Santa Cruz County
<u>Small Water Systems Forum</u>
September 22, 2016
Santa Cruz County

Library – Monterey Bay Academy
783 San Andreas Rd. Watsonville, CA 95076

I.	*Introductions/Sign In*	*7:00 - 7:10*
II.	*Guest Speaker- Thomas Ballard (PG, CHG), Hydrogeological Associates*	
	A. Common Well Problems- Identification and Solutions	*7:25 - 8:40*
III.	*Closing*	
	A. Discussion- Topics for Next Meeting	*8:40 – 8:45*
	B. Mingle & Network	*8:45 – 9:00*

County of Santa Cruz

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Minutes
Small Water Systems Forum Meeting- Third Quarter 2016
September 22nd, 2016
Monterey Bay Academy Library
783 San Andreas Rd, Watsonville, CA 95076

Introductions

Troy Boone and Nathan Salazar
Drinking Water Program

Tools and Techniques to Measure the Performance of a Well

Thomas Ballard, PG, CHG
Principal Hydrogeologist, Hydrogeological Associates

- Introduction/Overview
    - Maintenance is key: water quality issues can affect the long-term effectiveness of a well
    - Why is assessing well performance important?
    - Life cycle costs of wells- cheapest well upfront may not result in the lowest cost total over the life of the well

- How to determine when rehabilitation for a well is needed?
    - <u>Establish performance indicators/parameters</u>
        - Some common, some unique

- Causes of decline in well performance
    - Chemical incrustations
        - On screen, can also extend back into gravel pack, which is more challenging to address
    - Biofouling
        - Native bacteria
        - Precipitate (iron, manganese)

        - Iron bacteria is involved in more than 80% of well plugging
    - Filter pack clogging
        - Natural process
        - Alluvial, bedrock filter pack types
    - Corrosion/structural failure
        - Natural process which occurs due to dissimilarities in metal composition
        - Bacteriologically induced corrosion (sulfur-reducing)
        - Structural failure caused by ground shifting
    - Fissure plugging/collapse
        - Causes
            - Changes in groundwater velocity
    - Pump failure

- Chemical/Biological Measurement Techniques
    - Interpreting the data
    - Biological Activity Reaction Test
        - "BART"
        - Specific to certain species of bacteria
        - Tests for Iron, sulfur-reducing, slime-producing bacteria
        - ~$125, available from a variety of vendors
    - ATP testing
        - Compound present in living cells, released when cell is destroyed for testing purposes
        - Test destroys bacteria, uses luminometer to measure activity and convert to Most Probable Number (MPN) measurement

    - Water quality monitoring
        - Iron
            - Can be an indicator of bacteriological activity
        - Manganese
        - Bacteria
        - Hardness
        - Turbidity
    - Stiff Diagrams
        - Normalizes concentrations of cations and anions, allows for creation of water source signatures
    - Energy usage
    - Sand production
        - Sand will cause pumps to wear down quickly
    - Specific Capacity
        - Baselines are crucial here as well
        - Great tool for monitoring well performance
    - Well Efficiency
        - Theoretical drawdown of well divided by actual drawdown of well
        - Well Efficiency Elements
            - Head loss

        - Efficient vs. Inefficient well
        - Well Efficiency and Energy Costs
    - Water Level Trends
        - Seasonal fluctuations vs. long-term trends

- Recommendations for Maintaining Well Performance
    - Key Performance Indicators (KPIs)
    - KPI Changes Over Time
    - Rehabilitate as Indicated by KPIs
        - Recommended practice: every time the pump is pulled, have the well videoed to assess condition. A relatively inexpensive strategy to gain valuable information.
    - Budget Accordingly

- Wrap-Up

Tools and Techniques to Measure the Performance of a Well

Thomas E. Ballard, PG, CHG
Hydrogeological Associates
Sacramento, CA

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Why Is Assessing Well Performance Important?

