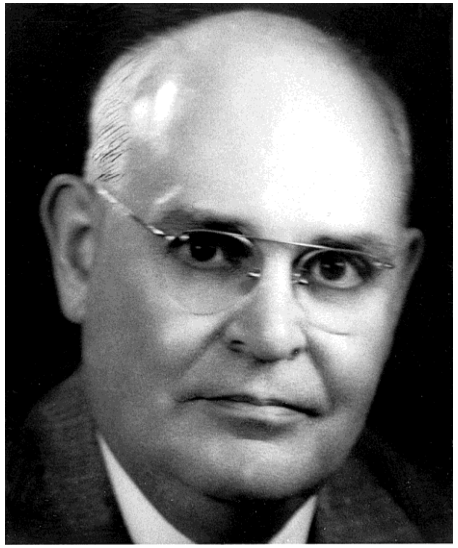
William A. McEllhiney Distinguished Lecture Series in Water Well Technology



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.

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Michael J. Schnieders, PG, PH-GW

2017 McEllhiney Lecture:

Defining the Operational Age of a Well: Predicting Maintenance Issues in Advance of Failure

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Failure (noun) \’fāl-yer\ 1. the state of inability to perform a normal function; 2. an abrupt halt of normal operation.

per Merriam-Webster

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*

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Changing View of Groundwater:

- *water found underground in soil, rock, and unconsolidated materials, to include aquifers as well <u>as the areas of recharge</u>*
- *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”

