Water Storage Tank Mixing

NDWPCC

October 12, 2011

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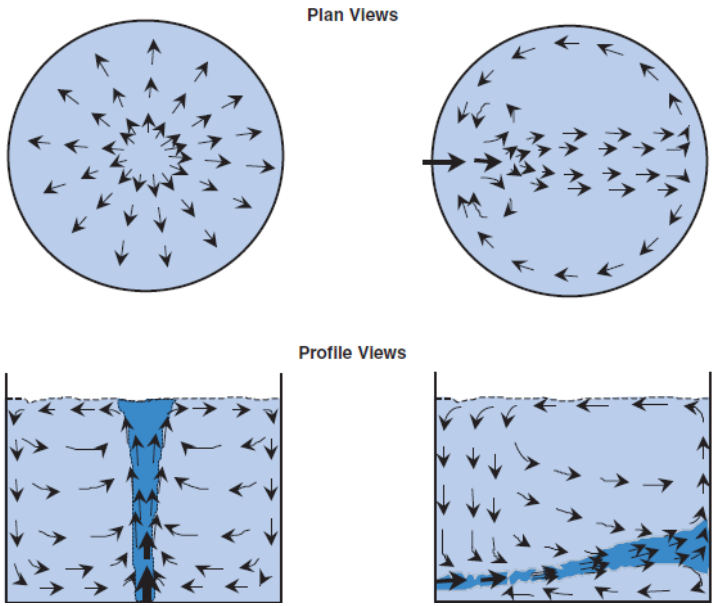
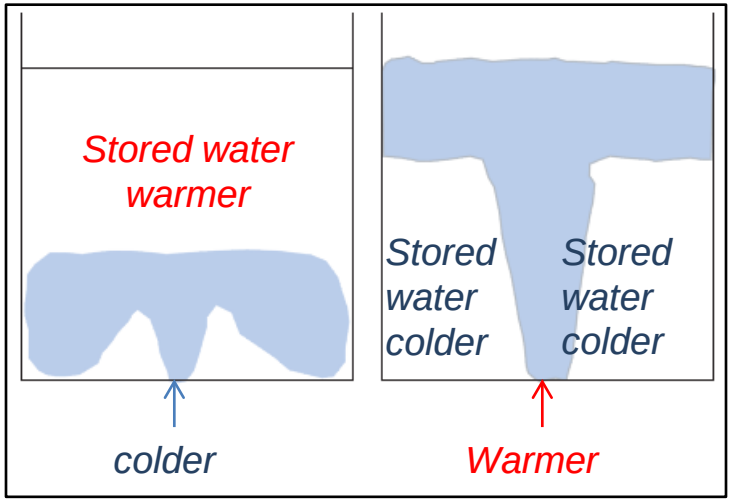
Water & Environmental Engineering Research Center
South Dakota State University

Background



Ideal Jet Mixing Process of Vertical and Horizontal Inlets
Okita and Oyama, (1963)



Negatively buoyant jet

Positively buoyant jet

Adapted from Grayman, et al. (2004)

Poor Mixing Affects Water Quality

- High water age
  - Low chlorine residuals
    - Increased microbial activity
    - Nitrification
  - DBP formation

Tank Mixing - Scope

- Literature review of mixing behavior
- Select tanks
- Modeling
  - Compartment models
  - Elementary CFD software
- Full Scale Testing at Varying Depths
  - Temperature Profile
  - Disinfection residual measurement
- Evaluation of Data and Report
- 2011 Extension of Scope

Acknowledgements

- Graduate Research Assistants, Chris Olson, Andy Lemke
- Systems responding to survey
- System Operators
  - Aurora Brule RWS
  - BY RWS
  - Mni Wiconi Core Line
  - Randall RWS
  - WR/LJ RWS
  - Brookings/Deuel RWS
  - Lincoln/Pipestone RWS
  - Minnehaha Community Water Co.
  - Kingbrook RWS
  - Big Sioux RWS
  - Mid Dakota RWS
  - Clay RWS
  - Grant/Roberts RWS
- Consulting Firms
  - Johnson Engineering
  - DGR
- Regional Water System Research Consortium
- Water & Environmental Engineering Research Center

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Regional Water System Research Consortium

South Dakota depends on rural water systems to supply safe, potable water to farms, country dwellings, communities, and industries. Thirty-three rural water systems supply water to more than 260 of South Dakota's public water systems (cities, towns, subdivisions), comprising more than 70% of the city or town public water supply systems in South Dakota. Regional rural water systems serve a large percentage of South Dakota's area and are a vital contributor the quality of life and economic development.

The Regional Water System Research Consortium (RWSRC) was created to sustain the development and service life of regional rural water systems. RWSRC supports research, development and outreach activities that provide planning and management, operations, and education tools to advance the efficiency and sustainability of regional rural water systems. Stakeholder groups, including several South Dakota rural water systems, the South Dakota Association of Rural Water Systems, and Water Development Districts provided the initial seed funding for projects selected by the RWSRC research advisory group. Representatives of the stakeholder groups are members of the research advisory group. The RWSRC is directed by Delvin DeBoer, Professor of Civil and Environmental Engineering and director of the WEERC at South Dakota State University.

STAKEHOLDERS

PROJECTS

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Click Here for High Def Map of South Dakota Rural Water Systems

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RWSRC Projects

The Regional Water System Research Consortium has supported projects regarding the management and operation of regional rural water systems. To date, two generations of projects have been initiated, the first in 2007 and the second in 2010. These projects have been conducted through the SDSU Water and Environmental Engineering Research Center by graduate research assistants and other research personnel under the supervision of Dr. Delvin DeBoer. Some of the projects have been funded by sponsors in addition to the RWSRC

Project Topic	Year Initiated	Funding Sponsors
Regional Water System Demand Variations and Trend Analysis	2007	Regional Water System Research Consortium South Dakota Department of Environment and Natural Resources SDSU Water and Environmental Engineering Research Center
Economic/Social Impacts of South Dakota's Rural Water Systems	2007	Regional Water System Research Consortium SDSU Water and Environmental Engineering Research Center
Development of Rural Customer Meter Autoread System	2007	Regional Water System Research Consortium SDSU Water and Environmental Engineering Research Center
Variations in Quality of Regional Water System Water Sources	2010	Regional Water System Research Consortium
Improving Safety of Crude Oil and Regional Water System Pipeline Crossings	2010	Regional Water System Research Consortium South Dakota Department of Environment and Natural Resources US Department of Transportation/PHMSA
Water Storage Tank Mixing Study	2010	Regional Water System Research Consortium

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RWSRC Stakeholders and Funding Sources

Regional rural water systems provide quality tap water to many homesteads, farms, towns, cities and industries of South Dakota. Recognizing the need to develop and sustain these regional water systems, these stakeholders have contributed funds for projects of the Regional Water System Research Consortium.

Rural Water Systems

Aurora Brule RWS
BDM RWS
Big Sioux CWS
Brookings-Deuel RWS
Clark RWS
Clay RWS
Davison RWS
Grant-Roberts RWS
Hanson RWS
Kingbrook RWS
Lewis & Clark RWS
Lincoln County RWS
Mid-Dakota RWS
Minnehaha CWC
Perkins County RWS
Randall CWD
Sioux RWS
TM RWD
WEB WDD
West River-Lyman Jones RWS

South Dakota Association of Rural Water Systems

Water Development Districts

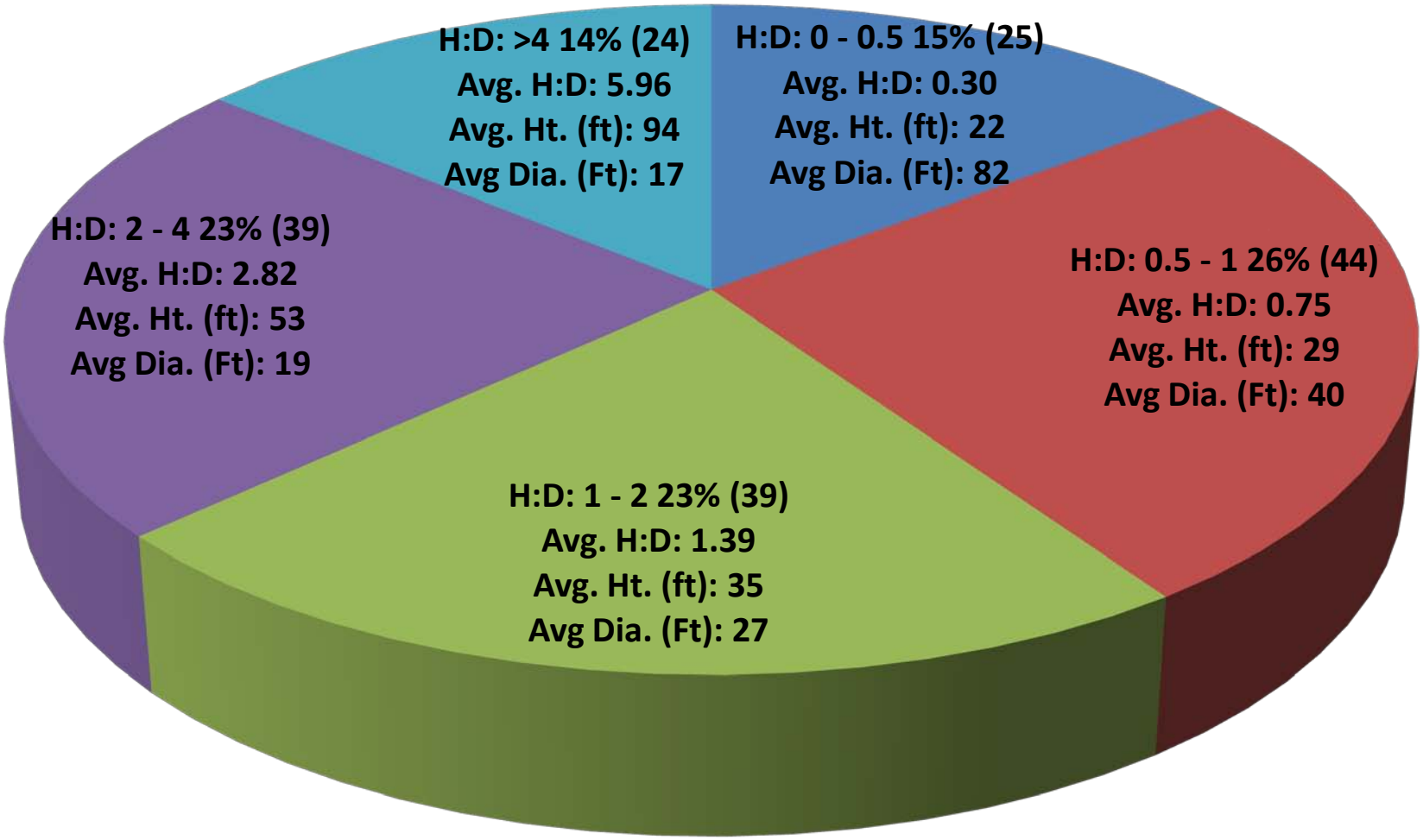
Central Plains WDD
East Dakota WDD
James River WDD
South Central WDD
Vermillion Basin WDD

Other Funding Sources

South Dakota Department of Water and Natural Resources
US Department of Transportation/Pipeline and Hazardous Materials Safety Administration

Rural Water Tank Survey

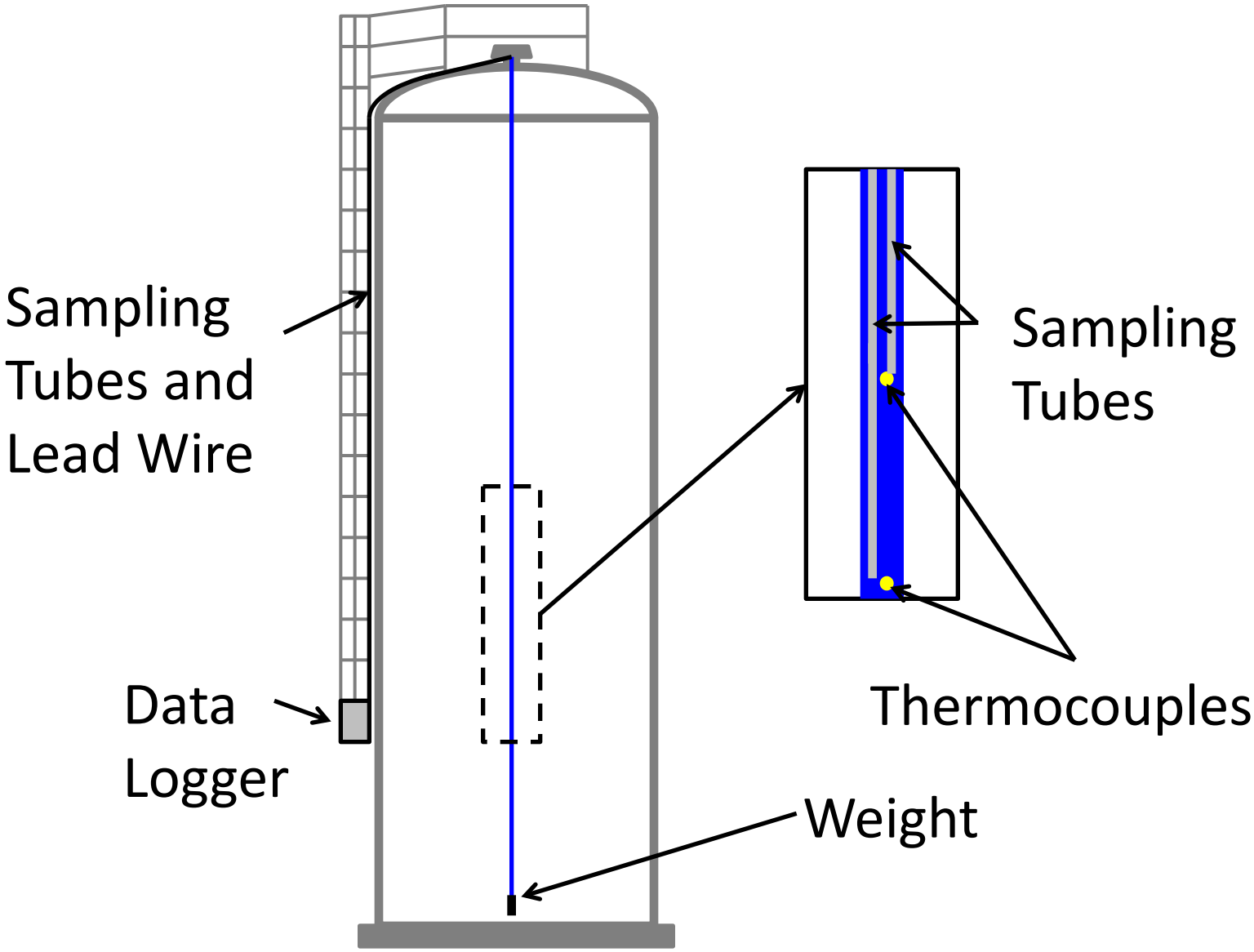
Distribution of At-Grade Tanks by H:D category



Tank selection - characteristics of the selected long term tanks

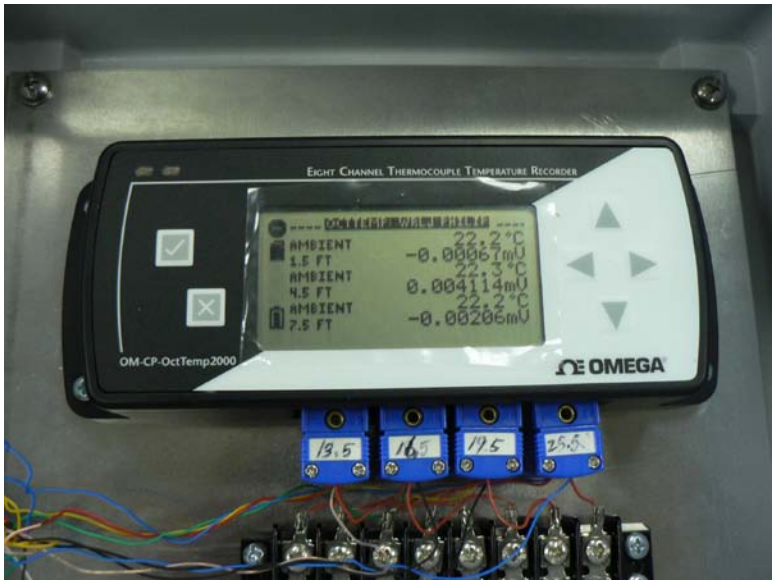
H:D Category	Tank Name	Capacity (gal)	Height (ft)	Dia. (ft)	H:D Ratio	Common Inlet/Outlet	SCADA for Water Level	Artificial Mixer Installed
0-0.5	A	948,000	24	81	0.30	Y	Y	N
0.5-1	B	559,000	38	50	0.76	N	Y	N
1-2	C	65000	28	20	1.41	Y	Y	N
2-4	D	175,000	75	20	3.75	Y	Y	Y
>4	E	140,000	86	14	6.14	Y	Y	Y
1-2	F	55,000	34	17	2.00	N	Y	N
1-2	G	140,000	44	24	1.83	N	Y	N

Long Term Temperature and Water Sampling



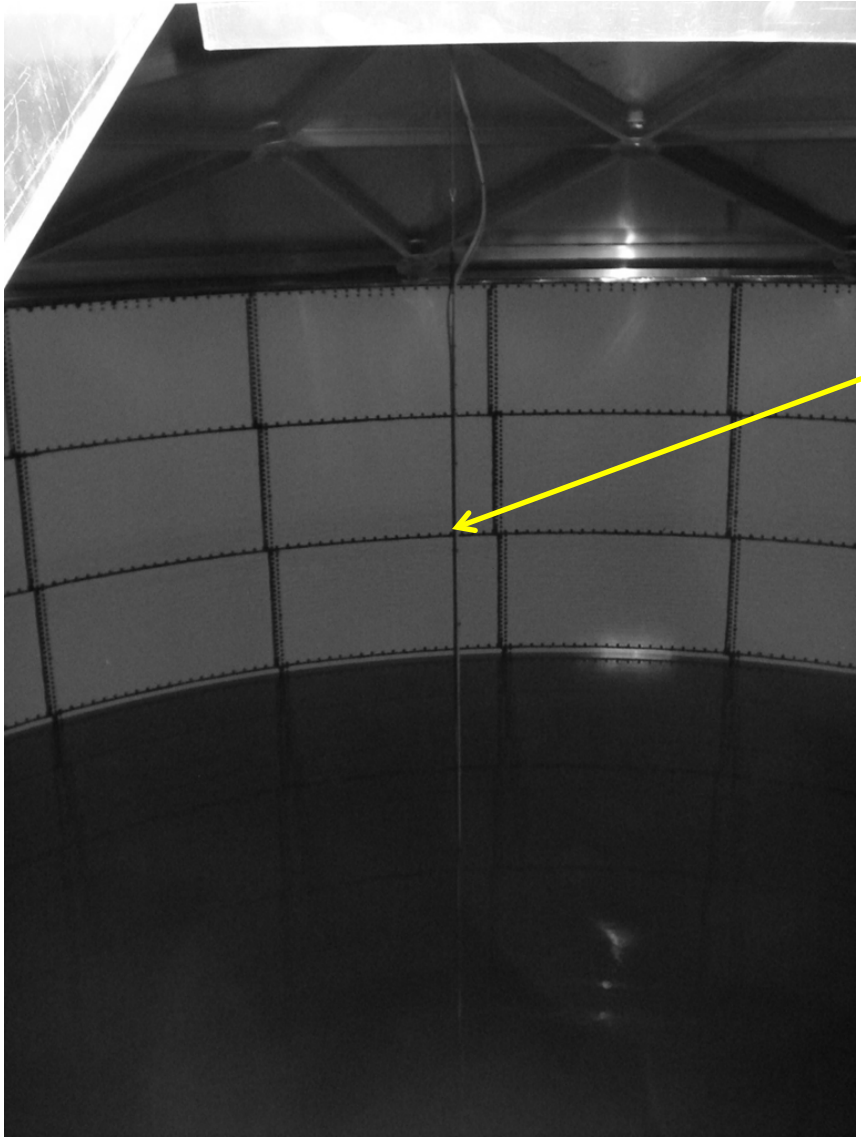
Methods – Long term temperature and water sampling

