Storage Tank Assessment
Special Study Protocol
(January 2018)

Overview:

The Storage Tank Assessment Special Study is designed to assess the impact of tank operations on water quality at a single storage tank and estimate average tank turnover time and mixing performance at all storage tanks in a distribution system. A continuous chlorine monitor is used to measure chlorine residual at the inlet/outlet of the "worst performing" storage tank, which is identified based on the water system's best judgement and the output of the tank turnover time and mixing estimates (if available at the time of the study). Tank level data and physical characteristics from all storage tanks in the system will be collected and entered into a spreadsheet that will be used to estimate average tank turnover time and mixing performance for each tank. The spreadsheet may also be used to evaluate potential strategies that may improve storage tank performance and improve water quality.

This special study can be used to accomplish various objectives:

- Identify the most critical, or worst performing, tanks in the 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 whether 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).

The *Storage Tank Assessment Spreadsheet.xlsx* can be used to support this special study. This spreadsheet has several limitations (including certain types of tanks) and is 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.

Hypothesis:

The study hypothesis will be system specific and depends on the study objective (discussed in the *Overview* section, above).

Resources:

- Required Personnel:
    - One to two (1-2) investigators
- Required Equipment:
    - One (1) continuous free chlorine monitor with data logger (recording at ten minute intervals or less) and necessary operation and maintenance materials (continuous free chlorine monitors may be installed at multiple tanks if available)
    - One (1) hose (length and diameter are site specific), two (2) hose clamps, and one (1) screwdriver (confirm type)
    - Electrical power source (AC outlet, batteries, or solar power)
    - One (1) colorimetric chlorine test kit with necessary instructions and DPD reagents for free chlorine analysis
    - One (1) computer with Microsoft Excel

- 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:
  - One (1) large measuring cup to adjust flow rate through continuous free chlorine monitor(s)
  - One (1) hydrant adapter (confirm system thread and diameter; if installed at hydrant near tank)
  - One (1) chain (length is site specific) and one (1) lock (if installed at hydrant near tank) to secure the monitor.
  - One (1) 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 SCADA is 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 (i.e., worst performing) tank 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 free 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 free chlorine residual data from the most critical tank (i.e., "worst performing") 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'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 quality data after it is installed. In general, amperometric technologies may require multiple calibrations during first few days after installation. Additionally, some continuous monitors are capable of measuring multiple water quality parameters (e.g., pH, conductivity, temperature). These "secondary" parameters can provide additional information that can be used to asses storage tank performance, but these additional parameters are not required. An AC power source 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)