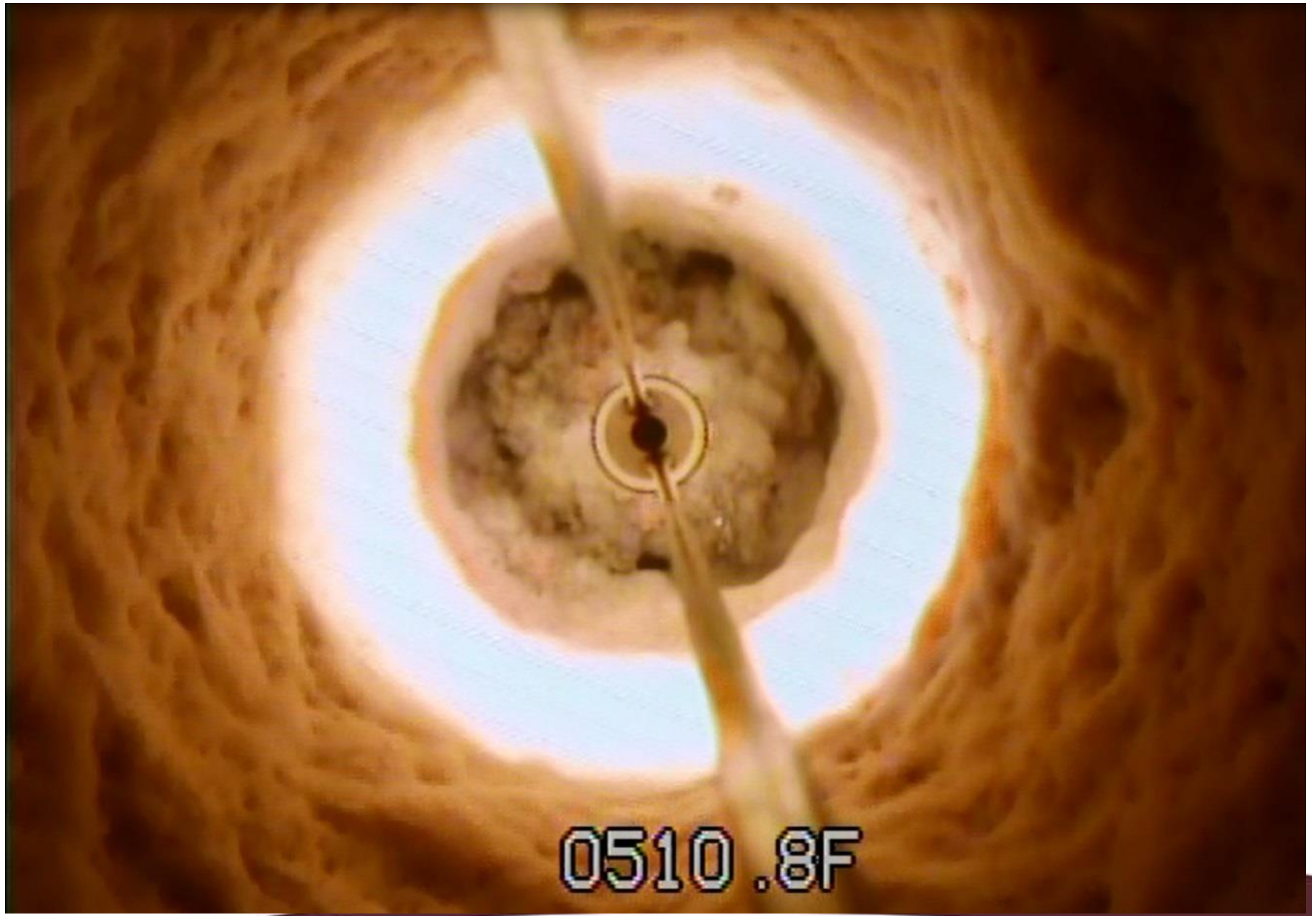
Image courtesy of Johnson Screens

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

Photo courtesy of Don Caillouet, Layne



- "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

Well Maintenance Observations

Photo courtesy of Terrane Resources

- 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

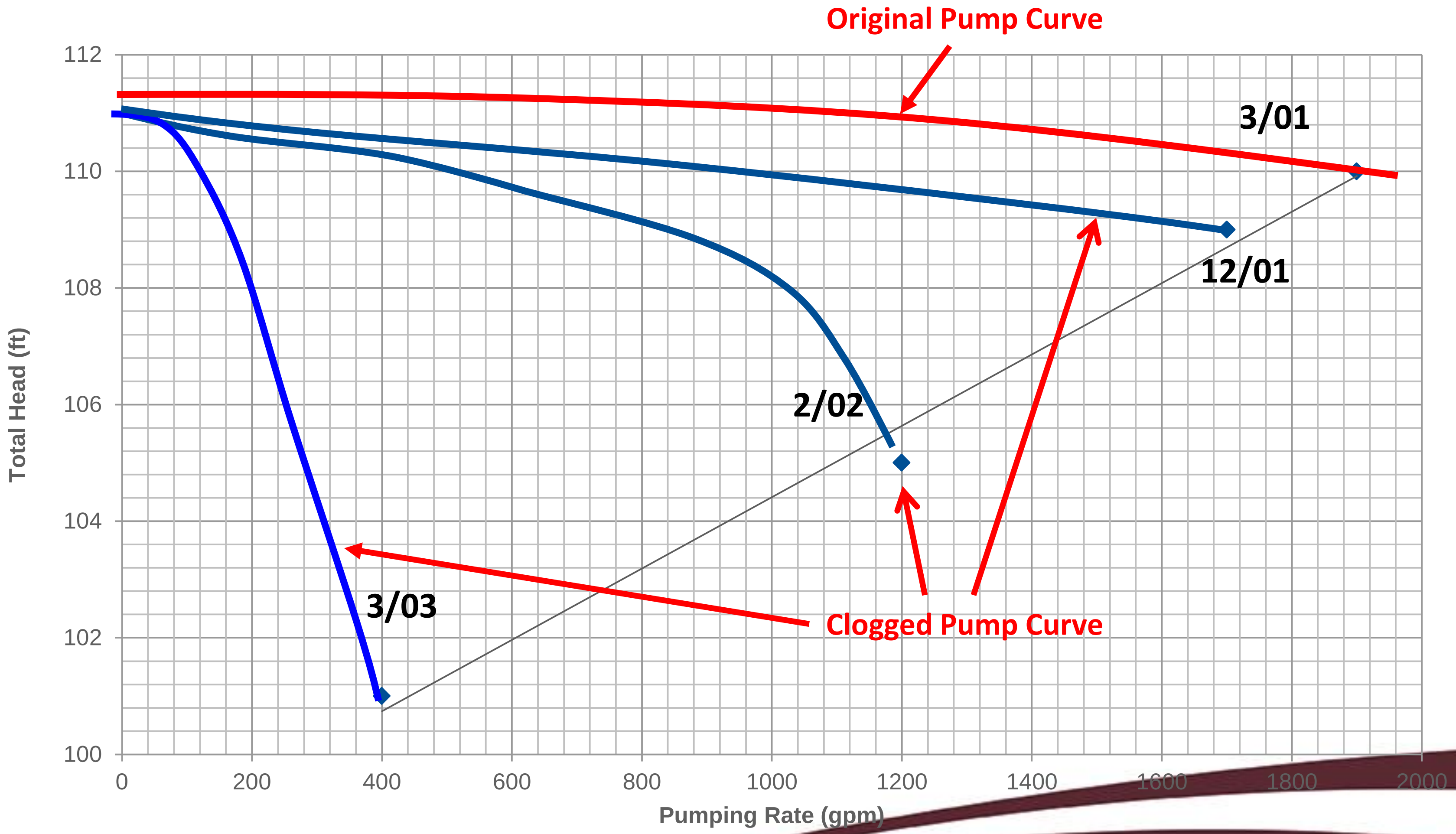
Decrease in Specific Capacity	Decrease in Wire to Water Efficiency	Corrosion Structural Issue	Increase in Sand Pumping or Turbidity	IRB per 10 ml	SRB per 5 tube culture	Anaerobic	Population	Coliform or Pathogen	TDS	Ca/Mg	Fe / Mn	ORP	Contaminant
< 1% 0	< 1% 0	No Change 0	No change 0	Absent 0	Absent (0 tubes) 0	< 1% Present 0	ATP <20,000 or HPC <100 0	Absent 0	<5% increase 0	<10% increase 0	<10% increase 0	<10% change 0	Absent 0
			Increase of 2	Low	Low		ATP 75,000 -						
3 - 10% decrease 4	3 - 10% decrease 4	Significant corrosion of casing small holes in casing or screen 12	Increase of 2 - 7 ppm or total < 6 ppm or > 1.0 ntu 4	Moderate Occurrence (4 -7 bacteria) 6	Moderate Occurrence (2 or 3 tubes) 6	11-20% Present 6	ATP 125,000-175 or HPC 500-1000 6		11-20% increase 4	21 - 40% increase 4	21 - 40% increase 4	26 - 40% increase 4	
> 10 % decrease 6	> 10 % decrease 12	Loss of significant portions of screen or holes in casing 20	Increase of 2 - 7 ppm or total < 7 ppm, or > 1.0 ntu 6	Heavy Occurrence (>7) 8	Heavy Occurrence (4 or 5 tubes) 8	> 20% Present 8	ATP >200,000 or HPC >1000 8		>20% increase 6	>40% increase 6	>40% increase 6	> 40% increase 6	
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**

Physical Biological Chemical

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



Data and Graphic courtesy of Bob Pritchard, Serv-Tech, Inc.