- Average time to first well rehabilitation is 12 years.
- Average time to second well rehabilitation is 5 years.

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Rehabilitating wells when performance starts to decline can extend the life of a well far beyond that of an unmaintained well.

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Difficult to restore performance in a well that has been neglected for too long.

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Lowest life-cycle costs come from a well that is maintained on an optimal schedule.

Well performance indicators allow determination of the optimal rehabilitation schedule.

CAUSES OF DECLINE IN WELL PERFORMANCE

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Chemical Incrustation

- Mineral incrustations can develop due to water quality issues
- Lower quality screens more subject to mineral incrustations
- Velocity drop at the well screen can also contribute

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Chemical Incrustation - Causes

- Well Construction
  - High entrance velocity
  - Turbulent flow
  - Low well efficiency
  - Poor quality filter pack
- Water Quality
  - Hardness > 300 mg/L
  - Chemistry changes due to pumping
  - Iron content
  - Manganese content
  - pH > 7.5

Biofouling

- Native bacteria present in many wells precipitate Fe or Mn
- Involved in more than 80% of well plugging cases
- Can also result in accelerated corrosion
- Bacteria produce tubercules and protective slime coating

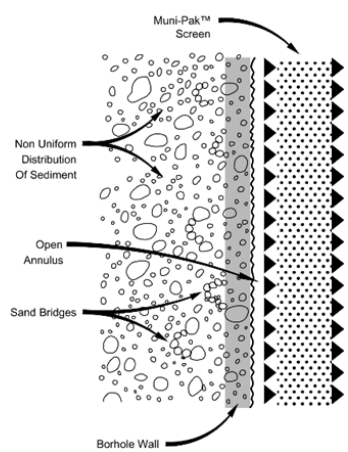
Biofouling - Causes

- Bacteria produce a slimy coating as opposed to a hard coating caused by mineral incrustations
- The slimy coating is a biofilm to protect the underlying bacteria
- Aerobic conditions at the well screen enhance iron bacteria growth

Filter Pack Clogging

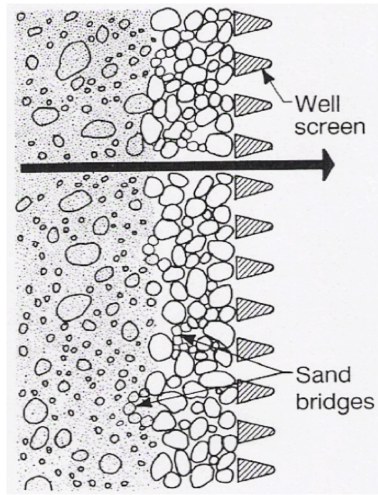
Reduces flow to the well due to:

- Development of sand bridges
- Plugging with fines
- Biofouling
- Mineral precipitation



Filter Pack Clogging - Causes

- One-way flow to the well causes silt/clay clogging over time
- Sand bridge development
- Improper/incomplete well development
- Water chemistry with chemical precipitation potential



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Corrosion/Structural Failure

- Dielectric corrosion
- Bacterially-induced corrosion
- Improper seals
- Ground shifting
- Improper design for ground conditions

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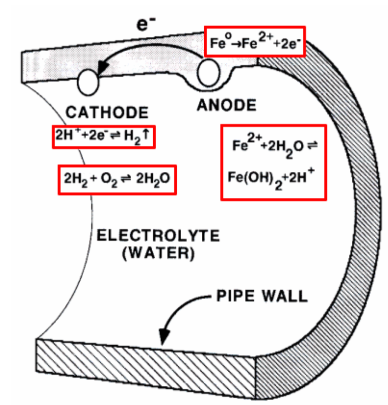
Corrosion/Structural Failure - Causes

- Poor quality steel casings/screens can increase corrosion potential
- Dissimilar metals can create a dielectric cell
- Sulfur-reducing bacteria and H_2S