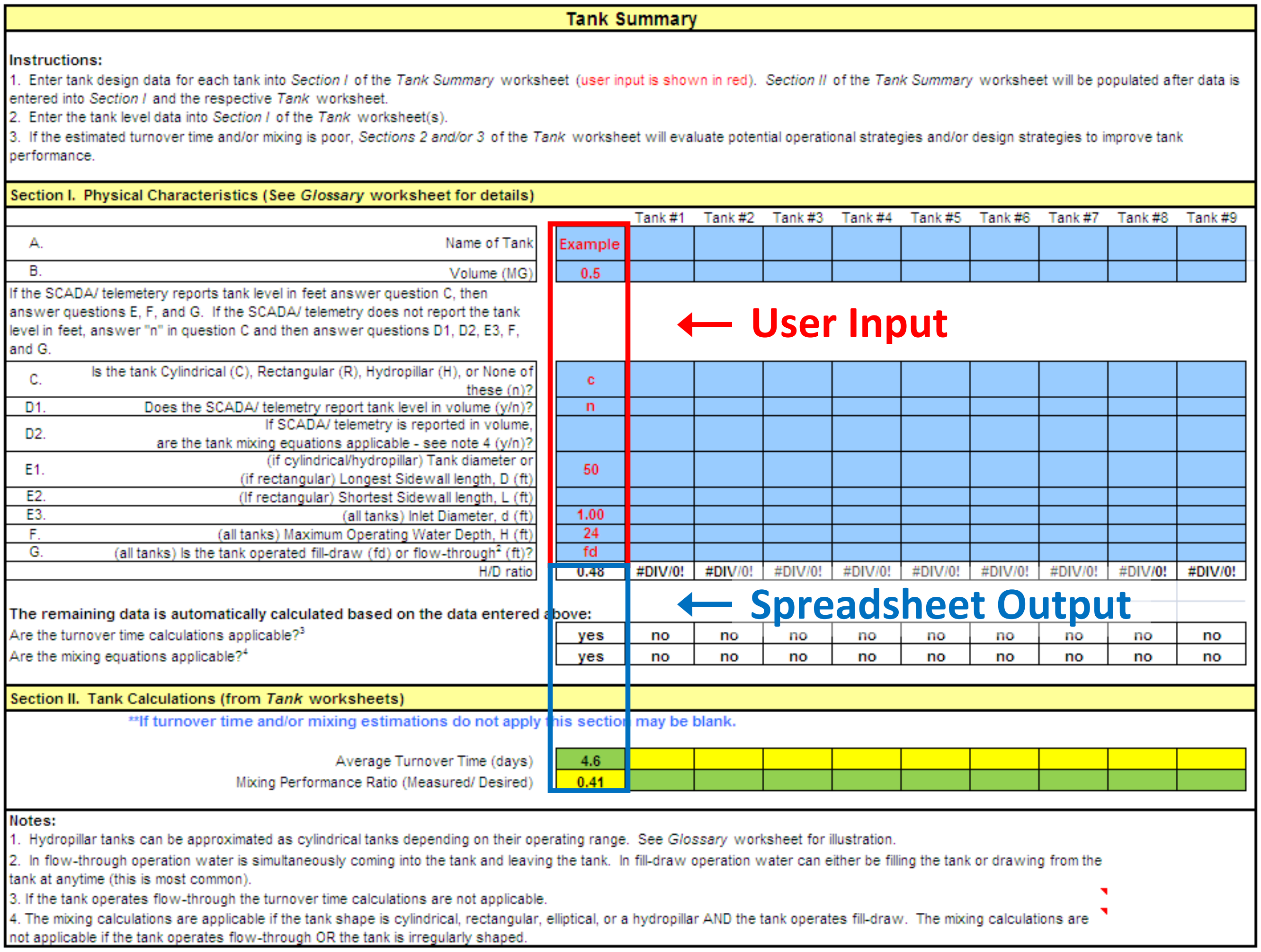
      v. Maximum operating depth (ft)

      vi. Inlet/outlet configuration ("fill-and-draw" or "flow-through")

While tank drawings are (ideally) the best place to obtain physical characteristics of storage tanks, they may not be available; if this is the case, use the water system's best judgement.

2. Tank Turnover and Mixing Performance Assessment:

   a. Complete *Section I* of the *Tank Summary* worksheet (*see Figure 1*) in the *Storage Tank Assessment Spreadsheet.xlsx* with physical characteristics of each tank (up to nine). At this time, determine the applicability of the spreadsheet on 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, *Sections 2 and/or 3* 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
A.	Name of Tank	Example									
B.	Volume (MG)	0.5									
If the SCADA/ telemetery reports tank level in feet answer question C, then answer questions E, F, and G. If the SCADA/ telemetry does not report the tank level in feet, answer "n" in question C and then answer questions D1, D2, E3, F, and G.											
C.	Is the tank Cylindrical (C), Rectangular (R), Hydropillar (H), or None of these (n)?	c									
D1.	Does the SCADA/ telemetry report tank level in volume (y/n)?	n									
D2.	If SCADA/ telemetry is reported in volume, are the tank mixing equations applicable - see note 4 (y/n)?										
E1.	(if cylindrical/hydropillar) Tank diameter or (if rectangular) Longest Sidewall length, D (ft)	50									
E2.	(If rectangular) Shortest Sidewall length, L (ft)										
E3.	(all tanks) Inlet Diameter, d (ft)	1.00									
F.	(all tanks) Maximum Operating Water Depth, H (ft)	24									
G.	(all tanks) Is the tank operated fill-draw (fd) or flow-through[2] (ft)?	fd									
	H/D ratio	0.48	#DIV/0!	#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?[3]	yes	no	no	no	no	no	no	no	no	no
	Are the mixing equations applicable?[4]	yes	no	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.

