Nitrification Control in the Distribution System to Reduce Resource Requirements

Lean Six Sigma Black Belt Project

by

pHishbone out of H₂O

January 25, 2018
Project team

• Team members:
  – Melissa Gray, Project Manager, LSS black belt candidate
  – Stefanie Hunter, LSS black belt candidate
  – Eric Lee, LSS black belt candidate
  – Eric Parker, LSS black belt candidate
  – Benita Becton, LSS green belt
  – Jhoanna Murray, LSS green belt
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Training and project

• Classroom training conducted August 1st through August 31st
  – Conducted by Walter Miller and Mark Reid through Oklahoma City Community College
• Project team met each Thursday afternoon from September 2017 to January 2018
• Benita Becton and Jhoanna Murray were added to the team as the project progressed
Define Phase
Project selection and process

• Nitrification Control in the Distribution System to Reduce Resource Requirements
  – Historical data related to nitrification in the distribution system was analyzed to determine if there were opportunities available to reduce the amount of resources required to respond to water quality events that required additional resources
History

• In July 2012, the City of Tulsa switched from chlorine to chloramines for secondary disinfection of the water distribution system.

• The switch was to ensure compliance with the EPA’s Stage 2 Disinfectants and Disinfection Byproducts Rule.

• The regulation reduces the risk of disinfection byproducts that can form when free chlorine combines with naturally occurring organic matter in the water.
What is nitrification?

- Chloramines are formed by adding ammonia that binds to the free chlorine.
- Nitrification occurs when microbes present in the biofilm lining the distribution pipes consume the available ammonia then sequentially oxidize it to form nitrites and nitrates, which are regulated contaminants.
2017 Monitoring sites

Compliance Monitoring
- 111 sites approved by ODEQ
- Monitored twice monthly
- Minimum of 2,664 annual tests

Nitrite Monitoring
- Goes above and beyond compliance
- Early detection/mitigation of potential nitrification conditions
Storage tanks are located throughout the City to equalize daily demands and to ensure adequate pressures throughout the water supply system.

- Tanks provide critical storage needed for firefighting purposes.
- Of the City’s total storage capacity of roughly 104.5 million gallons, the four tanks located at 61st and Sheridan account for just over half of that capacity.
# Project charter

## Team Members

**Executive Sponsor:** Clayton Edwards, W&S Director

**Project Champion:** Jo Brown, WQA Manager

**Black Belt Advisors:** Walter Miller, Eschelon LLC; Robyn Unideme, OPSI Project Manager

**Team Members:** Stefanie Hunter, Eric Lee, Eric Parker, Melissa Gray

## Process

**Process being evaluated:** Reducing nitrification exceedances in Tulsa's water distribution system

**Process Owner(s) - Individual(s) responsible for the business process being evaluated:**
- Roy Foster, Water Supply Systems
- Jo Brown, Water Quality Assurance
- Eric Parker, Water Distribution Systems

**What is the output from the process? (e.g. work product? Report? Inspection? Permit?)**
- Improved drinking water quality to utility customers
- Less time expended on remedial sampling
- Less water consumed due to unnecessary flushing
- Improved compliance with Federal Regulations

**Process Stakeholders (Who will be affected by the potential outcome):**
- Water Quality Assurance Field Staff
- Water Distribution Maintenance Crews
- Water Supply, Engineering Inspectors
- Contractors
- Utility Customers
- TMUA
- Elected officials
## Project charter – roles

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Problem statement

- Nitrification related water quality events in the distribution system can result in reduced disinfection levels (<1.0 mg/L total Cl2) and increased nitrite (>0.010 mg/L) levels. During the period of January 2013 – August 2017, there were 149 nitrification related events that required additional resources including multiple site visits, repeated sampling, and/or large amounts of treated water required to flush distribution lines and fill the multi-million gallon storage tanks that were drained.
### Define phase – Project timeline

