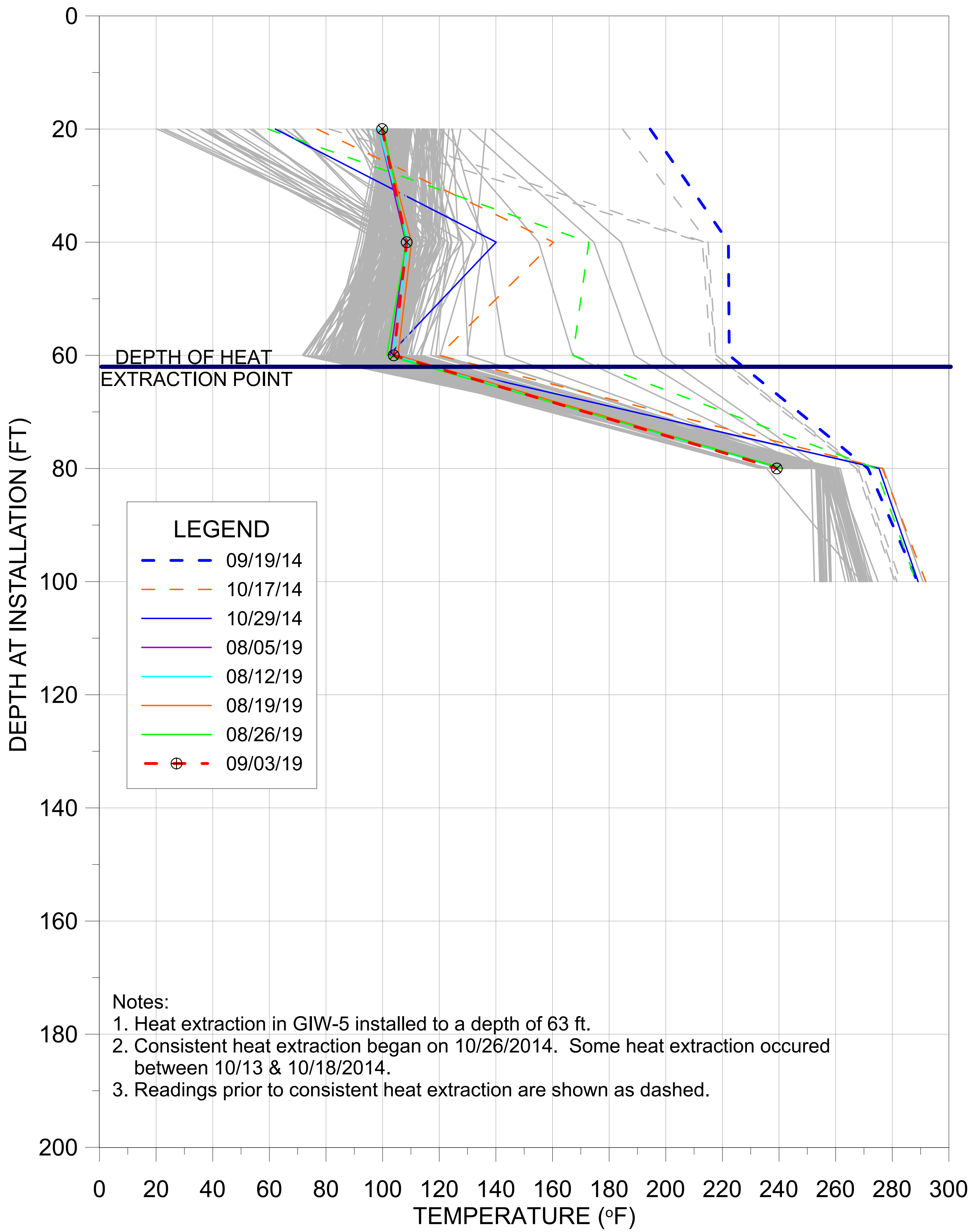
TMP vs DEPTH and TMP vs ELEVATION (for **09/03/19**):

1. There were no reliable temperature readings for TMP-13 since 3/19/2014.
2. There were no reliable temperature readings for TMP-7R, as determined by the connectivity test on 4/11/2014.
3. There were no reliable temperature readings for TMP-5 since 11/5/2014.
4. There were no reliable temperature readings for TMP-12 since 9/28/2015.
5. There were no reliable temperature readings for TMP-8 since 9/9/2015.
6. There were no reliable temperature readings for TMP-14, confirmed since 3/7/2016.
7. There were no reliable temperature readings for TMP-11 as determined by the connectivity test on 11/23/2016.
8. TMP-2 has been replaced by TMP-2R and will no longer be monitored.
9. TMP-11 is no longer in service and will not be included in the presentation.
10. There were no reliable temperature readings for TMP-10 since 5/30/2017.
11. TMP-16, 25, and 28 have been replaced by TMP-16R, 25R, and 28R and will be no longer reported since 1/15/2018.
12. TMP-26 has been replaced by TMP-26R and will be no longer reported since 5/21/2018.
13. TMP-36 has been replaced by TMP-36R and will be no longer reported since 4/1/2018.