Data logger



Temperature cable and sampling tubes

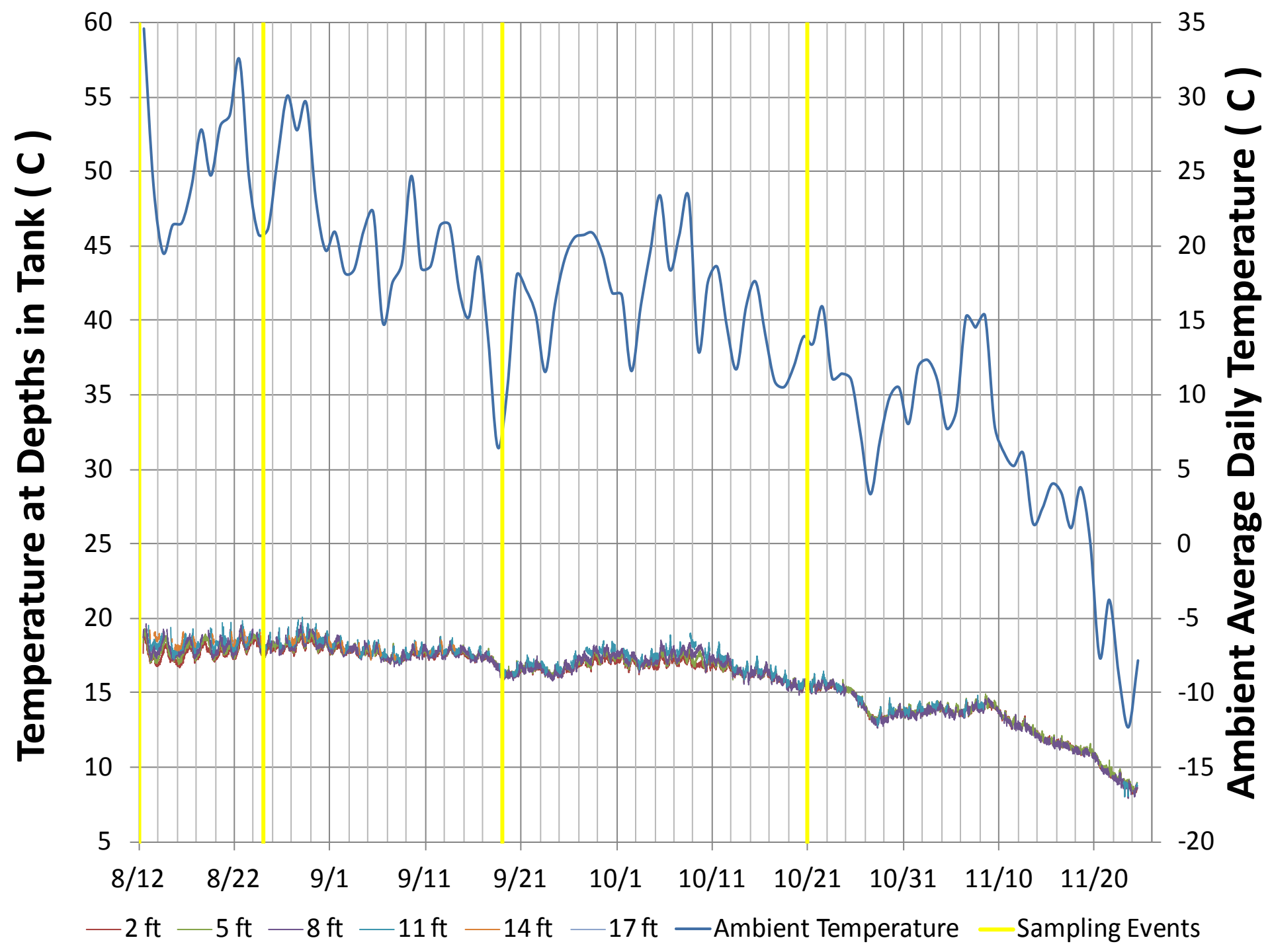
Long Term Temperature and Water Sampling

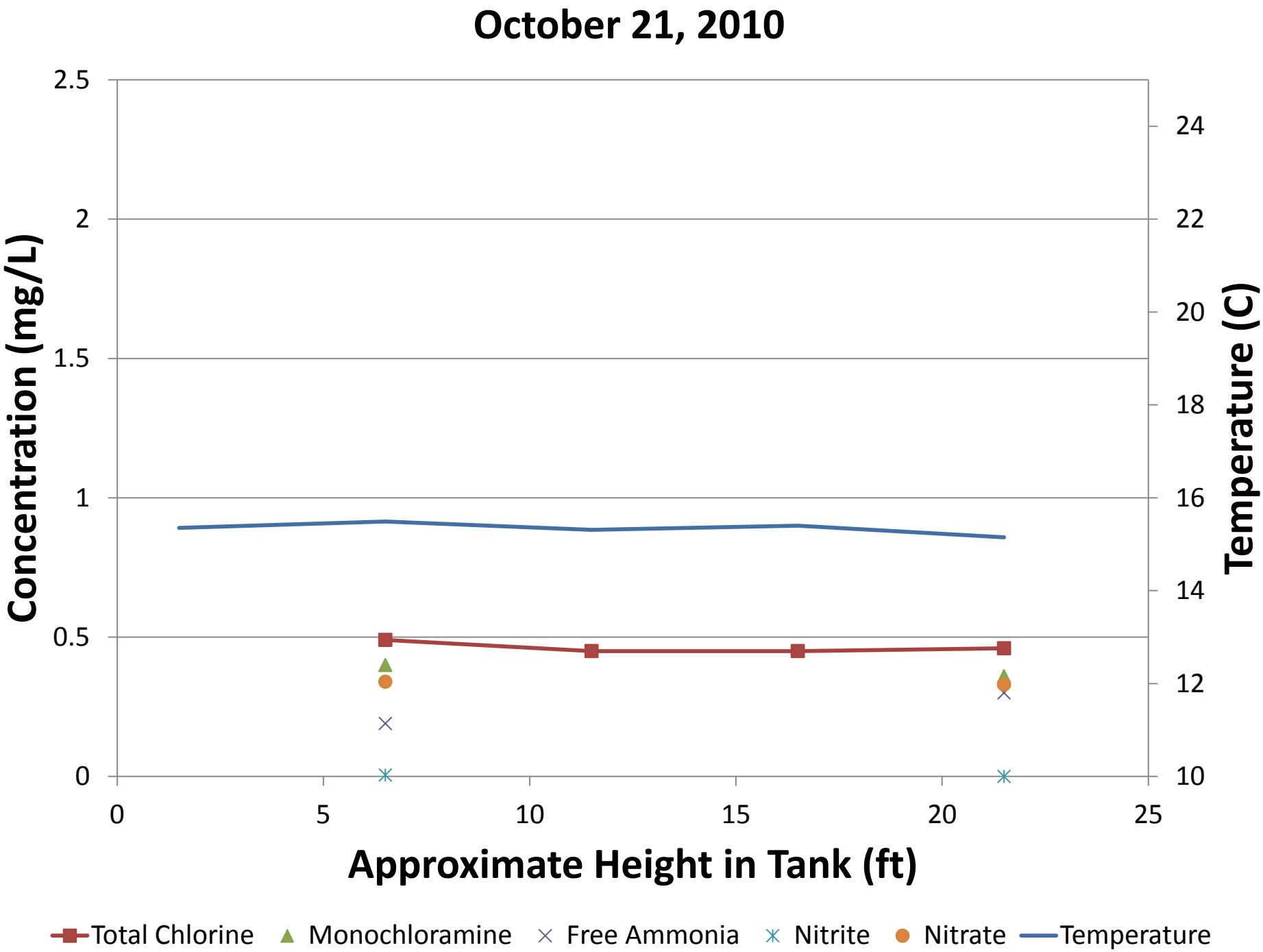


Thermocouple Cable and Sampling Tubes

Tank A

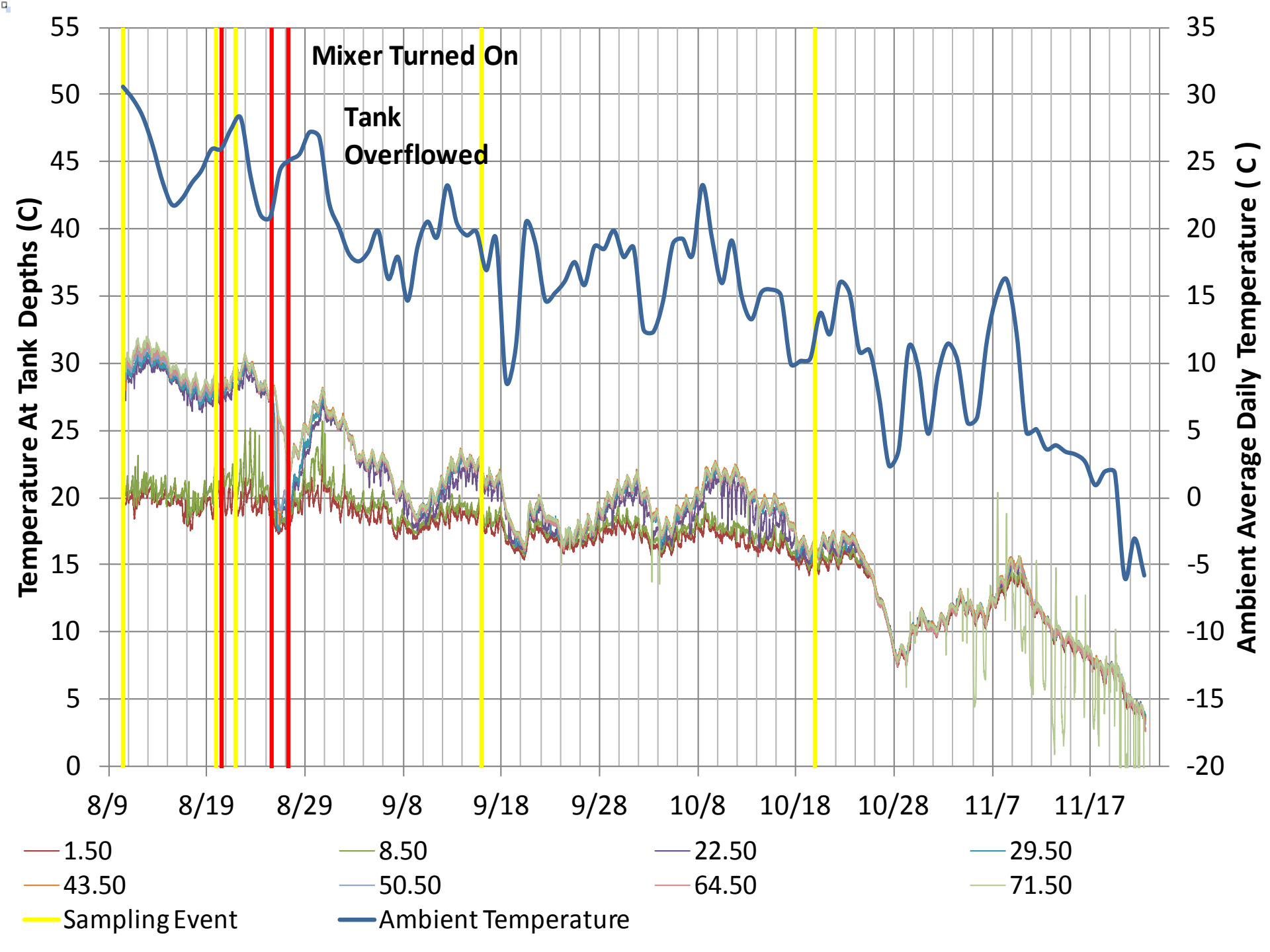
Aspect Ratio Category	0-0.5
Capacity	948,000 gal
Height	24 ft
Diameter	81 ft
H:D Ratio	0.3

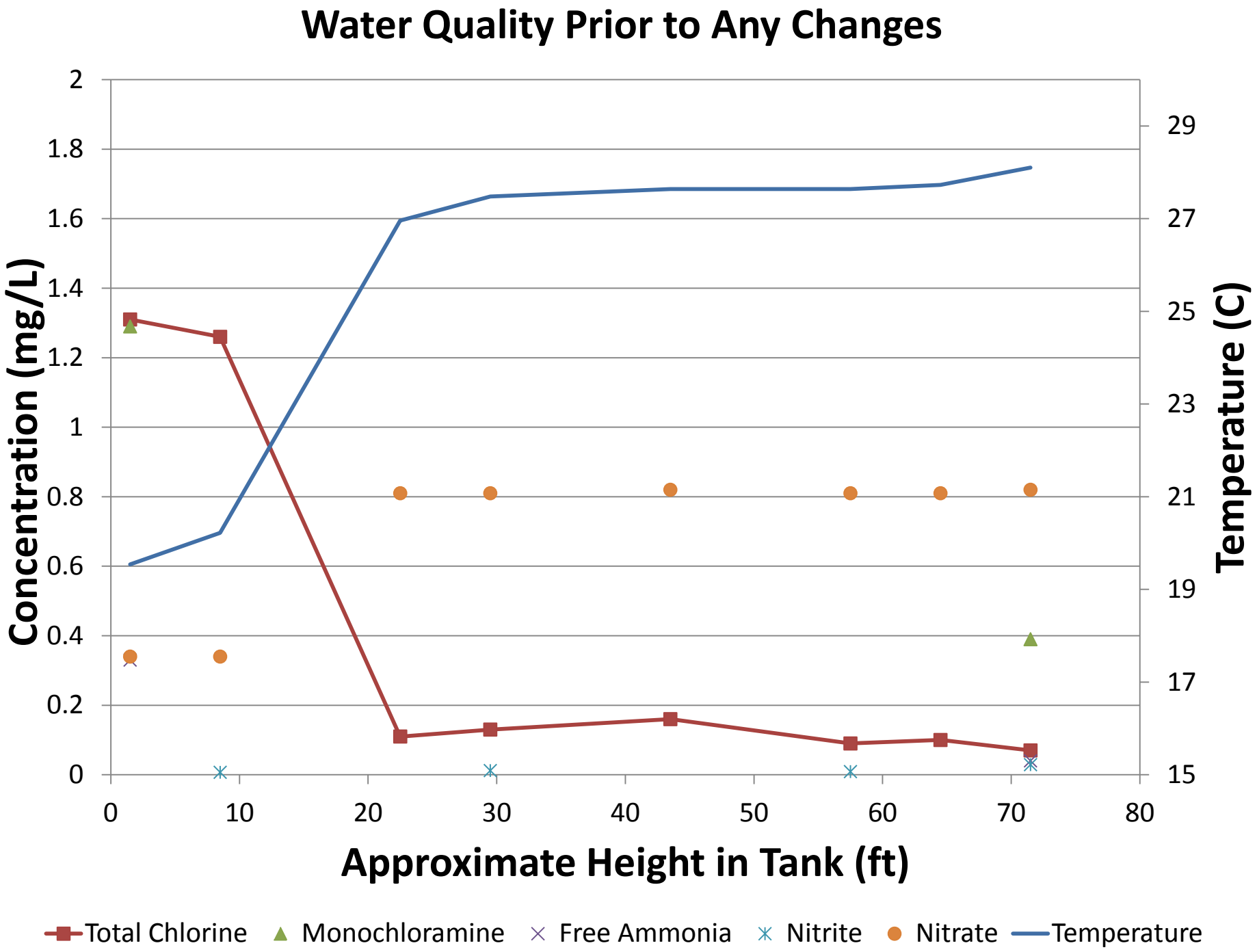

Temperature at Depths in Tank (C)
Ambient Average Daily Temperature (C)
60
55
50
45
40
35
30
25
20
15
10
5
35
30
25
20
15
10
5
0
-5
-10
-15
-20
8/12
8/22
9/1
9/11
9/21
10/1
10/11
10/21
10/31
11/10
11/20
2 ft
5 ft
8 ft
11 ft
14 ft
17 ft
Ambient Temperature
Sampling Events

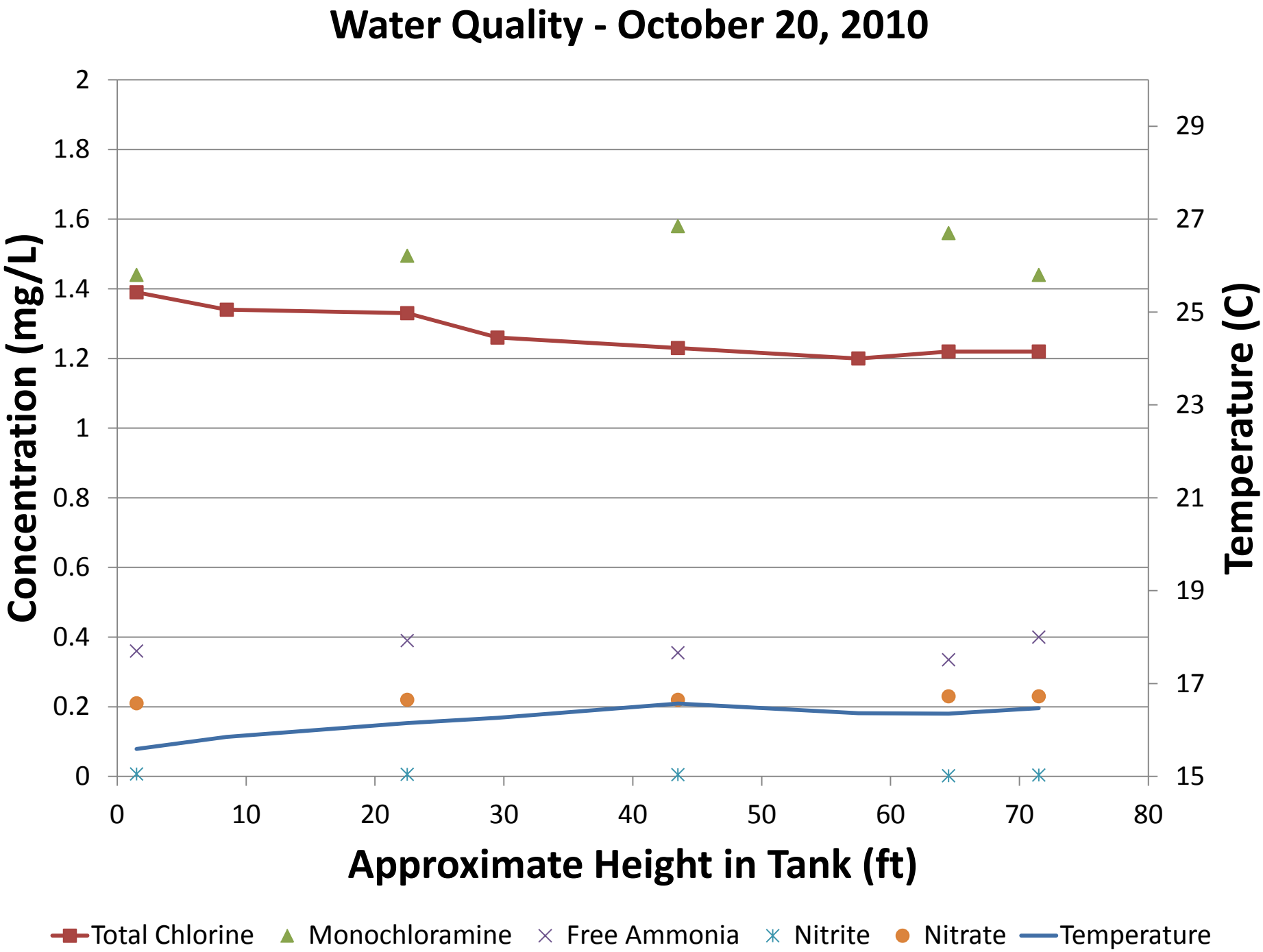

October 21, 2010
Concentration (mg/L)
Temperature (C)
Approximate Height in Tank (ft)
2.5
2
1.5
1
0.5
0
24
22
20
18
16
14
12
10
0
5
10
15
20
25
Total Chlorine
Monochloramine
Free Ammonia
Nitrite
Nitrate
Temperature