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Fissure Plugging/Collapse

- Applies to open borehole wells
- Fractured rock or karst
- Fractures can collapse due to pumping
- Plugging can occur through chemical or physical processes

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Fissure Plugging/Collapse - Causes

- Changes in groundwater velocity
- Changes in groundwater chemistry near well (higher O_2)
- Silt/Clay accumulation

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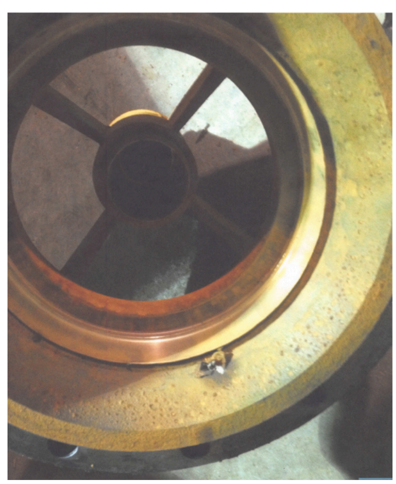
Pump Failure



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Pump Failure - Causes

- Excess sand production
- Biofouling
- Incorrect installation
- Lack of routine maintenance
- Routine wear and tear

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Assessing Well Performance

CHEMICAL/BIOLOGICAL MEASUREMENT TECHNIQUES

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Interpreting the Data

Not Necessarily Absolute Numbers, But Relative Changes Over Time

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Biological Activity Reaction Test

- Colorimetric test for:
  - Iron Reducing Bacteria
  - Sulfate Reducing Bacteria
  - Others
- Time for color change indicates population size and activity
- Oxygen gradient differentiates aerobic vs. anaerobic
- 2-8 day test time

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BART Tests Available

- Iron Related Bacteria
- Sulfur Reducing Bacteria
- Slime Producing Bacteria
- Heterotrophic Aerobic Bacteria
- Micro-Algae
- Fluorescent Pseudomonas
- Denitrifying Bacteria
- Nitrifying Bacteria
- Acid Producing Bacteria
- Biological Oxygen Demand

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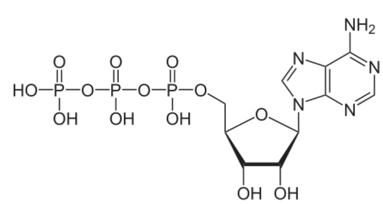
Adenosine triphosphate (ATP)

- ATP is present in all living cells
- Released when cell wall is destroyed during testing process
- ATP only persists for about 15 seconds after a cell dies
- All bacteria have ATP, so all bacteria are counted – both aerobic or anaerobic
- Cells per milliliter count



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Adenosine triphosphate (ATP)

- Test only takes about 15 minutes
- Excellent repeatability
- Uses luminometer to measure ATP content
- Convert to MPN per milliliter
- Relatively inexpensive test
- Field kits available

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Water Quality Monitoring

- Changes in groundwater quality can be an indicator of a wide range of issues:
  - Biofouling
  - Well contamination
  - Potential for incrustations
- Iron
- Manganese
- Total Coliform
- Hardness
- Turbidity
- pH
- Total Cations/Anions
- General Minerals

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Iron and Manganese

- Increases in Fe and/or Mn may indicate increased chemical precipitation/incrustation s
- Fe increases can also indicate the presence of Iron Related Bacteria
- Fe and Mn have secondary drinking water MCLs
- Monitor changes over time

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Bacteria

Total Coliform

- A group of bacteria including fecal coliform and E. coli
- Typically present in stagnant well water
- Backup wells susceptible to Total Coliform issues due to lack of use

Fecal Coliform/E. coli

- Most fecal coliform are harmless
- O157:H7 strain of Escherichia coli (E. coli) can cause severe illness
- Strong indicator of fecal contamination of groundwater