		Tank #1	Tank #2	Tank #3	Tank #4	Tank #5	Tank #6	Tank #7	Tank #8	Tank #9
Average Turnover Time (days)	4.6									
Mixing Performance Ratio (Measured/ Desired)	0.41									

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).
3. If the tank operates flow-through the turnover time calculations are not applicable.
4. The mixing calculations are applicable if the tank shape is cylindrical, rectangular, elliptical, or a hydropillar AND the tank operates fill-draw. The mixing calculations are not applicable if the tank operates flow-through OR the tank is irregularly shaped.

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

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

      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, gal., 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, it does not matter if you start with a minimum or maximum tank level value; however, you must enter the data in sets/pairs (i.e., if you start with a min level you must also enter a paired max value). Tank level data may be entered in depth (ft) or volume (gallons). For more details on converting tank level data from various formats, see *Data Considerations* worksheet.

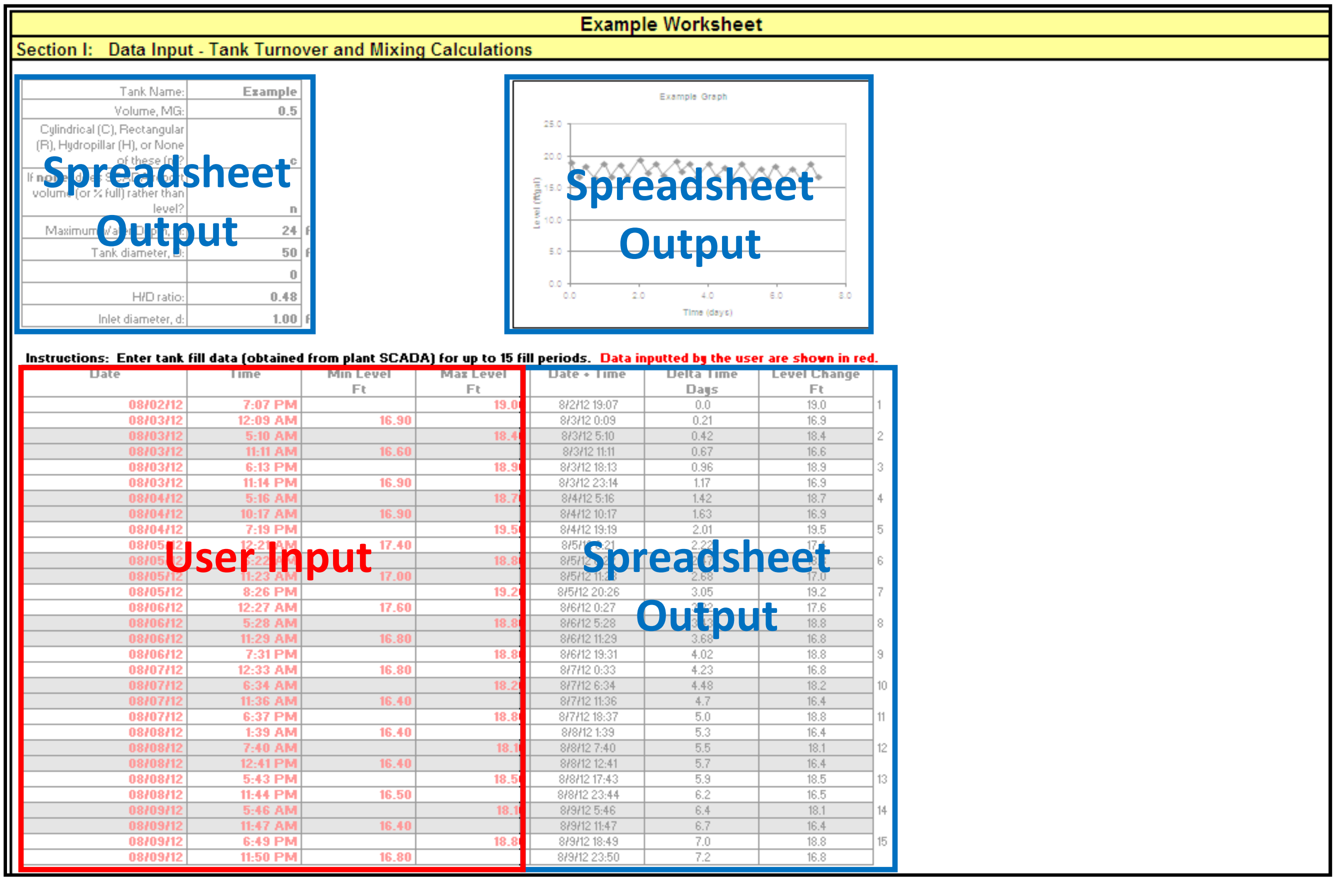


Figure 2: Screenshot of Upper Portion of *Section #1* of *Tank #1* Worksheet in *Storage Tank Assessment Spreadsheet.xlsx*

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/desired): ≥ 1.0 is desired.

