The 9 Lives of Coliforms

Michigan DEQ Studies: Why Disinfection Fails 50% of the Time

By LeRoy Palmer, AWWS

Our Shared Mission

To protect the public health by ensuring safe and reliable drinking water.

The Well Environment: What's Going On Down There?

Fouling in the Well

- Initiates on screens or slot openings
- Develops and spreads to gravel pack as the
    - Blocks flow
    - Reduces capacity
- Accumulations slough off into the flowing water
    - Bacteria infest well, distribution lines and treatment systems

Biological Incrustation

- Plugging occurs due to biofilm buildup
- Microbial Organisms
  - Iron related bacteria
  - Slime related bacteria
  - Sulfate reducing bacteria
  - Anaerobic bacteria
  - Coliforms

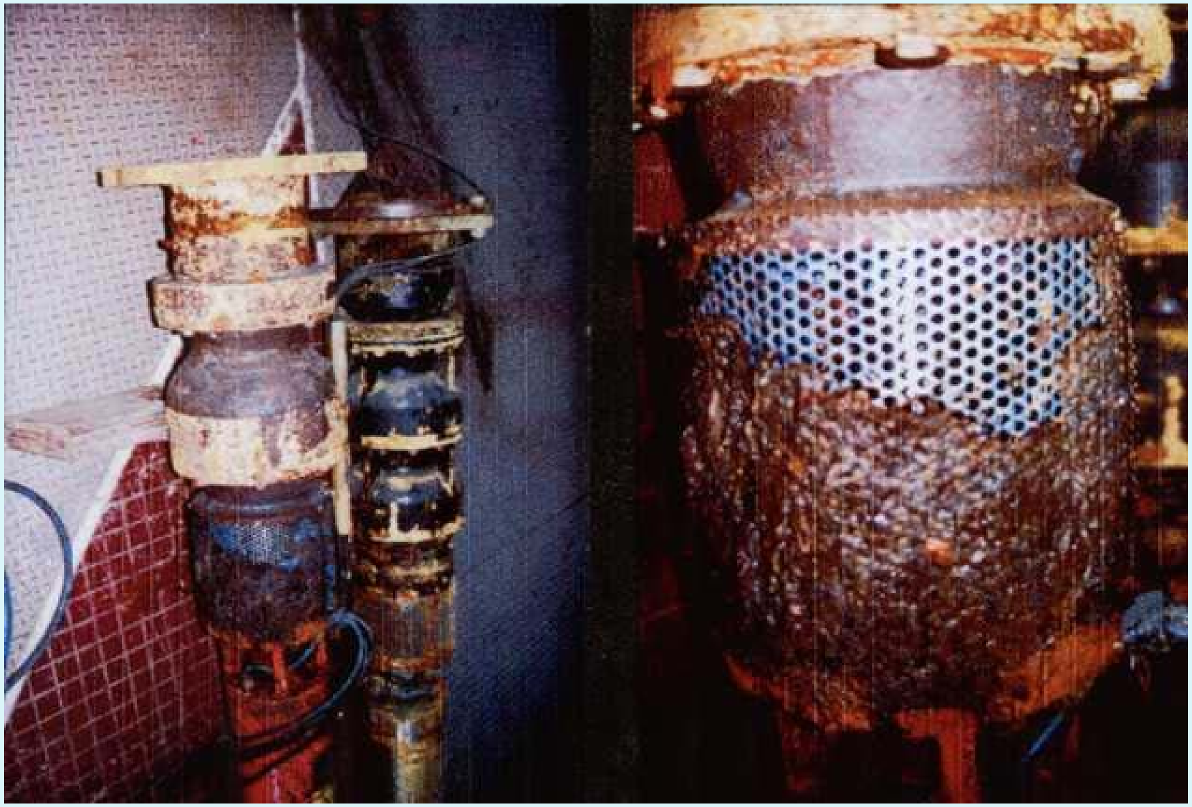
The orange color is an insoluble “slime”

a polysaccharide polymer that is produced by the bacterium as a means of attaching to a surface.

Well 10A - April 13, 2004
Photograph of the lower pump bowl removed after 17 years of service.