Wire to Water Efficiency

WTW Efficiency = Pump Eff. X Motor Eff. X MCS Eff. X Cable Eff. X Piping Eff. **

- 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

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Tracking Physical Changes

Decrease in Specific Capacity	Decrease in Wire to Water Efficiency	Corrosion or Structural Issue	Increase in Sand Pumping or Turbidity
<1% **0**	<1% 0	No Change 0	No Change 0
0-3% decrease **2**	0-3% decrease **2**	Slight corrosion of casing **2**	Increase of 2 ppm **2**
3-10% decrease **4**	3-10% decrease **4**	Significant corrosion of casing **12**	Increase of 2-7 ppm or >1 ntu **4**
>10% decrease **6**	>10% decrease **12**	Los of portions of casing or screen **20**	Increase of >7 ppm or >1 ntu **6**

Water Chemistry Impacts:

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

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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

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Tracking Water Chemistry Changes

TDS (mg/L)	Ca / Mg (mg/L)	Fe / Mn (mg/L)	ORP (mv)	Contaminant
<5% increase **0**	<10% increase **0**	<10% increase **0**	<10% increase **0**	absent **0**
6-10% increase **2**	11-20% increase **2**	11-20% increase **2**	11-25% increase **2**	>WQ objective (MCL) **35**
11-20% increase **4**	21-40% increase **4**	21-40% increase **4**	26-40% increase **4**	-
>20% increase **6**	>40% increase **6**	>40% increase **6**	>40% increase **6**	-

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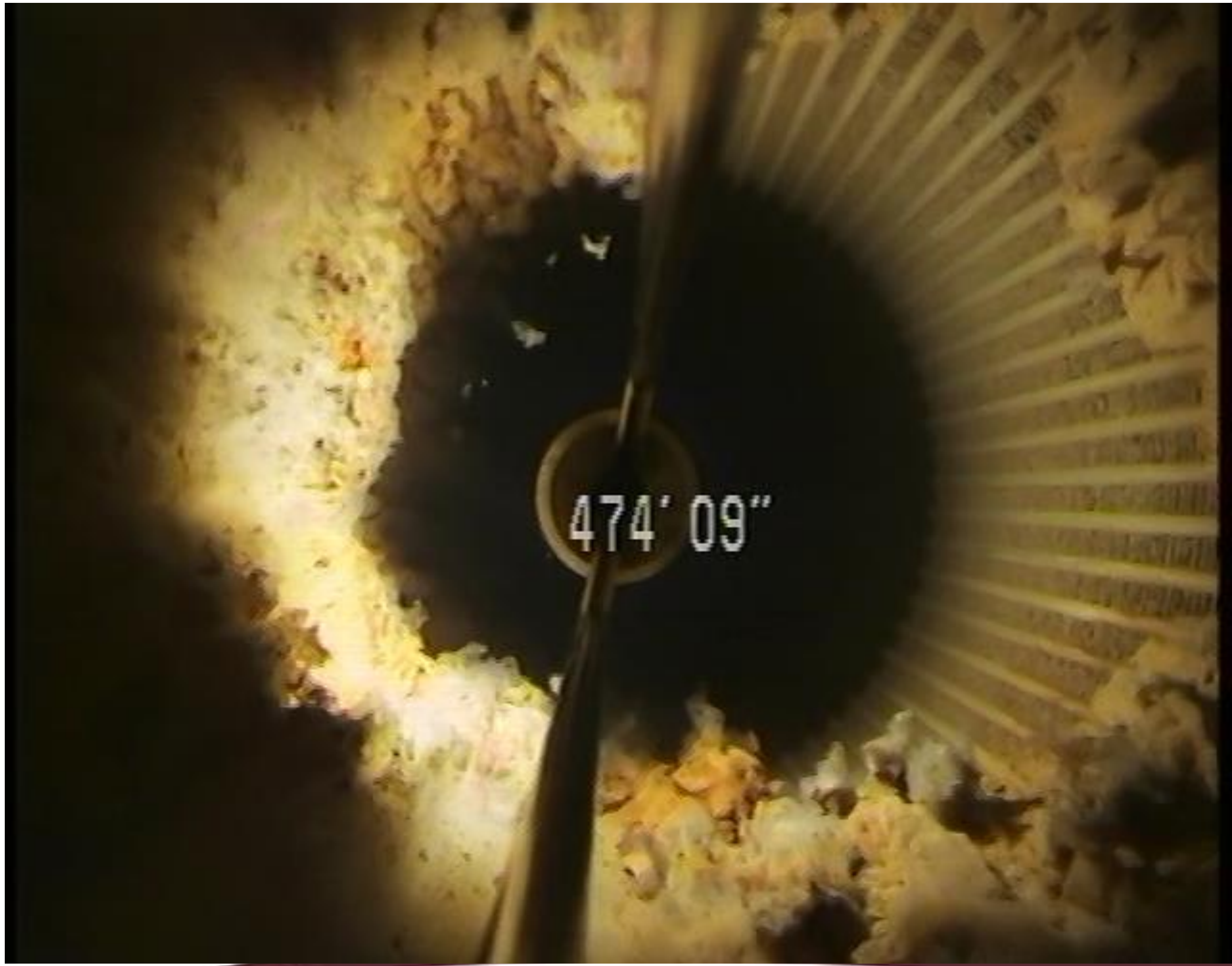
Photo courtesy of Layne, Kansas City, KS