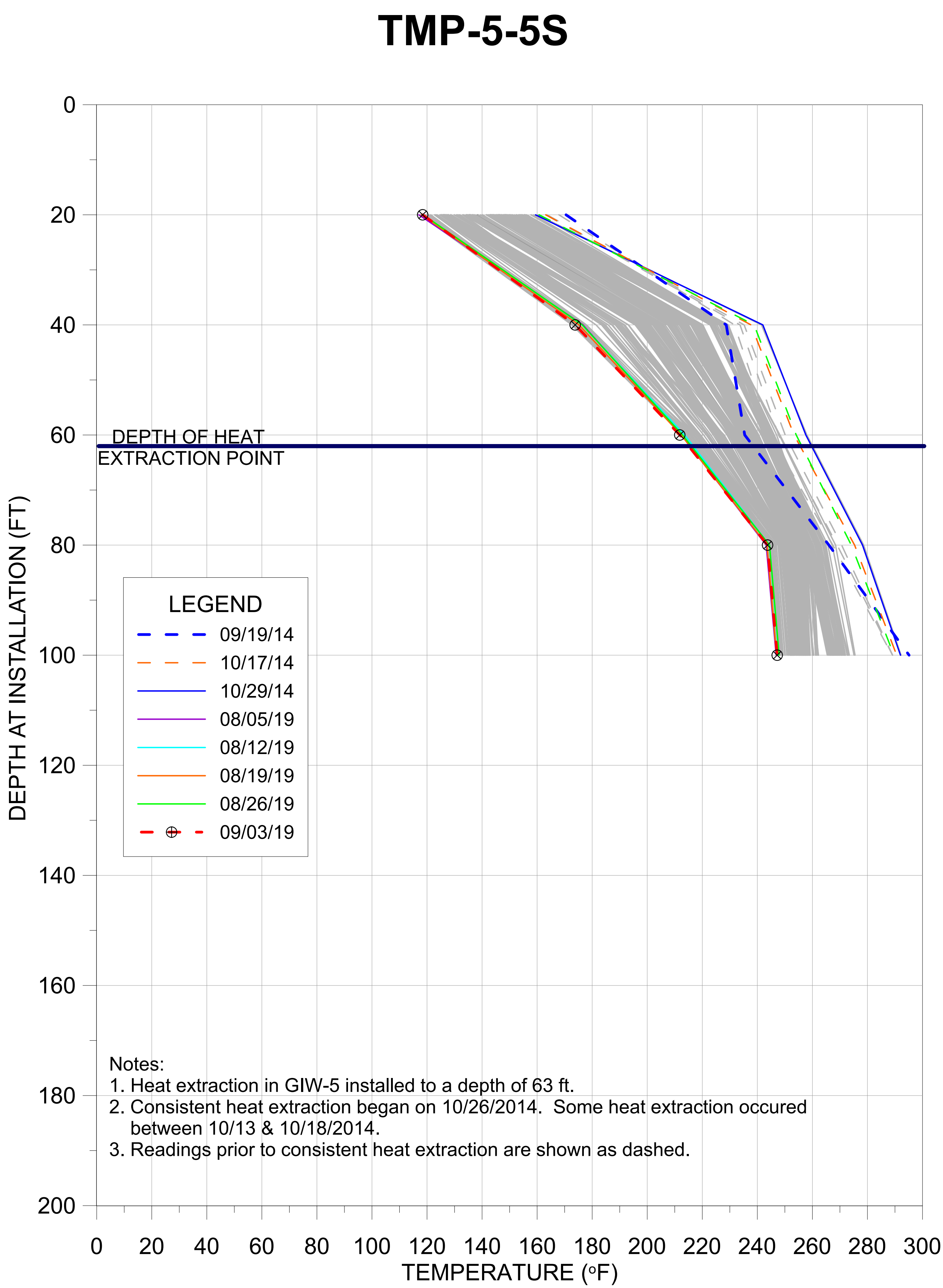
APPENDIX D

GIW PILOT SYSTEM TMP GRAPHS AS OF 9/3/2019

TMP-5-5N

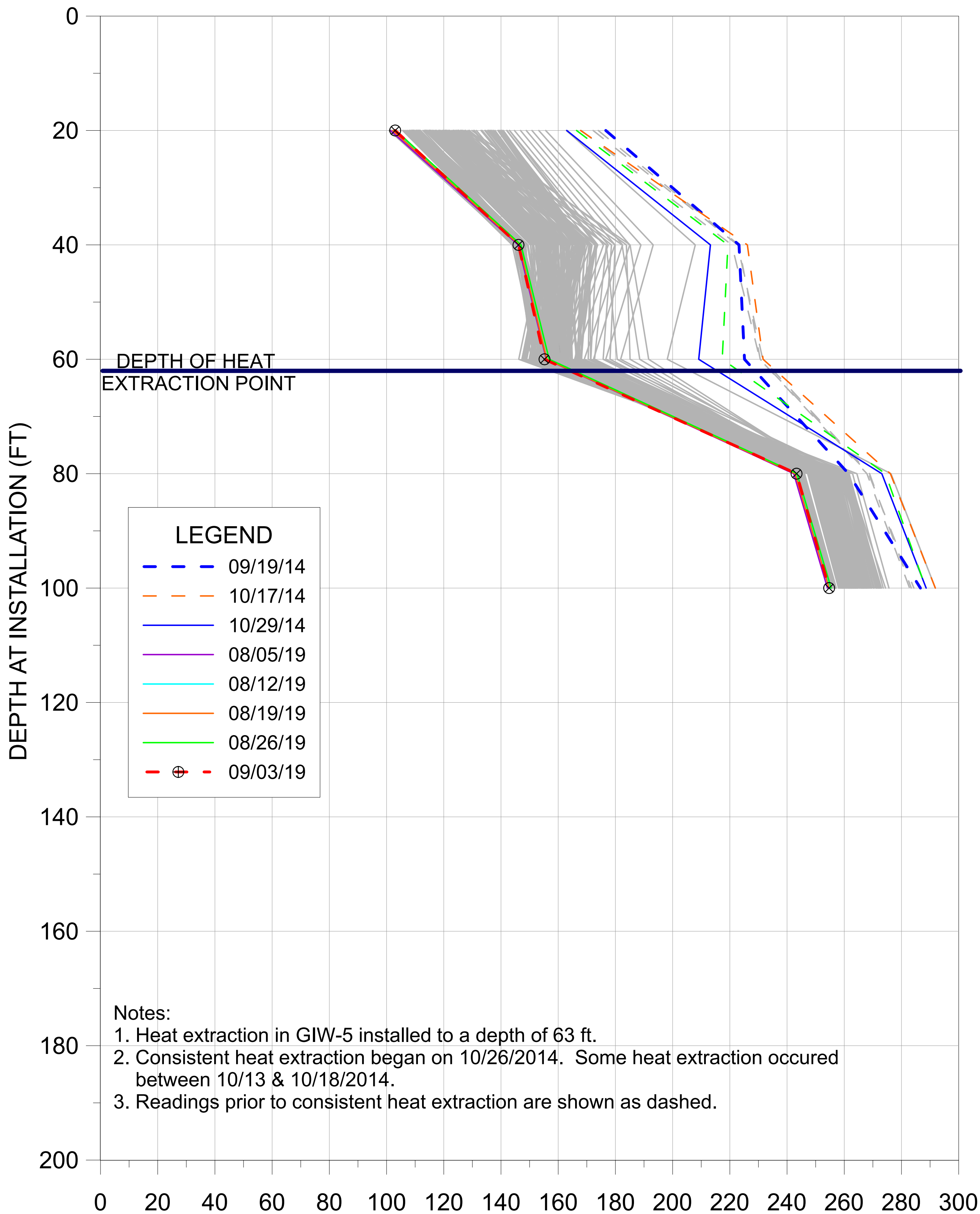


TEMPERATURE VS DEPTH
BRIDGETON LANDFILL



TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

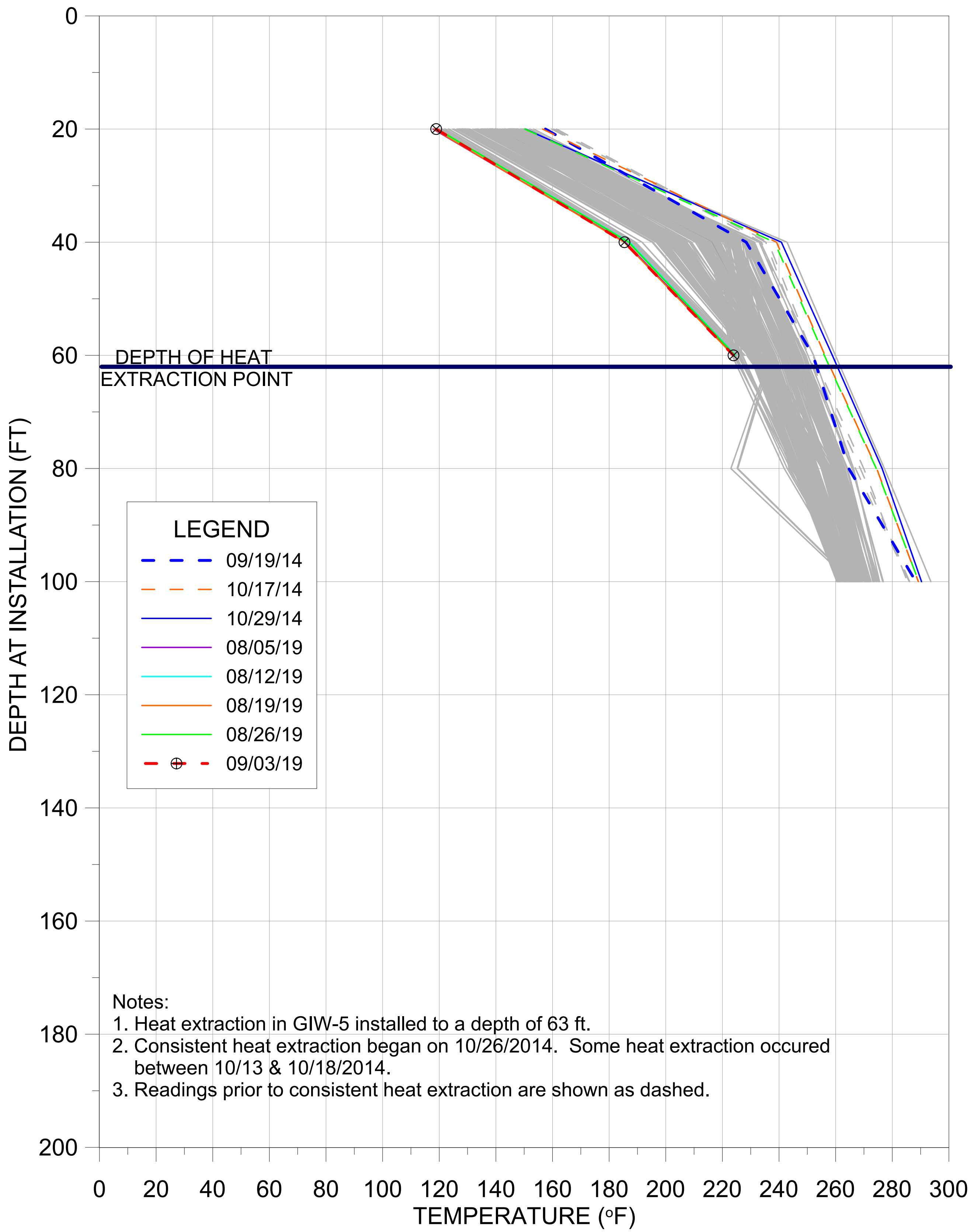
TMP-5-9N



Notes:
1. Heat extraction in GIW-5 installed to a depth of 63 ft.
2. Consistent heat extraction began on 10/26/2014. Some heat extraction occured between 10/13 & 10/18/2014.
3. Readings prior to consistent heat extraction are shown as dashed.

TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

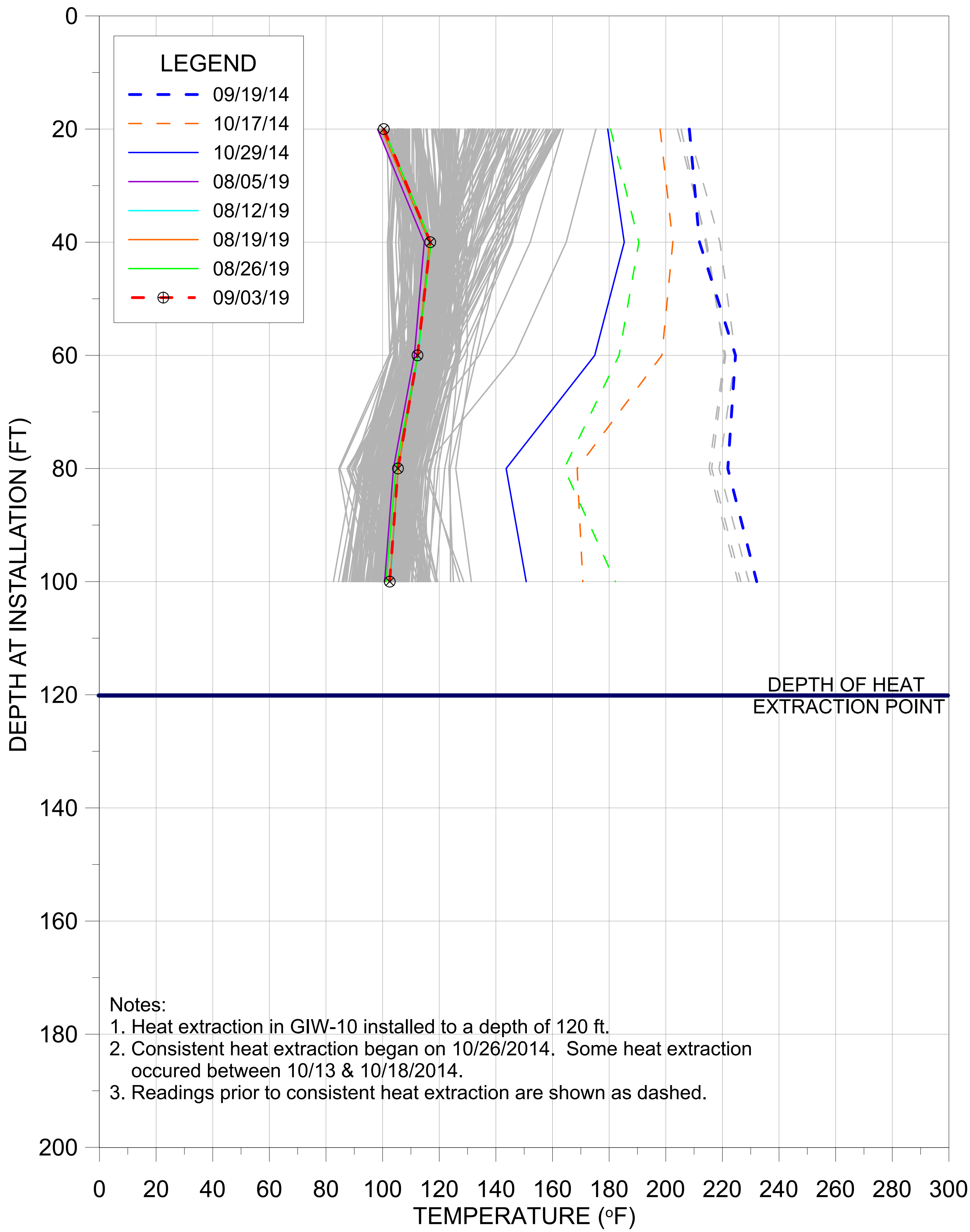
TMP-5-9S



Notes:
1. Heat extraction in GIW-5 installed to a depth of 63 ft.
2. Consistent heat extraction began on 10/26/2014. Some heat extraction occured between 10/13 & 10/18/2014.
3. Readings prior to consistent heat extraction are shown as dashed.

