Production Wells – Strategies for Sustaining Operational Life Cycles
Monroe Utilities Department, Middlesex County
February 19, 2020

OVERVIEW OF PRODUCTION WELL ASSET MANAGEMENT AND DIAGNOSTIC PROGRAMS

PRESENTED BY:
ASHISH DAW
UHL & ASSOCIATES, INC.
SESSION 8:30 TO 9:45 AM

Acknowledgements

North Jersey Water Conference

Richard Howlett, Executive Director,
NJ Water Association

Joseph E. Stroin Jr.
Director, Monroe Township Utility Department
Accreditation:

- 3.0 TCH for NJ-Licensed Water Operators
  - TCH Course Number 04-101901-10
- 3.0 Hours, CPWM, Technical.
  - DLGS-NJWA-181

Program Outline for Today

Overview of Production Well Asset Management and Diagnostic Programs
Ashish Daw, UHL & Associates, Inc.

Well Rehabilitation Methods

Using Continuous Monitoring to Circumvent Catastrophic Failure
Matt Maloney, Morehouse Engineering, Inc.
Production Wells are an invaluable asset to any Groundwater Based Water Department/Utility.

- Reactive Management approach to a Proactive Management approach.
- Operate, maintain, upgrade and retire aging infrastructure in a cost-effective manner.
- Continue to maintain a level of service that is acceptable to the stakeholders.

PRODUCTION WELL ASSET MANAGEMENT

A Production Well

- Out of sight – Out of Mind
- The most critical component in a groundwater based public utility
- Most expensive component, hidden, and can be difficult to repair and/or replace
- Other components such as the pump, motor, motor controls, valves etc., are designed around the production capacity of the well

1. Borehole
2. Stainless Steel Screen
3. Steel Casing
4. Gravel Pack
5. Cement Grout
Production Well Asset Management Plan (PWAMP)

Condition Assessment
- Well age and baseline performance
- Well construction (depth of grout, casing and screen diameter, screen slot size)
- Historical performance

Well Performance, Data Collection and Assessment
- What are the Causes for Well Failure/Yield Decline?
- Downhole Video Inspection
- Perform yield or specific capacity tests

Water Quality
- Chemical and Bacteriological Parameters
- TDS
- Turbidity
- Sand pumping

Well Redevelopment/Replacement Program
- What redevelopment method is ideal?
- Mechanical methods (surging, jetting, air-surging, air-burst)
- Use of chemicals (acid, chlorine)?
- Replacement or Re-drill
Advantages of an Asset Management Plan

- Extend Life of the Well
- Extend Life of Pump and Motor
- Maintain Well Performance
- Lower Operational Costs
- Consistent Water Quality
- Recording Keeping of Baseline and Historical Performance
- Proactive Well Management

Causes for Well Failure

**Poor to No Maintenance**
- Over pumping
- Sand pumping
- Clogging of well screen (fines, chemical, encrustation)
- Well screen failure
- Pumping equipment failure due to wear and tear

**Physical Failures**
- Initial well design – poor design can cause sand pumping and screen failure
- High screen entrance velocities:
  - Degradation of well screen
  - Tightening of gravel pack
  - Increase in turbidity
  - Increased turbulence
Causes for Well Failures, contd.

Physical Failures
- Blockage/restriction of filter pack and well screen due to naturally occurring fines – silt and clay
- Lack of flow control systems at the well head
- Soft start
- VFDs
- Frequent start/stop
- No continuous monitoring

Chemical Failures
- Hardness – Can cause Calcium and Magnesium precipitation
- Iron and Manganese precipitate buildup
- Corrosion

Sand Pumping

Jordan, 2007
Erosion of Well Screen

- Vertically slotted well screen
- Screen blocked due to incrustation
- Blocked portions of screen results in greater entrance velocities from open sections of screen

Precipitate Buildup on Pump Bowls

EOWC, Dickinson D-3
April, 2010
Cracked Screen

- Morris County Almatcong Well #6.
- Top screen shot – May 1996.
- Bottom screen shot – March 2006.
- Due to age of well?
- Vertically slotted screen, and increased entrance velocities?

Loss of Filter Pack Due to Sand Pumping

Filter pack went through compromised 16-inch screen and incorrectly sized 12-inch screen

Original 16-inch Well screen failed

Telescoped a 12-inch well screen. Incorrectly designed

EOWC, Dickinson D-2
Sept., 2009
Causes for Well Failures, contd.