Fill period	Low/Min Level	High/Max Level	Vol at start of fill cycle	Vol added during fill cycle	Volume drawn during drain cycle	Ave Tank Vol during fill cycle	Mixing calculations			Fill Time	Draw Time
							Actual Volume Exchange Fraction (VEF)	Dimension-less Mixing Time	Req'd Volume Exchange Fraction (VEF)		
	(ft)	(ft)	(MG)	(MG)	(MG)	(MG)				(days)	(days)
1	16.90	19.00	0.25	0.03		0.26	0.12	10.20	0.28	n/a	0.21
2	16.60	18.40	0.24	0.03	0.04	0.26	0.11	10.20	0.28	0.21	0.25
3	16.90	18.90	0.25	0.03	0.02	0.26	0.12	10.20	0.28	0.29	0.21
4	16.90	18.70	[illegible]	[illegible]	0.03	[illegible]	0.11	10.20	0.28	0.25	0.21
5	17.40	19.50	0.26	0.03	0.02	0.27	0.12	10.20	0.28	0.38	0.21
6	17.00	18.80	0.25	0.03	0.04	0.26	0.11	10.20	0.28	0.25	0.21
7	17.60	19.20	0.26	0.02	0.02	0.27	0.09	10.20	0.28	0.38	0.17
8	16.80	18.80	0.25	0.03	0.04	0.26	0.12	10.20	0.28	0.21	0.25
9	16.80	18.80	0.25	0.03	0.03	0.26	0.12	10.20	0.28	0.33	0.21
10	16.40	18.20	0.24	0.03	0.04	0.25	0.11	10.20	0.28	0.25	0.21
11	16.40	18.80	0.24	0.04	0.03	0.26	0.15	10.20	0.28	0.29	0.29
12	16.40	18.10	0.24	0.02	0.04	0.25	0.10	10.20	0.28	0.25	0.21
13	16.50	18.50	0.24	0.03	0.02	0.26	0.12	10.20	0.28	0.21	0.25
14	16.40	18.10	0.24	0.02	0.03	0.25	0.10	10.20	0.28	0.25	0.25
15	16.80	18.80	0.25	0.03	0.02	0.26	0.12	10.20	0.28	0.29	0.21

Spreadsheet Output

Turnover Summary		
Avg Vol Added in One Fill Period	0.03	MG
Avg Vol Drawn in One Drain Period	0.03	MG
Avg Fill Time	0.27	days
Avg Draw Time	[illegible]	days
Avg Fill Rate	71	gpm
Avg Draw Rate	88	gpm
Avg Duration (Fill + Draw Time)	0.5	days
Avg Flow Rate into tank	0.06	MGD
Avg Tank Vol	0.26	MG
Turnover Time	4.6	days

Spreadsheet Output

Turnover Time

Turnover Time is at a desired level.

Mixing Summary		
Avg Min Water Level	16.8	ft
Avg Actual VEF	0.11	
Avg VEF Needed for Good Mixing	0.28	
Avg Measured Water Level Change	[illegible]	ft
Desired Water Level Change Needed for Good Mixing	4.7	ft
Mixing Performance Ratio (Measured/Desired)	0.41	
Inlet Diameter Needed for Good Mixing	5	inches

Spreadsheet Output

Mixing Performance Ratio

Mixing is at an undesirable level, use Mixing Analysis (Step 2) to determine strategies that will increase mixing.

Figure 3: Screenshot of Lower Portion of *Section 1* of *Tank #1* Worksheet in *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). It is strongly recommended that any operational and/or design changes should 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 (H/D>1)!

