Drinking Water Storage Tank Assessment

Study Protocol

The views expressed in this protocol are those of the authors and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

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OVERVIEW:

The Storage Tank Assessment Study is an optional activity designed to help drinking water systems assess the impact of tank operations on water quality, as well as estimate average tank turnover time and mixing performance within drinking water storage tanks in a distribution system. EPA designed this study in partnership with state drinking water programs through the EPA's Area-Wide Optimization Program (AWOP).

A continuous chlorine monitor is used to measure chlorine residual at the inlet/outlet of the storage tank expected to have the lowest and/or most variable residual concentrations (i.e., the most critical tank, with respect to water quality). This is identified based on the water system operator's best judgement and the output from the Storage Tank Assessment SpreadsheetV11.xlsx. This spreadsheet is a tool that can be used to estimate turnover time and mixing performance of distribution system storage tanks based on their physical characteristics and tank level data. The spreadsheet may also be used to evaluate potential strategies that may improve storage tank performance and water quality. However, the spreadsheet does have some limitations; for example, tank turnover estimates do not apply to tanks that operate with simultaneous inflow and outflow (i.e., "flow-through" tanks). The applicability of this spreadsheet should be determined for each individual tank. For more details, see the Applications and Limitations section on the Introduction worksheet in the Storage Tank Assessment Spreadsheet.xlsx file.

STUDY OBJECTIVES:

This study can be used to accomplish various objectives:

- Identify the most critical tank (i.e., with lowest and/or most variable residual concentrations) in the distribution system based on estimated tank operations (from the tank spreadsheet) and water quality (from the continuous monitor).
- Continuously monitor chlorine residual and water levels at tanks to assess the impact of tank operation on water quality.
- Determine if estimated average tank turnover time or mixing performance may be contributing to water quality problems in the distribution system.
- Provide data to support the identification and prioritization of efforts (operational changes or capital expenditures) to address water quality issues based on individual tank performance (if applicable).

RESOURCES:

Recommended Personnel:

- One to two investigators

Primary Equipment/Software/Data:

- One continuous chlorine monitor with data logger (recording at ten-minute intervals or less) and necessary operation and maintenance materials (continuous chlorine monitors may be installed at multiple tanks if available)
- One large (500 mL or greater) graduated cylinder or measuring cup to adjust flow rate through continuous chlorine monitor(s)
- One hose (length and diameter are site specific), two hose clamps, and a flat-head screwdriver
- Electrical power source (AC outlet, batteries, or solar panel)
- Colorimetric chlorine test kit with necessary instructions and DPD reagents for chlorine analysis
- Computer with Microsoft Excel (Office 2000 or later)
- Storage Tank Assessment Spreadsheet (Storage Tank Assessment Spreadsheet.xlsx)

- Tank level data (two to three weeks at ten-minute intervals or less) from all storage tanks in the water system that is obtained from SCADA (preferred) or continuous pressure recorder(s)

Optional Equipment/Software:

- Hydrant adapter (confirm system thread and diameter; if installed at hydrant near tank)
- Chain (length is site specific) and lock (if installed at hydrant near tank) to secure the monitor.
- Continuous pressure recorder (if tank level data is not recorded by SCADA/telemetry; pressure recorders may be installed at multiple tanks if available)
- Data logger software (if applicable)

Approach:

1. Data Collection:

   a. *Tank Level Data* – Tank level data will be needed from each tank that will be assessed. If recorded level data are not available at any tanks of interest, a pressure recorder can be used to collect the necessary data. If the quantity of available pressure recorders is limited, prioritize their locations starting with the most critical tank (i.e., with lowest and/or most variable residual concentrations) based on input from the water system. Tank level data should be representative of normal operating conditions (e.g., without line breaks or fires), recorded over two to three weeks at ten-minute intervals or less, and coincide with reliable continuous chlorine data for a minimum of three days. The output of tank level data is generally in either tabular or graphical form and reported in depth (ft) or volume (percent full).