**Bacteriological**

- Iron-related (IRB), Sulphate-reducing (SRB), and Slime-forming Bacteria (SFB).
- Iron and Manganese biofouling.
- Exposing the screened of well to oxygen setting pump in screen and over pumping.
- Formation of iron oxide in the aquifer matrix (ochre).

**IRB, SRB, SFB Testing**

- Red – IRB; Black – SRB; Green – SFB.
- Indicate presence/absence of related bacteria.
- Measure of their “aggressivity” (high/medium/low) based on bacteria population.
Testing Procedure

1. Remove the inner tube from the outer tube.

2. Pour at least 20 mL of sample in the outer tube.

3. Fill the inner tube to the fill line with the sample that is in the outer tube. Tighten the cap on the inner tube. Discard the unused sample in the outer tube.

4. Put the inner tube in the empty outer tube. Tighten the cap on the outer tube. Do not shake or swirl the tubes after the sample is added. Let the ball float to the top with no help.

5. Write the date and sample name on the outer tube.

6. Keep the tube at room temperature and away from direct sunlight for 8 days. Do not move the tube.

7. Examine the tube each day. Record the date when a reaction is first seen. Refer to Test results on page 2.

Iron-related Bacteria (IRB)

Figure 1 Negative versus positive test results

- Negative (absent/non-aggressive): The solution has no foam or brown slime.
- Positive (present/aggressive): Foam or a brown slime ring forms around the ball and/or there is a brown slime growth at the bottom of the tube.

Figure 2 Dominant bacteria

- Anaerobic bacteria: Foam around the ball
- Iron-related bacteria: Brown rings, gel and/or clouds
- Pseudomonads: Green cloudy
- Enteric bacteria: Red cloudy
- Heterotrophic bacteria: Cloudy
- Pseudomonads and enterics: Black solution
Iron Related Bacteria (IRB)

Table 1 Approximate bacteria population

<table>
<thead>
<tr>
<th>Days to reaction</th>
<th>Approximate slime population (cfu/mL)</th>
<th>Aggressivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>540,000</td>
<td>Very high</td>
</tr>
<tr>
<td>2</td>
<td>140,000</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>35,000</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>9000</td>
<td>Moderate</td>
</tr>
<tr>
<td>5</td>
<td>2300</td>
<td>Moderate</td>
</tr>
<tr>
<td>6</td>
<td>500</td>
<td>Moderate</td>
</tr>
<tr>
<td>7</td>
<td>150</td>
<td>Moderate</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>Low</td>
</tr>
</tbody>
</table>

Sulfate-reducing Bacteria (SRB)

Figure 1 Negative versus positive test results

Negative (absent/no aggressive)
The solution has no black slime.

Positive (present/aggressive)
A black slime ring forms around the ball; there is black slime growth at the bottom of the tube.

Figure 2 Dominant bacteria

- Dense anaerobic bacteria dominated by Desulfovibrio
  - Black slime on the bottom only

- Aerobic SRB with anaerobic slime forming heterotrophs
  - Black slime around the ball only

- Aerobic and anaerobic SRB
  - Black slime on the bottom and around the ball

- Anaerobic bacteria
  - Cloudy solution
Sulphate Reducing Bacteria (SRB)

Table 1 Approximate bacteria population

<table>
<thead>
<tr>
<th>Days to reaction</th>
<th>Approximate slime population (cfu/mL)</th>
<th>Aggressivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6,800,000</td>
<td>Very high</td>
</tr>
<tr>
<td>2</td>
<td>700,000</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>100,000</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>18,000</td>
<td>Moderate</td>
</tr>
<tr>
<td>5</td>
<td>5000</td>
<td>Moderate</td>
</tr>
<tr>
<td>6</td>
<td>1200</td>
<td>Moderate</td>
</tr>
<tr>
<td>7</td>
<td>500</td>
<td>Moderate</td>
</tr>
<tr>
<td>8</td>
<td>200</td>
<td>Low</td>
</tr>
</tbody>
</table>

- Strong odors
- Blackening of equipment
- Slime formation, start of corrosive processes

Slime-forming Bacteria (SFB)

Figure 1 Negative versus positive test results

Figure 2 Dominant bacteria
### Slime-forming Bacteria (SFB)