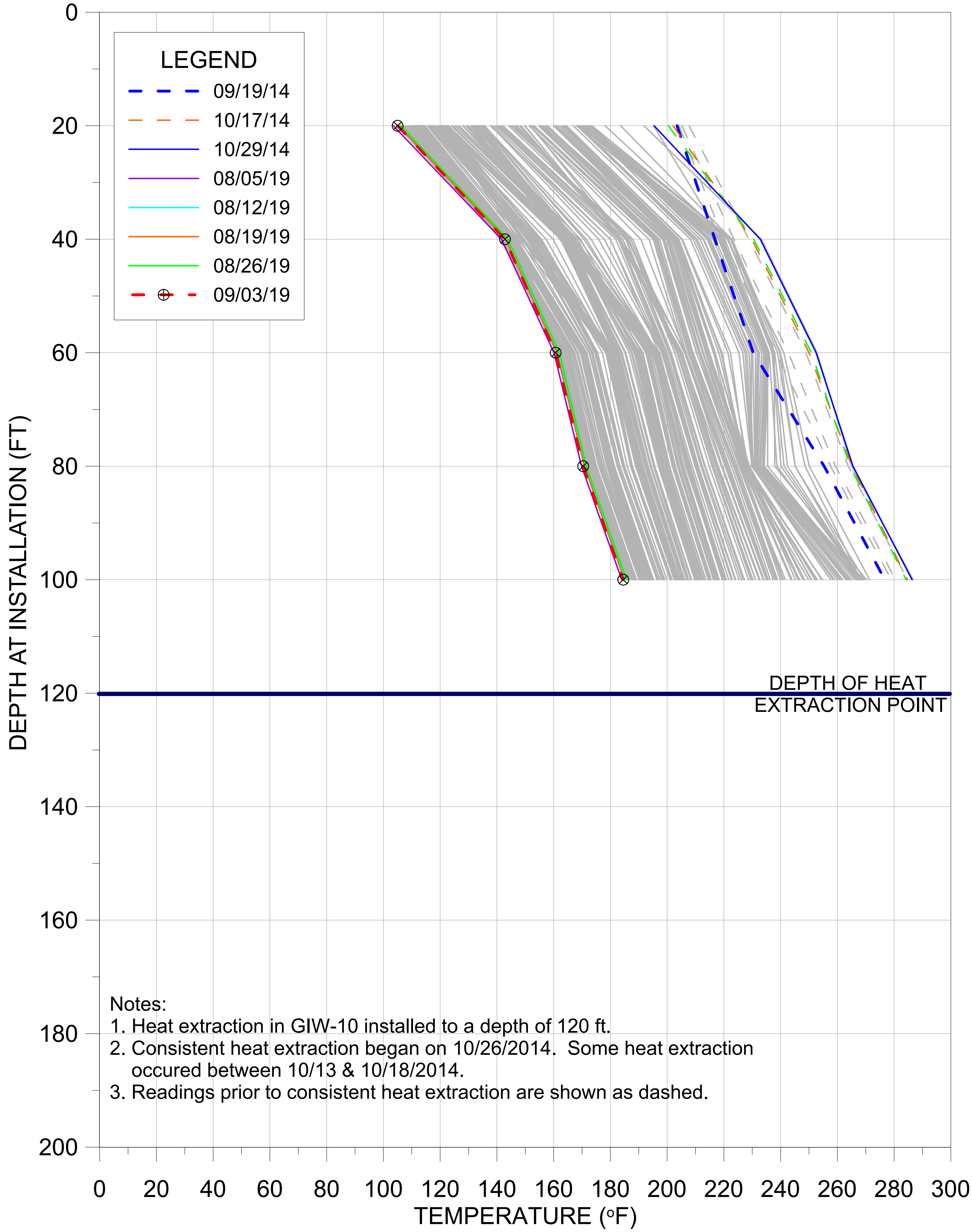
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-10-5N



TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

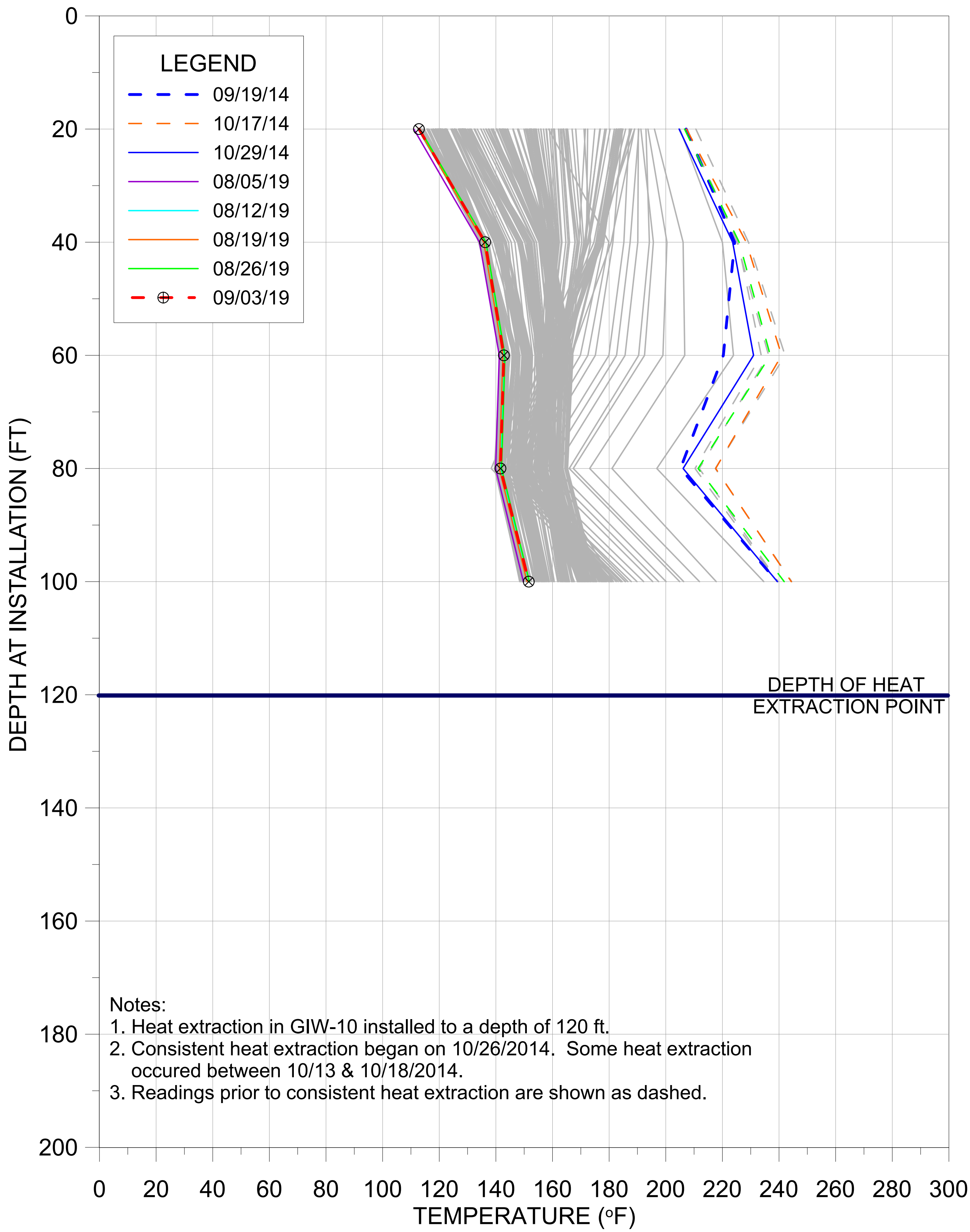
TMP-10-5S



Notes:
1. Heat extraction in GIW-10 installed to a depth of 120 ft.
2. Consistent heat extraction began on 10/26/2014. Some heat extraction occured between 10/13 & 10/18/2014.
3. Readings prior to consistent heat extraction are shown as dashed.

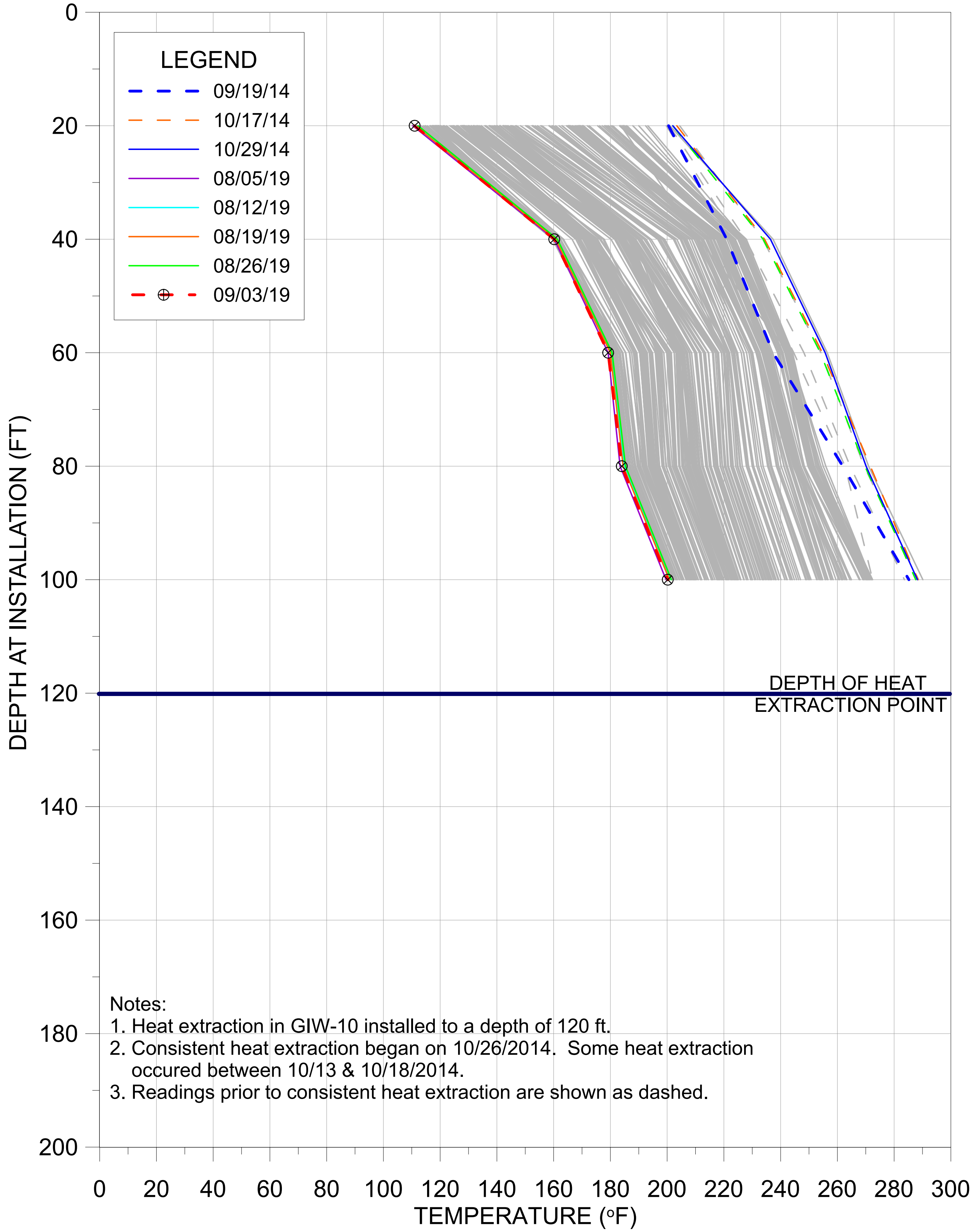
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-10-9N