   b. *Water Quality Data* – Collect continuous chlorine residual data for a minimum of three days at ten-minute intervals or less. If additional monitors are available, prioritize their locations based on the water system operator's best judgement and/or output from the tank spreadsheet. Depending on the continuous chlorine monitoring technology, it may take several days for the monitor to stabilize and provide water quality data after it is installed. In explanation, amperometric technologies may require multiple calibrations during first the few days after installation. Additionally, some continuous monitors can measure multiple water quality parameters (e.g., pH, conductivity, temperature). These "secondary" parameters can provide additional information that can be used to assess storage tank performance, but these additional parameters are not necessary. An AC outlet will be needed to power the monitor, unless it is equipped with a solar panel and/or battery. A chlorine test kit will also be needed to collect grab samples for monitor calibration. Refer to the manufacturer's instruction manual for proper installation and calibration procedures.

   c. *Physical Characteristics* – Determine the following physical characteristics for each tank:

      i. Volume (MG)
      ii. Shape (cylindrical, rectangular, hydropillar, or other)
      iii. Tank diameter (ft) or sidewall length (ft)
      iv. Inlet/outlet diameter (ft)
      v. Maximum operating depth (ft)
      vi. Inlet/outlet configuration ("fill-and-draw" or "flow-through")

   While tank drawings are (ideally) the best source of information about the physical characteristics of storage tanks, they may not be available; if this is the case, the water system operator should use its best judgement.

2. Tank Turnover and Mixing Performance Assessment:

   a. Complete *Section I* of the *Tank Summary* worksheet (*see* **Error! Reference source not found.**) in the *Storage Tank Assessment Spreadsheet.xlsx* with physical characteristics of each tank (up to nine); if a system has more than nine tanks, save a copy of the spreadsheet to use for the additional tanks. Determine the applicability of the spreadsheet to each individual tank based on their physical characteristics. For more details, see the *Applications and Limitations* section on the *Introduction* worksheet.

Tank Summary

Instructions:

1. Enter tank design data for each tank into *Section I* of the *Tank Summary* worksheet (user input is shown in red).
   Section II of the Tank Summary worksheet will be populated after data is entered into Section I and the respective Tank worksheet.
2. Enter the tank level data into *Section I* of the *Tank* worksheet(s).
3. If the estimated turnover time and/or mixing is poor, *Section II* of the *Tank* worksheet will evaluate potential operational strategies and/or design strategies to improve tank performance.

Section I. Physical Characteristics (See *Glossary* worksheet for details)

		Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank #9
Name of Tank	**Example**	**West Tank**								
Volume (MG)	**0.3**	**1**								
Is the tank Cylindrical (C), Rectangular (R), Hydropillar (H), or None of these (n)?	**r**	**c**								
Is tank level data in volume (y/n)?	**n**	**n**	← **User Input**							
Are tank mixing equations applicable based on the *Introduction* worksheet (y/n)?	**y**	**y**								
Tank diameter (if cylindrical/hydropillar) or longest sidewall length (if rectangular)(ft)	**50**	**75**								
Shortest sidewall length (If rectangular) (ft)	**30**									
Inlet Diameter (ft)	**1.00**	**2.00**								
Maximum Operating Water Depth (ft)	**24**	**30**								
Is the tank operated fill-draw (fd) or flow-through[2] (ft)?	**fd**	**fd**								
H/D ratio	**0.48**	**0.40**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**	**#DIV/0!**

The remaining data is automatically calculated based on the data entered above:

Are the turnover time calculations applicable?	**yes**	**yes**	**no**	**no**	**no**	**no**	**no**	**no**	**no**	**no**
Are the mixing equations applicable?	**yes**	**yes**	**no**	**no**	**no**	**no**	**no**	**no**	**no**	**no**

Section II. Tank Calculations (from *Tank* worksheets)

****If turnover time and/or mixing estimations do not apply this section may be blank.**

Average Turnover Time (days)	**4.6**	**7.8**	← **Spreadsheet Output**							
Mixing Performance Ratio (Measured/ Desired)	**0.37**	**0.18**								

Notes:

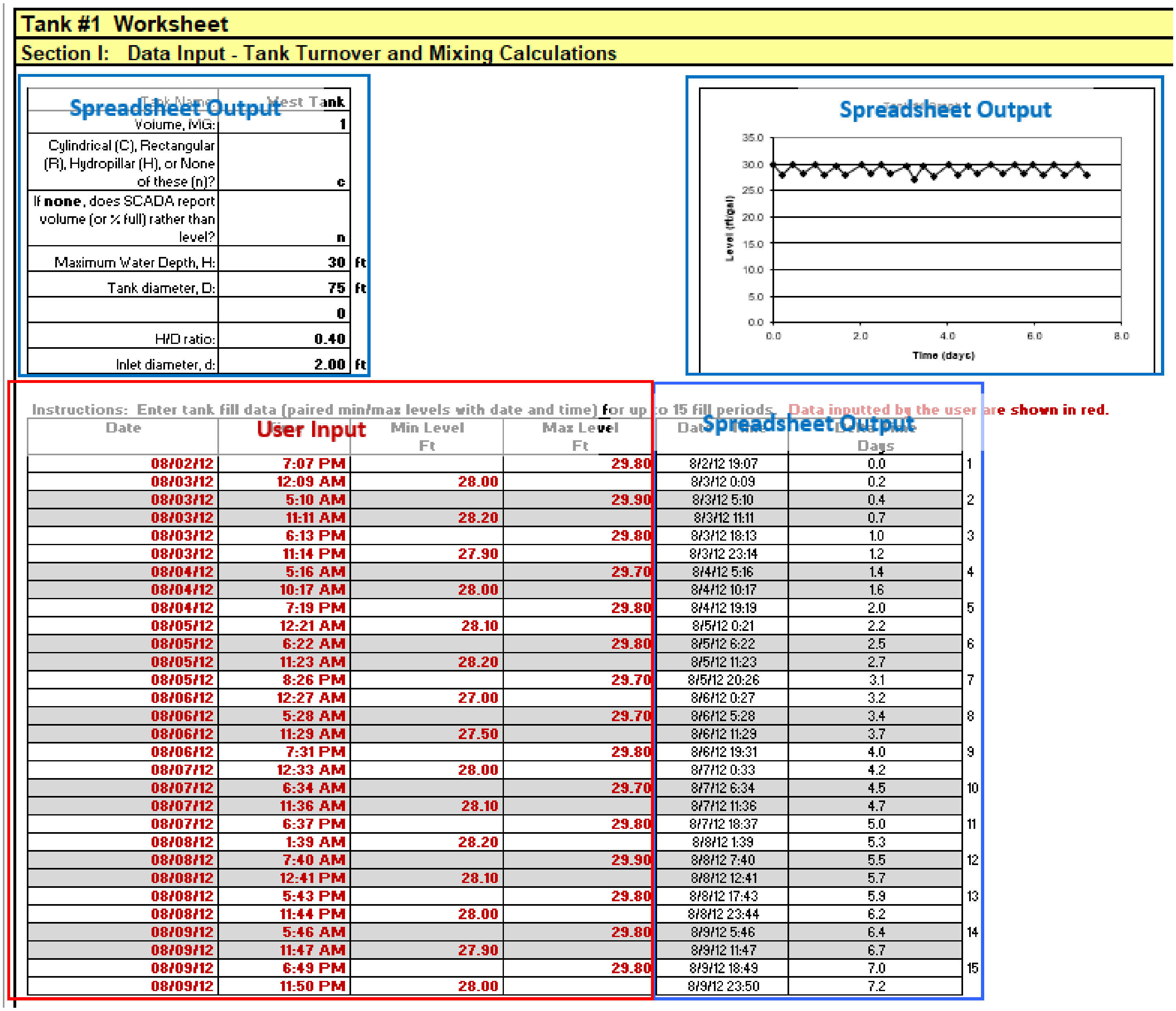
1. Hydropillar tanks can be approximated as cylindrical tanks depending on their operating range. See *Glossary* worksheet for illustration.
2. In flow-through operation water is simultaneously coming into the tank and leaving the tank. In fill-draw operation water can either be filling the tank or drawing from the tank at anytime (this is most common).