Tank E

Aspect Ratio Category	>4.0
Capacity (gal)	140,000
Height (ft)	86
Diameter (ft)	14
H:D Ratio	6.14


Mixer Turned On
Tank Overflowed
Temperature At Tank Depths (C)
Ambient Average Daily Temperature (C)
55
50
45
40
35
30
25
20
15
10
5
0
35
30
25
20
15
10
5
0
-5
-10
-15
-20
8/9
8/19
8/29
9/8
9/18
9/28
10/8
10/18
10/28
11/7
11/17
1.50
8.50
22.50
29.50
43.50
50.50
64.50
71.50
Sampling Event
Ambient Temperature


Water Quality Prior to Any Changes
Concentration (mg/L)
Temperature (C)
Approximate Height in Tank (ft)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
29
27
25
23
21
19
17
15
0
10
20
30
40
50
60
70
80
Total Chlorine
Monochloramine
Free Ammonia
Nitrite
Nitrate
Temperature


Water Quality - October 20, 2010
Concentration (mg/L)
Temperature (C)
Approximate Height in Tank (ft)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
29
27
25
23
21
19
17
15
0
10
20
30
40
50
60
70
80
Total Chlorine
Monochloramine
Free Ammonia
Nitrite
Nitrate
Temperature

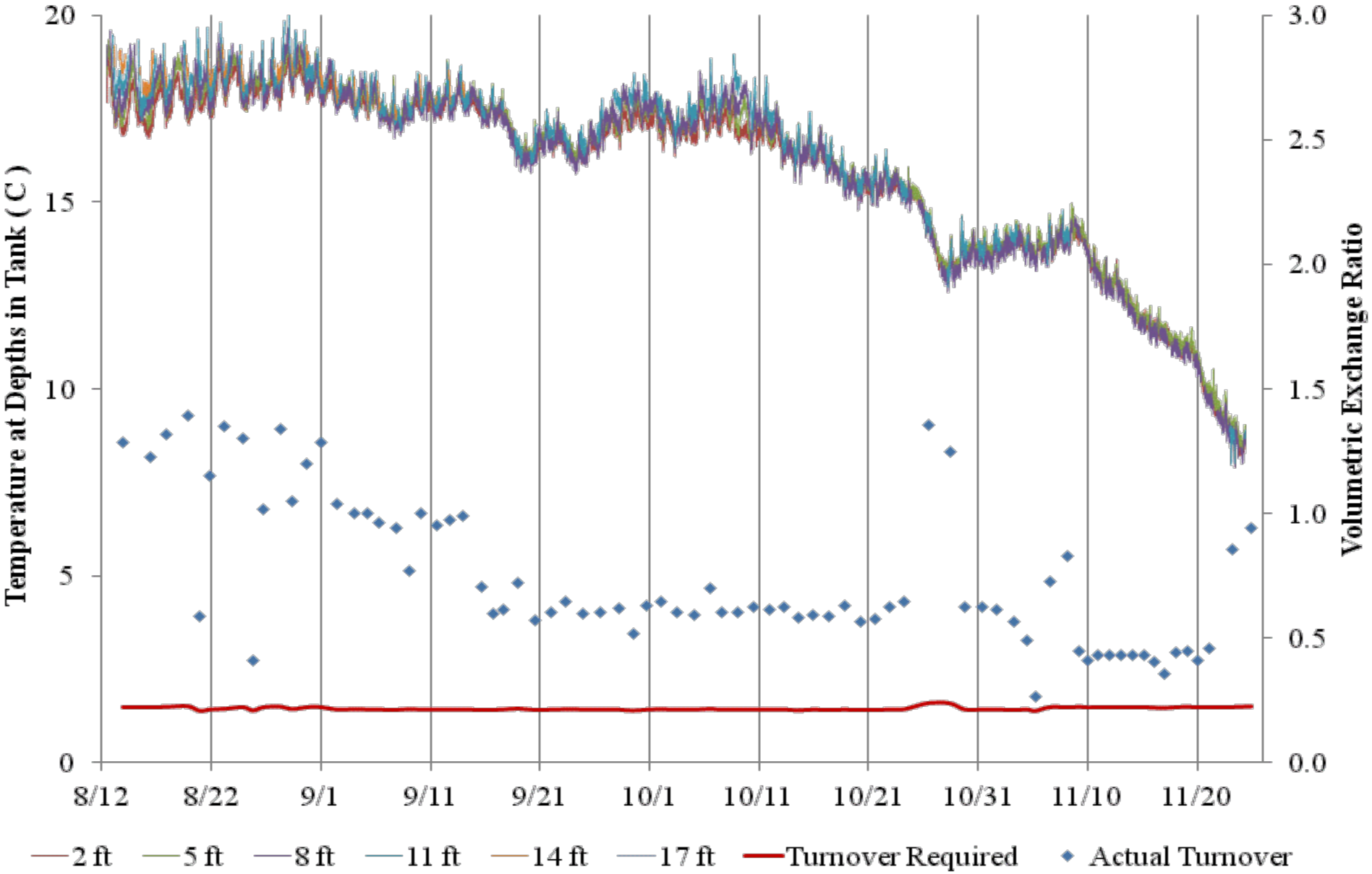
Evaluation of Hydraulic Parameters

- Theoretical time to mix tanks
- Change in water volume during fill cycle to mix tanks
- Hydraulic retention time (assuming complete mix)
- Reynolds number
- Inlet momentum
- Critical temperature difference to cause stratification
- Densimetric Froude number
- Momentum needed to overcome thermocline
- Modeling tanks (CFD or systematic)

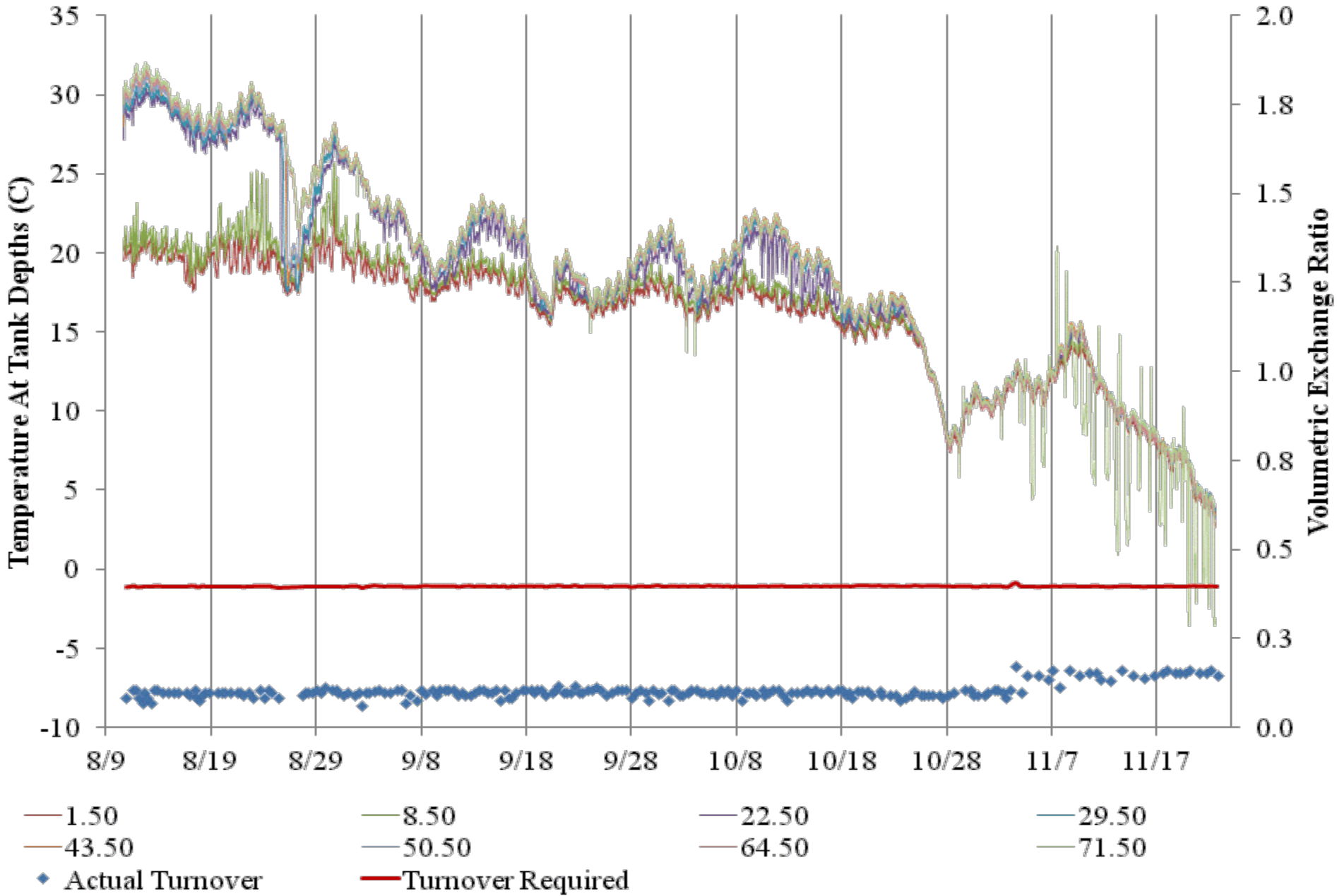
Key Hydraulic Parameters

- **Change in water volume during fill cycle to mix tanks**
  - **Related to inlet and tank diameters, as well as water depth and volume**
- **Densimetric Froude number**
  - **Ratio of inertial force to buoyant force caused by density differences**
  - **Required densimetric Froude number related to inlet orientation and diameter, as well as water depth**

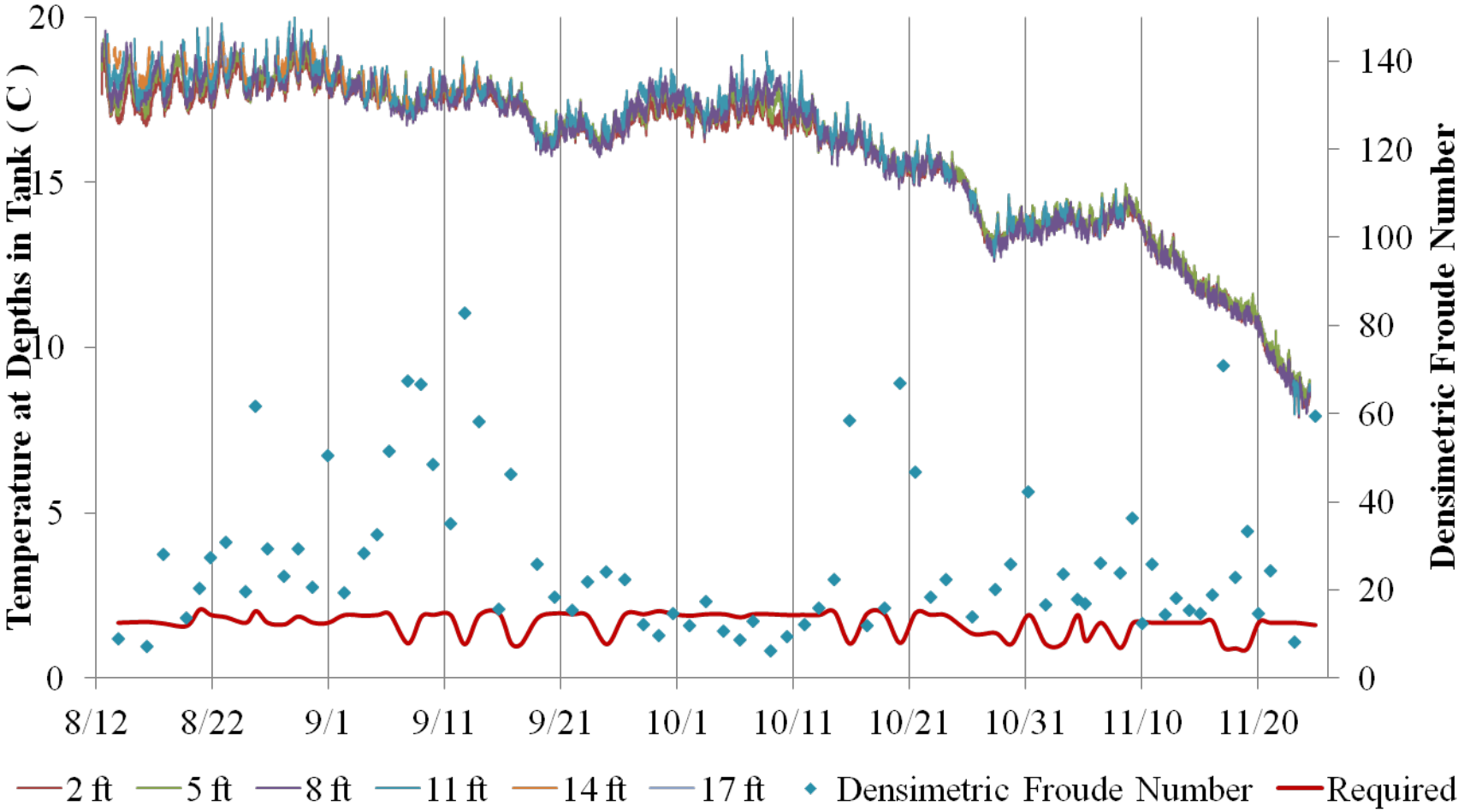
Volumetric Exchange – Tank A



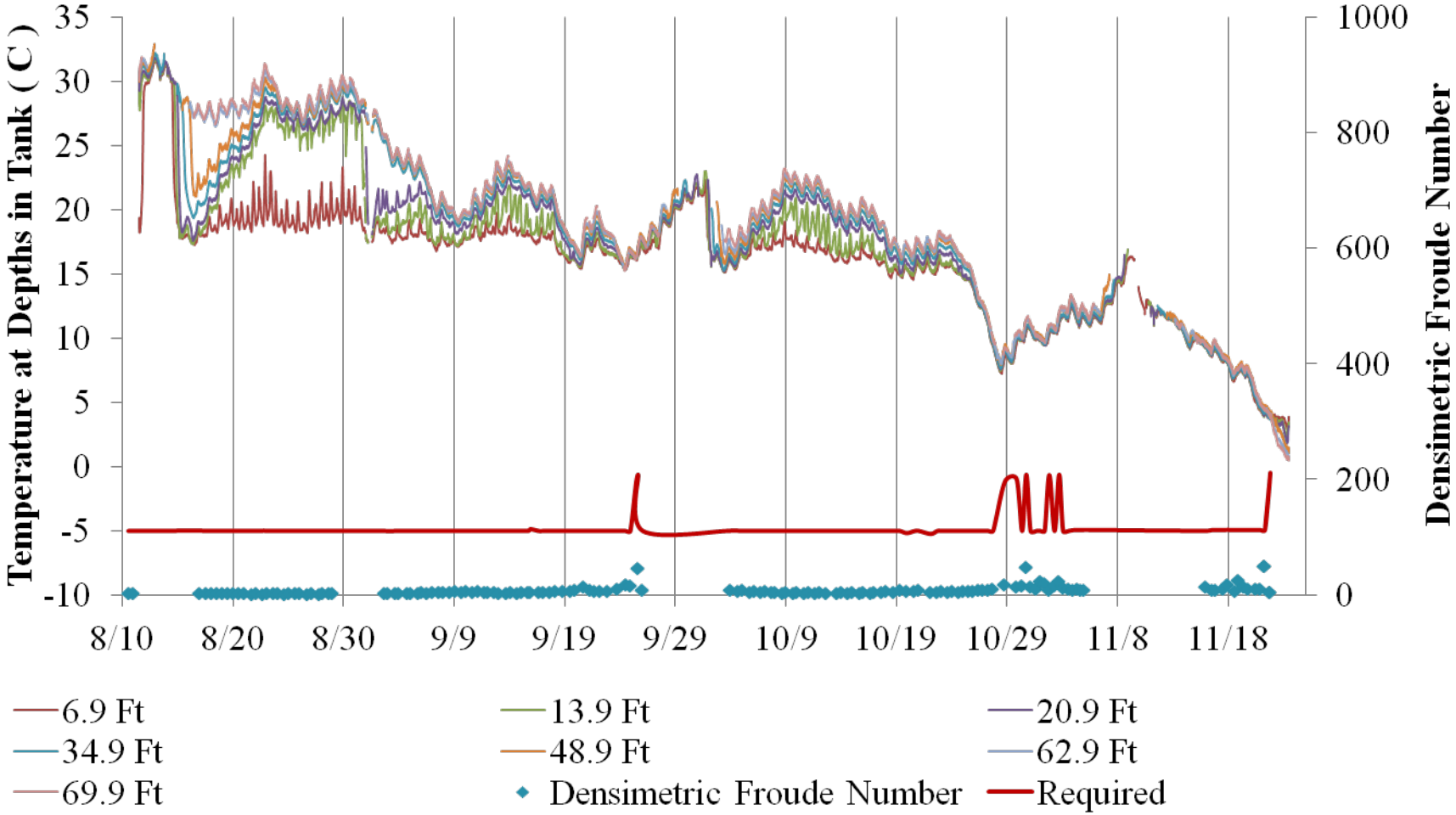
Volumetric Exchange – Tank E



Densimetric Froude # – Tank A



Densimetric Froude # – Tank D



Conclusions

- Tanks can be poorly mixed leading to water quality concerns
- Tanks with low aspect ratios do not all behave similarly
- Stratification in standpipes is most prevalent when the ambient temperature is above 15 degrees C
- Designing and operating tanks to meet certain hydraulic parameters can enhance mixing

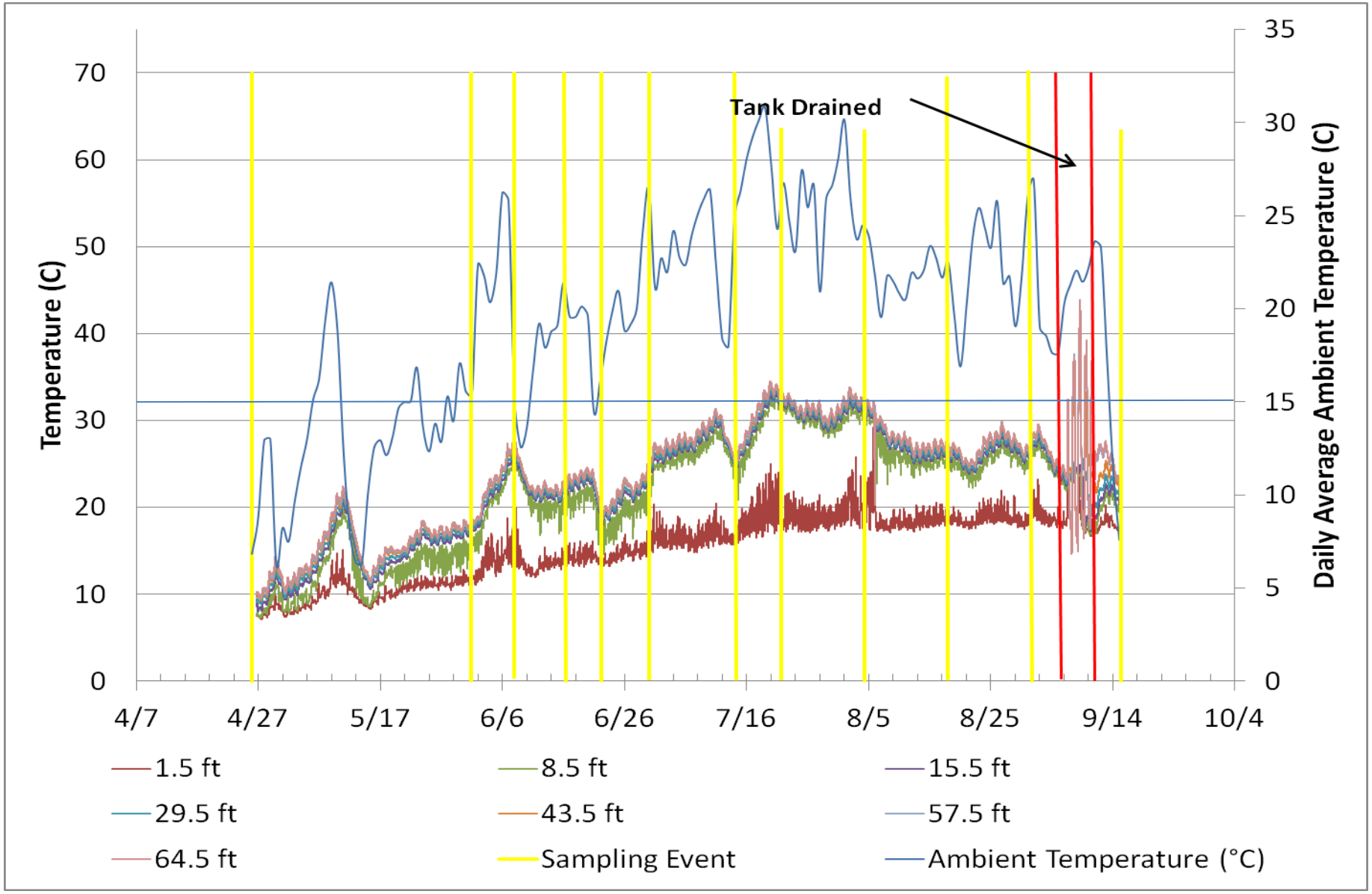
Recommendations for tank design and operation

- Operation of tanks should maximize volumetric exchange during fill cycles to enhance mixing
- Inlet momentum should be maximized to promote mixing
- Tanks may be drained into the system before disinfectant concentrations decrease to levels of concern (and refilled with fresh water)
- Analyzing water samples collected at the tank inlet/outlet may not measure water quality throughout the entire depth of the tank.