Photo by Stan French, L.G., L.HG.
Water Quality/Production Engineer
Lakehaven Utility District
Federal Way, WA

Chronic bio-fouling caused by Iron bacteria



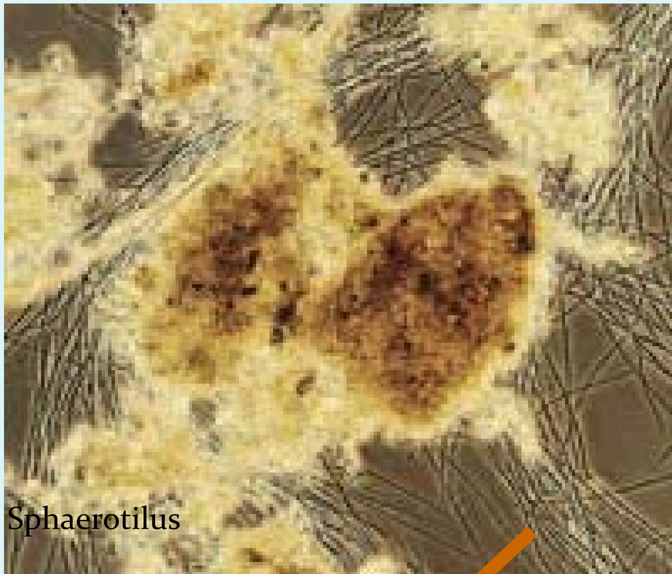
Many wells have been abandoned because of biofouling.

Water flow area virtually eliminated

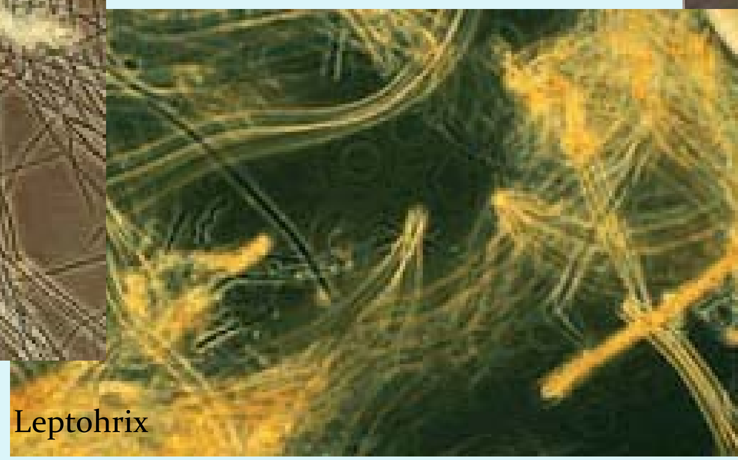



Iron Oxide Entrained Biomass

Iron Related Bacteria
(Iron, Sulfate, Manganese Utilizing Species)