Figure 1: Screenshot of *Tank Summary* Worksheet in the *Storage Tank Assessment Spreadsheet.xlsx*

b. Complete *Tank* worksheet(s) for each individual storage tank

   i. Interpret maximum and minimum tank levels of each cycle with corresponding time and date for all tanks. Tank level data may be found in tabular or graphical form and reported in depth (ft) or volume (MG, gallons, or percent full). For more details on interpreting tank cycles, see the *Data Considerations* worksheet.

   ii. Enter storage tank level data into the upper portion of *Section I* of the *Tank* worksheet(s) for each individual storage tank (*see figure 2)*. When entering the data into the spreadsheet, one may start with a minimum or maximum tank level value; however, **the data need to be entered in sets/pairs** (i.e., for every minimum (min) level entered, there must be a paired maximum (max) level value). Tank level data may be entered in depth (ft) or volume (MG, gallons, percent full). For more details on converting tank level data from various formats, see the *Data Considerations* worksheet.



Tank Name:	West Tank	
Volume, MG:	1	
Cylindrical (C), Rectangular (R), Hydropillar (H), or None of these (n)?	c	
If **none**, does SCADA report volume (or % full) rather than level?	n	
Maximum Water Depth, H:	30	ft
Tank diameter, D:	75	ft
	0	
H/D ratio:	0.40	
Inlet diameter, d:	2.00	ft

Instructions: Enter tank fill data (paired min/max levels with date and time) for up to 15 fill periods. Data inputted by the user are shown in red.

Date	Time	Min Level Ft	Max Level Ft	Date/Time	Elapsed Time Days	
08/02/12	7:07 PM		29.80	8/2/12 19:07	0.0	1
08/03/12	12:09 AM	28.00		8/3/12 0:09	0.2	
08/03/12	5:10 AM		29.90	8/3/12 5:10	0.4	2
08/03/12	11:11 AM	28.20		8/3/12 11:11	0.7	
08/03/12	6:13 PM		29.80	8/3/12 18:13	1.0	3
08/03/12	11:14 PM	27.90		8/3/12 23:14	1.2	
08/04/12	5:16 AM		29.70	8/4/12 5:16	1.4	4
08/04/12	10:17 AM	28.00		8/4/12 10:17	1.6	
08/04/12	7:19 PM		29.80	8/4/12 19:19	2.0	5
08/05/12	12:21 AM	28.10		8/5/12 0:21	2.2	
08/05/12	6:22 AM		29.80	8/5/12 6:22	2.5	6
08/05/12	11:23 AM	28.20		8/5/12 11:23	2.7	
08/05/12	8:26 PM		29.70	8/5/12 20:26	3.1	7
08/06/12	12:27 AM	27.00		8/6/12 0:27	3.2	
08/06/12	5:28 AM		29.70	8/6/12 5:28	3.4	8
08/06/12	11:29 AM	27.50		8/6/12 11:29	3.7	
08/06/12	7:31 PM		29.80	8/6/12 19:31	4.0	9
08/07/12	12:33 AM	28.00		8/7/12 0:33	4.2	
08/07/12	6:34 AM		29.70	8/7/12 6:34	4.5	10
08/07/12	11:36 AM	28.10		8/7/12 11:36	4.7	
08/07/12	6:37 PM		29.80	8/7/12 18:37	5.0	11
08/08/12	1:39 AM	28.20		8/8/12 1:39	5.3	
08/08/12	7:40 AM		29.90	8/8/12 7:40	5.5	12
08/08/12	12:41 PM	28.10		8/8/12 12:41	5.7	
08/08/12	5:43 PM		29.80	8/8/12 17:43	5.9	13
08/08/12	11:44 PM	28.00		8/8/12 23:44	6.2	
08/09/12	5:46 AM		29.80	8/9/12 5:46	6.4	14
08/09/12	11:47 AM	27.90		8/9/12 11:47	6.7	
08/09/12	6:49 PM		29.80	8/9/12 18:49	7.0	15
08/09/12	11:50 PM	28.00		8/9/12 23:50	7.2	

Figure 2: Screenshot of Upper Portion of *Section I* of *Tank #1* Worksheet in the *Storage Tank Assessment Spreadsheet.xlsx*

c. Review Assessment Summary on the lower portion of Section I on the Tank worksheet(s).

   i. Turnover time is quantified in days: < 3 to 5 days is desired.

   ii. Mixing performance is quantified as a ratio (estimated mixing / desired mixing). A ratio greater than 1.0 is desired. The "estimated mixing" is determined based on the fill/draw cycles and tank design characteristics. The "desired mixing" is the level of mixing needed to achieve 95% uniformity throughout the tank, the equation for which was determined based on tracer studies conducted on scale-model tanks by Rossman & Grayman 1999 (see the References section in the Introduction worksheet in the spreadsheet).

