William A. McEllhiney
Distinguished Lecture Series in Water Well Technology

National Ground Water Research and Educational Foundation’s McEllhiney Lecture Series is supported by a grant from Franklin Electric.
To foster professional excellence in water well technology, the National Ground Water Research and Educational Foundation, established the William A. McEllhiney Distinguished Lecture Series in Water Well Technology in 2000.

The lecture series honors William A. McEllhiney, a groundwater contractor and civil engineer from Brookfield, Illinois, who served as the founding president of the National Ground Water Association in 1948.
Defining the Operational Age of a Well: Predicting Maintenance Issues in Advance of Failure
Failure (noun) \ˈfāl-yər\ 1. the state of inability to perform a normal function; 2. an abrupt halt of normal operation.

Well Failure

Stoppage? Sanding? Poor quality?

Efficiency? Cost? Sustainability?
Why the Concern with Well Failure?

• Significant Source of Supply
• Need for water: health, agriculture, energy
• Prolonged drought in the West
• Population density shifts
• Cost and availability of replacement wells
• Cost and ability to treat and distribute water
Factors that Impact Well Management

- Changes in groundwater theory and well design
- Aquifer Challenges / Role
- Well Design and Construction (inconsistent)
- Well Operation, Monitoring, and Maintenance (or lack thereof)
- Decrease in Specific Capacity and Well Efficiency
- Degradation and aging of materials
- Water chemistry
- Microbiology
Historical View of Groundwater:

• Water located below the earth’s surface, existing primarily in aquifers
• Usage and design, commonly defined by land ownership and political boundaries, not by aquifer
• Ground Water and Surface Water are separate entities with no communication, ever
Historical Well Design Goals & Objectives:

• Achieve a desired Yield
• Protection from Contamination
• Reasonable Sand Production
• Design Life of 25 Years or More
• Ease of Operation & Maintenance
• Minimal up-front cost
Changing View of Groundwater:

- Water found underground in soil, rock, and unconsolidated materials, to include aquifers as well as the areas of recharge
- Extends beyond political boundaries
- Use it or lose it attitude towards water rights is counter to conservation efforts

Image courtesy of USGS Fact Sheet 2011-3070
Trending Well Design Goals & Objectives:

- Sustainable yield with minimal drawdown
- Targeted efficiency
- Protection from contaminants, aquifer interaction
- Sand production of < 10 ppm
- Design Life of 75 years, minimum
- “manageable operating costs”
Aquifer Challenges

• Localized versus Regional Governance
• Water level focus
• Failure to address natural challenges: corrosion, hardness, native bacteria
• Typically knowledge is separated from new well design
• Reactive in nature
Well Operation Observations

• “Run to Failure” attitude
• Monitoring and testing goals are rarely tied to the well health
• Testing is regulatory driven
• Operations follow a set schedule that rarely accounts for the well health or aquifer challenges

Photo courtesy of Don Caillouet, Layne
Well Maintenance Observations

• Maintenance is generally not planned
• When cleaning, wells are considered all the same:
  • Chemicals and mechanical methods are not tailored to the well & problem
• Monitoring during treatment is not typically conducted
• Little follow-up is performed
  • Pump testing
  • Water testing
  • Video inspection
So... how do we harness this information?

Goal: Be proactive and not run to failure.

Goal: Predicting Maintenance Issues in Advance of Failure and Design More Effective Response