#### pHiShbone Out of Water

#### Project Milestone Timeline

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*Updated 09/27/17 MMG*
Define phase - SIPOC

Controlling Nitrification in the Distribution System

**SUPPLIERS**
- A.B. Jewell Water Treatment Plant
- Mohawk Water Treatment Plant
- Water Distribution Systems

**INPUTS**
- Sufficient volume of treated water to satisfy system demand:
  - 5 yr. Average: 121 MGD
  - Max: 207.86 MGD
  - Max capacity: 220 MGD

**PROCESS**
- Water is pumped from treatment plants into the distribution system
- Water travels through 2,227 miles of pipe and into storage tanks
- Samples are collected throughout the system and analyzed to ensure quality
- Water is delivered to homes and businesses in and around the community

**OUTPUTS**
- Safe drinking water
- Water for firefighting, industrial, commercial, and other uses
- Lab results that indicate possible nitrification:
  - Total chlorine < 1.0 mg/L
  - Nitrate-N > 0.010 mg/L
- QA/QC repeats sampling until targets are met
- Treatment plants make adjustments
- Distribution crews flush lines and drain affected tanks when necessary

**CUSTOMERS**
- Internal
  - A.B. Jewell WTP
  - Mohawk WTP
  - Water Distribution Systems
  - Water Quality Assurance
  - TMUA
- External
  - Customers inside City limits
  - Customers outside City limits
  - Elected Officials
  - Regulatory Agencies

Water is pumped from treatment plants into the distribution system. The water travels through 2,227 miles of pipe and into storage tanks. Samples are collected throughout the system and analyzed to ensure quality. Water is delivered to homes and businesses in and around the community. Lab results that indicate possible nitrification are monitored: Total chlorine is less than 1.0 mg/L and Nitrate-N is greater than 0.010 mg/L. QA/QC repeats sampling until targets are met. Treatment plants make adjustments. Distribution crews flush lines and drain affected tanks when necessary.
## Define phase – RACI Chart

### Project:
Nitrification Control in the Distribution System to Reduce Resource Requirements

### Define and understand the Issue

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<td>R R R R</td>
<td>A A - -</td>
</tr>
</tbody>
</table>

**Legend:**
- **R:** Responsible (Person responsible for the task completion.)
- **A:** Accountable (Person accountable for task being completed.)
- **C:** Consulted (Stakeholders or subject matter experts.)
- **I:** Informed (Person receiving information from task.)

**Informed Person:**
- receiving information from task.

**Person responsible for the task completion:**
- completes the task.

**Accountable Person:**
- accountable for the task being completed.

**Consulted Stakeholders or subject matter experts:**
- consulted by the project team.

**Informed Person:**
- receiving information from the task.
### Define phase – Voice of the Customer and Critical to Quality

#### Critical to Quality

<table>
<thead>
<tr>
<th>Voice of the Customer</th>
<th>KEY PROCESS OUTPUT VARIABLES</th>
<th>KEY PROCESS INPUT VARIABLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>CUSTOMER NEED</td>
<td>Treated water that is free from harmful substances, such as nitrites.</td>
<td>Total chlorine between 2.50 - 3.25 mg/L&lt;br&gt;Regulatory Requirement: ≥ 2.0 mg/L at POE; ≥ 1.0 mg/L at furthest point in system</td>
</tr>
<tr>
<td></td>
<td>Monitor and control nitrite levels as water enters distribution system</td>
<td>Target goal: &lt; 0.01 mg/L&lt;br&gt;Regulatory Requirement: &lt; 1.0 mg/L</td>
</tr>
<tr>
<td></td>
<td>Perform routine monitoring of total chlorine and nitrates throughout the distribution system</td>
<td>210 samples taken at 111 designated sites throughout system each month&lt;br&gt;Monthly samples taken from primary storage tanks when water temperature is ≥ 25°C.</td>
</tr>
</tbody>
</table>
|                       | Exercise storage tanks to reduce water age and minimize chloramine decay | Sheridan tanks: Minimum level = 8'; Maximum = 32';<br>Mechanical mixers installed in tanks to reduce stratification<br>Each tank inspected and cleaned every 2 years<br>Quarterly dead-end line flushing maintenance (DELM) program | Use technology to assist with early detection of nitrification in system<br>Perform routine maintenance on storage tanks and areas of distribution system with high potential for nitrification