**Table 1: Approximate bacteria population**

<table>
<thead>
<tr>
<th>Days to reaction</th>
<th>Approximate slime population (cfu/mL)</th>
<th>Aggressivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,750,000</td>
<td>Very high</td>
</tr>
<tr>
<td>2</td>
<td>440,000</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>67,000</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>13,000</td>
<td>Moderate</td>
</tr>
<tr>
<td>5</td>
<td>2500</td>
<td>Moderate</td>
</tr>
<tr>
<td>6</td>
<td>500</td>
<td>Moderate</td>
</tr>
<tr>
<td>7</td>
<td>100</td>
<td>Low</td>
</tr>
<tr>
<td>8</td>
<td>Less than 20</td>
<td>Low</td>
</tr>
</tbody>
</table>

#### Diagnosing the Problem

- Condition Assessment
- Downhole Video Inspections
- Establishing a pre-development Specific Capacity baseline
- Water quality and microbiological testing
Condition Assessment

- Age of Well
- Well construction method
- Well casing type and specifications
- Well screen type and specifications
- Historical Performance

Downhole Video Inspections

- Remove pumping equipment
- Lower camera down a well
- Check for integrity of casing (casing welds), note precipitate buildup at static water-level
- Check integrity of cement grout at end of casing – important in open hole constructed wells
- Screen integrity
- Corrosion and precipitate buildup up on screen
- Overall condition of screen
Dynamic Downhole Video Logging

- Lowering a test pump to simultaneously pump while video logging the well
- Identify areas for increased turbidity, turbulent flow, sand pumping
- In bedrock wells lowering water level into open-hole section will expose grout integrity at bottom of casing
Dynamic Downhole Video Logging: Turbidity

Morris County MUA Almatcong Well #6
March 2006

Dynamic Downhole Video Logging: Grout Failure

Bedrock Backup Production Well
March 2019
Downhole Video Inspections
Southern Senegal, 2017

Downhole Video Inspections
Southern Senegal, 2017
Downhole Video Inspections
Southern Senegal, 2017

Blocked Screen and Open Screen
**Specific Capacity Testing**

Key well performance indicator – easy to measure

Pumping Rate (Q) divided by water-level drawdown (s) = Q/s.

Unit for Specific Capacity is Gallons Per Minute Per Foot of Drawdown = gpm/ft.

Establish baseline Q/s.

Evaluate Q/s decline over time and compare to original Q/s.

A decline in Q/s of >25% is an indicator that well rehabilitation be initiated sooner than later

Provides a real time quantification of well redevelopment progress

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**Calculating Specific Capacity**

\[
\text{Specific Capacity} = \frac{Q}{s}
\]

Units = gpm/ft.
### Specific Capacity as a Diagnostic Tool

#### As a Diagnostic Tool for Boreholes in Service

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>PW-1</td>
<td>50 gpm/ft</td>
<td>48 gpm/ft</td>
<td>2 gpm/ft</td>
<td>4% loss in efficiency. Rehabilitation not required.</td>
</tr>
<tr>
<td>PW-2</td>
<td>50 gpm/ft</td>
<td>40 gpm/ft</td>
<td>10 gpm/ft</td>
<td>20% drop in efficiency. Rehabilitation recommended now.</td>
</tr>
<tr>
<td>PW-3</td>
<td>50 gpm/ft</td>
<td>20 gpm/ft</td>
<td>30 gpm/ft</td>
<td>60% drop in efficiency. Cost assessment on rehabilitation or replacement?</td>
</tr>
</tbody>
</table>

#### As a Diagnostic Tool While Redeveloping a Boreholes

<table>
<thead>
<tr>
<th>Baseline Q/s</th>
<th>Procedure</th>
<th>Incremental Increase</th>
<th>Improved Q/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 gpm/ft</td>
<td>Surging + Airlifting</td>
<td>3 gpm/ft</td>
<td>15 gpm/ft</td>
</tr>
<tr>
<td></td>
<td>Acid Treatment + Surging + Airlifting</td>
<td>5 gpm/ft</td>
<td>20 gpm/ft</td>
</tr>
<tr>
<td></td>
<td>Hypochlorite Treatment + Surging + Airlifting</td>
<td>8 gpm/ft</td>
<td>28 gpm/ft</td>
</tr>
</tbody>
</table>

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### Well Redevelopment Progress

**EWOC, Dickinson D-3**

April to June 2010

- **Initial Q/s**: 12 gpm/ft
- **Improved Q/s**: 30 gpm/ft
- **Incremental Increase**: 20 gpm/ft
Well Development (Post-Drilling)