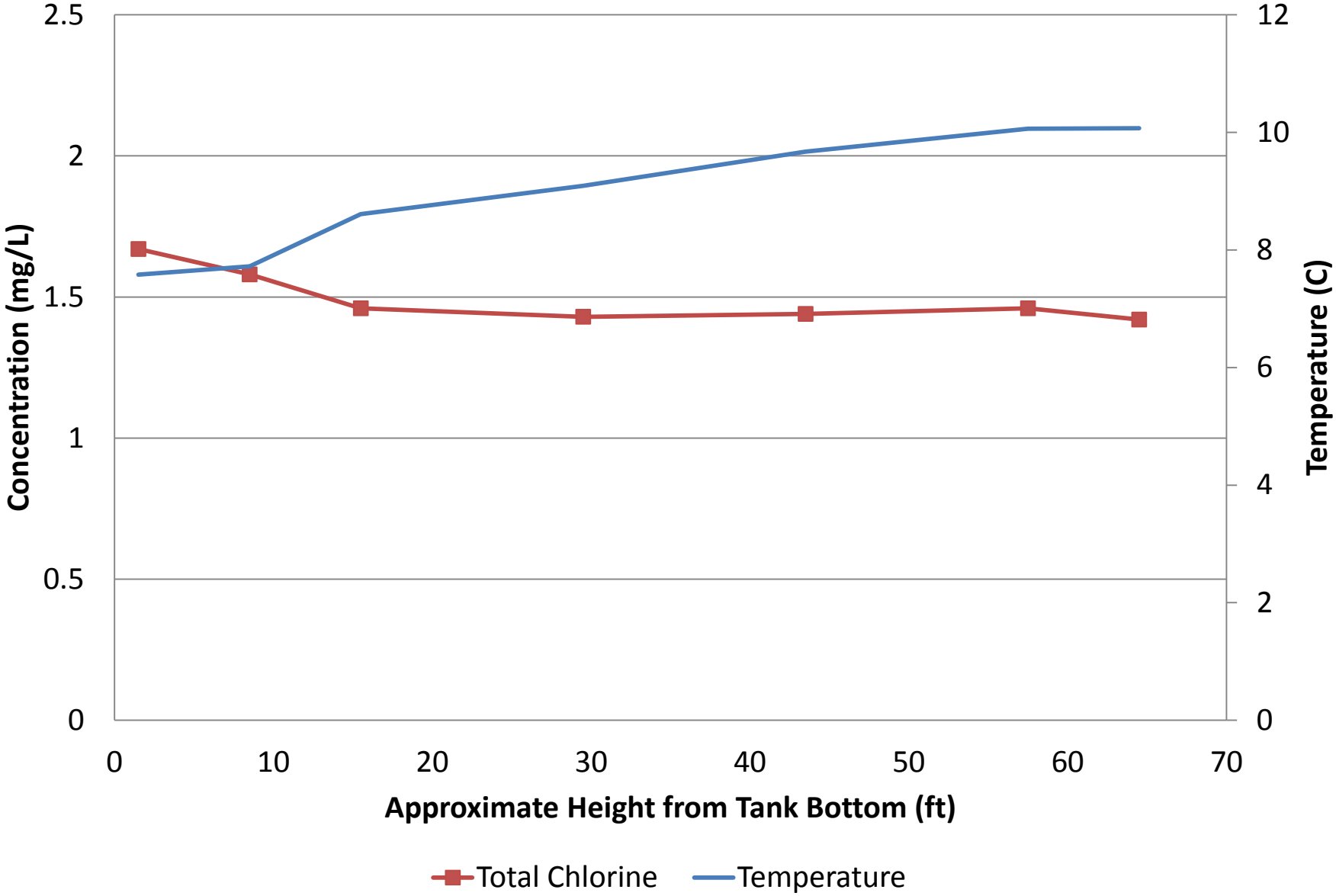
Project Extension - 2011

- Instrument two additional tanks with H:D 2:1
  - One in the shade of trees
  - One painted light blue
- Continue monitoring tanks C, D, and E – more frequent to collect info on water quality decay
- Conduct Short-term tests on two tanks with passive mixing systems
- Include microbial monitoring (total coliform and heterotrophic plate count)

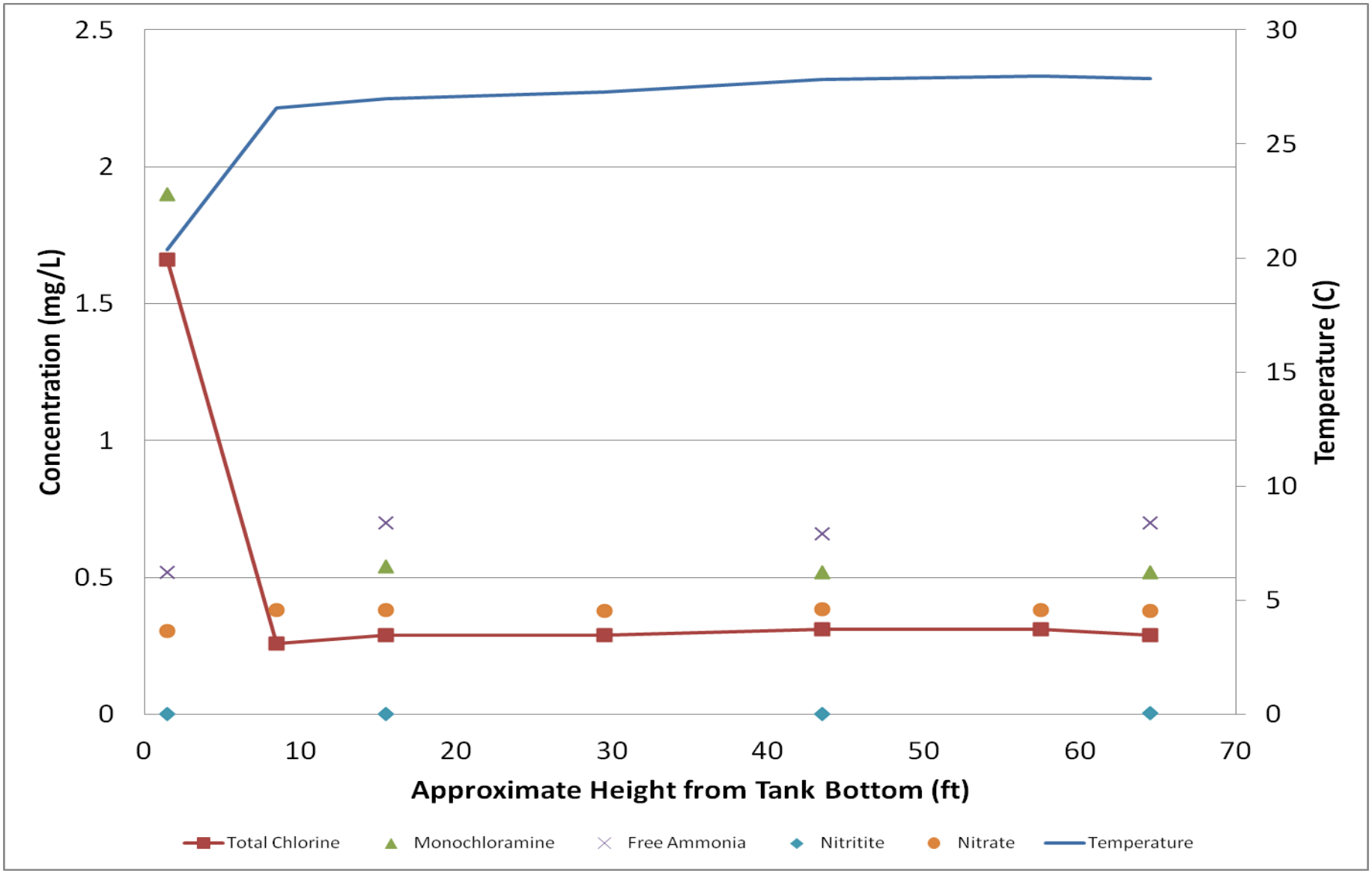
Tank D – temperature profile



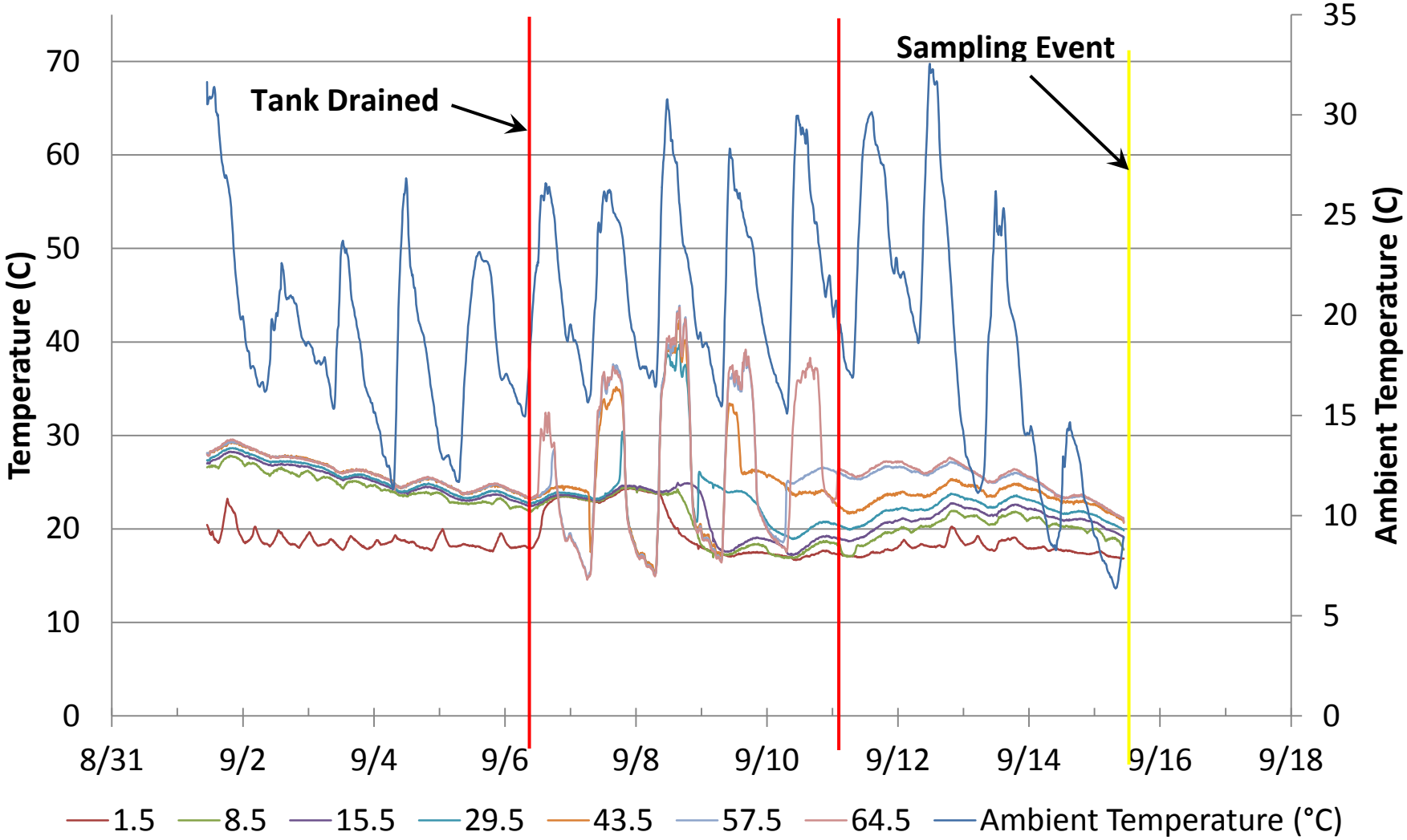
Long term tank D – initial water quality



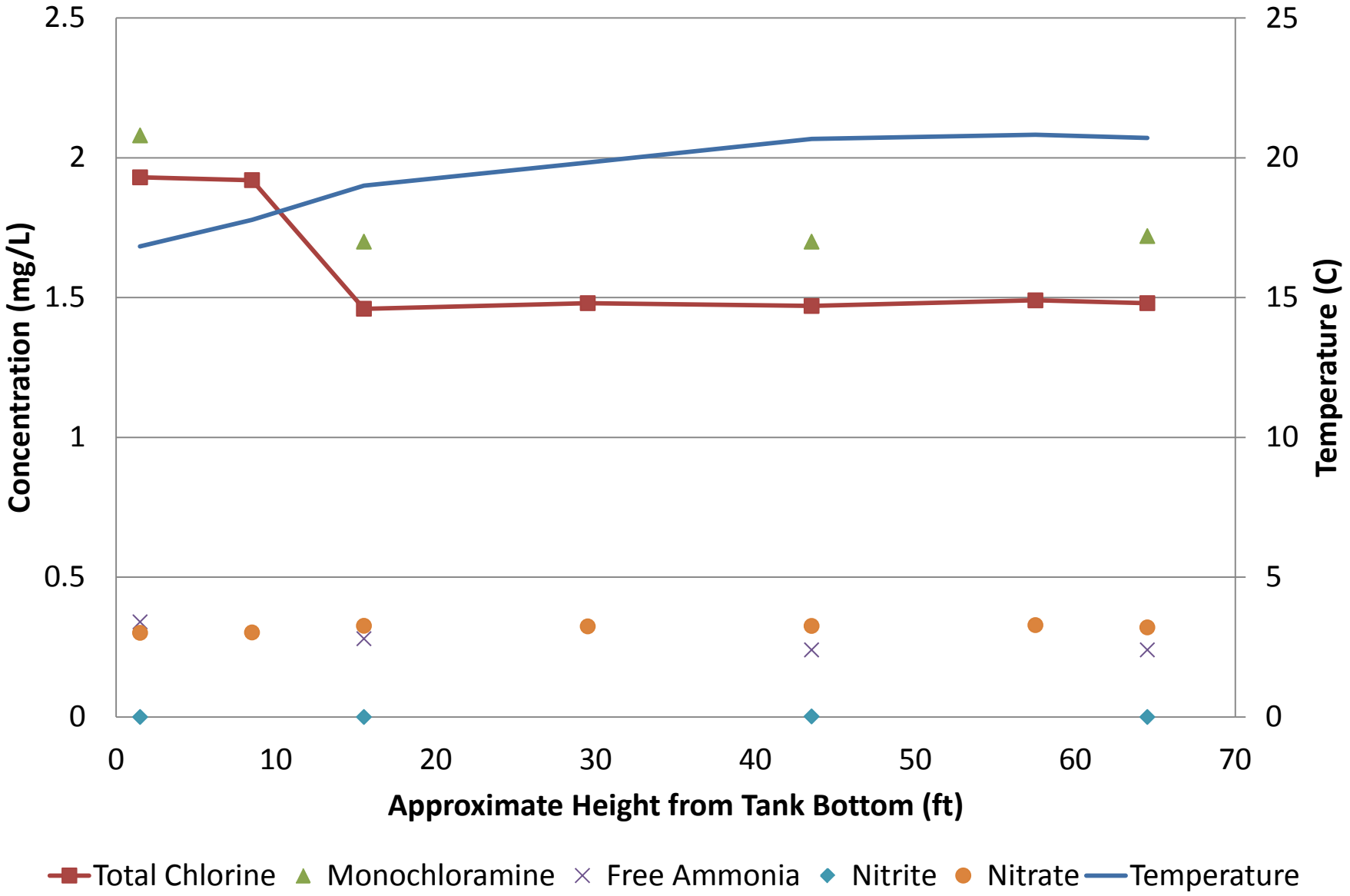
Tank D – before tank was drained



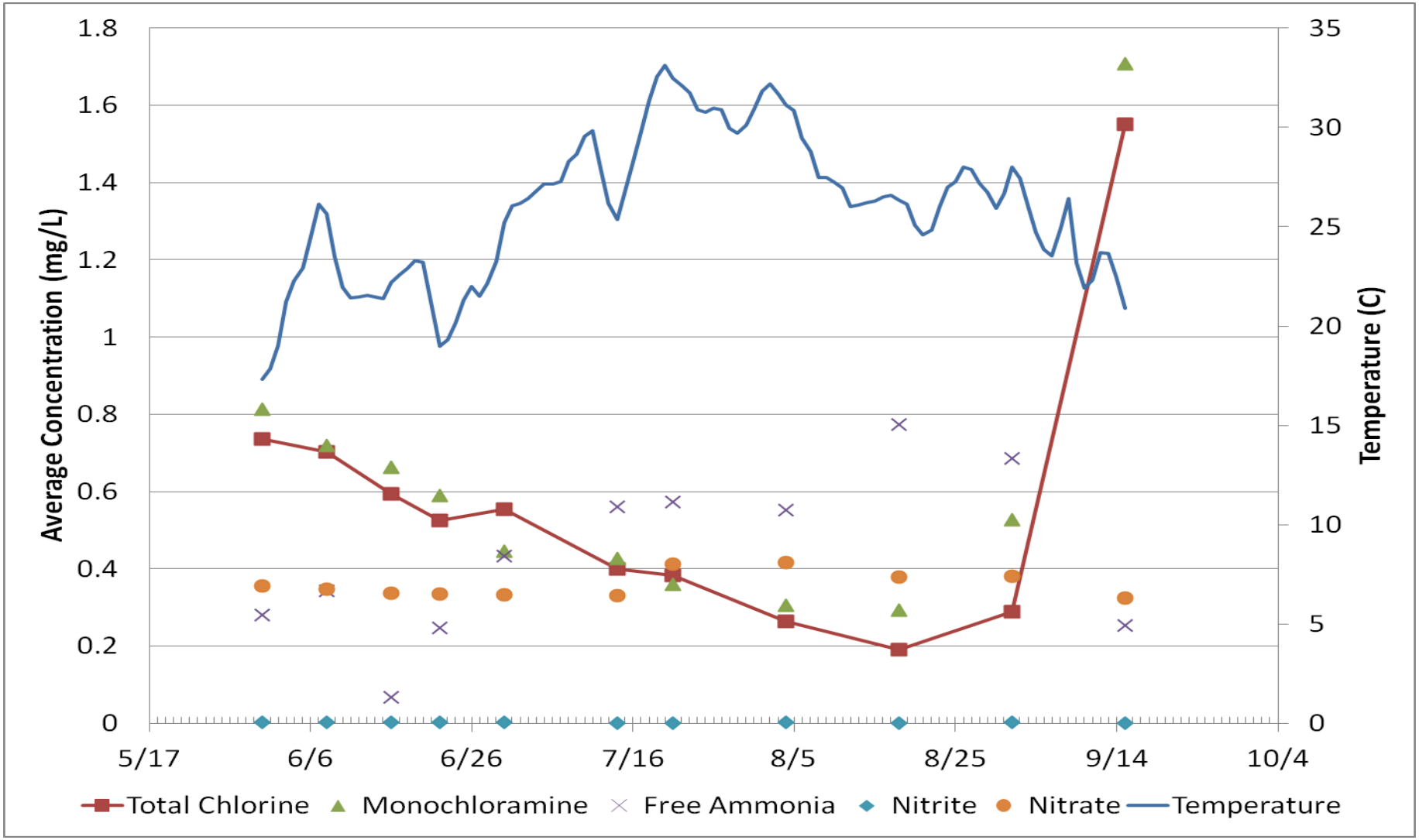
Long term tank D: temperature profile through tank draining