### KEY PROCESS OUTPUT VARIABLES

- Control total chlorine residual as water enters distribution system
- Balance effective monochloramine formation while minimizing free ammonia residual at treatment plants
- Monitor and control nitrite levels as water enters distribution system
- Perform routine monitoring of total chlorine and nitrates throughout the distribution system
- Exercise storage tanks to reduce water age and minimize chloramine decay
- Perform routine maintenance on storage tanks and areas of distribution system with high potential for nitrification
- Use technology to assist with early detection of nitrification in system
- Ensure proper operation and maintenance of distribution system components
## Define phase – Communications plan

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Objective</th>
<th>Message</th>
<th>Delivery</th>
<th>Frequency</th>
<th>Timing</th>
<th>Responsibility</th>
<th>Feedback</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive Sponsor - Clayton Edwards</td>
<td>Provide support to BB team and key stakeholders</td>
<td>Status update</td>
<td>Written report at end of each phase</td>
<td>End of each phase</td>
<td>Within one week of completion</td>
<td>BB Team</td>
<td>1. In person 2. Email 3. At meetings</td>
</tr>
<tr>
<td>Project Champion - Jo Brown</td>
<td>Provide support to BB team and key stakeholders</td>
<td>Status update</td>
<td>Written report at end of each phase</td>
<td>End of each phase</td>
<td>Within one week of completion</td>
<td>BB Team</td>
<td>1. In person 2. Email 3. At meetings</td>
</tr>
<tr>
<td>Master Blackbelt - Walter Miller</td>
<td>Provide support to BB team and key stakeholders</td>
<td>Status update</td>
<td>Email</td>
<td>1. As needed 2. At beginning and end of each phase</td>
<td>Within one week of completion</td>
<td>BB Team</td>
<td>Email</td>
</tr>
<tr>
<td>Blackbelt - Penny Macias</td>
<td>Provide support to BB team</td>
<td>Status update</td>
<td>1. In person 2. Email</td>
<td>Bi-weekly</td>
<td>Within one week of completion</td>
<td>BB Team</td>
<td>1. In person 2. Email 3. At meetings</td>
</tr>
<tr>
<td>Project Manager - Melissa Gray</td>
<td>Manage BB project</td>
<td>Teamwork</td>
<td>1. In person 2. Email</td>
<td>Weekly</td>
<td>At each meeting</td>
<td>BB Team</td>
<td>1. In person 2. Email 3. At meetings</td>
</tr>
<tr>
<td>Stefanie Hunter</td>
<td>Contribute to BB project</td>
<td>Teamwork</td>
<td>1. In person 2. Email</td>
<td>Weekly</td>
<td>At each meeting</td>
<td>BB Team</td>
<td>1. In person 2. Email 3. At meetings</td>
</tr>
<tr>
<td>Eric Parker</td>
<td>Contribute to BB project</td>
<td>Teamwork</td>
<td>1. In person 2. Email</td>
<td>Weekly</td>
<td>At each meeting</td>
<td>BB Team</td>
<td>1. In person 2. Email 3. At meetings</td>
</tr>
<tr>
<td>Eric Lee</td>
<td>Contribute to BB project</td>
<td>Teamwork</td>
<td>1. In person 2. Email</td>
<td>Weekly</td>
<td>At each meeting</td>
<td>BB Team</td>
<td>1. In person 2. Email 3. At meetings</td>
</tr>
<tr>
<td>Benita Becton</td>
<td>Contribute to BB project</td>
<td>Teamwork</td>
<td>1. In person 2. Email</td>
<td>Weekly</td>
<td>At each meeting</td>
<td>BB Team</td>
<td>1. In person 2. Email 3. At meetings</td>
</tr>
<tr>
<td>Jhoanna Murray</td>
<td>Contribute to BB project</td>
<td>Teamwork</td>
<td>1. In person 2. Email</td>
<td>Weekly</td>
<td>At each meeting</td>
<td>BB Team</td>
<td>1. In person 2. Email 3. At meetings</td>
</tr>
</tbody>
</table>
Measure Phase
Measure phase