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

Iron Bacteria	Sulfate Reducing Bacteria	Anaerobic Growth	Population (ATP or HPC)	Coliform or Pathogen Presence
absent **0**	absent **0**	< 1% present **0**	ATP < 20,000 HPC <100 **0**	Absent **0**
low occurrence **2**	low occurrence **2**	2 to 10% presence **2**	ATP 75,000 to 100,000 HPC 200-400 **2**	present **35**
moderate occurrence **6**	moderate occurrence **6**	11-20% presence **6**	ATP 125,000 to 175,000 HPC 500-1000 **6**	-
heavy occurrence **8**	heavy occurrence **8**	>20 % present **8**	ATP >200,000 HPC >1500 **8**	-

Physical | Biological | Chemical

The results of the monitoring yield a numerical value that allows us to identify what “stage” the well is in within it’s life cycle

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Stage A (0-12 pts)	• Monitor • Most Regularly Operated Wells
Stage B (13-25 pts)	• Fouling is present and beginning to impact well • Plan Rehab within 18 to 24 months
Stage C (26-35 pts)	• The well is impacted, but failure is not imminent • Plan Rehab within 4 to 6 months
Stage D (>35 pts)	• Significant Event / Fouling • Immediate Rehab or Replacement

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

Common Mechanical Methods

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

Characteristics of Common Well Cleaning Acids

Acid	Sulfamic	Hydrochloric	Phosphoric	Hydroxyacetic	Oxalic
Appearance	White Crystal	Yellowish Liquid	Clear Liquid	Clear Liquid	White Crystal
Formula	H_2NSO_3H	HCl	H_3PO_4	$CH_2OHCOOH$	$H_2C_2O_4$
Type	Mineral	Mineral	Mineral	Organic	Organic
Hazardous Fumes	None	High	None	Some	None
Relative Strength	Strong	Strong	Strong	Weak	Moderately Strong
PH at 1% Solution	1.2	0.6	1.5	2.33	1.25
Relative Reaction Time*	< 2	1	4 – 5	4 - 5	2
Corrosiveness to: Metals Skin	 Moderate Moderate	 Very High Severe	 Slight Moderate	 Slight Slight	 High Severe
Reactivity vs: Carbonate Scale Sulfate Scale Fe/Mn Oxides Biofilm	 Very Good Poor Fair Poor	 Very Good Good-Poor Very Good Poor	 Very Good Good-Poor Good Poor	 Poor Very Poor Good Moderately Good	 Moderately Good Poor Good Moderately Good
Pounds of Acid (100%) required to dissolve 1-lb of Calcium Carbonate.	2.0	0.73	0.65	4.5	2.0

*Reaction Time: (1 = Fast, 10 = Slow)