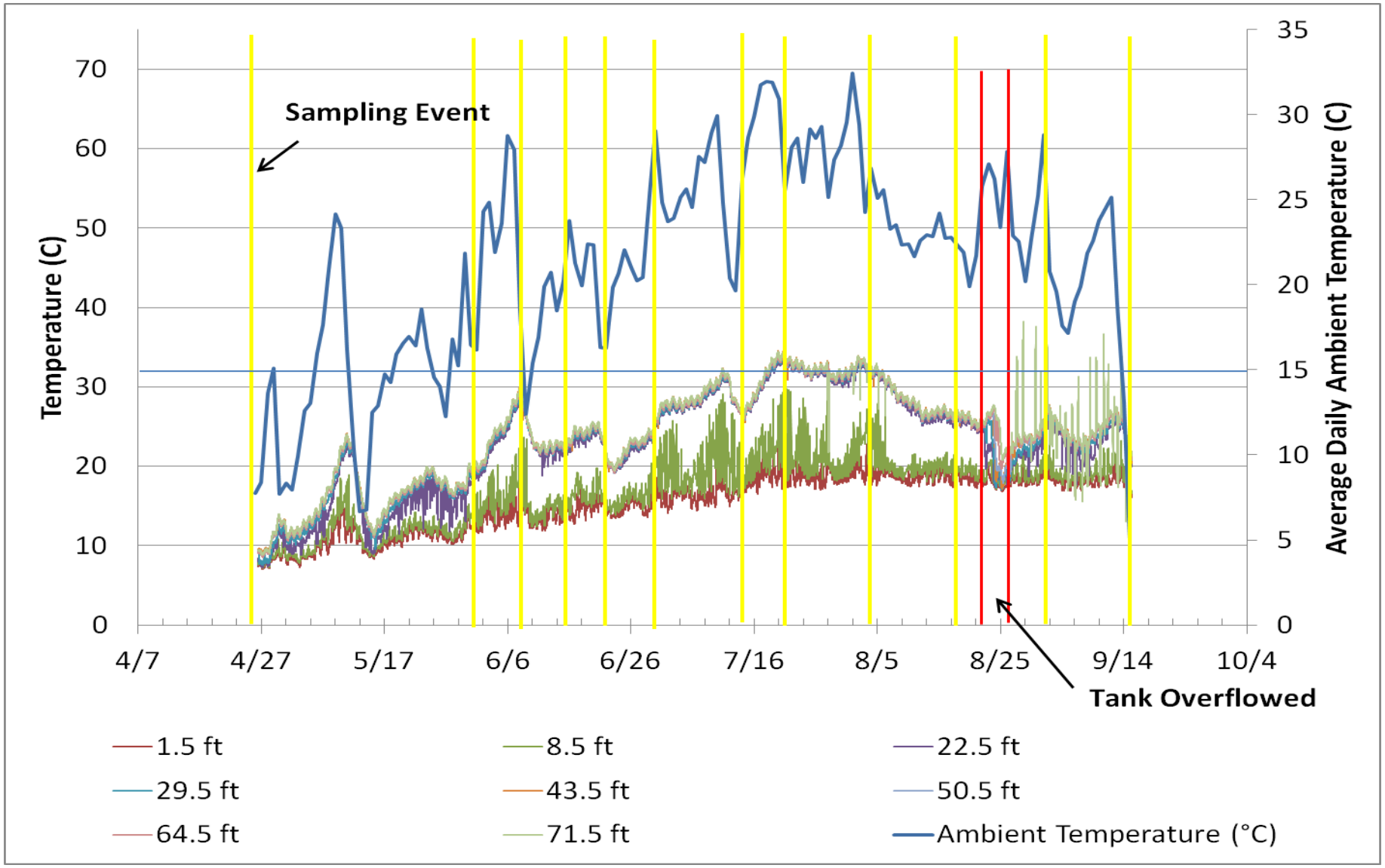
Tank D – four days after tank drain



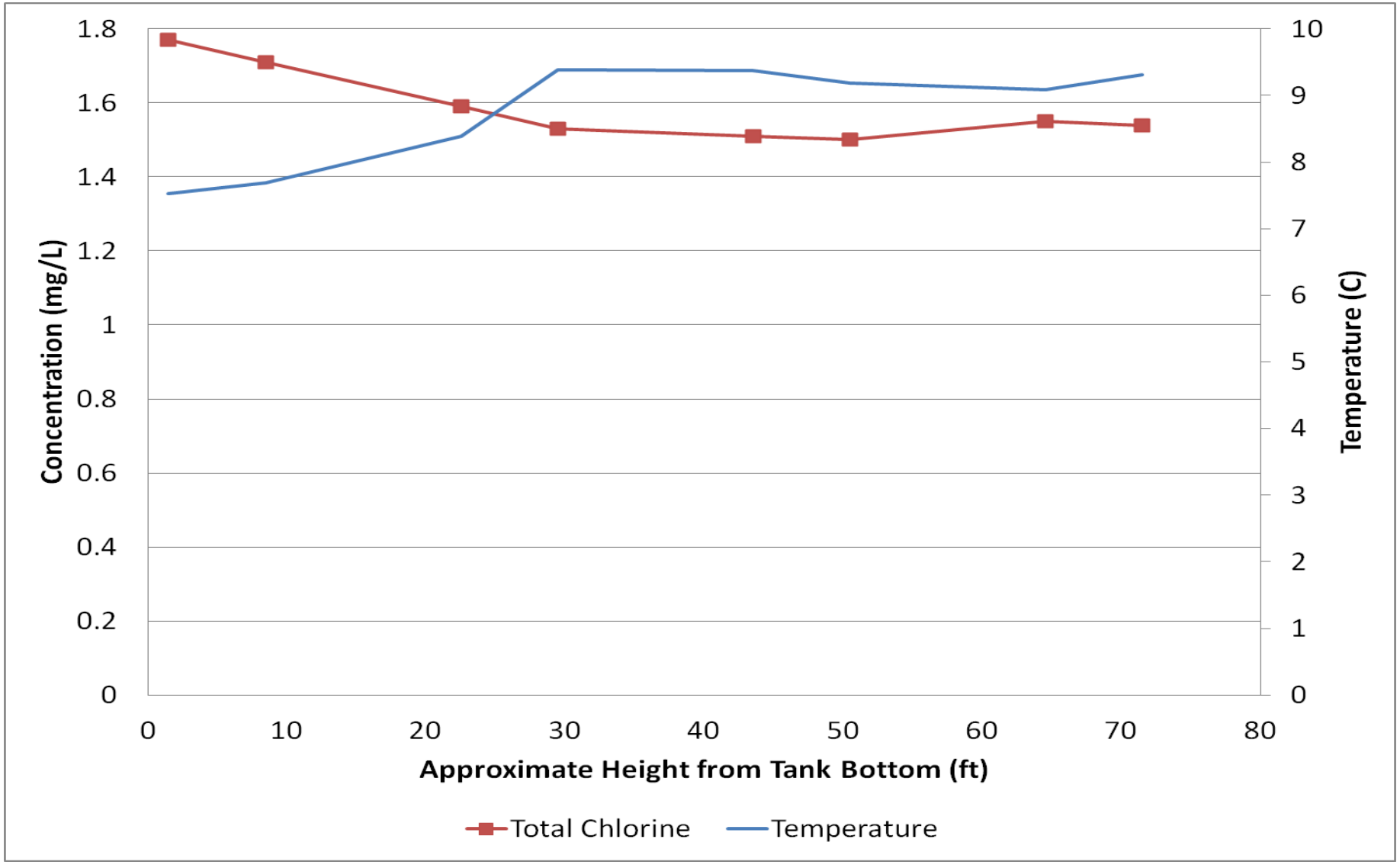
Tank D – water quality throughout the summer