Nitrification Contributing Factors 2013-2017

- Unknown: 70
- Mainline Work: 20
- Closed Valve: 10
- System Design: 10
- Dead End Line: 5
- Premise Plumbing: 5

Number of Investigations
Measure phase – Sigma level

Yearly Sigma 2013-2017

- 2013: 3.83σ
- 2014: 3.75σ
- 2015: 53 events
- 2016: 3.73σ
- 2017: 3.66σ

Events 2013-2017

Year 2013 2014 2015 2016 2017
Events 11 32 53 33 20

Sigma level

- 2013: 3.83σ
- 2014: 3.75σ
- 2015: 3.75σ
- 2016: 3.73σ
- 2017: 3.66σ
Measure phase – Water tank levels

Sheridan No. 1 Tank Levels for the Month of July

MIN | MAX | AVG | Linear (MAX)

Level, ft.

2013 | 2014 | 2015 | 2016 | 2017
Measure phase – Valves

46,987 valves in the distribution system
Measure phase

# Valves Inspected 2012-2017

<table>
<thead>
<tr>
<th>Year</th>
<th># Valves Inspected</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td></td>
</tr>
</tbody>
</table>
Measure phase – Flushing dead-end water lines

<table>
<thead>
<tr>
<th>Month</th>
<th>Dead-end lines</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>222,460</td>
<td>638,700</td>
</tr>
<tr>
<td>February</td>
<td>249,397</td>
<td>498,000</td>
</tr>
<tr>
<td>March</td>
<td>69,555</td>
<td>540,025</td>
</tr>
<tr>
<td>April</td>
<td>172,190</td>
<td>51,000</td>
</tr>
<tr>
<td>May</td>
<td>417,085</td>
<td>143,560</td>
</tr>
<tr>
<td>June</td>
<td>186,377</td>
<td>1,045,800</td>
</tr>
<tr>
<td>July</td>
<td>194,425</td>
<td>710,818</td>
</tr>
<tr>
<td>August</td>
<td>586,930</td>
<td>1,319,800</td>
</tr>
<tr>
<td>September</td>
<td>325,707</td>
<td>709,547</td>
</tr>
<tr>
<td>October</td>
<td>294,025</td>
<td>1,106,500</td>
</tr>
<tr>
<td>November</td>
<td>385,735</td>
<td>716,000</td>
</tr>
<tr>
<td>December</td>
<td>569,986</td>
<td>810,500</td>
</tr>
<tr>
<td>TOTAL GALLONS</td>
<td>3,673,872</td>
<td>8,290,250</td>
</tr>
</tbody>
</table>
Analyze Phase
Analyze phase

Nitrification Related Sampling Events Per Month
2013-2017

Number of Events

Month

January
February
March
April
May
June
July
August
September
October
November
December

0
5
10
15
20
25
30
35
40
45
50
Analyze phase – Pareto chart

Nitrification Related Sampling Events Per Month

8/22/2013 - 7/21/2017
Analyze phase – Nitrification events in a Pareto chart

Nitrification Contributing Factors 2013-2017

Number of Investigations

Unknown | Mainline Work | Closed Valve | System Design | Dead End Line |
---------|---------------|--------------|---------------|---------------|
        |               |              |               |               |
| 80      | 20            | 40           | 60            | 80            |