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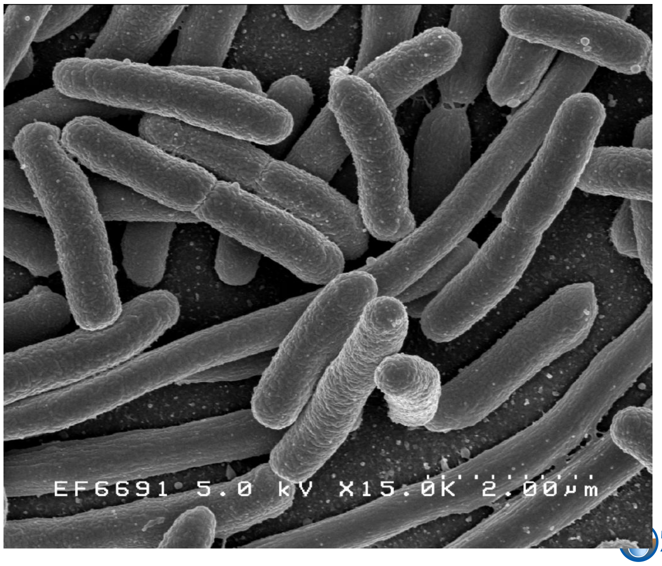
Escherichia coli



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Hardness

- Hardness is directly related to calcium and magnesium cation concentrations
- Calcium combines with bicarbonate and carbonate to form calcium carbonate
- Calcium carbonate is the most common type of mineral incrustation
- Changes in Hardness over time indicate increased potential for incrustations or fissure plugging
- Hardness of pumped water vs static water could indicate precipitation is occurring

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Turbidity

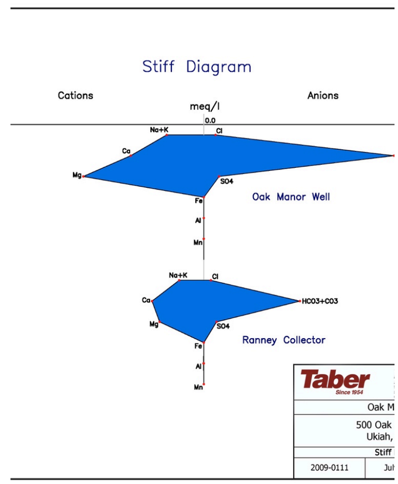
- Solids and organic matter which do not settle of out water.
- Measured in Nephelometric Turbidity Units (NTU)
- 5 NTU for drinking water
- Increase caused by
  - Air Entrainment
  - Sand
  - Suspended Solids
  - Colloidal particles
  - Bacterial Loads

pH

- A measure of alkalinity or acidity based on relative concentration of hydrogen ions
- 7 is neutral
- Low pH increases potential for corrosion
- High pH increases potential for incrustations
- Changes in pH can be caused by:
  - Contamination
  - Biofouling (particularly SRB)
  - Surface water infiltration
  - Increase in organic material

Stiff Diagrams

- Measures relative concentrations of cations and anions
- Can be used to compare differences in water sources
  - Surface vs. groundwater
  - Different bedrock sources
  - Changes over time in a single well



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Assessing Well Performance

PHYSICAL TECHNIQUES

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Energy Usage

- Measured in gallons per kilowatt-hour
- Chart trends in energy usage ratio
- Increase in energy usage per gallon indicates loss of efficiency in the well

- Potential causes:
  - Well screen plugging
  - Filter pack plugging
  - Well damage = more turbulent flow
  - Pump damage
  - Motor damage

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Sand Production

- Should be <5 ppm
- Symptomatic of:
  - Improper Design
  - Incomplete Development
  - Well Damage
  - Overpumping
- Solutions:
  - Redevelopment
  - Sand Separator
  - Well Repair
  - Reduced Pumping Rate