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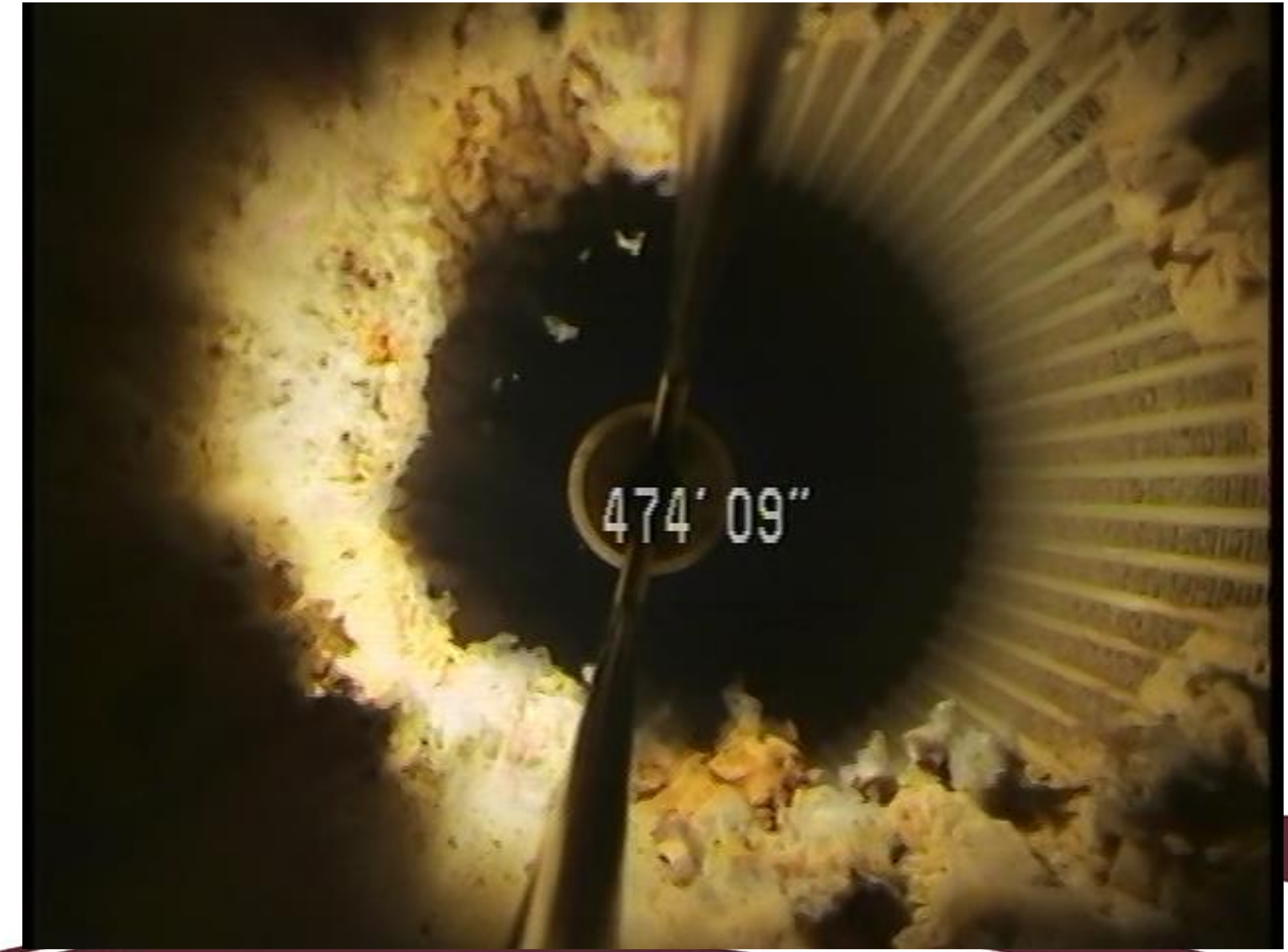
Example:

Jetting of this predominantly biological issue



Example:

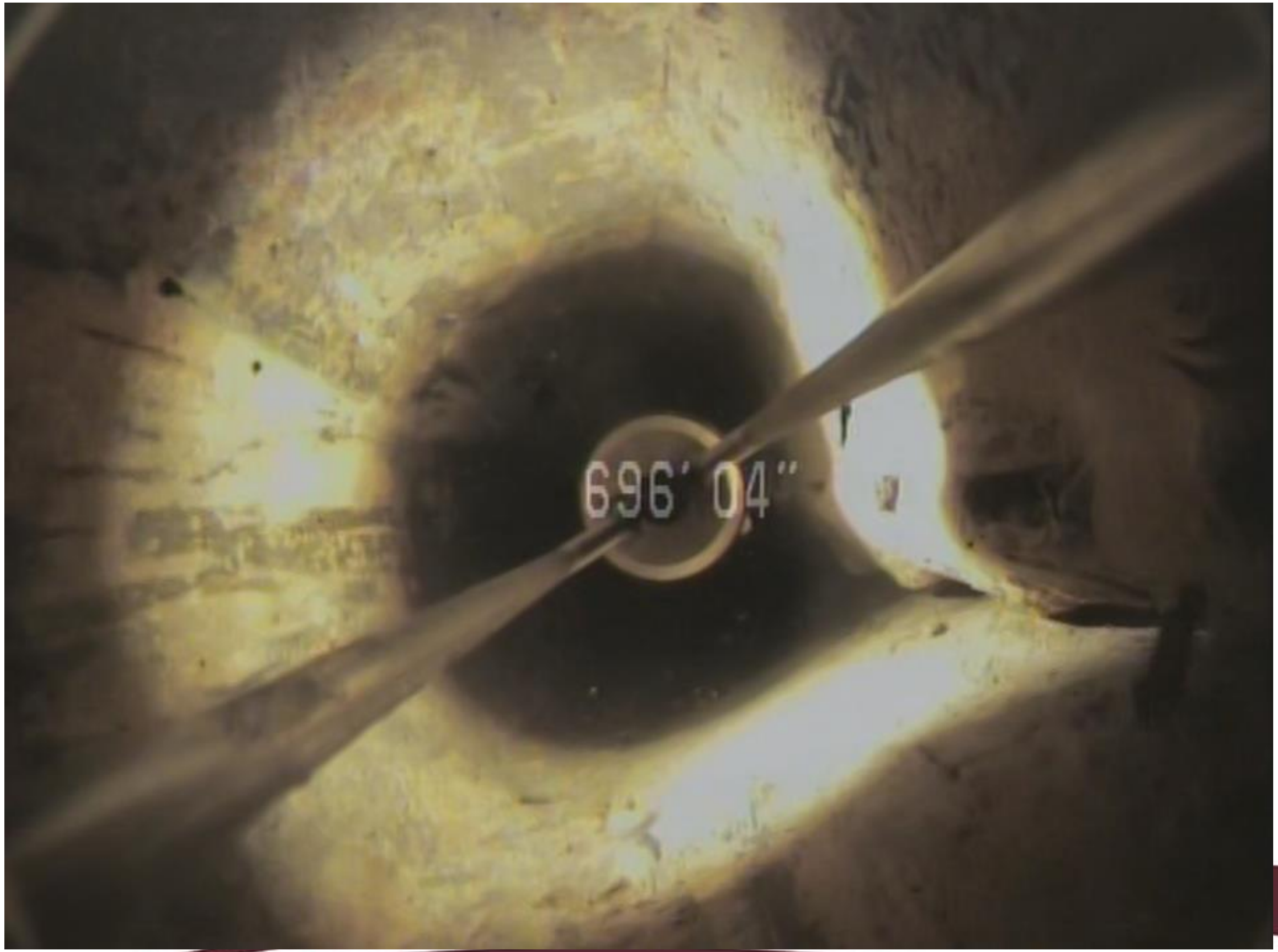
Accumulations of iron oxide entrained biomass within the upper production zone