Nitrification Contributing Factors 8/22/13 through 7/20/2017

Unknown | Mainline Work | Closed Valve | System Design | Premise Plumbing |
---------|---------------|--------------|---------------|-----------------|
| 68      | 22            | 19           | 15            | 13              |

Unknown | Mainline Work | Closed Valve | System Design | Dead End Line | Premise Plumbing |
---------|---------------|--------------|---------------|--------------|-----------------|
| 0        | 10            | 20           | 30            | 40           | 50              |

Unknown | Mainline Work | Closed Valve | System Design | Dead End Line | Premise Plumbing |
---------|---------------|--------------|---------------|--------------|-----------------|
| 0%       | 10%           | 20%          | 30%           | 40%          | 50%             |
Analyze phase – Process map

Water Quality in Distribution System

1. Start
   - Routine FTQR monitoring, sampling schedule for CO2 & NO2.
     - Weekly for confirmed NO2 – no follow-up sampling

2. Routine CO2 monitoring
   - Total CO2 > 1.5 mg/L & NO2-N < 0.010 mg/L
     - YES → End
     - NO → Checks closest fire hydrant to confirm issues exist in distribution system & not due to premise plumbing

3. Nozzle Valve
   - NO → Notify WD of water quality issue
     - YES → End

4. Water Distribution
   - Begins NO2-N investigation
     - Issue found?
       - YES → Notifies finding to WQA
         - End
       - NO → Notifies finding to WQA
         - End
     - NO → Closed or broken valve
       - Dead end line
       - Water line construction
       - System design
Analyze phase – Fishbone

METHOD
- Lack of understanding
- Track valve position
- Design of WDS – line size, storage
- Flushing program
- Lack of nitrification prevention plan

MATERIAL
- Chloramination
- Unlined iron pipe
- Premise plumbing

MACHINE
- Open system
- Dead-end lines
- Size of WDS extra capacity

MEASUREMENT
- Customer usage – trend pumpage
- Water quality data
- Water age
- Tank levels

PEOPLE
- Economic Development
- Contractors
- ODEQ
- WDS
- WS
- Engineering
- Customers
- Water Quality Assurance

ENVIRONMENT
- Water Temperature
- Complacency culture
- Customer usage patterns
- Seasonal Consideration

Process Problem: Nitrification in water distribution system
Analyze phase – Water age and events
Analyze phase – Root cause
Improve Phase
Improve phase – Focus group & Affinity diagram
Improve phase – Focus group results

Contributing Factors as Identified by Front-Line Employees

- Closed valves
- Dead-end lines
- Low usage
- Source water
- Disinfectant
- Biofilm and microbial growth
- Broken pipes
- Capacity of the system
- Lead service lines
- Water age
- Nitrification
- Secondary system operation
- Contamination

Number of Responses
Improve phase – Using survey results

• Focus Group and survey results – Water Distribution, Water Supply, Quality Assurance, Engineering Services
  – Employees feel a high standard of water quality exists in the City of Tulsa
  – Few employees felt they directly impacted water quality in the system
  – Many employees not aware of water quality indicators or how actions performed in the distribution system can directly affect water age and quality
Improve phase – Solution selection method

• Using results of focus group, survey, fishbone diagram (Ishikawa), etc., the primary contributing factors are:
  – Water age
  – Water temperature
  – Employee (and contractor) knowledge

• The solution is:
  – Optimizing control of storage tank levels
  – Error proof (poka-yoke) valve opening and closing procedures
  – Employee education and training
Control Phase
Control phase – Plant standard operating guideline (SOG) and plant controls

---

**Introduction**

The four storage tanks located at 61st and Sheridan account for slightly greater than half of the City’s available storage capacity. The treatment plants use these tanks to gauge system demand then increase, or decrease, production to meet current needs. When tank levels decrease to a certain level, the plants will increase production. When the tanks reach an upper limit level, the plants decrease production.