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Measuring Sand Production

Rossum Sand Tester

- Functions like a centrifugal sand separator
- Measures the quantity of sand in milligrams per liter (mg/L)
- Can be used at a high rate of flow and turbulent discharge
- Capable of accurately measuring sand content as low as 0.5 ppm

Imhoff Cone

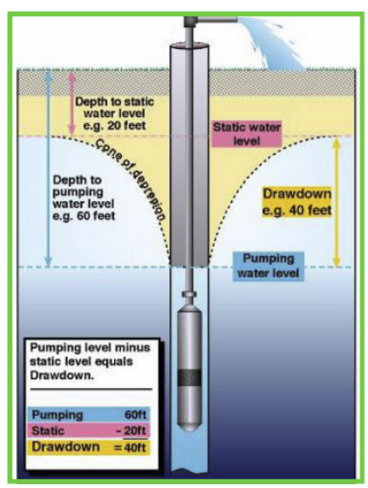
- Sample collected during initial stages of pumping and surging
- Cone is set in a holder to permit the contents to settle for approximately 10 minutes
- Incapable of accurately measuring sand content below 10 ppm

Specific Capacity

An expression of the productivity of a well.

SC = Q/ds

SC = specific capacity
Q = discharge
ds = drawdown



Specific Capacity

- Measure changes in water well performance over time
- Simple and reliable method
- Decline in SC due to biomass plugging, mineral incrustations and filter pack clogging
- Most effective when the original SC was taken immediately after well was developed and brought online = baseline
- Changes of 5-15% loss indicate the need for well rehabilitation

Using Specific Capacity

- Setting the pump in the well – optimal at 70% of available drawdown
- Assessing performance of the well over time
- Estimating transmissivity
  - T = SC x 2,000 (confined aquifers)
  - T = SC x 1,500 (unconfined aquifers)

Specific Capacity

- Well plugging may not reflect reduced specific capacity due to "Excess Capacity" in some part of the aquifer that can compensate for loss of production capacity in some of the plugged zones
- The specific capacity of a multi-aquifer well is the numeric sum of the specific capacities of the individual aquifer units

Specific Capacity

- Specific Capacity can be influenced by temperature – especially when the aquifer is hydraulically connected to surface water such as rivers and streams.

Corrections for:

- River Infiltration
- Barometric Pressure
- Temperature
- Seasonal Variations
- Changes in Pumping Rate

Seasonal variations up to 15% are possible

Well Efficiency

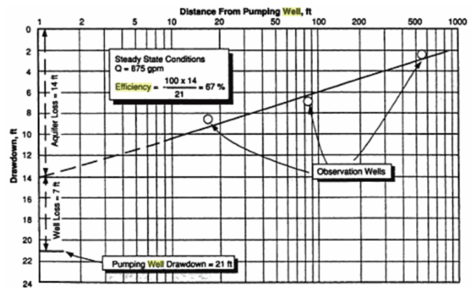
W.E. = s_t/s_a x 100%

W.E. = well efficiency

s_t = theoretical drawdown

s_a = actual drawdown

80% well efficiency may be reached under ideal circumstances, but 60% is more realistic.



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Well Efficiency

$$Efficiency = 100 \times \frac{Aquifer\ losses}{Aquifer\ losses + Well\ losses}$$

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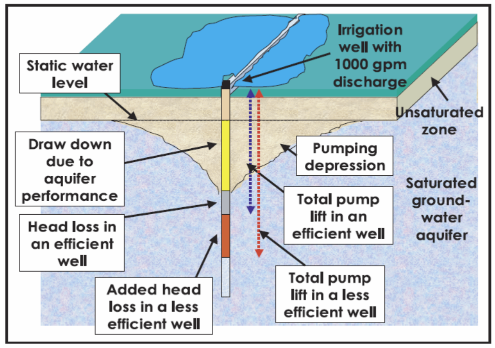
Well Efficiency Elements