- Similar methods to well redevelopment
- No chemicals
- Mechanical surging and simultaneous airlifting
- Submersible pump
- Measure Q/s to gage well development progress

Purpose of well development:
- Settle gravel pack evenly around the screen
- Flush out fines

**Plot of Specific Capacity vs. Time For Production Well D-3**
Dickinson Well Field, East Orange Water Reserve

- No Redevelopment Work Done Between 08/20/2010 to 06/20/2012
- After 1st Chlorine Application and Mechanical Surfing
- After 1st Acid Application and Mechanical Surfing
- After 2nd Acid Application, Air Surfing, and Mechanical Surfing
- After 2nd Chlorine Application, Air Surfing, and Mechanical Surfing
Asset Management Plan

- Set a 3-5 year schedule to have wells inspected.
- Downhole video inspections.
- Specific capacity testing.

Montville Township, PW-1
March to April, 2014

Figure 1: Plot of Specific Capacity (Qa) vs. Time

<table>
<thead>
<tr>
<th>Date of Development</th>
<th>Specific Capacity in Gallons per Minute per Foot (GPM/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/18/14</td>
<td>5</td>
</tr>
<tr>
<td>4/10/14</td>
<td>7.7</td>
</tr>
<tr>
<td>4/11/14</td>
<td>10.5</td>
</tr>
<tr>
<td>4/14/14</td>
<td>10.5</td>
</tr>
<tr>
<td>4/16/14</td>
<td>16.8</td>
</tr>
<tr>
<td>4/17/14</td>
<td>15.0</td>
</tr>
<tr>
<td>4/18/14</td>
<td>20.3</td>
</tr>
<tr>
<td>4/22/14</td>
<td>21.8</td>
</tr>
<tr>
<td>4/24/14</td>
<td>23.9</td>
</tr>
</tbody>
</table>

Table 1: PW-1 Well Efficiency Testing and Water Quality Data Summary

<table>
<thead>
<tr>
<th>Step</th>
<th>Duration (minutes)</th>
<th>Pumping Rate, Q (gpm)</th>
<th>Drawdown, s (feet)</th>
<th>Specific Capacity, Qa (gpm/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>550</td>
<td>30.5</td>
<td>6.36</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>600</td>
<td>90.0</td>
<td>6.12</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>600</td>
<td>112.8</td>
<td>5.89</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>720</td>
<td>127.8</td>
<td>5.67</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Step</th>
<th>Duration (minutes)</th>
<th>Pumping Rate, Q (gpm)</th>
<th>Drawdown, s (feet)</th>
<th>Specific Capacity, Qa (gpm/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>530</td>
<td>65</td>
<td>8.15</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>620</td>
<td>79</td>
<td>7.85</td>
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<td>3</td>
<td>60</td>
<td>715</td>
<td>94</td>
<td>7.60</td>
</tr>
<tr>
<td>4</td>
<td>60</td>
<td>720</td>
<td>127.8</td>
<td>5.67</td>
</tr>
</tbody>
</table>

Summary of Results:

1. A direct comparison of specific capacities at 548 gpm between the 2007 and 2012 efficiency testing shows a decrease from 8.15 gpm/ft to 7.67 gpm/ft, which translates to a 42% reduction in well efficiency.
2. Total dissolved solids has increased by 8%.

Table 2: November 13, 2007 Field Water-Quality Testing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids (mg/l)</td>
<td>420</td>
</tr>
<tr>
<td>Specific Conductance (µS)</td>
<td>600</td>
</tr>
<tr>
<td>pH</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Table 3: July 7, 2012 Field Water-Quality Testing

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Dissolved Solids (mg/l)</td>
<td>655</td>
</tr>
<tr>
<td>Specific Conductance (µS)</td>
<td>701</td>
</tr>
<tr>
<td>pH</td>
<td>7.8</td>
</tr>
</tbody>
</table>
Table 2: PW-2 Well Efficiency Testing and Water Quality Data Summary