Turnover Summary		
Avg Vol Added in One Fill Period	0.06	MG
Avg Vol Drawn in One Drain Period	0.06	MG
Avg Fill Time	0.27	days
Avg Draw Time	0.22	days
Avg Fill Rate	154	gpm
Avg Draw Rate	190	gpm
Avg Duration (Fill + Draw Time)	0.5	days
Avg Flow Rate into tank	0.12	MGD
Avg Tank Vol	0.95	MG
Turnover Time	7.8	days

Spreadsheet Output

Turnover time is at an undesirable level, use Turno[...] Time Analysis (Step 2) to determine operational str[...] that will reduce turnover time.

Turnover Time

Mixing Summary		
Avg Min Water Level	27.9	ft
Avg Actual VEF	0.07	
Avg VEF Needed for Good Mixing	0.36	
Avg Measured Water Level Change	1.8	ft
Desired Water Level Change Needed for Good Mixing	10.1	ft
Mixing Performance Ratio (Measured/Desired)	0.18	
Inlet Diameter Needed for Good Mixing	4	inches

Spreadsheet Output

Mixing Performance Ratio

Mixing is at an undesirable level, use Mixing Analysis (Section II) to determine strategies that will increase mixing.

Figure 3: Screenshot of Lower Portion of *Section I* of Tank #1 Worksheet in the *Storage Tank Assessment Spreadsheet.xlsx*

d. (Optional) Estimate the impact of operational changes (i.e., modifying minimum and/or maximum tank levels) and/or design changes (i.e., modifying inlet diameter) on turnover time and mixing using Section II on the Tank worksheet(s). The Area Wide Optimization Program strongly recommends that any operational and/or design changes be based on water quality data, and not solely on the estimates generated by the spreadsheet.

Section II: Turnover Time & Mixing Analysis

Instructions: Five scenarios are available for experimenting with changing tank operations to improve turnover time. Experiment with lowering the both the Max and Min levels, only the Min level, and only the Max level. Modify data shown in red. Do not use this analysis if the turnover time equations are not applicable!

These five scenarios are also available for experimenting with reducing inlet diameter to improve mixing. Note that improving the level change will also improve mixing. Modify data shown in red. Do not use this analysis if the mixing equations are not applicable.

This analysis assumes that the fill (pump) rate and the draw rate (demand) on the tank doesn't change.

	No Changes	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	
Longest Sidewall Length	50	50	50	50	50	50	ft
Shortest Sidewall Length	30	~~30~~	~~30~~	~~30~~	~~30~~	~~30~~	ft
Inlet Diameter	1.00	1.00	0.50	0.50	0.50	0.75	ft
High/Max Level	18.71	18.00	18.00	17.00	17.00	17.00	ft
Low/Min Level	16.79	15.00	15.00	15.00	14.00	14.00	ft
H/D ratio	0.37	0.36	0.36	0.34	0.34	0.34	
Actual Level Change	1.92	3.00	3.00	2.00	3.00	3.00	ft
Dimensionless Mixing Time	10.20	10.20	10.20	10.20	10.20	10.20	
Desired Level Change Needed for Good Mixing	5.17	4.80	2.40	2.40	2.29	3.44	ft
Pressure Drop After Change in Min Water Level		0.8	0.8	0.8	1.2	1.2	psi
Fill Rate/ Pumping Rate	54	54	54	54	54	54	gpm
Draw Rate/ Consumer Demand	67	67	67	67	67	67	gpm
Avg Fill Time	0.27	0.43	0.43	0.29	0.43	0.43	days
Avg Draw Time	0.22	0.35	0.35	0.23	0.35	0.35	days
Avg Volume Added During Fill	0.02	0.03	0.03	0.02	0.03	0.03	MG
Avg Duration (fill +draw)	0.50	0.78	0.78	0.52	0.78	0.78	days
Avg Flow Rate	0.04	0.04	0.04	0.04	0.04	0.04	MGD
Avg Tank Vol	0.20	0.19	0.19	0.18	0.17	0.17	MG
Mixing Performance Ratio (Measured/Desired)	0.37	0.63	1.25	[illegible]	1.31	0.87	
Turnover Time	4.6	4.3	4.3	4.2	4.0	4.0	days