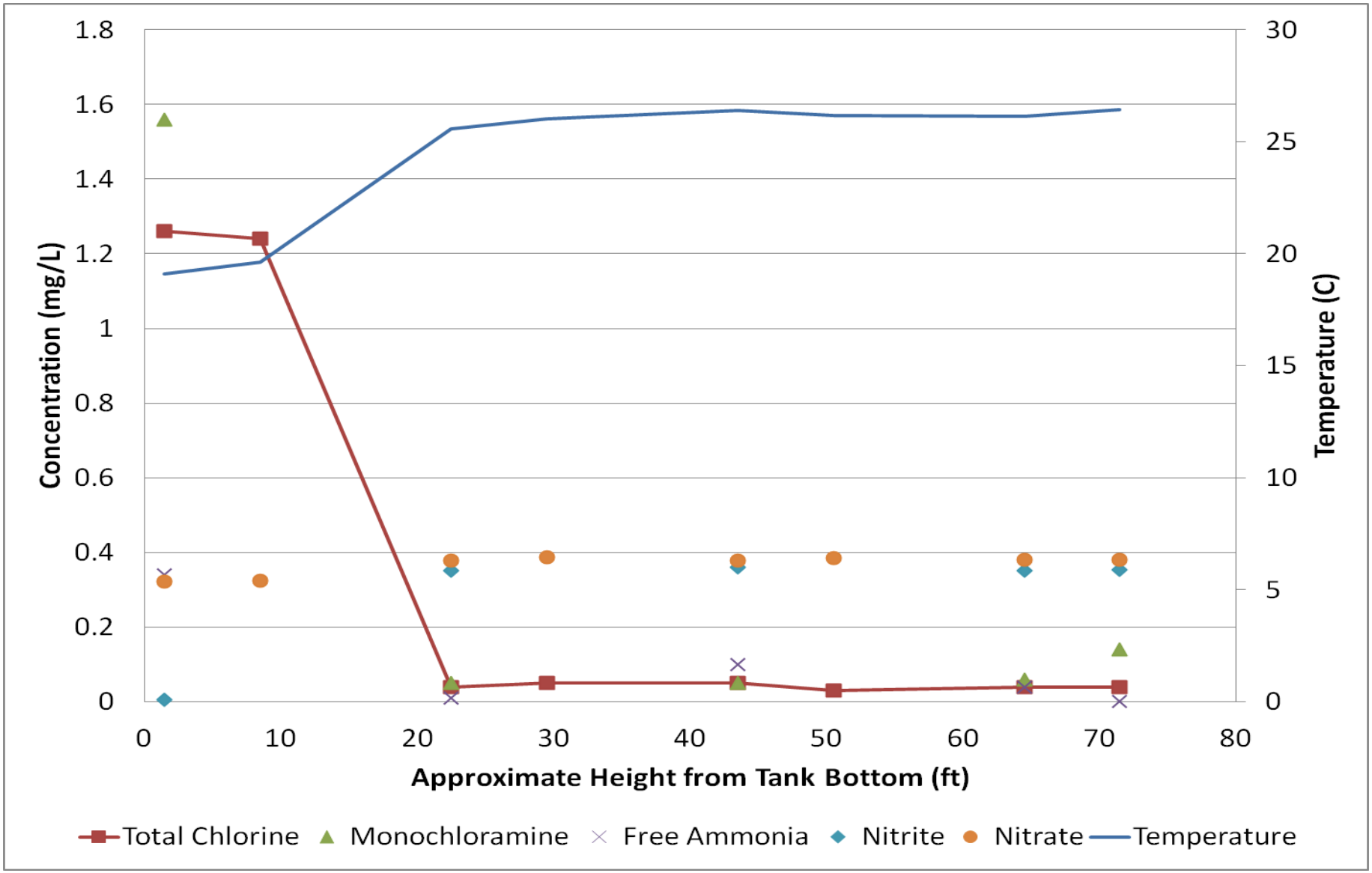
Tank E – temperature profile



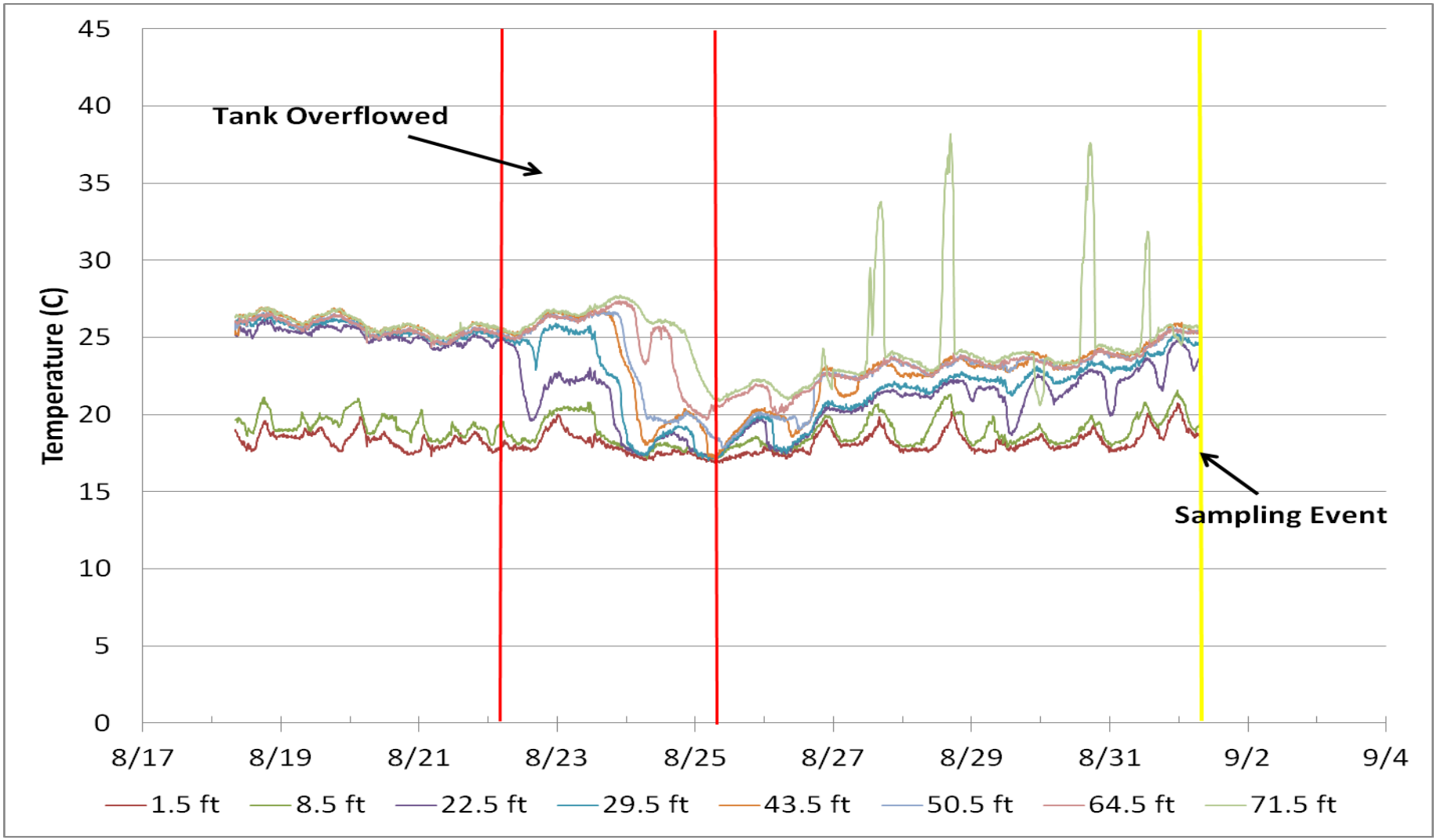
Tank E – initial water quality



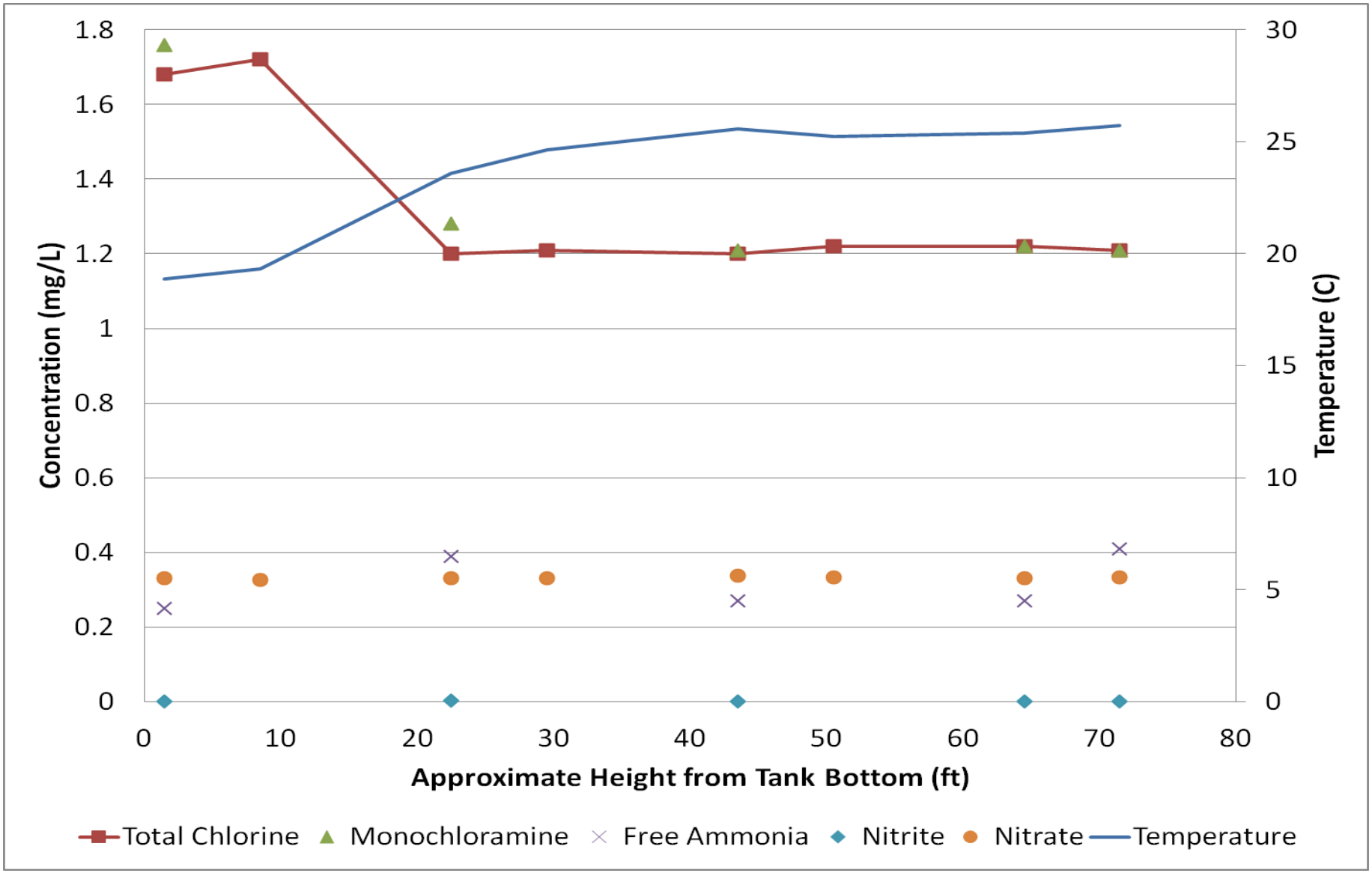
Tank E – before tank was overflowed



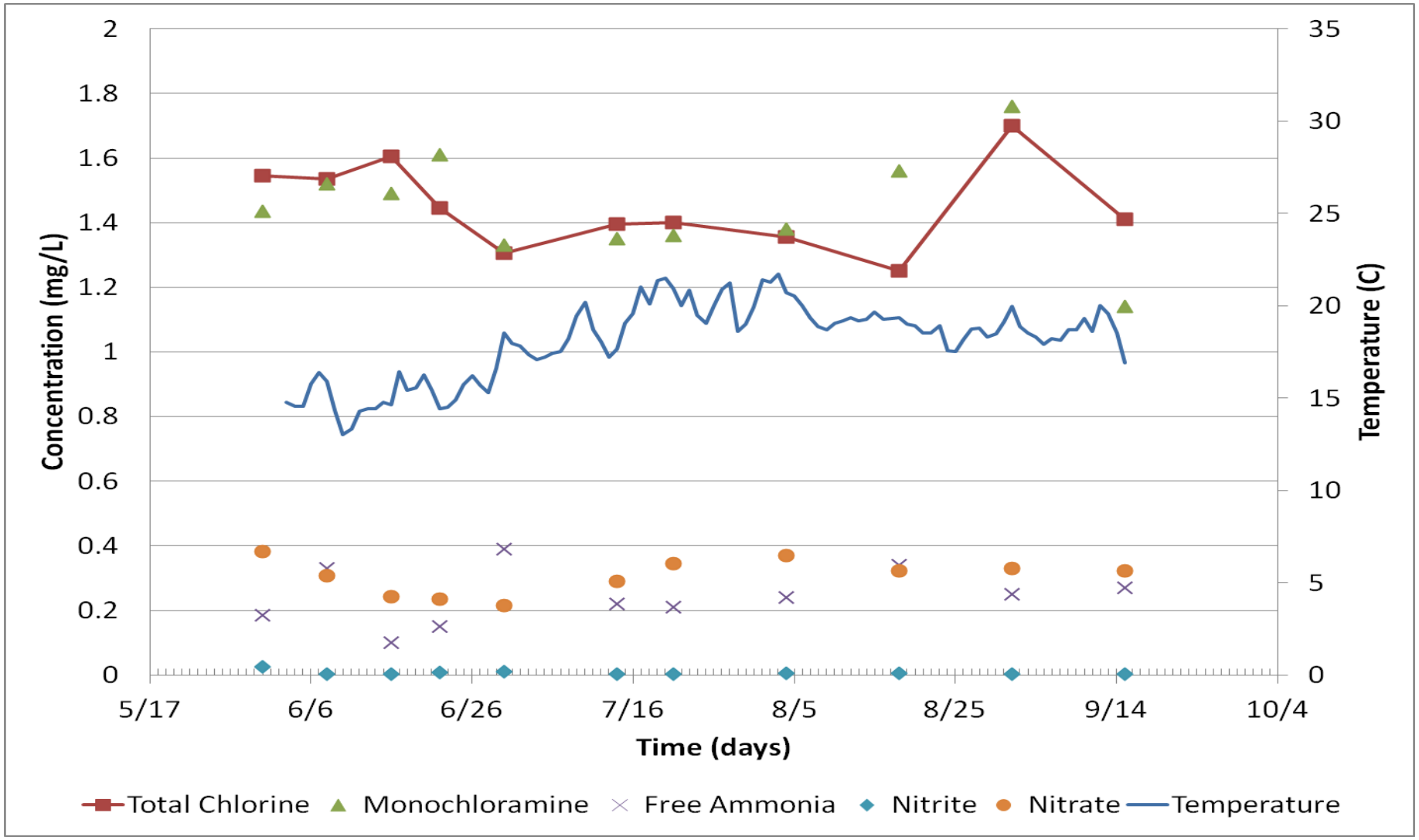
Tank E – temperature profile throughout tank during overflow event



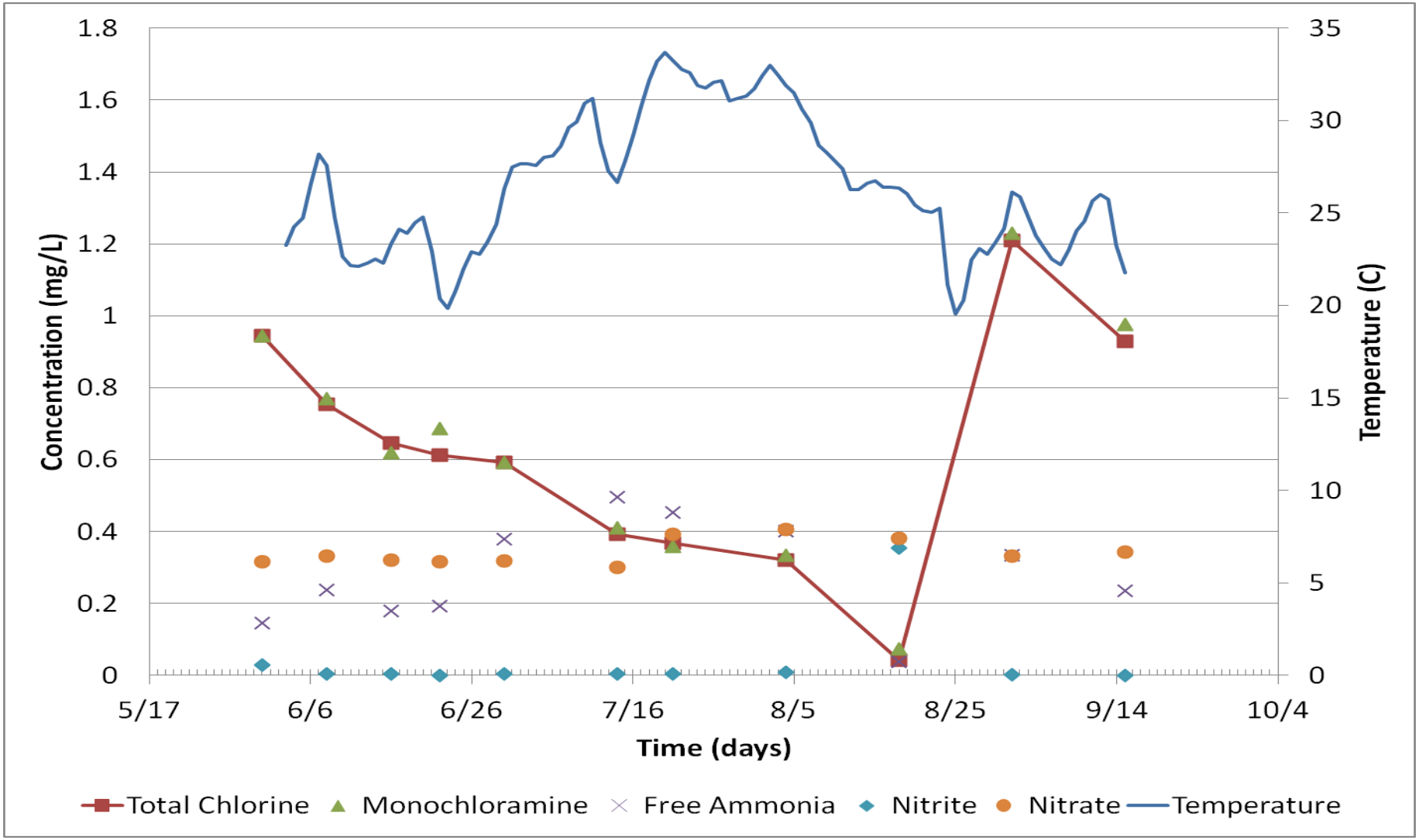
Tank E – after tank was overflowed



Tank E – water quality throughout summer below thermocline



Tank E – water quality throughout summer above thermocline



Total Coliforms

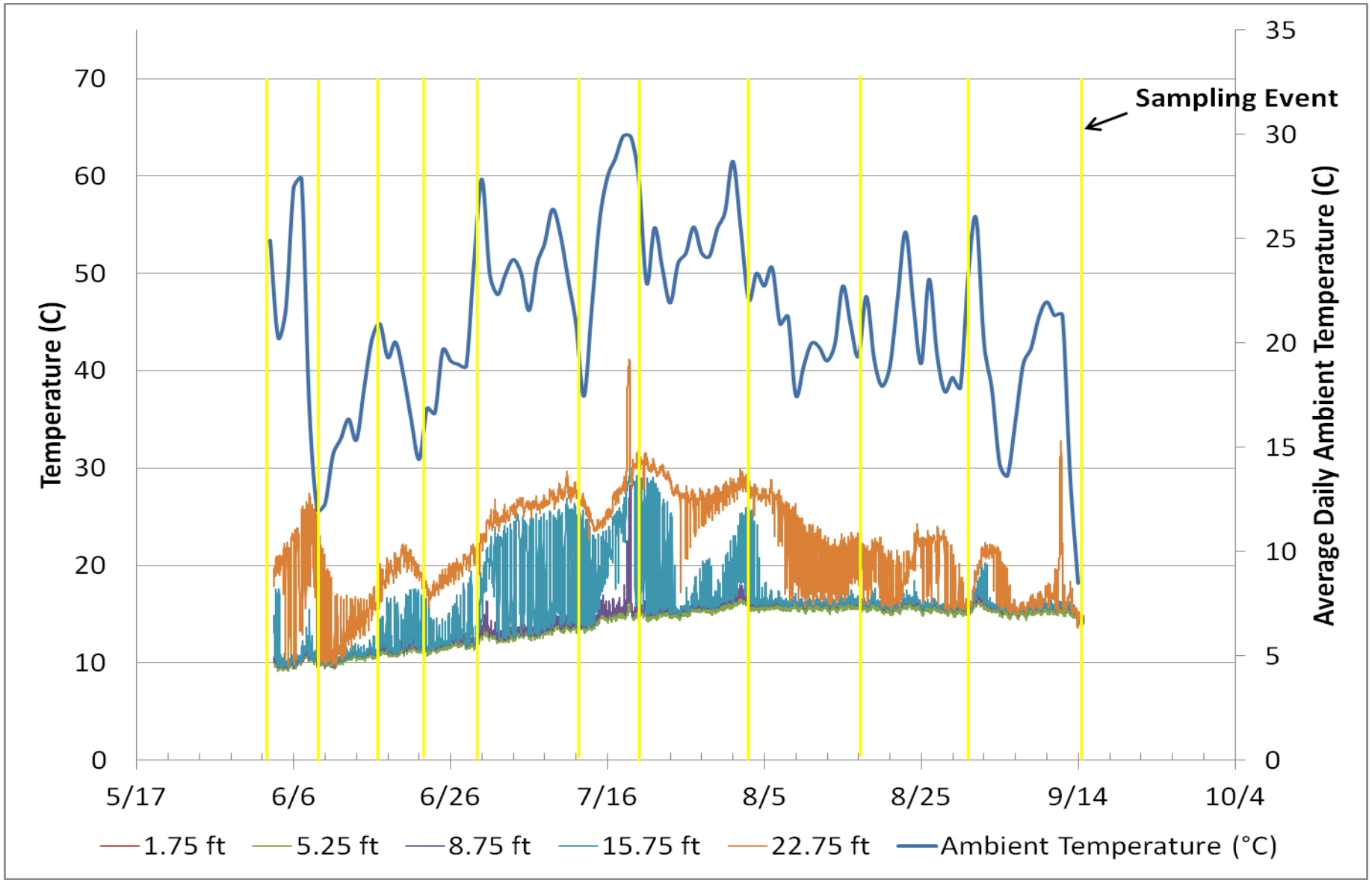
- Throughout the sampling the total coliform tests showed the trend that there were zero coliform colonies /100 ml for all of the tanks.

Heterotrophic Plate Count

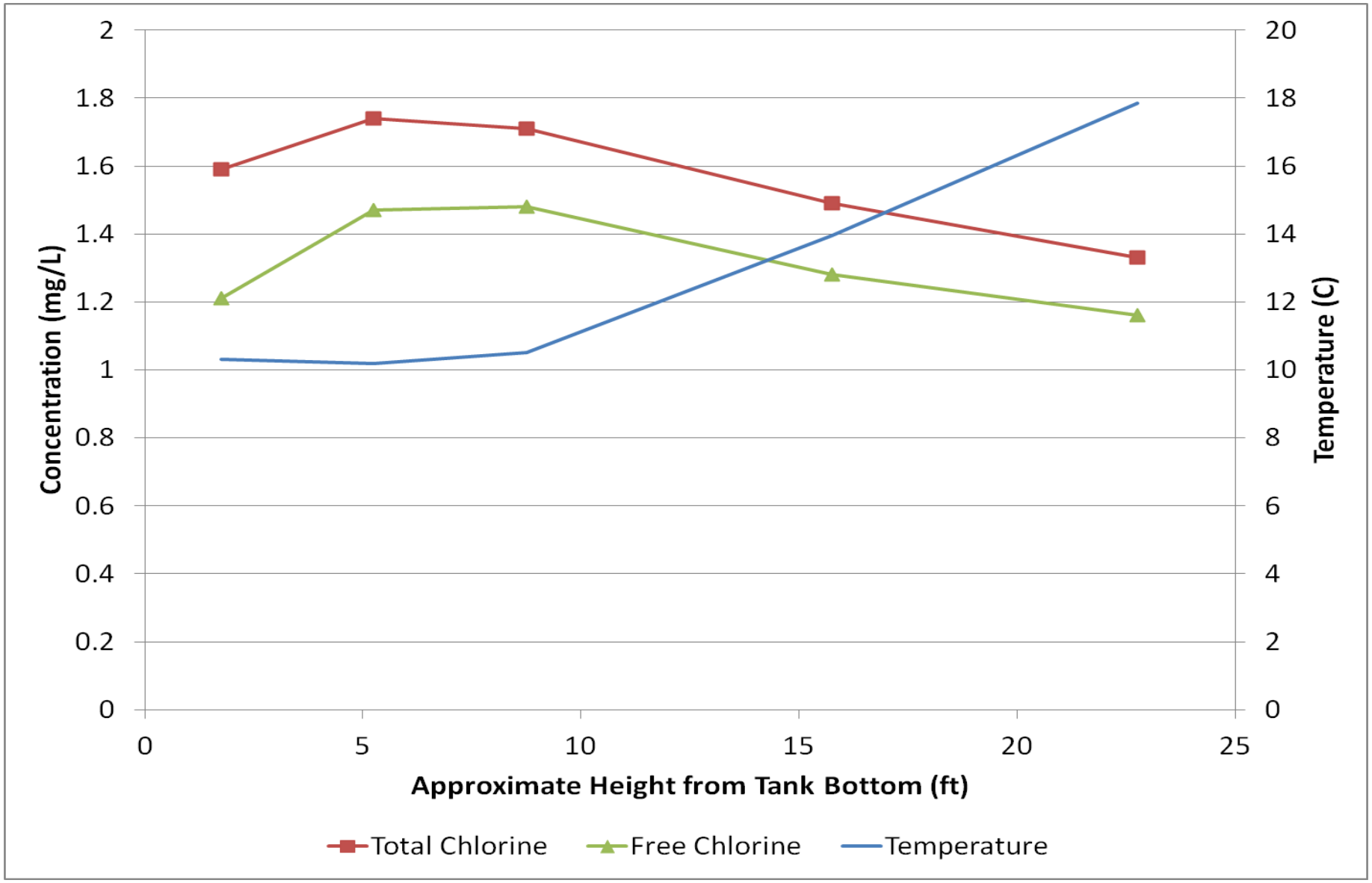
Heterotrophic Plate Count (MPN/ml) for Stratified Tanks										
	5/31	6/8	6/22	6/30	7/14	7/21	8/4	8/18	9/1	9/15
Long Term Tank D: Below Thermocline	0	0	4	6	10	0	0	2	0	0
Long Term Tank D: Above Thermocline	1.2	0.4	0	2	15.8	4	1.6	2.4	1.6	0.8
Long Term Tank E: Below Thermocline	1	2	0	6	0	0	0	0	0	0
Long Term Tank E: Above Thermocline	2	1.6	0	2	3.6	4	1.2	2.4	0	0.4