- Drawdown
- Head Loss
- Efficiency losses
- Pump Lift



Terms: Head Losses

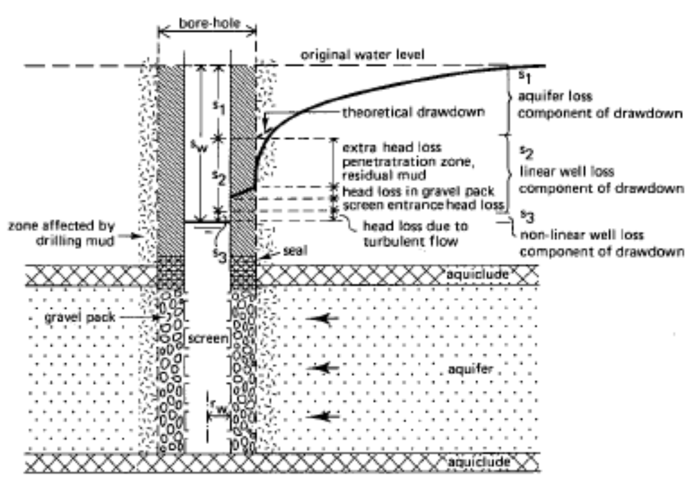


Figure 14.1 Various head losses in a pumped well

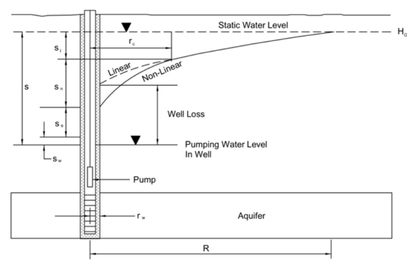
Source : Kruseman and de Ridder (1990)

Components of Drawdown

$$S = Sl + Sn + Se + Sw$$

Where:

S = total drawdown
Sl = head loss due to viscous drag of water moving through the aquifer with low laminar velocity.
Sn = head loss due to non-laminar flow in the aquifer in the high-velocity region in the immediate vicinity of the well.
Se = head loss as the water exits the aquifer into the wellbore.
Sw = head loss as the water flows within the wellbore to the pump intake.



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Actual vs. Theoretical Drawdown

Actual Drawdown

- Measured directly in the well as the pumping water level
- Can change over time due to deterioration of the well.

Theoretical Drawdown

- Can be extrapolated by use of observation wells
- Can be approximated by means of Theis Equation
- Other means to take into account variables

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Solution

- Use analytical solutions to model the measured water levels inside the pumping well in response to:
  - Pumping at the well
  - Effect of well losses
  - Pumping at neighboring wells
  - Surface water fluctuations, if applicable
- *Calculate Efficiency from the estimated well losses*

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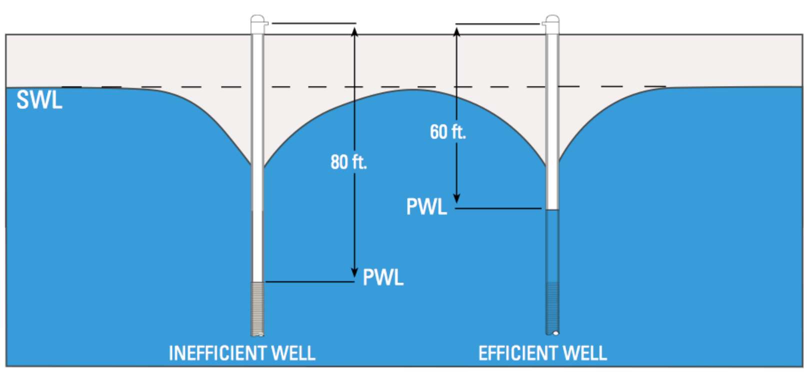
Efficient vs. Inefficient Well



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Well Efficiency and Energy Costs

Cost =
$(Q \times H_d \times 0.746 \times C_p)/(3960 \times E_p \times E_m)$ Eq. 1