	No Changes	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	
Tank diameter	50	50	50	50	50	50	ft
	0	0	0	0	0	0	ft
Inlet Diameter	1.00	1.00	1.00	1.00	0.50	0.50	ft
High/Max Level	18.71	17.00	[illegible]	[illegible]	18.71	18.71	ft
Low/Min Level	16.79	15.00	15.00	16.79	16.79	15.00	ft
H/D ratio	0.37	0.34	0.37	0.36	0.37	0.37	
Actual Level Change	1.92	2.00	3.71	1.21	1.92	3.71	ft
Dimensionless Mixing Time	10.20	10.20	10.20	10.20	10.20	10.20	
Desired Level Change Needed for Good	4.73	4.38	4.38	4.73	2.36	2.19	ft
Pressure Drop After Change in Min Water Level		0.8	0.8	0.0	0.0	0.8	psi
Fill rate/ Pumping rate	71	71	71	71	71	71	gpm
Draw rate/ consumer demand	88	[illegible]	[illegible]	[illegible]	[illegible]	88	gpm
Avg fill time	0.27	[illegible]	[illegible]	[illegible]	[illegible]	0.53	days
Avg draw time	0.22	0.23	0.43	0.14	0.22	0.43	days
Avg volume added during fill	0.03	0.03	0.05	0.02	0.03	0.05	MG
Avg Duration (fill	0.50	0.52	0.96	0.31	0.49	0.96	days
Ave Flow Rate	0.06	0.06	0.06	0.06	0.06	0.06	MGD
Ave Tank Vol	0.26	0.24	0.25	0.26	0.26	0.25	MG
Mixing Performance Ratio	0.41	0.46	0.85	0.26	0.81	1.69	
Turnover Time	4.6	4.2	4.4	4.5	4.5	4.4	days

User Input

Spreadsheet Output

Figure 4: Screenshot of *Section #2* of *Tank #1* Worksheet in *Storage Tank Assessment Spreadsheet.xlsx*

3. Continuous Chlorine Residual Assessment:

a. Combine continuous free chlorine residual data and tank level data collected from the most critical tank, as shown in Figure 5. 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 5 suggests that the tank is poorly mixed because free chlorine residual changed by approximately 1.0 mg/L during each fill-and-draw cycle.

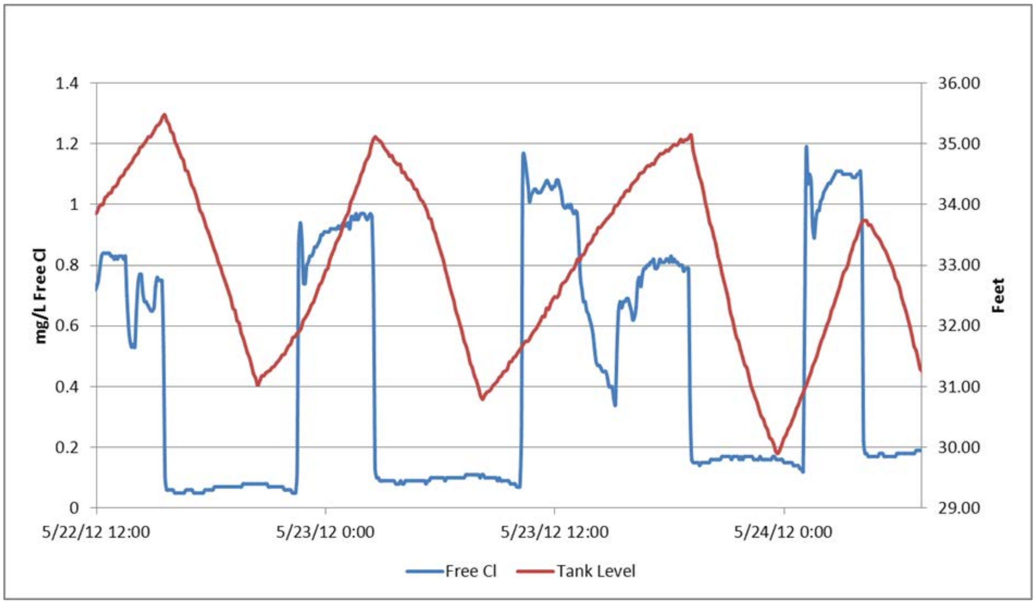


Figure 5: Example Continuous Free Chlorine and Tank Level Data

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.

Expected Results:

The results of this special study will be system specific, however it is anticipated that the data will support the study objective (discussed in the *Overview* section)

Summary and Conclusions:

This will be system specific, and should be documented once the study is complete.

Full-Scale Implementation:

This will be system specific, and should be documented once the study is complete.