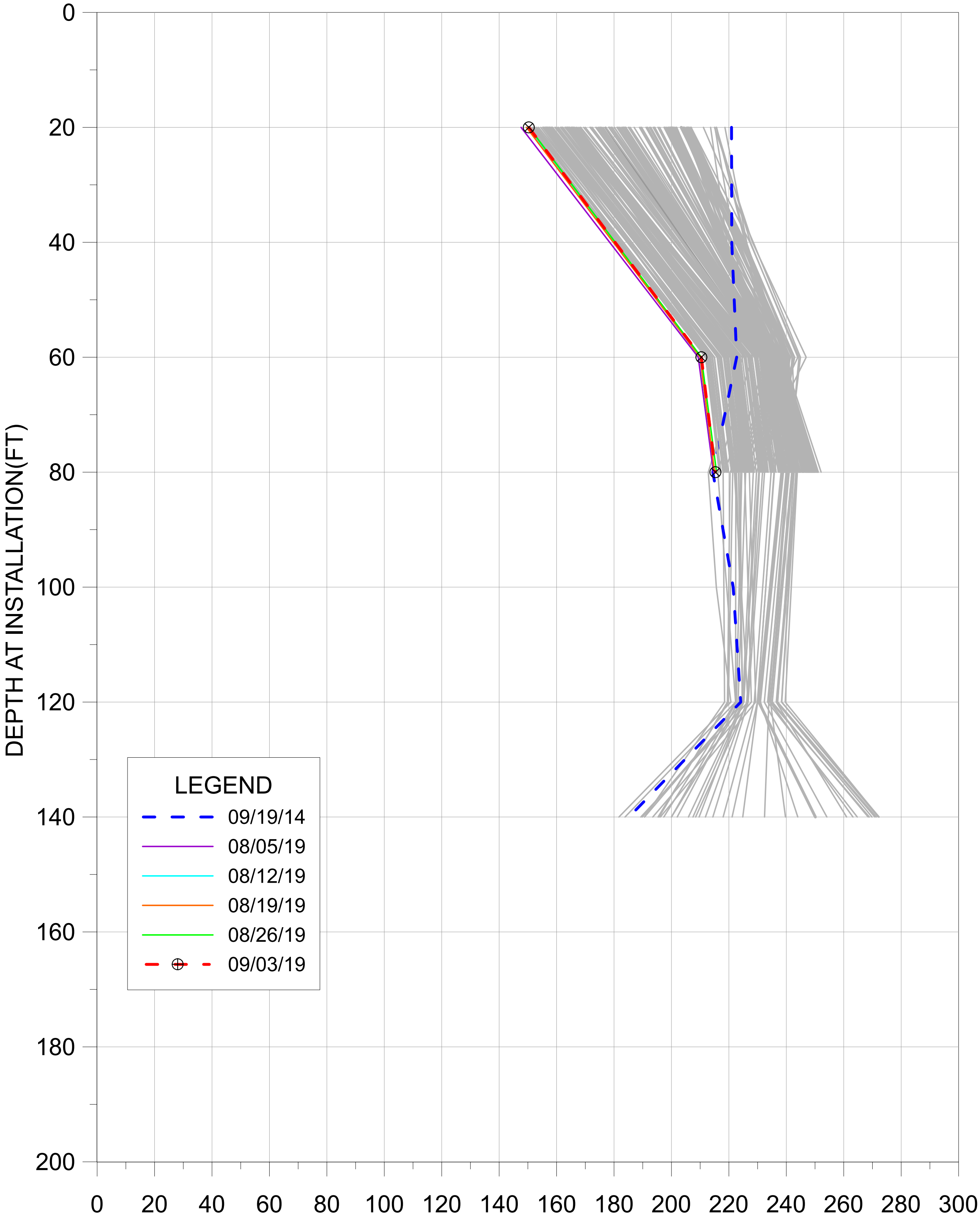
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-10-9S



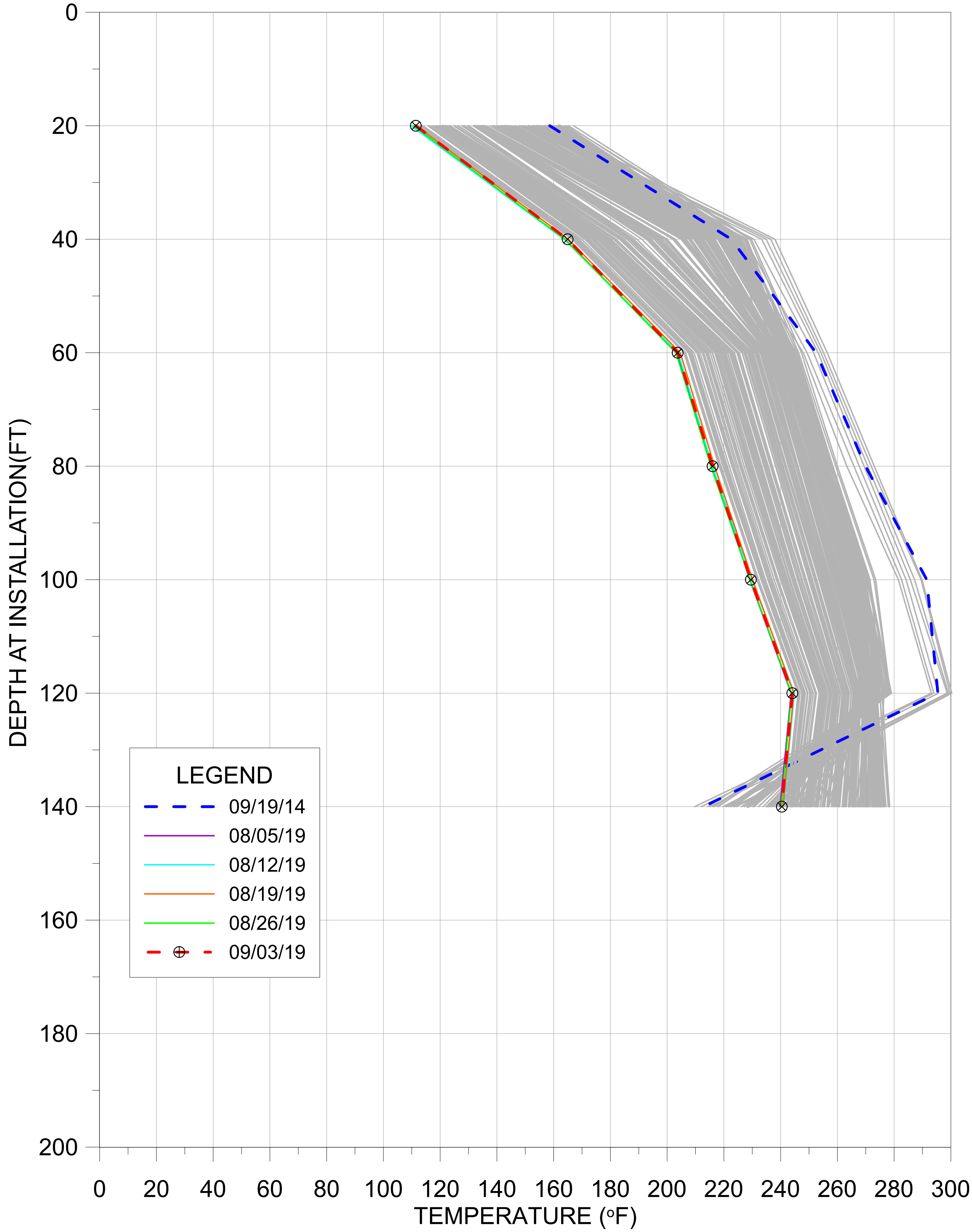
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-19



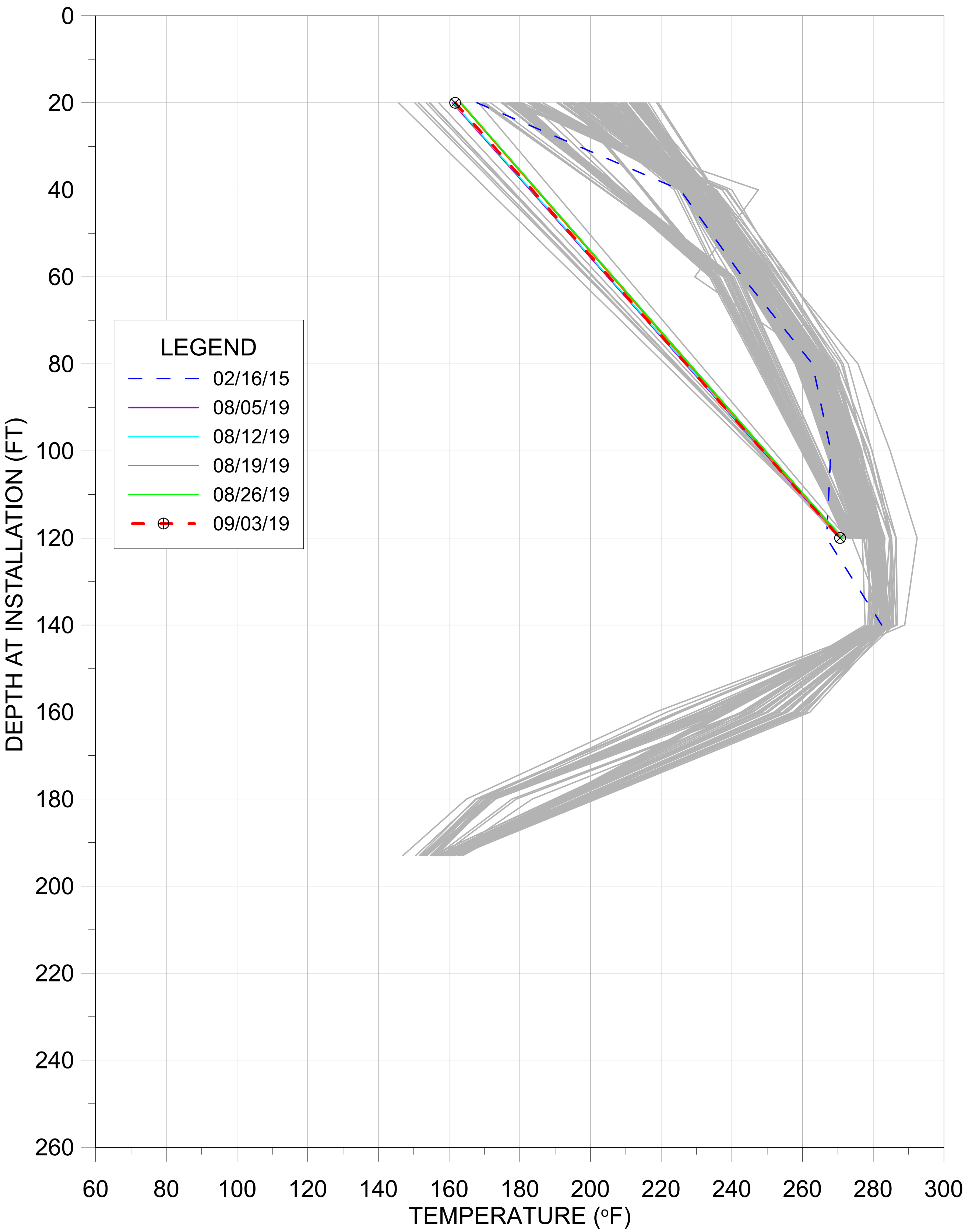
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-20