CLAY
RURAL
WATER

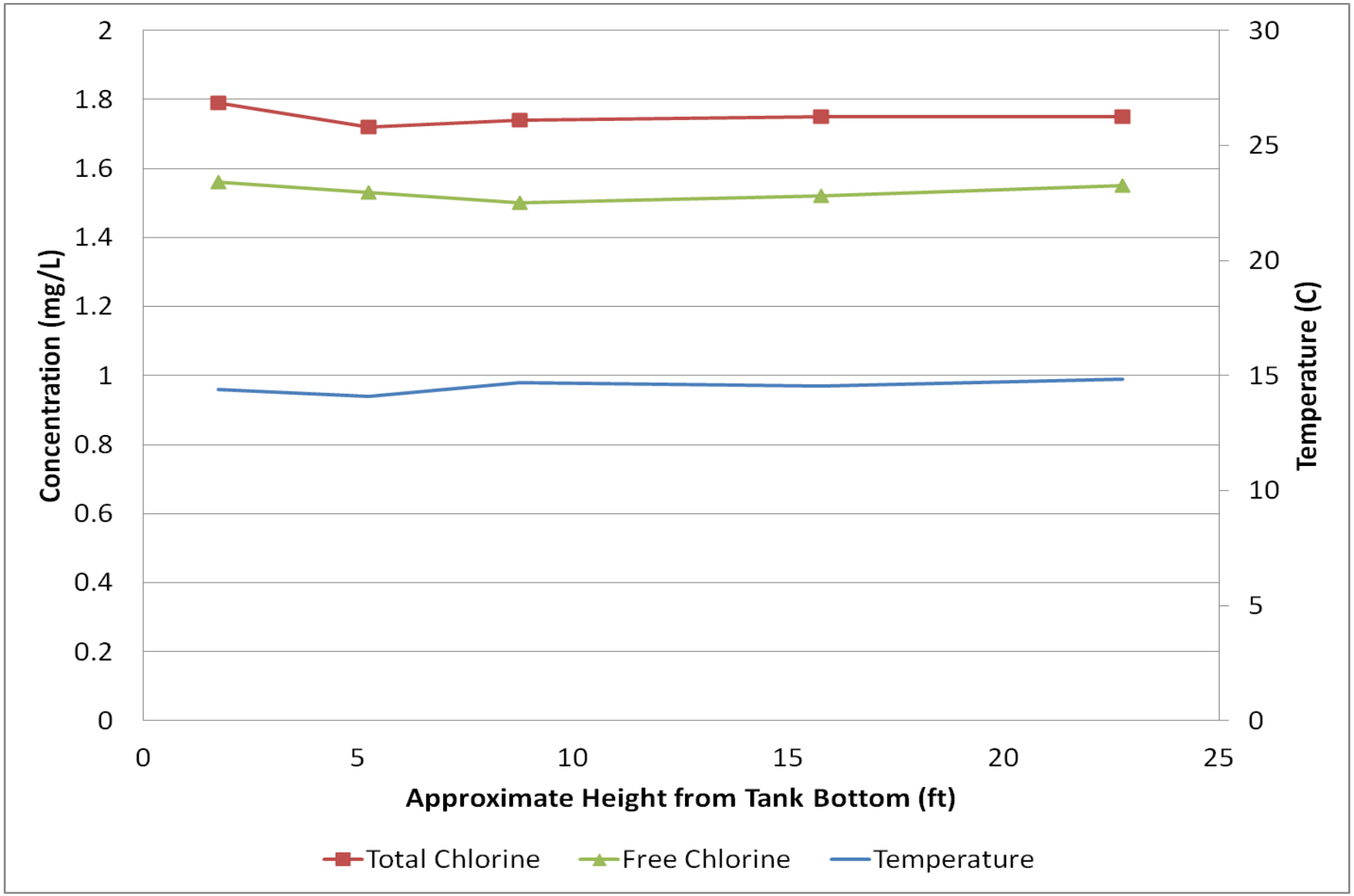
Tank F – temperature profile



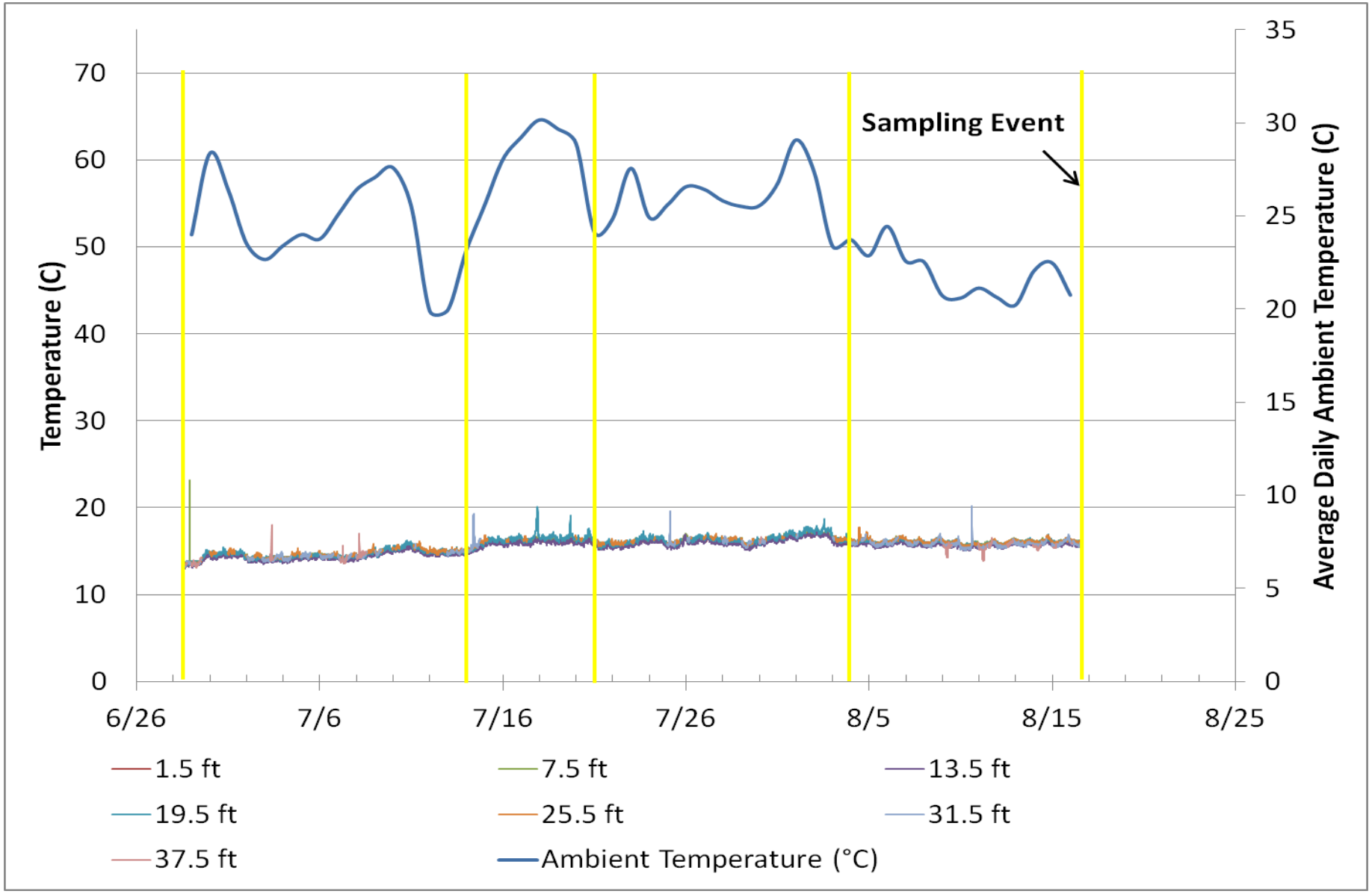
Tank F – initial water quality



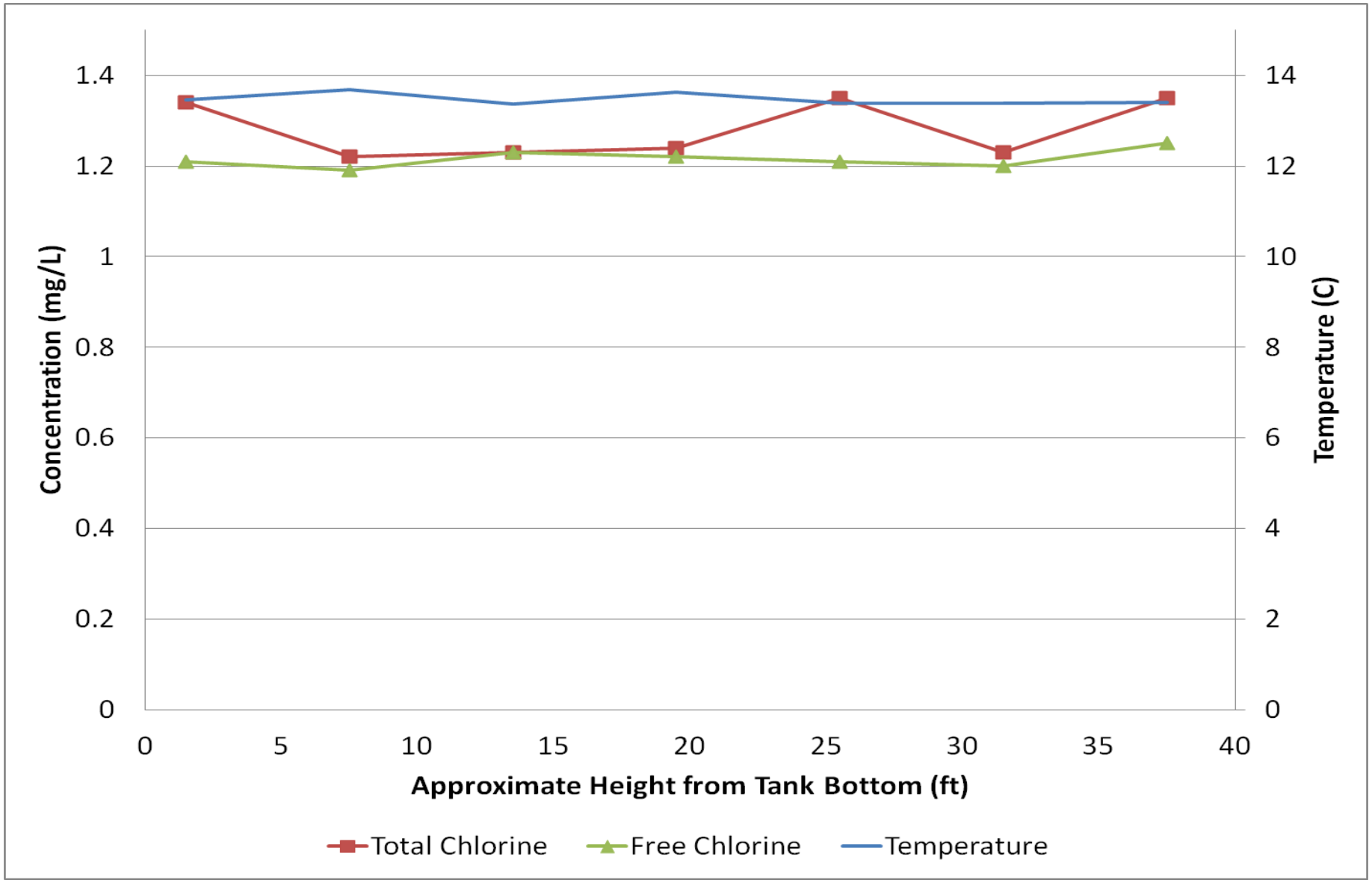
Tank F – water quality last sampling



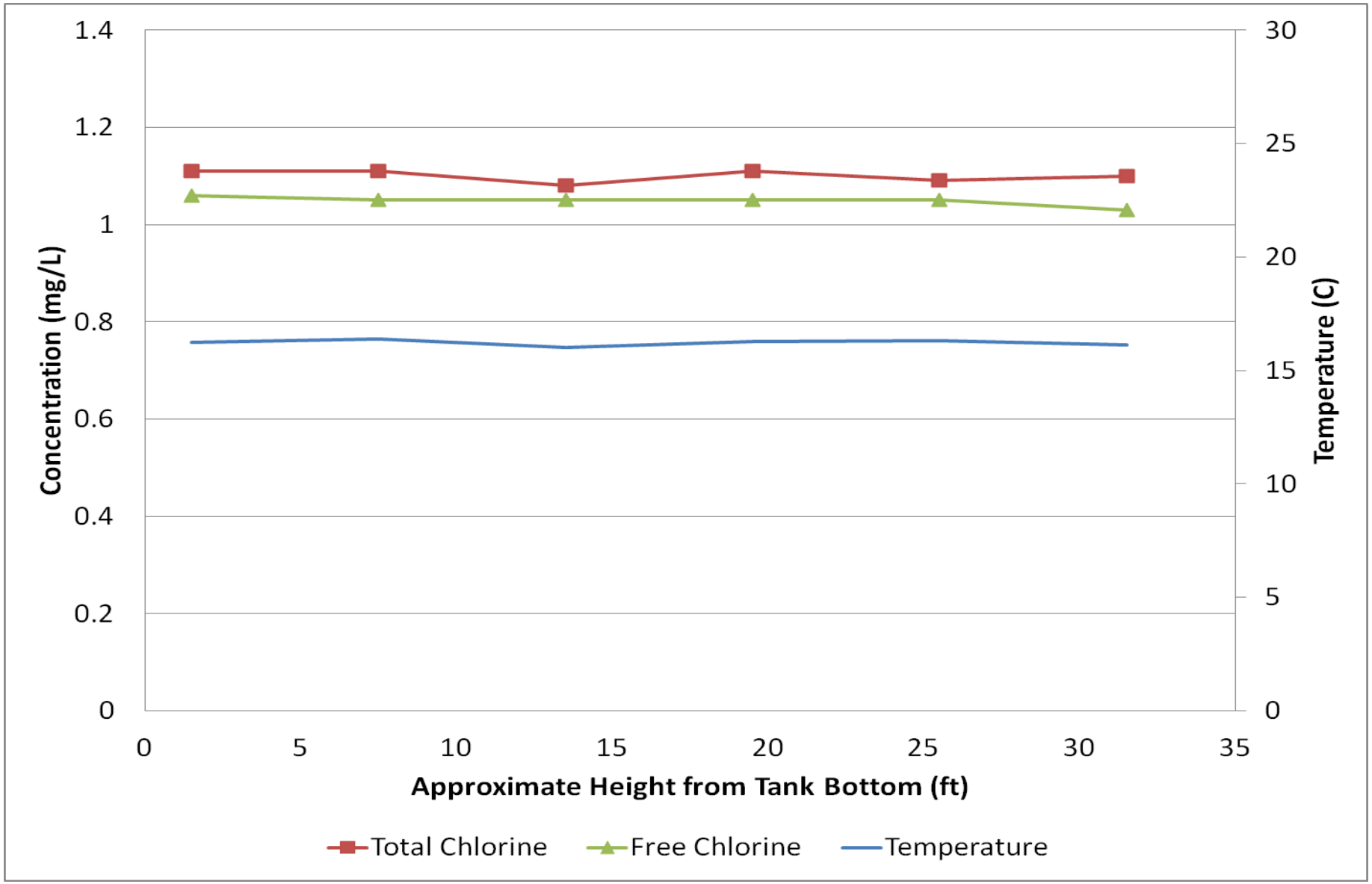
Tank G – temperature profile



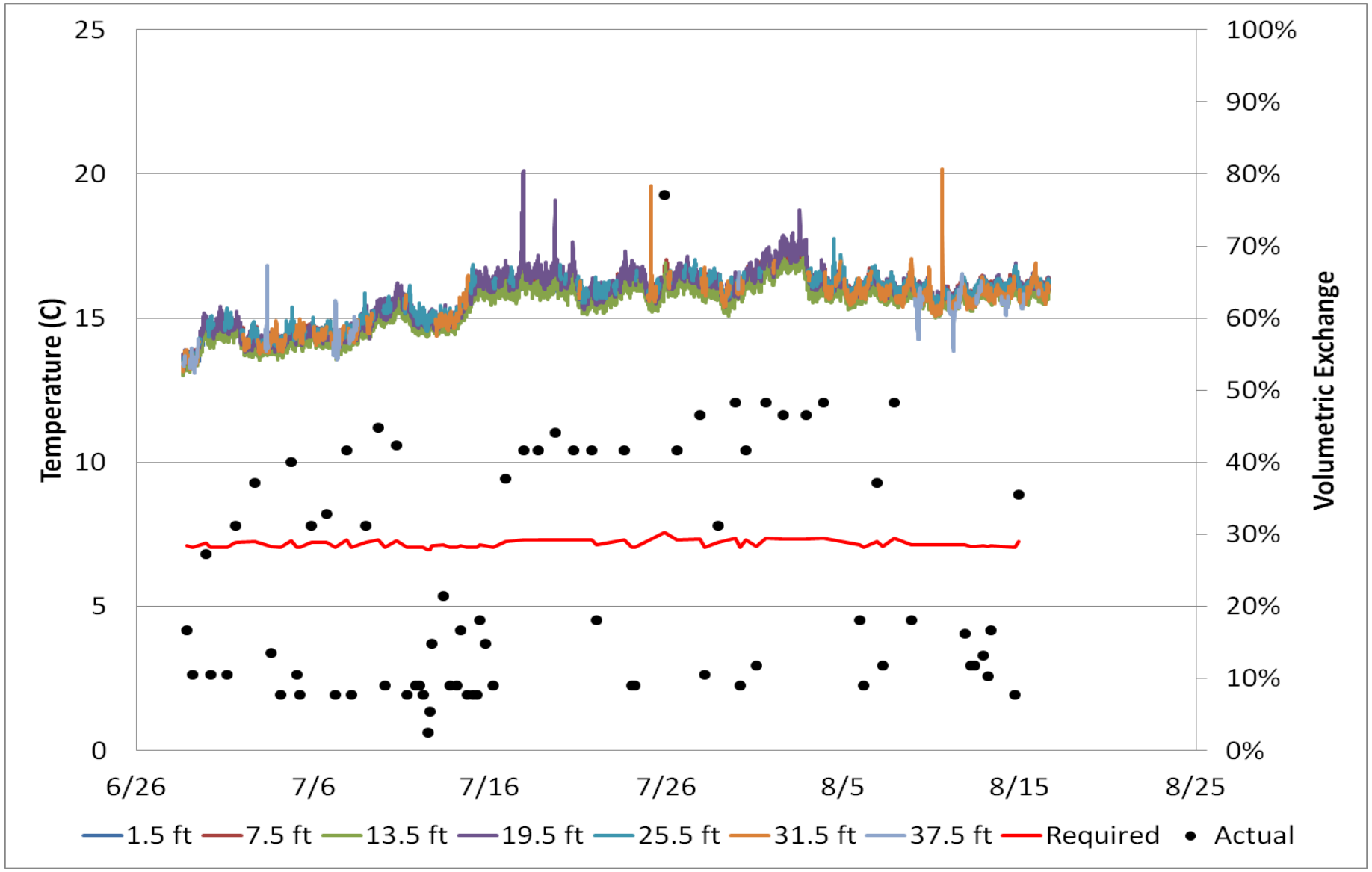
Tank G – initial water quality



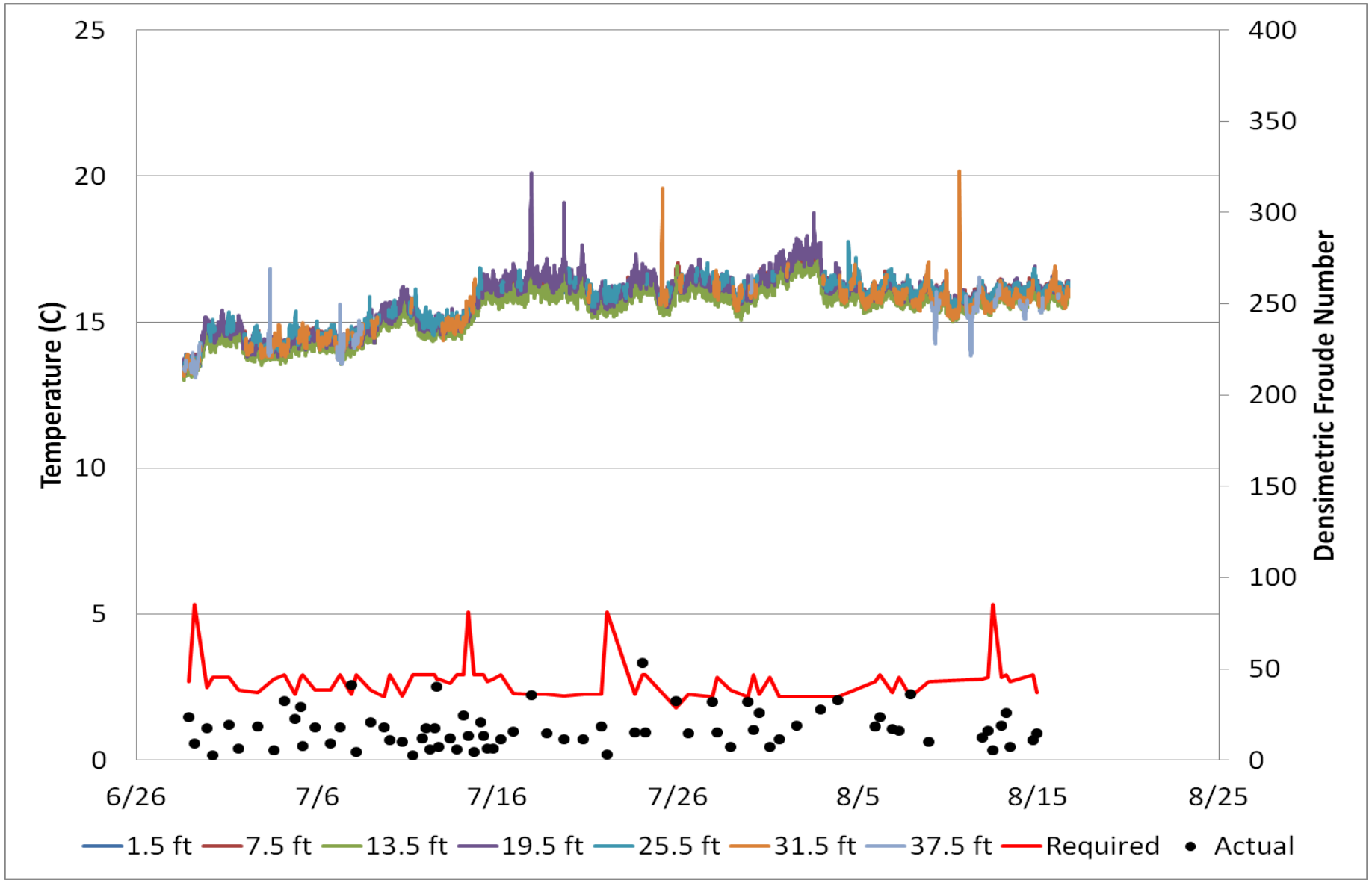
Tank G – water quality last sampling



Volumetric turnover – Tank G



Densimetric Froude # – Tank G



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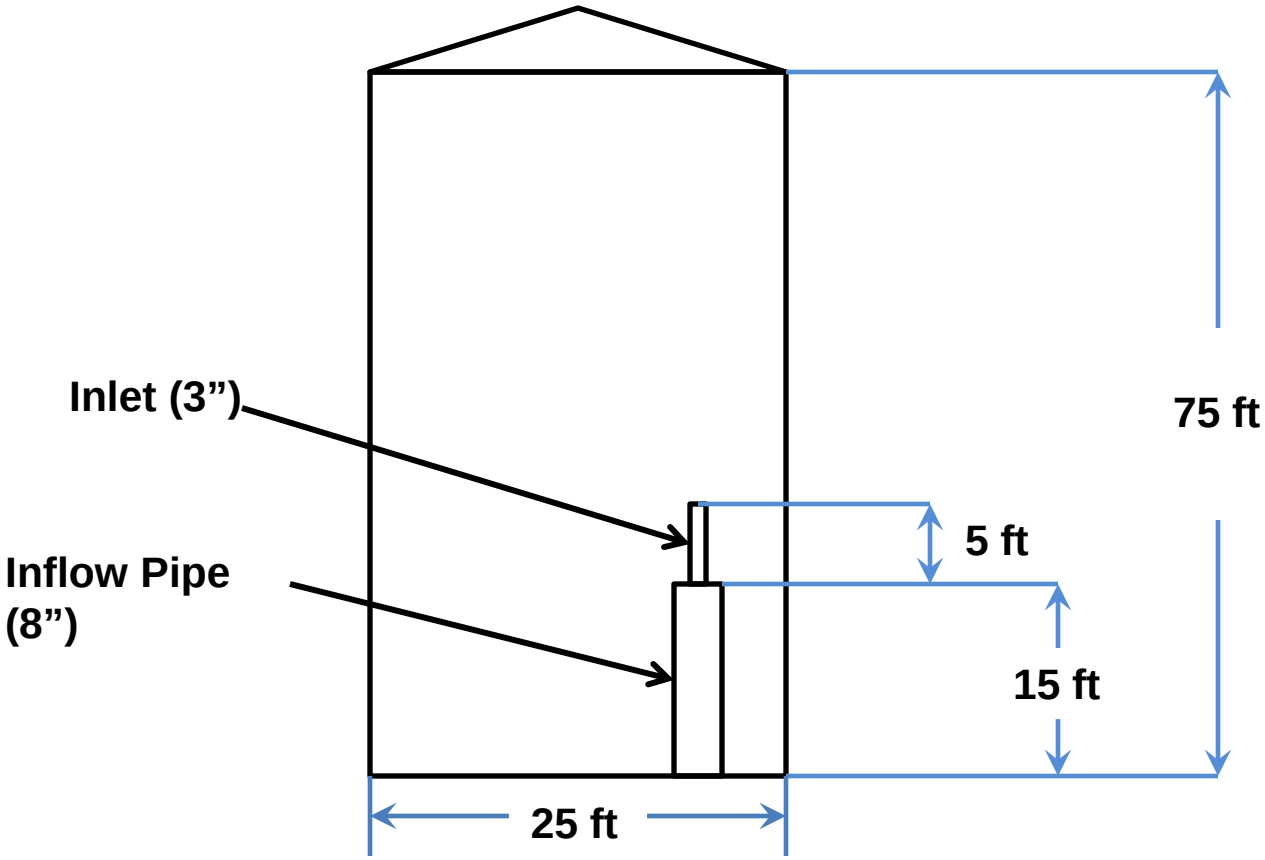
Short term tank 9

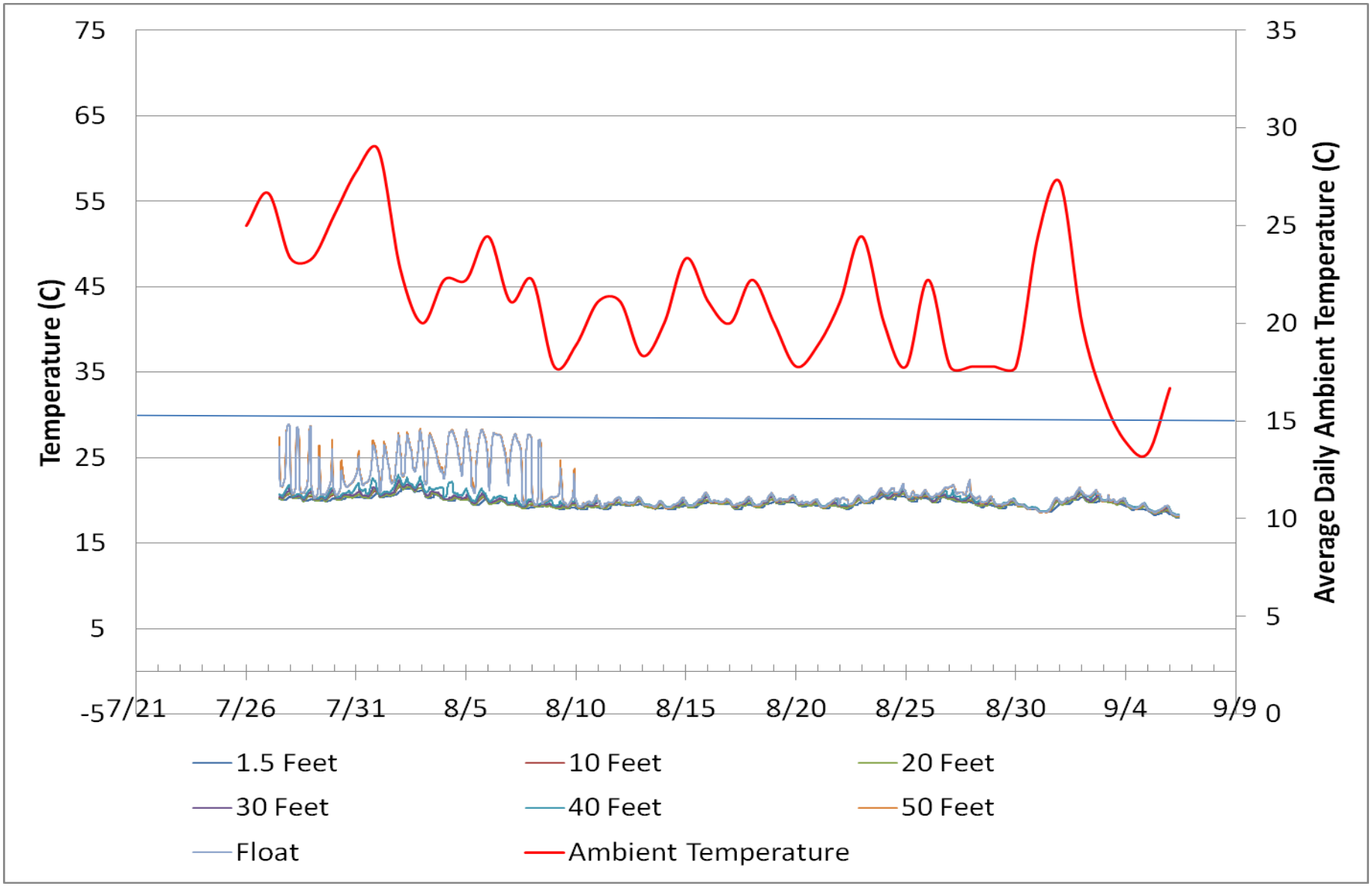


Note: Diagram is not to scale.