**Summary of Procedure**

During the months of June through October, Sheridan Tank No. 4 level is to be cycled between 12 and 24 feet, over a 3-day period. This means that the level should increase from 12 feet to 24 feet within 3 days, followed by a decrease to 12 feet over the next 3 days. In order to achieve this goal an average draft rate of 4 feet per day must be achieved.
Control phase – Monitoring Sheridan tank levels
Control phase – Utilizing technology to monitor water system activity
Control phase – Monitoring flows and tank levels in Hach WIMS
Control phase – Valve opening and closing procedures, valve tracking

• Debris caps – pilot program – phased-in approach for Water Distribution mainline crews and contractors
  – Cost: $8,990 ($58/cap, 5 per crew, 31 crews)
  – Rollout: starting in Spring

• Pilot program to include training, communication and deployment plan

• Utilize Lucity – computerized maintenance management system – to track valve positions
Control phase – Technology to track valve positions
Control phase – Employee education and knowledge

• Training program on tank standard operating guidelines – treatment plant operators
• Training program on valve operations – Water Distribution Systems operators, Field Engineering inspectors and contractors
• Nitrification education/water quality education – chloramines
• Pocket color wheels - $80/each – tools and training for chlorine analysis (program cost is $2,480)
Control phase – Sigma level

- We are 3.68σ level – goal is to be at a 4.0σ level within 4 years
- Reduction of nitrification related sampling events of approximately 30 per year (149 total events over five years) to an average of 13 per year (62 total events over four years)
- Cost Savings included on next slide
Nitrification Control in the Distribution System Savings

| FY 17 Nitrification Related Investigations | 25 |
| FY17 Repeat Site Visits | 225 |

**FY17 Budget Investigation Costs**

- Salaries & Benefits: $27,000
- Materials & Supplies: $4,000
- Other Services: $10,000
- Capital: -

**TOTAL SITE VISIT COST**

$41,000

**Water Tank Drainage Cost**

- Treatment cost/million gallons of water: $170
- Millions of gallons drained: 14

**TOTAL WATER DRAINAGE COST**

$2,000

**Water Flushing Cost**

- Total hours flushed: 450
- Millions of gallons flushed: 27

**TOTAL WATER FLUSHING COST**

$5,000

**FY17 Nitrification Cost Including Overhead**

- Site Visit Cost: $41,000
- Water Tank Drainage: $2,000
- Water Flushing Cost: $5,000
- FY17 Nitrification Events Cost: $48,000
- 30% Overhead: $14,000

**TOTAL YEARLY COST**

$62,000

**Estimated Yearly Cost Savings**

- 30% expenditure reduction to reach a 3.7σ level: FY19
  $19,000
- 35% expenditure reduction to reach a 3.8σ level: FY20
  $22,000
- 40% expenditure reduction to reach a 3.9σ level: FY21
  $25,000
- 4.0σ level: FY22
  $30,000

**Total Project Cost Savings**

$96,000

**Total Project Costs**

$11,470

**TOTAL NET PROJECT COST SAVINGS**

$84,530
Black belt project – Lessons learned

• BB Certification has allowed the application of the LSS tools – valuable experience that we will use for continual improvement
• Recruiting Green Belt members to assist strengthened the team effort
• TMUA and UEI set the framework for LSS implementation
  – Data management tools
  – Strategic planning
  – Top down support
Reference material

• City of Tulsa Nitrification Control and Response Plan rev3 February 2017
• EPA, Office of Water (4601M) Distribution System Issue Paper: Nitrification
• AWWA M56 Manual: Fundamentals and Control of Nitrification in Chloraminated Drinking Water Distribution Systems
• AWWA M68 Manual: Water Quality in Distribution Systems
Don’t want to be a farmer working in the sun
Don’t want to be an outlaw always on the run
Don’t want to be a climber reaching for the top
Don’t want to be anything where I don’t know when to stop

A dream it’s true
But I’d see it through
If I could be
Wasting my time with you

From the song “Waste” by Phish

THANK YOU!