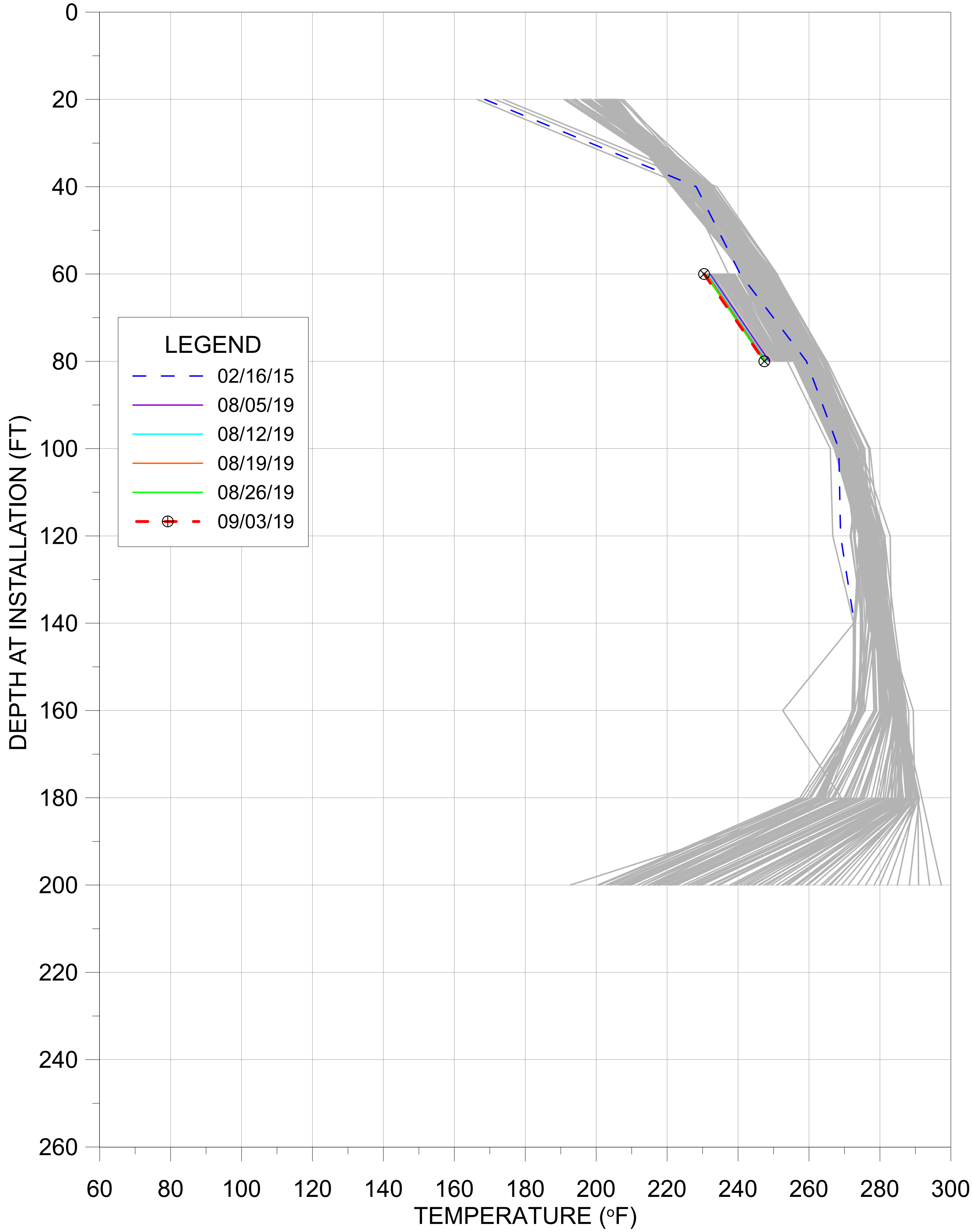
TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

TMP-31

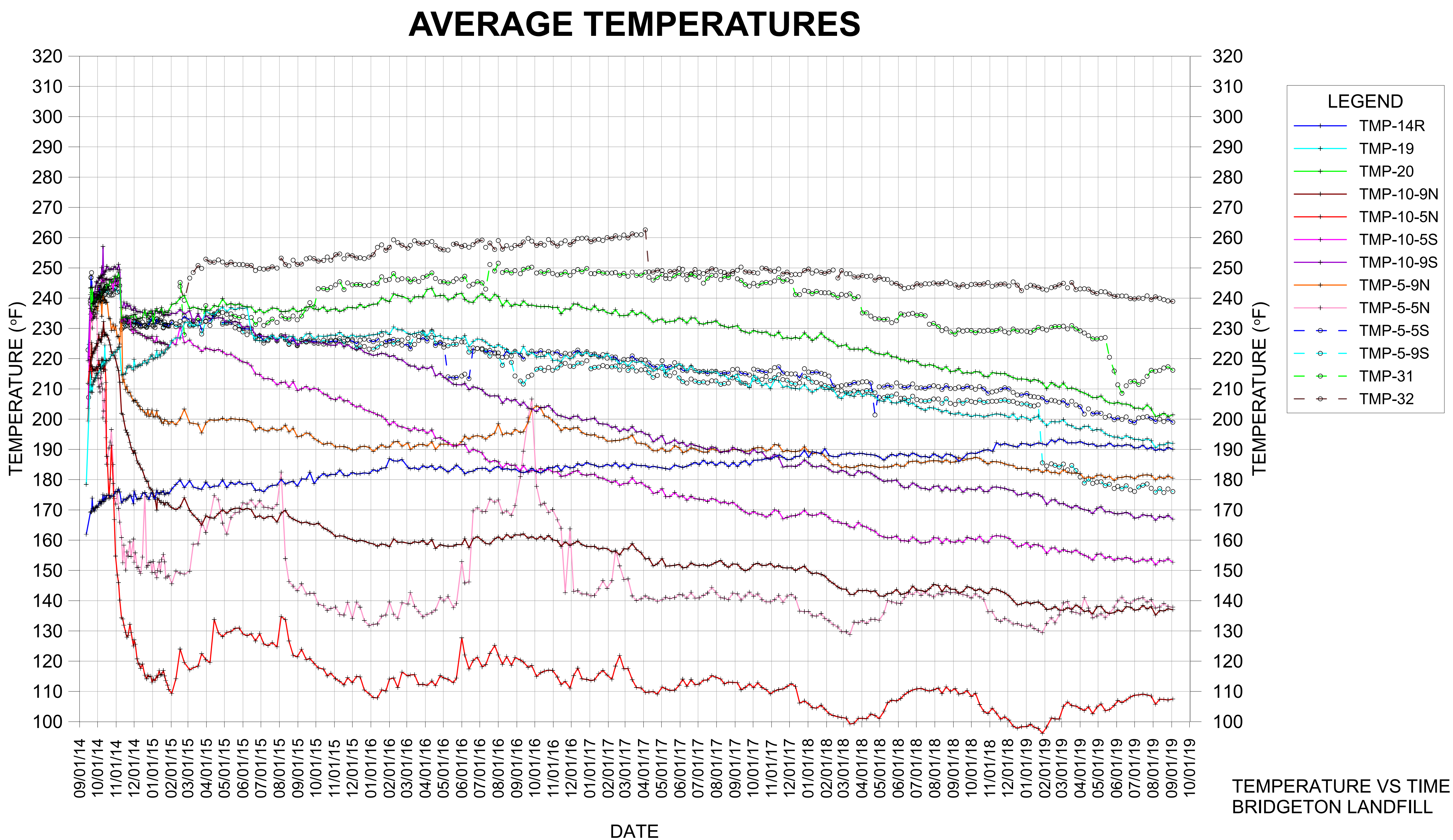


TEMPERATURE VS DEPTH
BRIDGETON LANDFILL

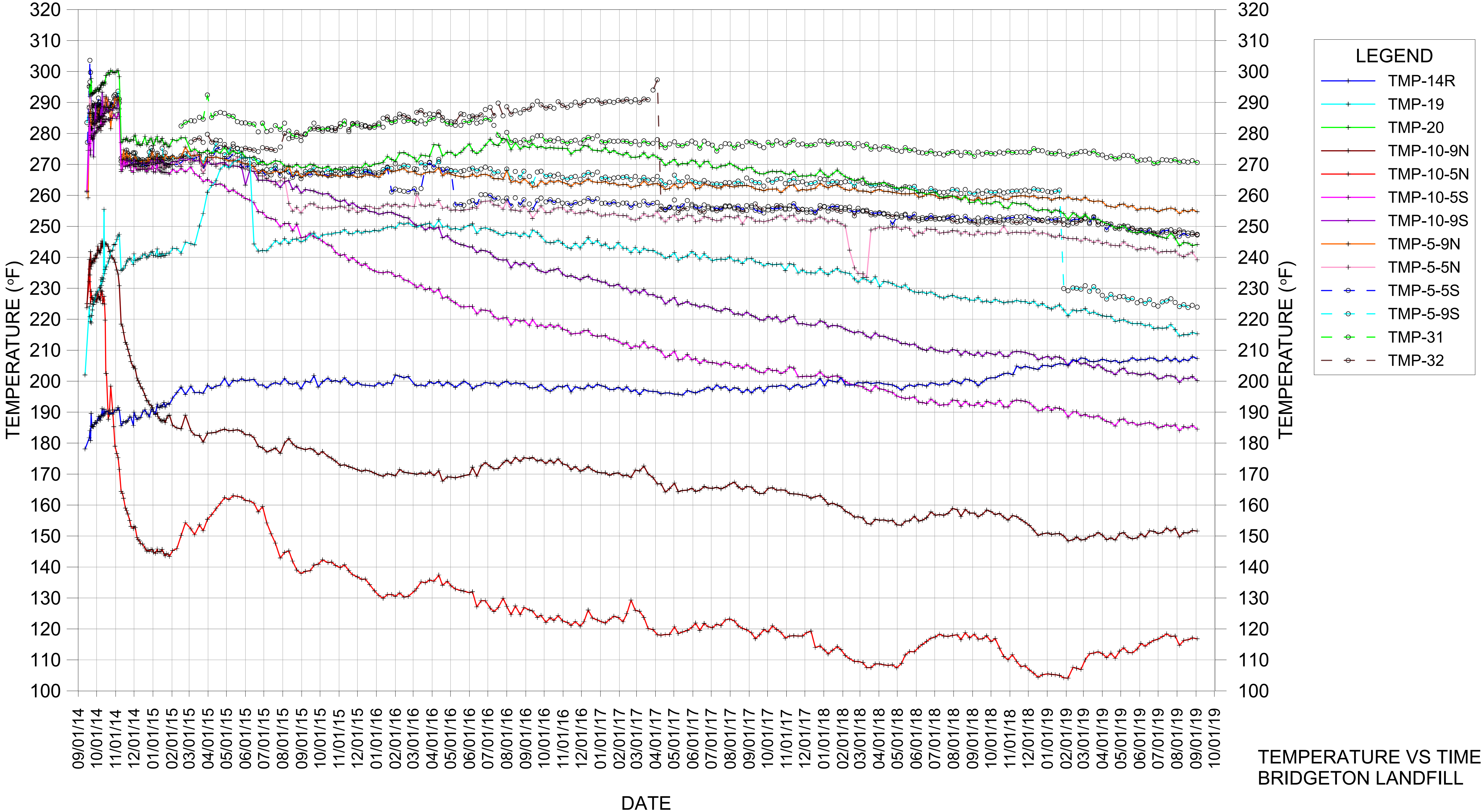
TMP-32



TEMPERATURE VS DEPTH
BRIDGETON LANDFILL


AVERAGE TEMPERATURES
TEMPERATURE (°F)
DATE
LEGEND
TMP-14R
TMP-19
TMP-20
TMP-10-9N
TMP-10-5N
TMP-10-5S
TMP-10-9S
TMP-5-9N
TMP-5-5N
TMP-5-5S
TMP-5-9S
TMP-31
TMP-32
TEMPERATURE VS TIME
BRIDGETON LANDFILL