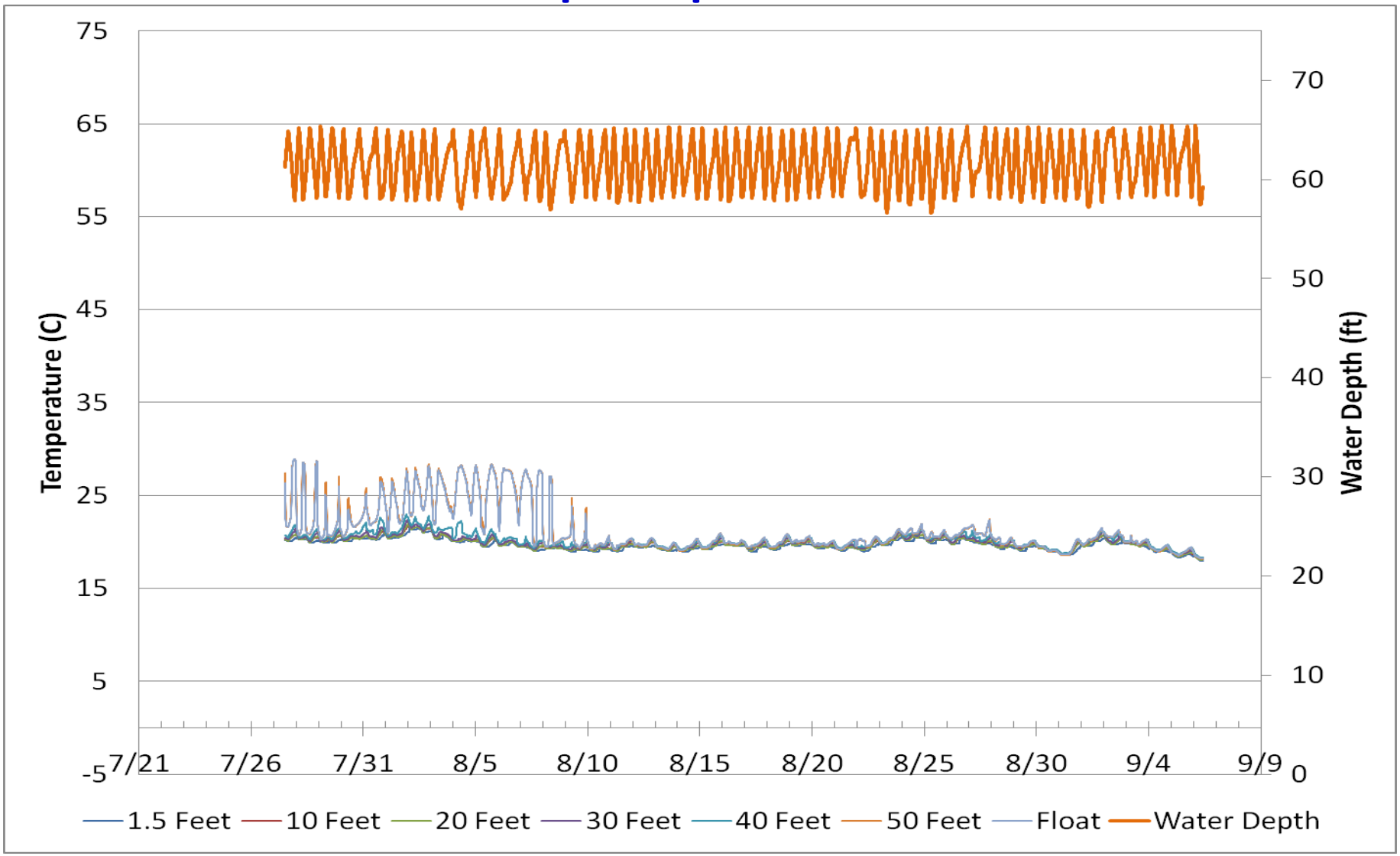
Methods – Short term temperature

- Data collected for a period of one to four weeks
- Temperature at several points and water level data collected

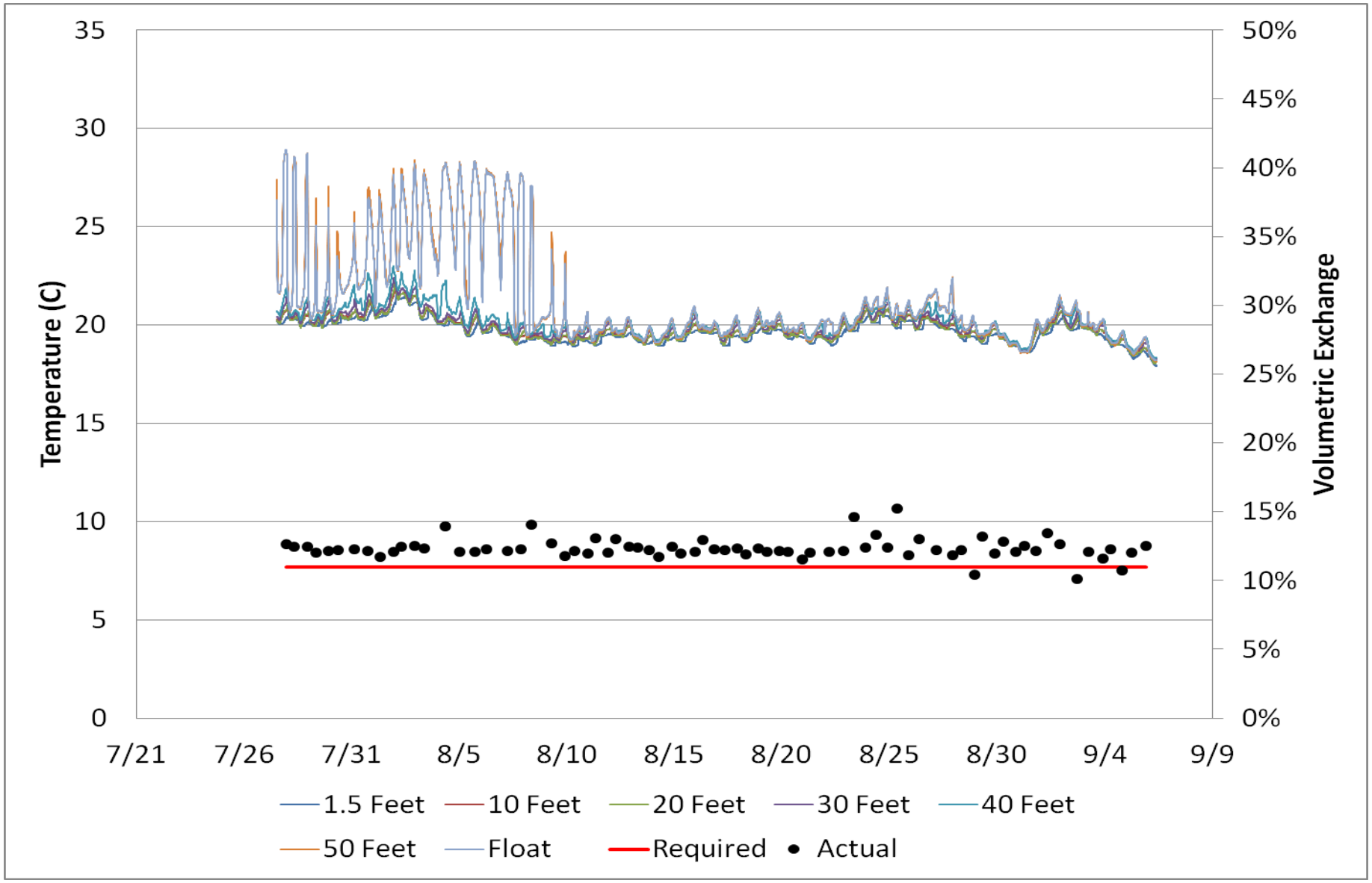
Short term tank 9 – temperature profile



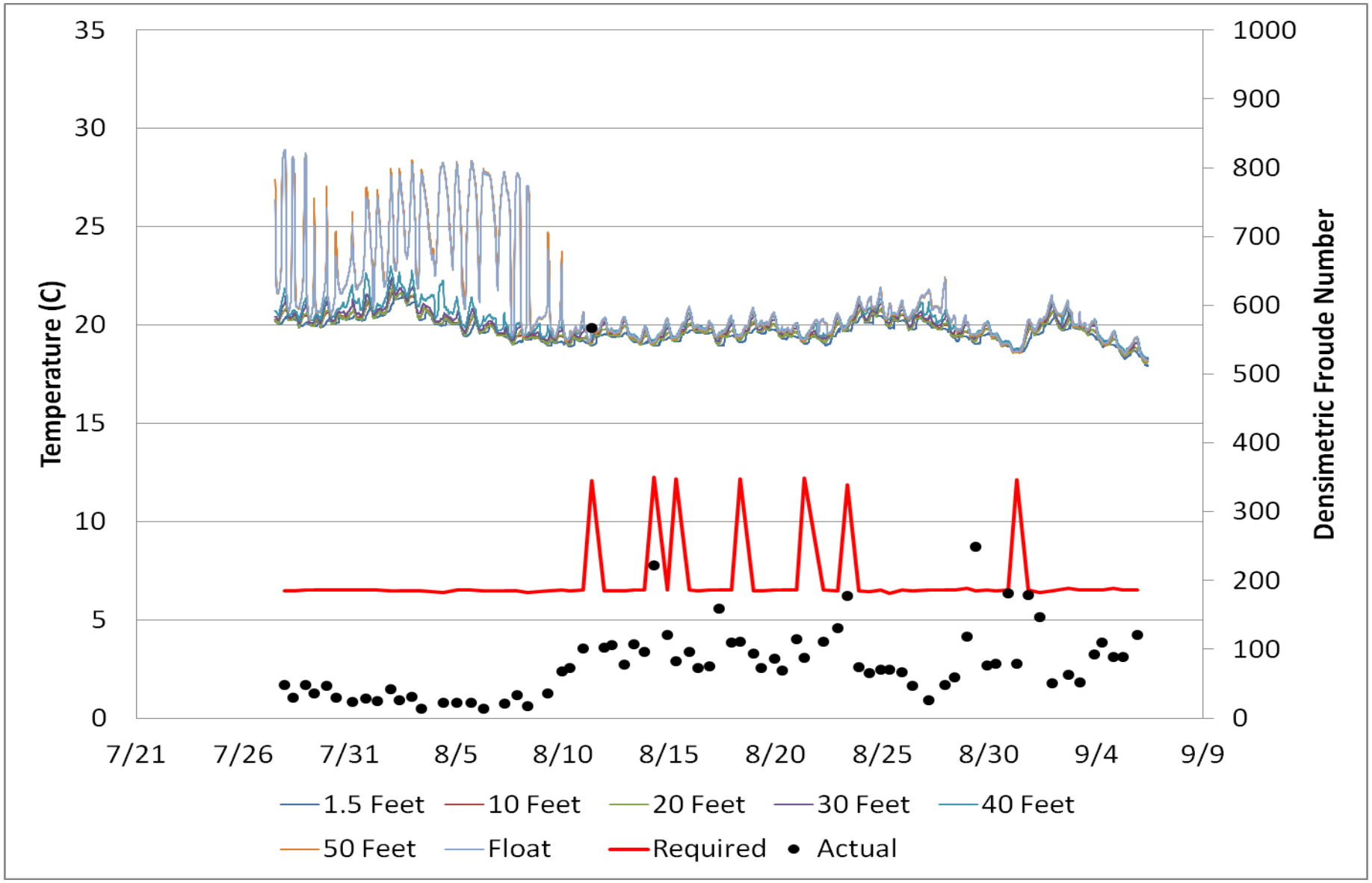
Short term tank 9 – temperature and depth profile



Volumetric turnover – tank 9



Densimetric Froude # – Tank 9



Summary

- Thermal stratification occurs in taller tanks
- Chlorine decay can result in nitrification
- Chlorine residual can be restored through deep cycle or overflow
- Passive mixing systems can prevent stratification

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