Photo courtesy of Aegis GW Consulting, Fresno, CA

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

Photo courtesy of Aegis GW Consulting, Fresno, CA

Example:

Video survey identified holes in the casing above the screened zone

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Monitoring During Treatment & Evacuation

- pH
- TDS / Conductivity
- Visual turbidity

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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

Operational Age of the Well:

Well Management Goals

- 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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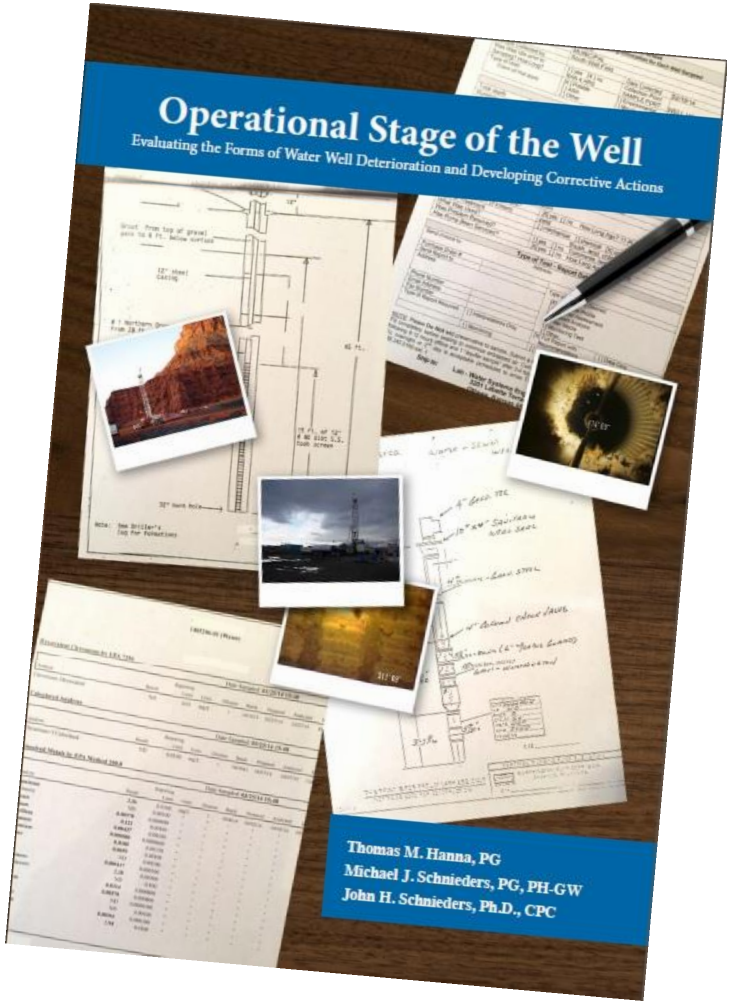
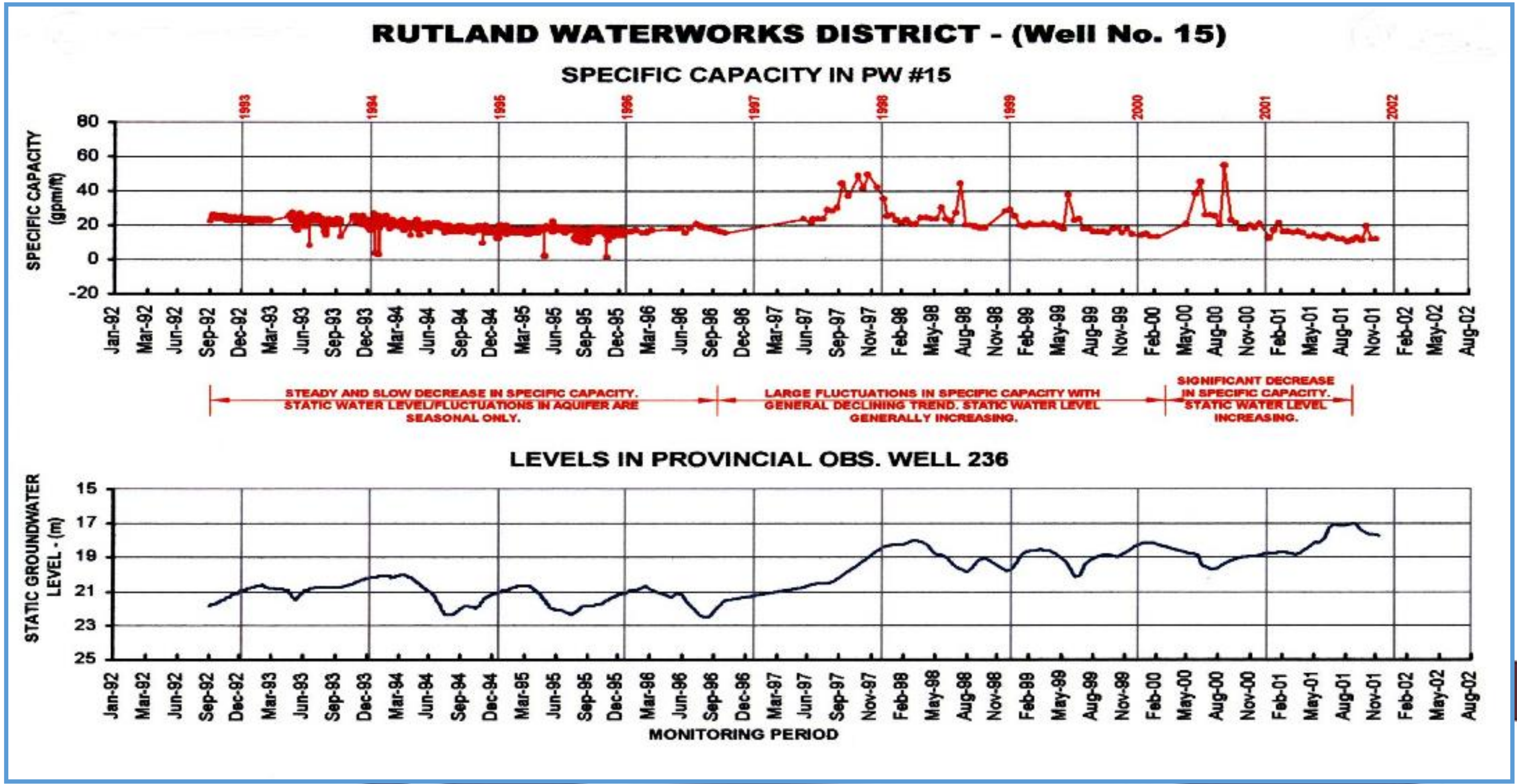
NGWA Press 2017