MAXIMUM TEMPERATURES



TEMPERATURE VS TIME
BRIDGETON LANDFILL

APPENDIX E

NECK AREA CONDITIONS DRAWING

NOTE:
AERIAL TOPOGRAPHY PROVIDED BY COOPER AERIAL SURVEYS, INC. AND IS DATED DECEMBER 12, 2018

JONATHAN E. WILKINSON
PE-2006029714

STATE OF MISSOURI — JONATHAN E. WILKINSON — NUMBER PE-2006029714 — PROFESSIONAL ENGINEER
9/20/2019

PREPARED BY
FEEZOR ENGINEERING, INC.
Engineering for a Better World
3377 Hollenberg Dr, Bridgeton, MO 63044, Ph: 217-483-3118
Missouri State Certificate Of Authority #: E-200912211

PROJECT	PREPARED FOR		DRAWING
BRIDGETON LANDFILL HEAT EXTRACTION SYSTEM BRIDGETON, ST. LOUIS COUNTY, MISSOURI	BRIDGETON LANDFILL LLC 13570 ST. CHARLES ROCK ROAD BRIDGETON, MO 63044	SEPTEMBER 2019 DESIGNED BY: PML APPROVED BY: JEW	E

DRAWING TITLE
NECK AREA CONDITIONS

REVISIONS:	DATE	DSN.	APV.

PROJECT NUMBER: BT-142 | FILE PATH: C:\Users\plins\Dropbox (Feezor Engineering)\Bridgeton\100-149\BT-142 (2017 Heat Extraction Reporting)\2019\2019 Annual Report\Drawings\BT-142 E Neck Area Conditions

APPENDIX F

REVIEW OF HEB EXTRACTION DATA THROUGH AUGUST 2019

BY P.J. CAREY & ASSOCIATES, P.C.

P. J. Carey & Associates, P.C.

5878 Valine Way, Sugar Hill, Georgia 30518
Telephone (678) 482-5193
Fax (866) 845-3898
Email pjcarey@pjcarey.com

Memorandum

To: File

From: Peter Carey

CC:

Date: 10/11/2019

Re: Review of HEB extraction data through August 2019

The data gathered for the year since August 2018 was reviewed to identify general trends and any signs of potential issues. The review of the information identified the following

- The average inflow temperature for the period from September 1, 2018 through August 31, 2019 was 62 degrees F. This was about 2 degrees higher than the previous period from September 1, 2017 through August 31, 2018, which was 61.2 degrees F.

- Inflow temperature was similar than the modelling assumed temperature for the year . A comparison of the modeled and actual temperatures are shown in Figure 1. The plots in Figure 1 indicate that the assumed modeling temperatures are a reasonable approximation of the actual temperatures over time, as long as the evaporative spraying system is operational. Some further adjustment to reflect higher temperatures in the summer months is appropriate, and will be used for projections in the future done by modeling.

- Total energy for the equivalent period in 2018-19 was 734,322 kW hrs versus 809,845 kW hrs for the September 1, 2018 through August 31, 2018 period. The drop is expected given that the overall extraction rates dropping with time would also be expected if overall heat generation rates are falling, as is reflected in some of the TMPs south of the extraction system. The reduction in energy collection year over year is smaller than predicted by the modelling performed in 2017 as can be seen in Figure 2. Figure 2 is based on only the energy extraction of the central HEW units and not the overall system. The difference suggests that the GIW system may be more effective than the idealized model predicts. However, both the model and the actual results are tracking parallel since 2017 and indicate a reduction in energy output was anticipated.

- The locally generated energy release quite likely includes some amount of increase in energy release from returning methano-genesis in near and north of the HEW units, where all temperatures to the north of the HEW line is now within the range of methano-genesis organisms. Trends of either upward flow rate with consistent methane content or increases in methane content are apparent in GEWs 10,38 ,39 ,40 ,41R and 109. This trend has continued from the previous year.

- Review of the relative contribution within the GIW and HEW groups of extractors was performed. The purpose of this was to see if there are any trends or changes that suggest problems with individual units or significantly increasing heat generation locally to any particular units.
    - Average Extraction rates, shown in Figure 3, show that reductions in rate of extraction occurred in all HEW units except HEW-15 where the values were nearly the same as the previous year. The central and deeper HEB units, which were originally installed in warmer material than the shallower units near the edge, showed a greater relative reduction in the rate of heat extraction. This is consistent with expectation.
        - The GIW units 2 and 5 exhibited higher extraction rates than the previous year. The increase was small and could reflect some rising temperatures in the areas surrounding the specific GIW units during the end of the reporting period in response to placement of fill materials just south of the units. The fill placement is likely to have resulted in some minor liquid flows to the north associated with consolidation of the underlying waste.
    - The amount heat extracted from the units divided by the total heat for the HEW or GIW units, for the annual reporting period, indicate the pattern of collection has shifted slightly on the HEB line to reflect the lesser level of collection within the center zones. This is expected give the lack of advancement of the heat front into the neck and the likely lateral spreading that should occur with time at lower temperatures. The relative extraction is determined as the total extracted by the unit for the reporting period divided by the total removed by the group during the reporting period. For example, if the total HEB line extracted 100 kW-hrs and extractor HEW A extracted 10 kW-hrs during the reporting period, then its relative extraction by Type or Group is 10%. This is shown in Figure 4. The GIW elements in Figure 4 indicates the shallower units (3,5 and 6) are collecting less energy proportionally than the other units and that that percentage dropped during the 2018-2019 reporting period. This is also expected as the near surface temperatures within the GIW area is dropping. The GIW units 2, 4, 8, 9, 11, 12 and 13 either represented the same percentage or a slightly increased percentage of group collection from the previous year. The differences were not substantial and likely indicate the persistence of retained heat at greater depth.
    - A review of the HE TMP logs also indicates that the maximum temperatures on the TMPs south of the HE units (GIW-5S- and GIW-10S) are reducing with time. Given these units are further from the extractor unit at depth than the nominal distances, it indicates the zone of influence of the GIW extraction units is still expanding.
- The GIW system of removal continues to remove more energy than the HEW system. This should be expected given the average temperature around the GIW's is significantly higher than that around the HEW line. It should be expected that energy extraction rates will continue to fall at the HEW line in the future.

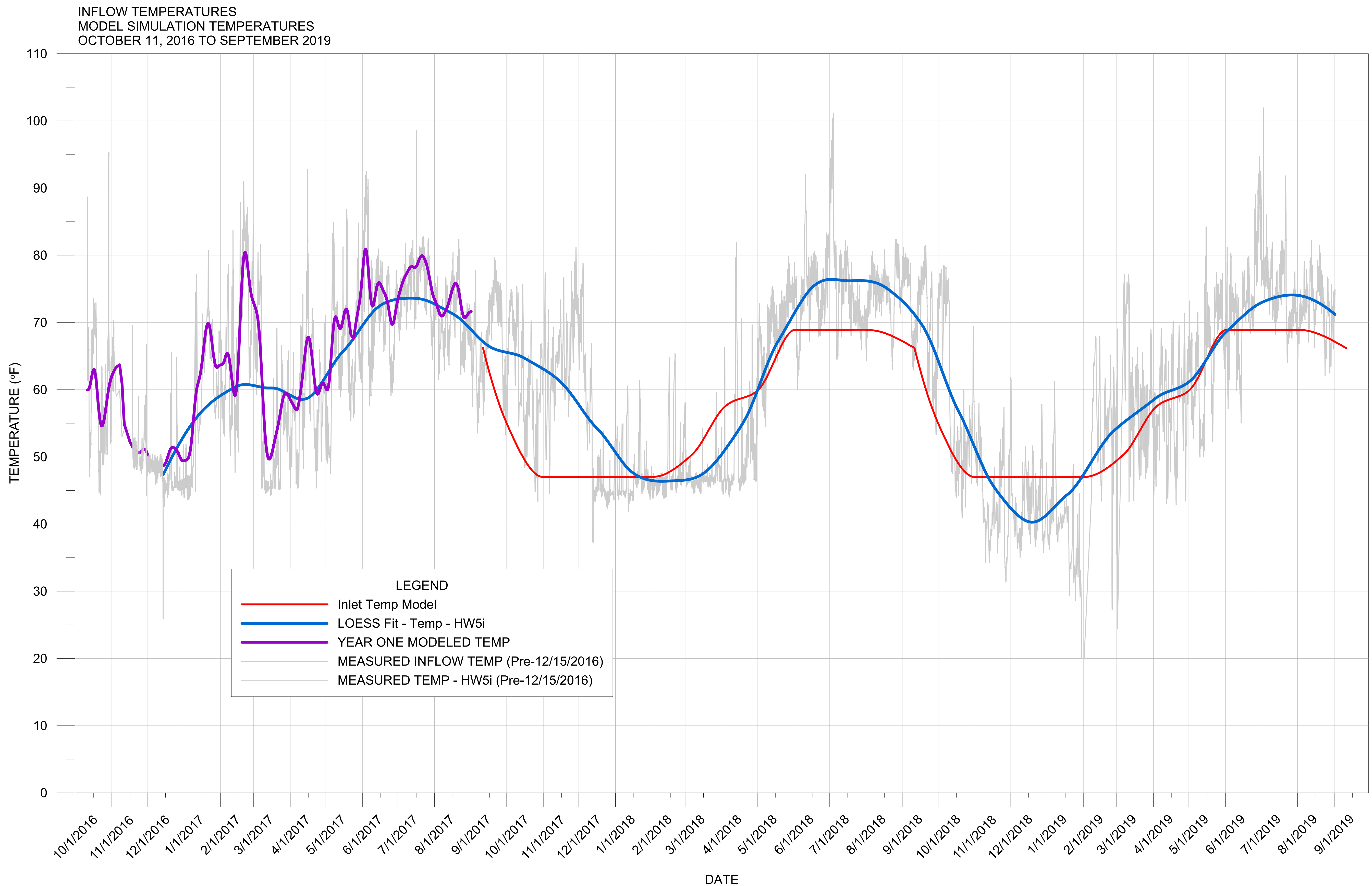

INFLOW TEMPERATURES
MODEL SIMULATION TEMPERATURES
OCTOBER 11, 2016 TO SEPTEMBER 2019
TEMPERATURE (°F)
DATE
LEGEND
Inlet Temp Model
LOESS Fit - Temp - HW5i
YEAR ONE MODELED TEMP
MEASURED INFLOW TEMP (Pre-12/15/2016)
MEASURED TEMP - HW5i (Pre-12/15/2016)