Operational Lifespan of a Water Well
## Operational Stage Matrix

<table>
<thead>
<tr>
<th>Physical</th>
<th>Biological</th>
<th>Chemical</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Decrease in Specific Capacity</th>
<th>Decrease in Wire to Water Efficiency</th>
<th>Corrosion Structural Issue</th>
<th>Increase in Sand Pumping or Turbidity</th>
<th>IRB per 10 ml</th>
<th>SRB per 5 tube culture</th>
<th>Anaerobic</th>
<th>Population</th>
<th>Coliform or Pathogen</th>
<th>TDS</th>
<th>Ca/Mg</th>
<th>Fe / Mn</th>
<th>ORP</th>
<th>Contaminant</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1%</td>
<td>&lt; 1%</td>
<td>No Change</td>
<td>No change</td>
<td>Absent</td>
<td>Absent (0 tubes)</td>
<td>&lt; 1% Present</td>
<td>Absent</td>
<td>&lt;5% increase</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>Absent</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Increase of 7%</td>
<td>Low</td>
<td>Absent</td>
<td>ATP 75,000</td>
<td>11-20% Present</td>
<td>ATP 125,000-175 or HPC 500-1000</td>
<td>ATP &gt;200,000 or HPC &gt;1000</td>
<td>ATP &gt;200,000 or HPC &gt;1000</td>
<td>&gt;20% increase</td>
<td>&gt;40% increase</td>
<td>&gt;40% increase</td>
<td>&gt;40% increase</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
Physical parameters Impacts

- Specific Capacity Monitoring
- Wire to Water Efficiency
- Corrosion of well structure
- Increases or changes in sand production or turbidity
Pump Tests and Well Efficiency

Graph showing the relationship between Total Head (ft) and Pumping Rate (gpm) for different dates:
- Original Pump Curve for 3/01, 2/02, and 3/03.
- Clogged Pump Curve for 12/01, 2/02, and 3/03.

Data and Graphic courtesy of Bob Pritchard, Serv-Tech, Inc.
Wire to Water Efficiency


- Evaluation of pump and motor efficiency
- Gives the ability to identify inefficient systems
- Estimate potential energy savings
- Predict pump/motor failure

**Wire to Water Efficiency courtesy of Bob Pritchard, Servtech**
Degradation and aging of materials: Corrosion and Structural Well Deterioration

- Misunderstood and Misapplied
- When evaluated, focus is on the screen
- Fail to incorporate the entire well system
- Assumptions abound
Increases in Sand or Turbidity

- Improper sizing of filter pack/slot size
- Poor placement of filter pack or poor development
- Indication of changes in flow profile such as
  - Blockage (fouling)
  - Sediment migration
- Physical corrosion of pump and column pipe

Photo courtesy of Layne, Aurora, IL
<table>
<thead>
<tr>
<th>Decrease in Specific Capacity</th>
<th>Decrease in Wire to Water Efficiency</th>
<th>Corrosion or Structural Issue</th>
<th>Increase in Sand Pumping or Turbidity</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1%</td>
<td>&lt;1%</td>
<td>No Change</td>
<td>No Change</td>
</tr>
<tr>
<td>0-3% decrease</td>
<td>0-3% decrease</td>
<td>Slight corrosion of casing</td>
<td>Increase of 2 ppm</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3-10% decrease</td>
<td>3-10% decrease</td>
<td>Significant corrosion of casing</td>
<td>Increase of 2-7 ppm or &gt;1 ntu</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>12</td>
<td>4</td>
</tr>
<tr>
<td>&gt;10% decrease</td>
<td>&gt;10% decrease</td>
<td>Loss of portions of casing or screen</td>
<td>Increase of &gt;7 ppm or &gt;1 ntu</td>
</tr>
<tr>
<td>6</td>
<td>12</td>
<td>20</td>
<td>6</td>
</tr>
</tbody>
</table>
Water Chemistry Impacts:

- Disinfection and Treatment
- Scale accumulation
- Corrosion of well structure
- Water Quality
- Taste, turbidity, and odor
Water Chemistry Parameters:

- Total Dissolved solids (TDS)
- Oxidation Reduction Potential (ORP)
- Hardness (as Ca and Mg)
- Total Iron (as Fe, mg/L)
- Manganese (as Mn, mg/L)
- Contaminants or water quality concerns specific to well site/region
<table>
<thead>
<tr>
<th>Contaminant</th>
<th>TDS (mg/L)</th>
<th>Ca / Mg (mg/L)</th>
<th>Fe / Mn (mg/L)</th>
<th>ORP (mv)</th>
<th>Tracking Water Chemistry Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;5% increase</td>
<td>0</td>
<td>&lt;10% increase 0</td>
<td>&lt;10% increase 0</td>
<td>&lt;10% increase 0</td>
<td>absent 0</td>
</tr>
<tr>
<td>6-10% increase</td>
<td>2</td>
<td>11-20% increase 2</td>
<td>11-20% increase 2</td>
<td>11-25% increase 2</td>
<td>&gt;WQ objective (MCL) 35</td>
</tr>
<tr>
<td>11-20% increase</td>
<td>4</td>
<td>21-40% increase 4</td>
<td>21-40% increase 4</td>
<td>26-40% increase 4</td>
<td>-</td>
</tr>
<tr>
<td>&gt;20% increase</td>
<td>6</td>
<td>&gt;40% increase 6</td>
<td>&gt;40% increase 6</td>
<td>&gt;40% increase 6</td>
<td>-</td>
</tr>
</tbody>
</table>
Implications of Biofouling

• Water quality
• Taste, turbidity or odor
• Flow impaction
• Aid in accumulation of mineral scale and sediment
• Microbiologically influenced corrosion (MIC)
Microbiological Factors

• Coliform or Pathogenic Bacteria Presence
• Total Microbial Load
• Anaerobic Percentage
• Iron Bacteria
• Sulfate Reducing Bacteria
## Tracking Biological Activity

<table>
<thead>
<tr>
<th>Iron Bacteria</th>
<th>Sulfate Reducing Bacteria</th>
<th>Anaerobic Growth</th>
<th>Population (ATP or HPC)</th>
<th>Coliform or Pathogen Presence</th>
</tr>
</thead>
<tbody>
<tr>
<td>absent 0</td>
<td>absent 0</td>
<td>&lt; 1% present</td>
<td>ATP &lt; 20,000 HPC &lt;100</td>
<td>Absent 0</td>
</tr>
<tr>
<td>low occurrence 2</td>
<td>low occurrence 2</td>
<td>2 to 10% presence</td>
<td>ATP 75,000 to 100,000 HPC 200-400</td>
<td>present 35</td>
</tr>
<tr>
<td>moderate occurrence 6</td>
<td>moderate occurrence 6</td>
<td>11-20% presence</td>
<td>ATP 125,000 to 175,000 HPC 500-1000</td>
<td>-</td>
</tr>
<tr>
<td>heavy occurrence 8</td>
<td>heavy occurrence 8</td>
<td>&gt;20 % present</td>
<td>ATP &gt;200,000 HPC &gt;1500</td>
<td>-</td>
</tr>
</tbody>
</table>
The results of the monitoring yield a numerical value that allows us to identify what “stage” the well is in within its life cycle.
<table>
<thead>
<tr>
<th>Stage</th>
<th>Description</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage A</td>
<td>Monitor&lt;br&gt;Most Regularly Operated Wells</td>
<td></td>
</tr>
<tr>
<td>Stage B</td>
<td>Fouling is present and beginning to impact well&lt;br&gt;Plan Rehab within 18 to 24 months</td>
<td></td>
</tr>
<tr>
<td>Stage C</td>
<td>The well is impacted, but failure is not imminent&lt;br&gt;Plan Rehab within 4 to 6 months</td>
<td></td>
</tr>
<tr>
<td>Stage D</td>
<td>Significant Event / Fouling&lt;br&gt;Immediate Rehab or Replacement</td>
<td></td>
</tr>
</tbody>
</table>
Factors When Evaluating Response to “Age”

- Well Age and Priority
- Well Performance (historical)
- Aquifer Condition
- Structural Integrity of the Well & Well Head
- Well Treatment History (successes & failures)
Well Maintenance (Stages B, C, & D)

**Disinfection** – chlorine treatment of the well to target bacteria

**Cleaning** – combined chemical and mechanical treatment of the well targeting biofouling and/or mineral scale

**Re-development** – combined chemical and mechanical efforts targeting muds and sediment within the borehole and aquifer
the treatment process:

Identify the Problem – using various methods to identify the main mechanisms of fouling

Degree of Impact – assess as to what level the identified problem is impacting production, water quality, or the well/aquifer

Develop a Plan – use the information available to develop the best plan to remediate the problem without causing additional issues.
the treatment process:

Follow the Plan—follow the outlined procedures

Monitor—during treatment to insure the process is progressing correctly, record conditions/observations, collect samples if needed

Post-Treatment—Evaluate the treatment efforts and assess the level of success; develop a new maintenance plan for the well
3 Key Points
For Well Maintenance

• Are we using the right tool/chemical/method?
  – Size appropriately & not overtly aggressive
  – Product(s) will target the identified fouling mechanism

• Are we applying it correctly?
  – Application method, location, & contact time
  – Using the correct means of monitoring during treatment

• Are we limiting harmful impacts?
  – Crew
  – Well Structure
  – Aquifer & Environment
<table>
<thead>
<tr>
<th>Procedure</th>
<th>Objective</th>
<th>Optimal Use</th>
<th>Challenges</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical (dump/pump)</td>
<td>Breakdown of mineral scale or targeted disinfection of biomass</td>
<td>Light fouling or non-aggressive bacterial problems</td>
<td>Rapid neutralization; poor diffusion into lower well or filter pack</td>
</tr>
<tr>
<td>Brushing</td>
<td>Physical breakdown of accumulations within the inner well</td>
<td>Targeting biomass or scale prior to evacuation and subsequent chemical treatment</td>
<td>Reaction to wire cable; potential damage, failure to evacuate material prior to next phase</td>
</tr>
<tr>
<td>Mechanical Surging</td>
<td>Agitation within the screened zone</td>
<td>Combined with chemicals to target fouling within the filter pack; development</td>
<td>Providing sufficient energy; telescoping screen designs</td>
</tr>
<tr>
<td>Single or double disc, bailer</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jetting with water</td>
<td>Focused energy that agitates and “fluffs” the filter pack</td>
<td>When used in conjunction with pumping to remove disrupted material</td>
<td>Balance force with integrity of the well; dilution factor with chemicals, introduction of air</td>
</tr>
<tr>
<td>Airlift</td>
<td>Used to remove detritus and fill within the well</td>
<td>Evacuation of debris from idle wells; evacuation of material post-treatment</td>
<td>Depth restrictions; delivering sufficient energy, surface management</td>
</tr>
<tr>
<td>Gas Impulse</td>
<td>Focused release of high energy within the screened zone to target sediment or scale within the filter pack and formation</td>
<td>Following mechanical pre-treatment for combined chemical cleaning or redevelopment</td>
<td>Balance force with integrity of the well; incompatibility of chemistry</td>
</tr>
</tbody>
</table>
### Characteristics of Common Well Cleaning Acids