Where:
- Q = Pumping rate (gpm)
- H_d = Additional head required as a result of increased drawdown (feet)
- C_p = Cost per kWh (dollars)
- E_p = Pump and drive efficiency (fraction)
- E_m = Motor efficiency (fraction)

Well Efficiency and Energy Costs

Example

Assume a well with 90% efficiency when producing 2000 gpm with 20 ft drawdown. Calculate the cost savings for 90% efficient well compared to a 45% efficient well for 800 hours per year of operation. The motor efficiency is 90%, the pump efficiency is 85%, and the power cost averages 10 cents per kWh.

Specific capacity for 90% efficiency = 2000 gpm/20 ft = 100 gpm/ft of drawdown

Specific capacity for 45% efficiency = 100/(90/45) = 50 gpm/ft

Drawdown for 45% efficient system to produce 2000 gpm = production/specific capacity = 2000/50 = 40 ft

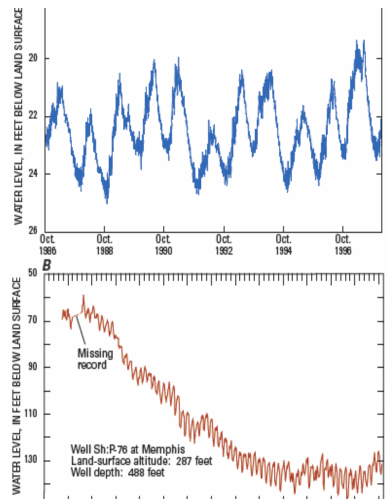
Additional head required (H_d) = 40 ft – 20 ft = 20 ft
- Q = 2000 gpm
- C_p = \$0.10 per kWh
- E_p = 85%
- E_m = 90%

Additional cost for 45% efficient system = (2000 x 20 x 0.746 x 0.10)/(3960 x 0.85 x 0.80)= \$1.10 per hour

Additional cost per year = \$1.10 per hour x 800 hour = \$880 per year

Water Level Trends

- Related to specific capacity
- Longer term trends can indicate problems with well or overall changes in aquifer or basin
- Decreased pumping water levels could indicate dewatering of aquifer
- Also helpful to have observation well data



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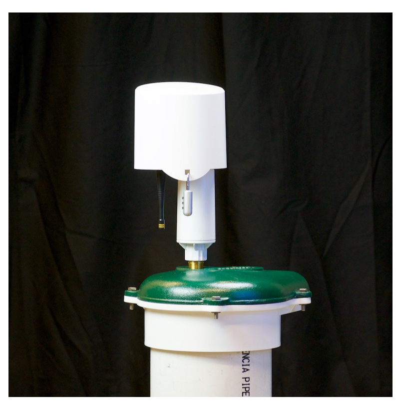
Measuring Water Levels

- Manual Water Level Meter/Tape
- Transducer/Datalogger
- Wireless Monitoring Systems Connected to the Internet



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Well Performance Tests

- One way to measure well efficiency
- Easily performed with existing pump in the well
- Will show changes over time that can reflect well or aquifer problems

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Well Performance Tests

- Shorter term tests to determine well performance and capacity.
- Can be conducted at the conclusion of rehabilitation to confirm successful results
- Usually conducted as a series of step tests to determine the current optimal pumping rate
- Start with the lowest pumping rate and work upward in a series of steps
- Current optimal rate balances production vs stable drawdown
- Comparison over time can be useful to determine when well rehabilitation is needed

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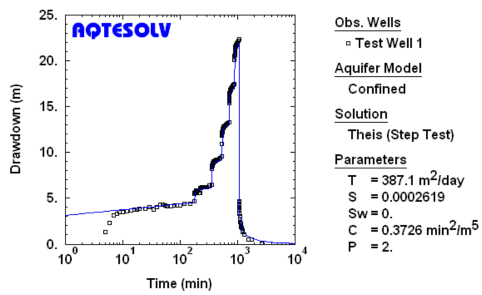
Step Test for Well Performance