FIGURE 1

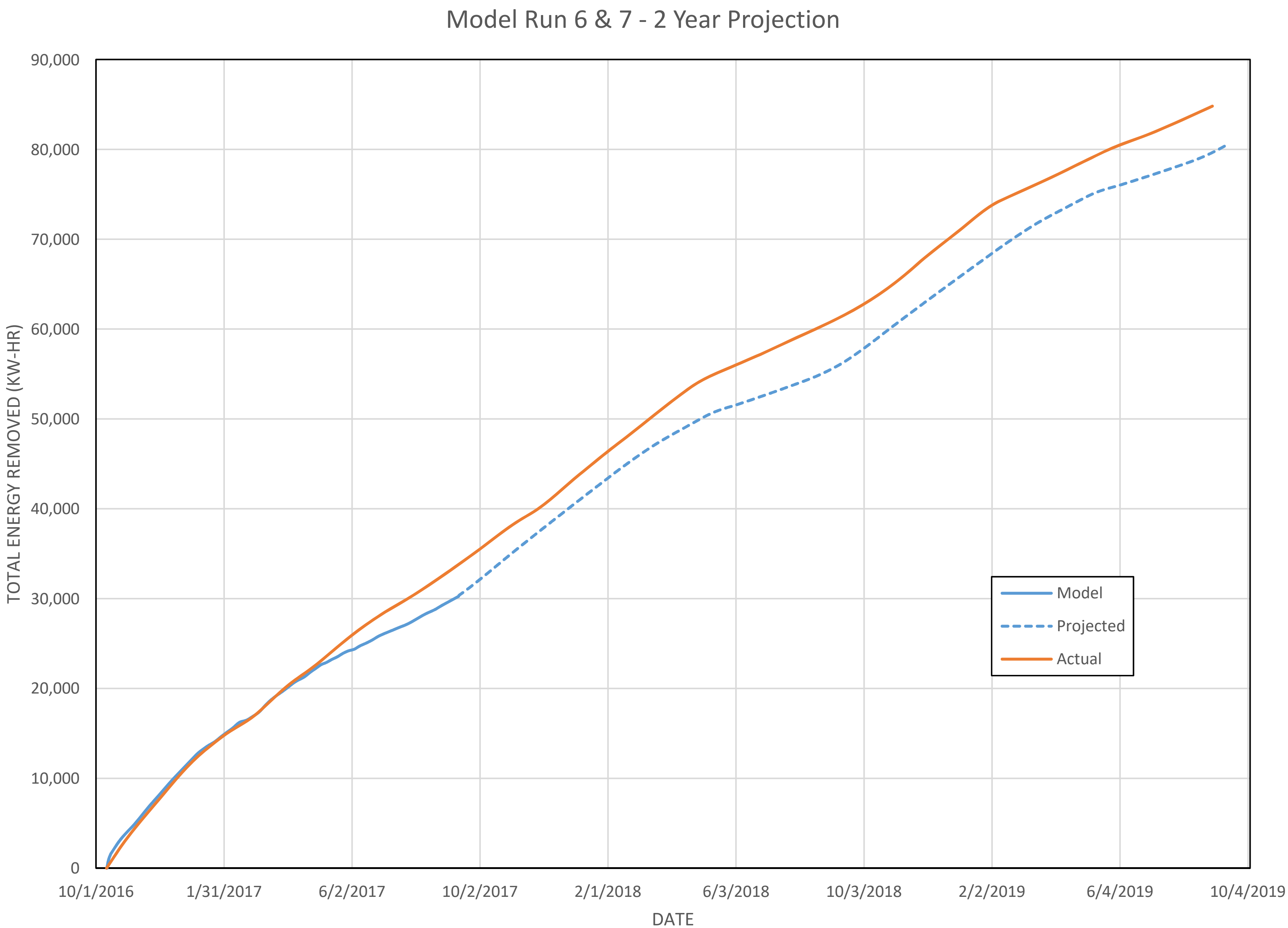
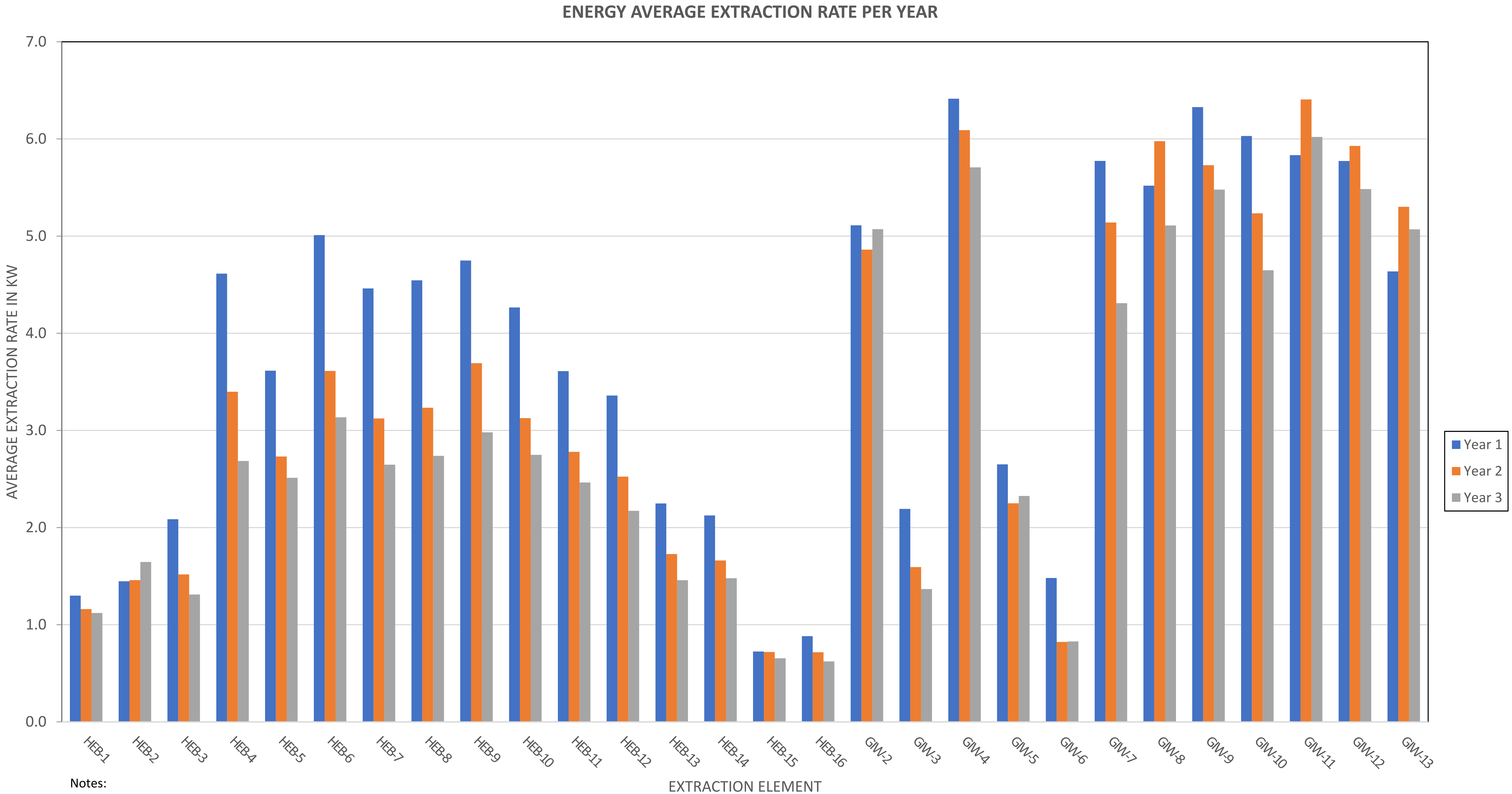
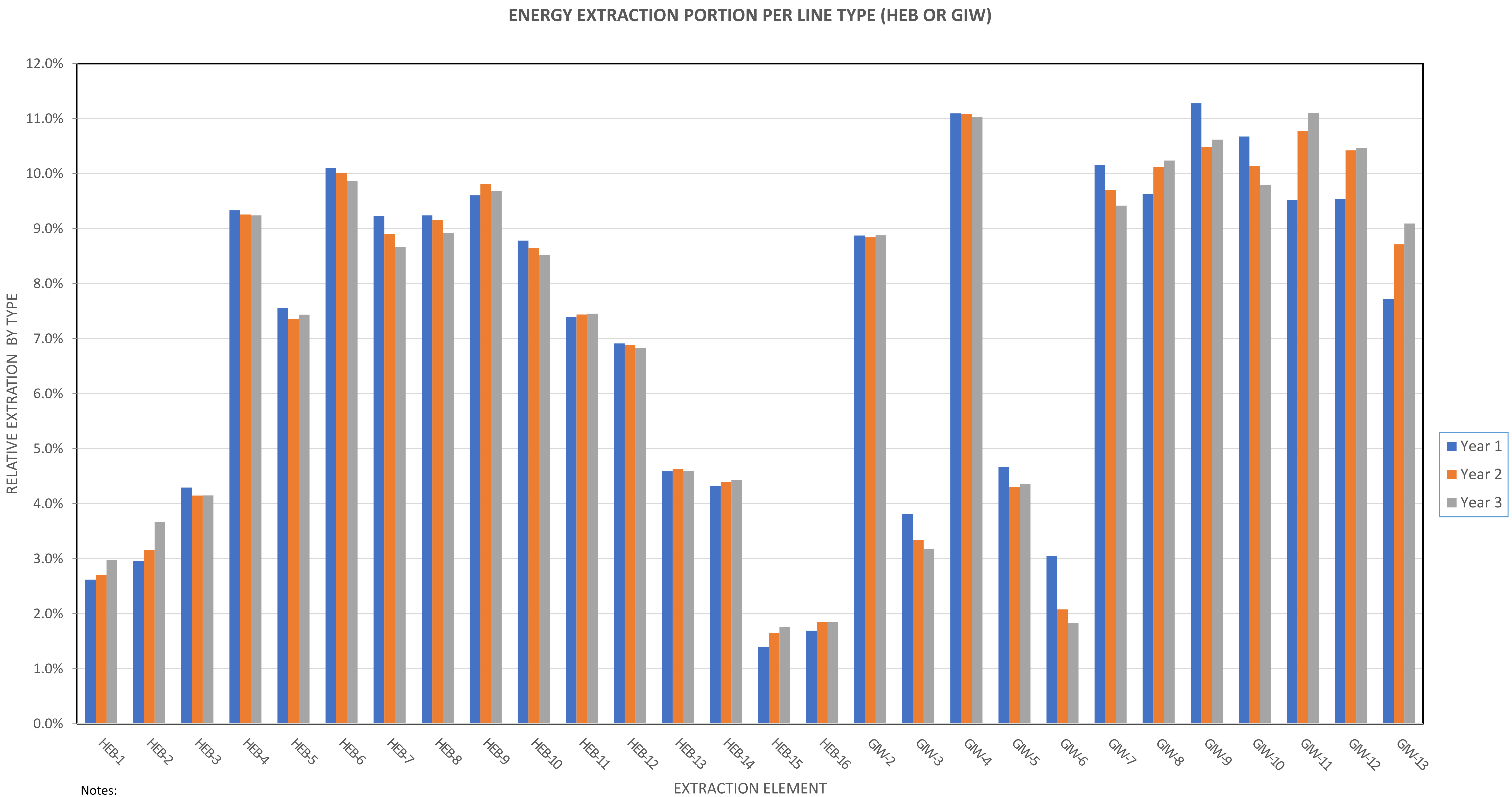