<table>
<thead>
<tr>
<th>Acid</th>
<th>Sulfamic</th>
<th>Hydrochloric</th>
<th>Phosphoric</th>
<th>Hydroxyacetic</th>
<th>Oxalic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appearance</strong></td>
<td>White Crystal</td>
<td>Yellowish Liquid</td>
<td>Clear Liquid</td>
<td>Clear Liquid</td>
<td>White Crystal</td>
</tr>
<tr>
<td><strong>Formula</strong></td>
<td>H₂NSO₃H</td>
<td>HCl</td>
<td>H₃PO₄</td>
<td>CH₂OHCOOH</td>
<td>H₂C₂O₄</td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td>Mineral</td>
<td>Mineral</td>
<td>Mineral</td>
<td>Organic</td>
<td>Organic</td>
</tr>
<tr>
<td><strong>Hazardous Fumes</strong></td>
<td>None</td>
<td>High</td>
<td>None</td>
<td>Some</td>
<td>None</td>
</tr>
<tr>
<td><strong>Relative Strength</strong></td>
<td>Strong</td>
<td>Strong</td>
<td>Strong</td>
<td>Weak</td>
<td>Moderately Strong</td>
</tr>
<tr>
<td><strong>PH at 1% Solution</strong></td>
<td>1.2</td>
<td>0.6</td>
<td>1.5</td>
<td>2.33</td>
<td>1.25</td>
</tr>
<tr>
<td><strong>Relative Reaction Time</strong>*</td>
<td>&lt; 2</td>
<td>1</td>
<td>4 – 5</td>
<td>4 - 5</td>
<td>2</td>
</tr>
<tr>
<td><strong>Corrosiveness to:</strong></td>
<td>Moderate</td>
<td>Very High</td>
<td>Slight</td>
<td>Slight</td>
<td>High</td>
</tr>
<tr>
<td>Metals</td>
<td>Moderate</td>
<td>Very High</td>
<td>Slight</td>
<td>Slight</td>
<td>High</td>
</tr>
<tr>
<td>Skin</td>
<td>Moderate</td>
<td>Very High</td>
<td>Slight</td>
<td>Slight</td>
<td>High</td>
</tr>
<tr>
<td><strong>Reactivity vs:</strong></td>
<td>Very Good</td>
<td>Very Good</td>
<td>Very Good</td>
<td>Poor</td>
<td>Moderately Good</td>
</tr>
<tr>
<td>Carbonate Scale</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Very Poor</td>
<td>Poor</td>
</tr>
<tr>
<td>Sulfate Scale</td>
<td>Fair</td>
<td>Good-Poor</td>
<td>Good-Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Fe/Mn Oxides</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td>Biofilm</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Poor</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Pounds of Acid (100%) required to dissolve 1-lb of Calcium Carbonate.</strong></td>
<td>2.0</td>
<td>0.73</td>
<td>0.65</td>
<td>4.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

*Reaction Time: (1 = Fast, 10 = Slow)
Example:
Jetting of this predominantly biological issue
Example:
Accumulations of iron oxide entrained biomass within the upper production zone.
Example:
The scale within the impacted louvers limit treatment of the filter pack

Photo courtesy of Aegis GW Consulting, Fresno, CA
Example:
Surge block would likely compound issues
Example:
Video survey identified holes in the casing above the screened zone
Monitoring During Treatment & Evacuation

• pH
• TDS / Conductivity
• Visual turbidity
Post Maintenance

• Chemical / biological testing
• Video Survey
• Pump Test

➢ Establish new benchmarks for the well
Summary: Well Management is a *Process*

- Each well is designed, constructed, and operated differently.
- Early identification of problems saves time and money, while extending the operational life of the well.
- Resolution (maintenance) should be well and problem specific.
- Follow-up is vital.
• Eliminate run to failure
• Ensure water quality
• Ensure water quantity and well efficiency
• Reduce ownership costs
• Extend the life of the well system
Thank you!

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Operational Stage of the Well

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ON-GOING CALCULATION OF SPECIFIC CAPACITY (SC)
Smart Choices
So, let’s ask ourselves a few questions...

• Do we provide a new well design/spec to City X that is right for the aquifer or a design that will win the bid?

• In completing a new well, we meet production goals despite just starting development – do we stop? Or do we complete development, likely increasing production and efficiency?

• City Y’s main well has had a Coliform hit, we super chlorinated it and it failed testing, are we going to repeat the process and pray, or take the time to investigate the well and identify the real problem, even though it’s a holiday weekend?
Putting Science into Materials Selection

• SS well screens will pay for themselves in approx. 6 years, and may provide savings of about $3M during a 75-year life cycle (Glotfelty, 2012)

• Reduced corrosion reduces need for iron removal and additional disinfection efforts of produced water (*significant cost savings*)
Table 6.7
Operational Costs Associated with Well Ownership
Disinfection

A chlorine treatment of the well and well components to target bacteria

New & Existing Wells
Cleaning or Rehabilitation

The combined chemical and mechanical treatment of the well targeting significant biofouling and/or mineral scale

Existing Well Systems
Development/Redevelopment

The combined mechanical and chemical efforts targeting muds and sediment within the borehole and near-well aquifer

New and Older Wells