<table>
<thead>
<tr>
<th>Step</th>
<th>Duration (minutes)</th>
<th>Pumping Rate, Q (gpm)</th>
<th>Drawdown, s (feet)</th>
<th>Specific Capacity, Q/s (gpm/ft)</th>
<th>Pumping Rate, Q (gpm)</th>
<th>Drawdown, s (feet)</th>
<th>Specific Capacity, Q/s (gpm/ft)</th>
<th>Pumping Rate, Q (gpm)</th>
<th>Drawdown, s (feet)</th>
<th>Specific Capacity, Q/s (gpm/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>540</td>
<td>78.5</td>
<td>6.11</td>
<td>485</td>
<td>39.5</td>
<td>32.20</td>
<td>540</td>
<td>51.0</td>
<td>18.59</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>585</td>
<td>94.5</td>
<td>5.71</td>
<td>470</td>
<td>144</td>
<td>3.26</td>
<td>585</td>
<td>59.0</td>
<td>5.32</td>
</tr>
</tbody>
</table>

Summary of Results:
1. A direct comparison of specific capacities at 600 gpm between the 2007 and 2012 efficiency testing shows a 4 times increase in Q/s due to the PW-2 redevelopment work in January/February 2010.
2. Total dissolved solids and specific conductance have increased by approximately 6%.

Table 3: PW-3 Well Efficiency Testing and Water Quality Data Summary

<table>
<thead>
<tr>
<th>Step</th>
<th>Duration (minutes)</th>
<th>Pumping Rate, Q (gpm)</th>
<th>Drawdown, s (feet)</th>
<th>Specific Capacity, Q/s (gpm/ft)</th>
<th>Pumping Rate, Q (gpm)</th>
<th>Drawdown, s (feet)</th>
<th>Specific Capacity, Q/s (gpm/ft)</th>
<th>Pumping Rate, Q (gpm)</th>
<th>Drawdown, s (feet)</th>
<th>Specific Capacity, Q/s (gpm/ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>1070</td>
<td>15.5</td>
<td>52.73</td>
<td>870</td>
<td>14.45</td>
<td>60.21</td>
<td>870</td>
<td>15.3</td>
<td>56.86</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>995</td>
<td>19.0</td>
<td>52.37</td>
<td>995</td>
<td>17.50</td>
<td>58.86</td>
<td>995</td>
<td>18.8</td>
<td>52.93</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>1240</td>
<td>24.0</td>
<td><strong>51.67</strong></td>
<td>1240</td>
<td>22.90</td>
<td><strong>56.15</strong></td>
<td>1240</td>
<td>24.4</td>
<td><strong>58.82</strong></td>
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<tr>
<td>4</td>
<td>30</td>
<td>1572</td>
<td>31.0</td>
<td>50.71</td>
<td>1390</td>
<td>27.90</td>
<td>49.82</td>
<td>1390</td>
<td>27.90</td>
<td>49.82</td>
</tr>
</tbody>
</table>

Results:
1. A direct comparison of specific capacities at 1240 gpm between the 2007 and 2012 efficiency testing shows a decrease from 51.67 gpm/ft to 50.82 gpm/ft, which translates to a 6% reduction in efficiency.
2. Total dissolved solids has decreased by approximately 7.5%.
Cures to the Diagnosed Problem!

- Hydraulic high-pressure jetting
- Mechanical agitation – wirebrush, double block surging, simultaneous airlift
- Air-burst/Borehole blast (with or without Chemical Application)
- Air-surge (with Chemical Application)
- Chemical Treatment
  - Acids – Incrustation
  - Chlorine – Biofilm, bacterial related growth, iron oxide
  - Polyphosphates – Silts and clays

TABLE 1
SUMMARY OF SPECIFIC CAPACITIES FOR STEP-DRAWDOWN PUMPING TESTS
PRODUCTION WELL PW-3.

<table>
<thead>
<tr>
<th>Pumping Rate (GPM)</th>
<th>Q/s Before Redevelopment</th>
<th>Q/s After Redevelopment</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>5.0</td>
<td>—</td>
</tr>
<tr>
<td>250</td>
<td>4.8</td>
<td>11.9</td>
</tr>
<tr>
<td>300</td>
<td>4.6</td>
<td>11.1</td>
</tr>
<tr>
<td>400</td>
<td>—</td>
<td>10.7</td>
</tr>
</tbody>
</table>

Q/s = Specific Capacity in Gallons per minute per foot of drawdown (GPM/ft)

GPM = Gallons per minute
Cures to the Diagnosed Problem!

- Chemical Treatment
  - Acids – Incrustation
  - Chlorine – Biofilm, bacterial related growth, iron oxide
  - Polyphosphates – Silts and clays
- Combination mechanical and chemical.
- Hydrofracking – Only in bedrock wells.

Thank You!

Ashish Daw  
adaw@vuawater.com

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Lambertville, New Jersey