ON-GOING CALCULATION OF SPECIFIC CAPACITY (SC)

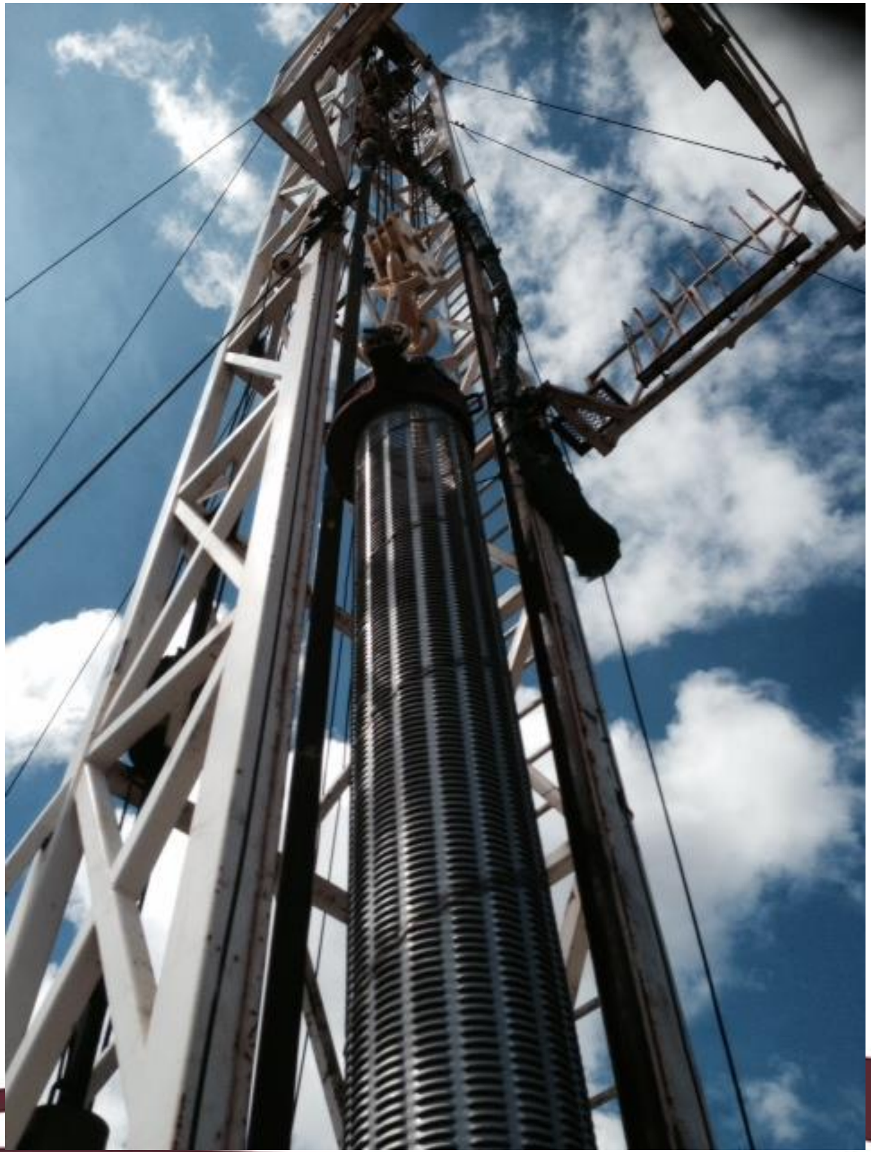


Smart Choices

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?

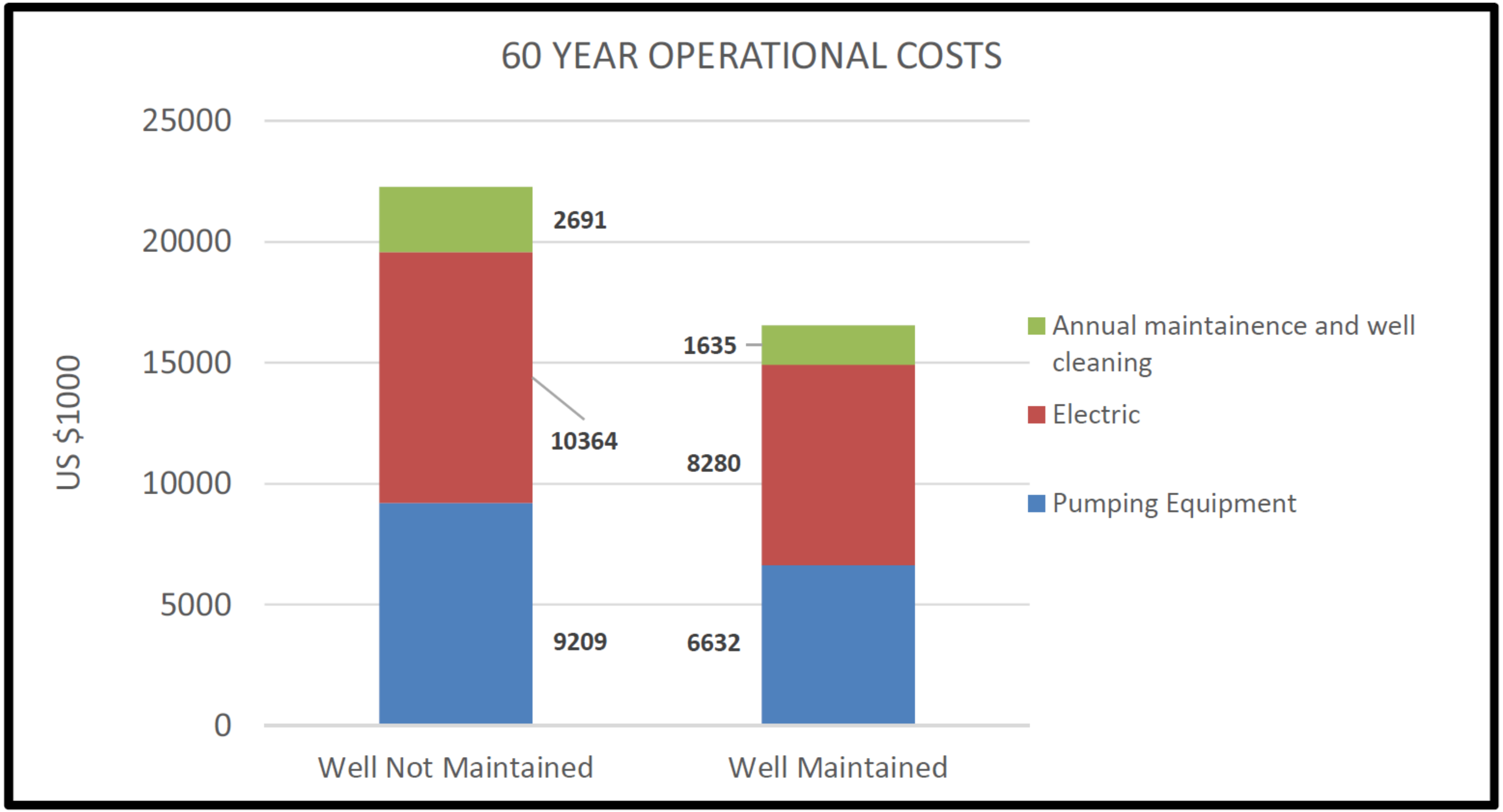
Photo courtesy of Roscoe Moss



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



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Disinfection

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

New & Existing Wells

Cleaning or Rehabilitation

Photo courtesy of Hydro Resources, Denver, CO

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

Existing Well Systems

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Development/Redevelopment

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

New and Older Wells