- Use a minimum of three steps
- Each step should run for a minimum of ½ hour
- Test should begin with the lowest pumping rate
- Test should conclude with the highest pumping rate
- No recovery in-between steps



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Video Logging

- Quick to do
- Relatively inexpensive
- Excellent visual diagnostics

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Video Well Logging

- Downhole video cameras are a versatile tool to assess a variety of well problems
- Typically cameras are 2-inches in diameter and can extend to depths of around 1000 feet
- Other variations include small diameter cameras for wells with pumps or long cables up to 5000 feet

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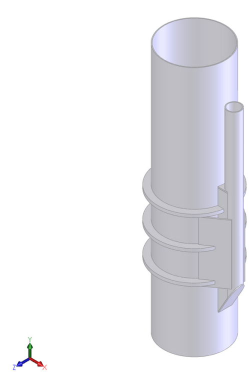
Video Logging

- Larger downhole cameras require the expense of pulling and re-installing the pump.
- Smaller cameras can use a camera tube on the well and are small enough to work with the pump in the well
- Advantage to see well while pump is working



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Karst Wells and KPIs

- Karst and Fractured Rock wells are usually open hole
- More subject to fracture related issues such as seasonal water level fluctuations and contaminants
- Subject to secondary porosity factors

Applicable KPIs for Karst:

- Water Quality Parameters
  - Especially Coliform Tests
- Specific Capacity
- Energy Measurements
- Well Performance Tests

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RECOMMENDATIONS FOR MAINTAINING WELL PERFORMANCE

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Key Performance Indicators

Key Performance Indicators (KPIs) are a powerful tool to indicate the health of a water supply well and determine the optimal schedule for rehabilitation.

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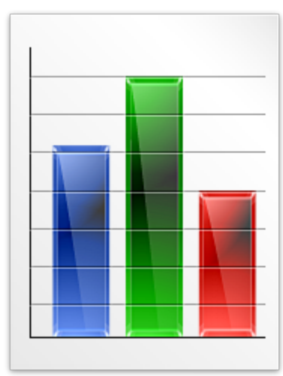
Key Performance Indicators (KPIs)

- KPIs are often used in business and finance
- Applicable to measuring water supply well performance over time
- Track the different performance factors specific to individual wells



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Not all performance measurements will be applicable to each well

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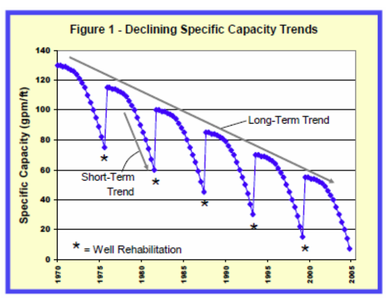
KPI Changes Over Time

- KPI changes over time can allow troubleshooting
- Using multiple KPIs is more reliable than a single KPI
- To be effective, must track KPIs at regular intervals over time



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Develop KPI Dashboard

- Determine 5-7 KPIs for tracking each well
- Wells can vary – even those close together
- Small operators can use a graphical spreadsheet as a dashboard
- Larger operators can develop web interface to share

Rehabilitate As Indicated by KPIs

- 5-15% decrease in specific capacity
- 10% decline in well efficiency
- 5-10% decrease in gallons per kilowatt-hour
- > 5 ppm sand
- BART/ATP tests indicate biofouling is occurring
- Video logging/geophysics indicate incrustations and/or filter pack plugging
- Water quality trigger levels

Budget Accordingly

- Well rehabilitation can be costly (5-15% of well replacement cost)
- Less expensive when done on optimal schedule
- Budgeting is important for smaller water districts
- Proper well rehabilitation and maintenance will extend the life of the well
- Overall life cycle costs will be reduced

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Questions?

For More Information:

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