User Input

Spreadsheet Output

Figure 3: Screenshot of *Section II* of *Tank #1* Worksheet in *Storage Tank Assessment Spreadsheet.xlsx*

3. Continuous Chlorine Residual Assessment:

Combine continuous chlorine residual data and tank level data collected from the tank, as shown in Figure 4. The combination of chlorine and tank level data may be used to determine the impact of tank operations on water quality. For example, the data shown in Figure 4 suggests that the tank is poorly mixed because the chlorine residual changed by approximately 1.0 mg/L during each fill-and-draw cycle.

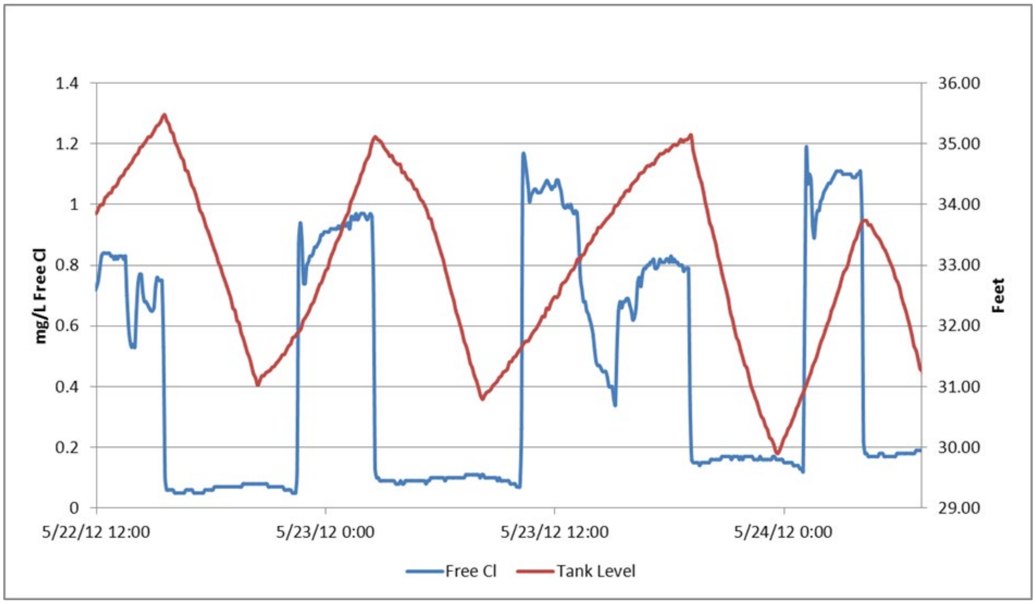


Figure 4: Example Continuous Free Chlorine and Tank Level Data

DURATION OF STUDY:

The duration of the storage tank assessment study varies depending on the availability of SCADA at all storage tanks and the continuous chlorine monitoring technology selected for the study. If a pressure recorder and/or a continuous chlorine monitor that requires an extended period of time to stabilize are used in the study, the duration of the study may be two weeks, or longer. If the continuous chlorine monitor requires a few hours to stabilize and a pressure recorder is not required, the duration of the study may be approximately four days. Additional logistics, such as travel time to the water system for equipment installation and/or calibration should be considered.

CONCLUSIONS AND FULL-SCALE IMPLEMENTATION:

Documenting the results and conclusions from this study will support system-specific decisions about changes in storage tank operations or designs that are made. That documentation can also serve as a resource for designing future studies.