Model Run 6 & 7 - 2 Year Projection
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
TOTAL ENERGY REMOVED (KW-HR)
10/1/2016
1/31/2017
6/2/2017
10/2/2017
2/1/2018
6/3/2018
10/3/2018
2/2/2019
6/4/2019
10/4/2019
DATE
Model
Projected
Actual

FIGURE 2



Notes:
1. Year 1 is from 10/2017 (startup) to 8/31/2017.
2. Year 2 is 9/1/2017 to 8/31/2018.
3. Year 3 is 9/1/2018 to 8/31/2019.

FIGURE 3



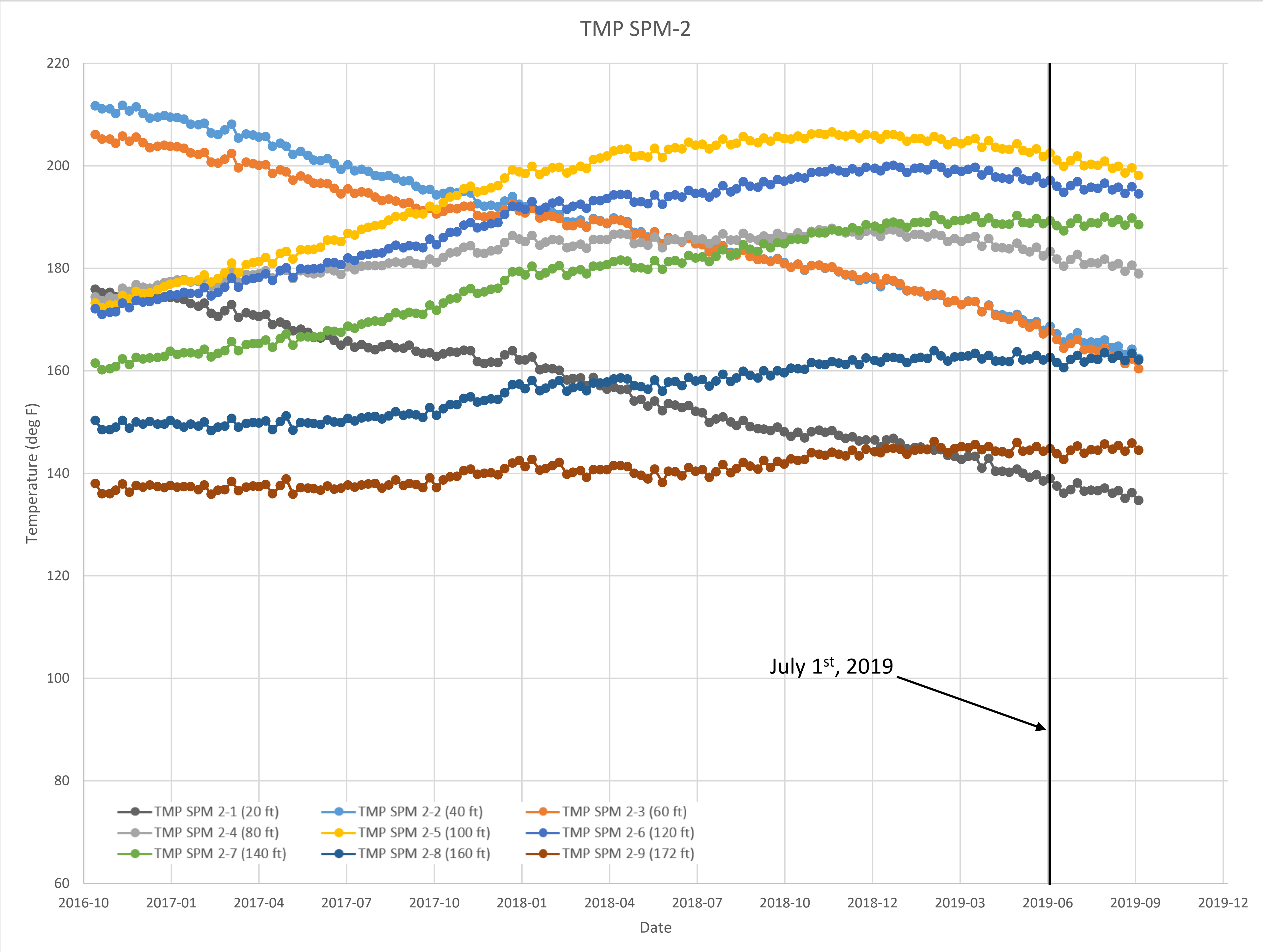
Notes:
1. Year 1 is from 10/2017 (startup) to 8/31/2017.
2. Year 2 is 9/1/2017 to 8/31/2018.
3. Year 3 is 9/1/2018 to 8/31/2019.

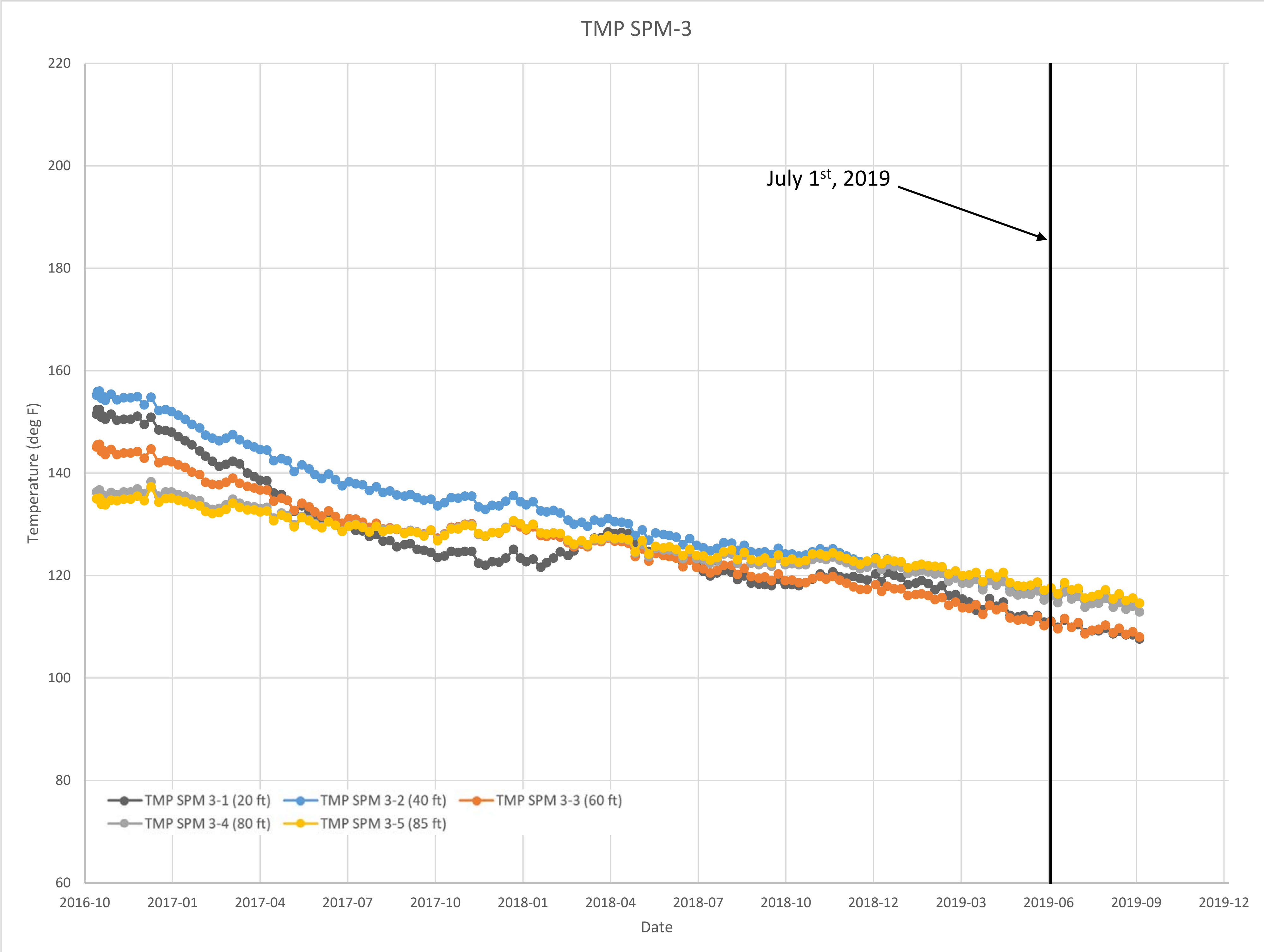
FIGURE 4

APPENDIX G

TIME SERIES GRAPHS OF TMP-SPM-2 AND TMP-SPM-3

TEMPERATURE MEASUREMENT RESULTS


TMP SPM-2
Temperature (deg F)
220
200
180
160
140
120
100
80
60
Date
2016-10
2017-01
2017-04
2017-07
2017-10
2018-01
2018-04
2018-07
2018-10
2018-12
2019-03
2019-06
2019-09
2019-12
July 1st, 2019
TMP SPM 2-1 (20 ft)
TMP SPM 2-2 (40 ft)
TMP SPM 2-3 (60 ft)
TMP SPM 2-4 (80 ft)
TMP SPM 2-5 (100 ft)
TMP SPM 2-6 (120 ft)
TMP SPM 2-7 (140 ft)
TMP SPM 2-8 (160 ft)
TMP SPM 2-9 (172 ft)



TMP SPM-3
July 1st, 2019
Temperature (deg F)
220
200
180
160
140
120
100
80
60
2016-10
2017-01
2017-04
2017-07
2017-10
2018-01
2018-04
2018-07
2018-10
2018-12
2019-03
2019-06
2019-09
2019-12
Date
TMP SPM 3-1 (20 ft)
TMP SPM 3-2 (40 ft)
TMP SPM 3-3 (60 ft)
TMP SPM 3-4 (80 ft)
TMP SPM 3-5 (85 ft)