Sphaerotilus



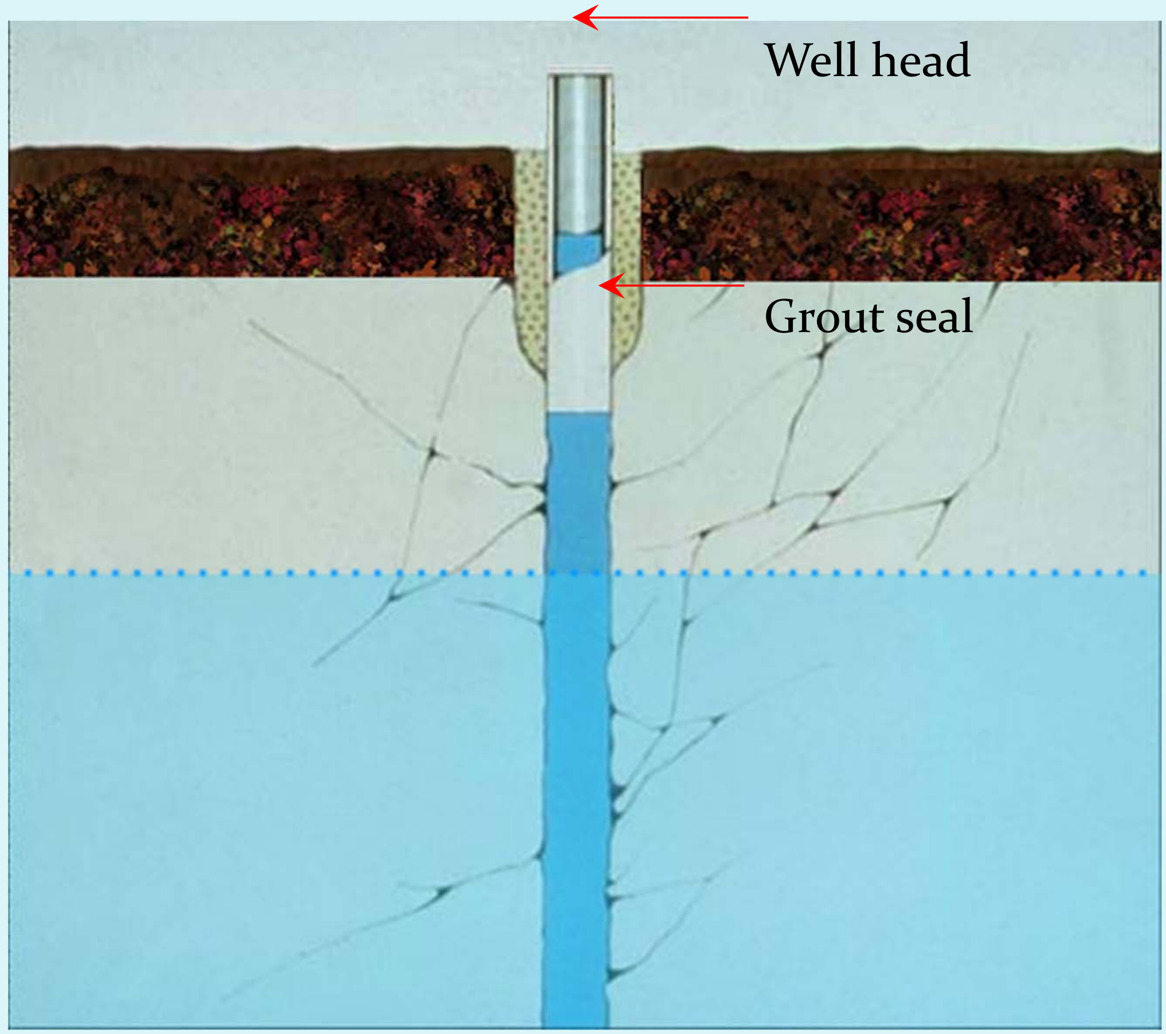
Leptohrix

Galionella
Ferruginea

E-Coli

Can encourage
pathogen growth

Think about it! Bacteria can easily gain entrance to the water well:



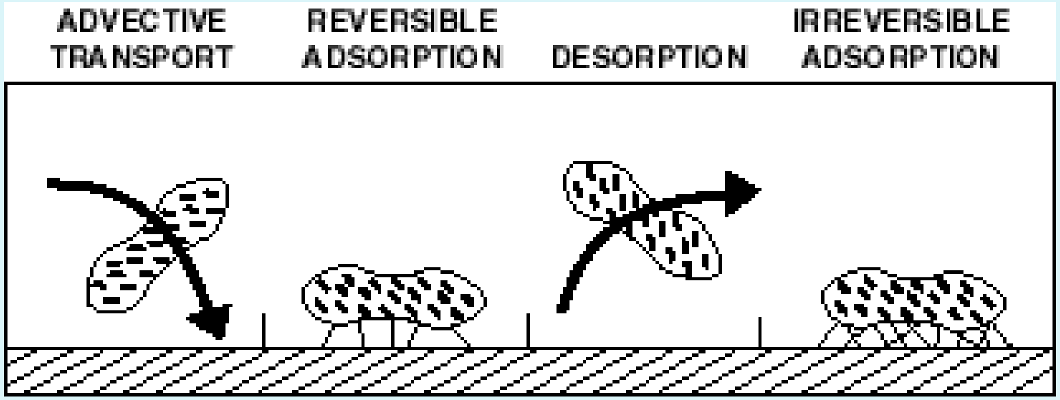
Understanding Biofilm Development

The instant a clean pipe is filled with water,

a biofilm begins to form.

Adhesion of 'pioneer' bacteria

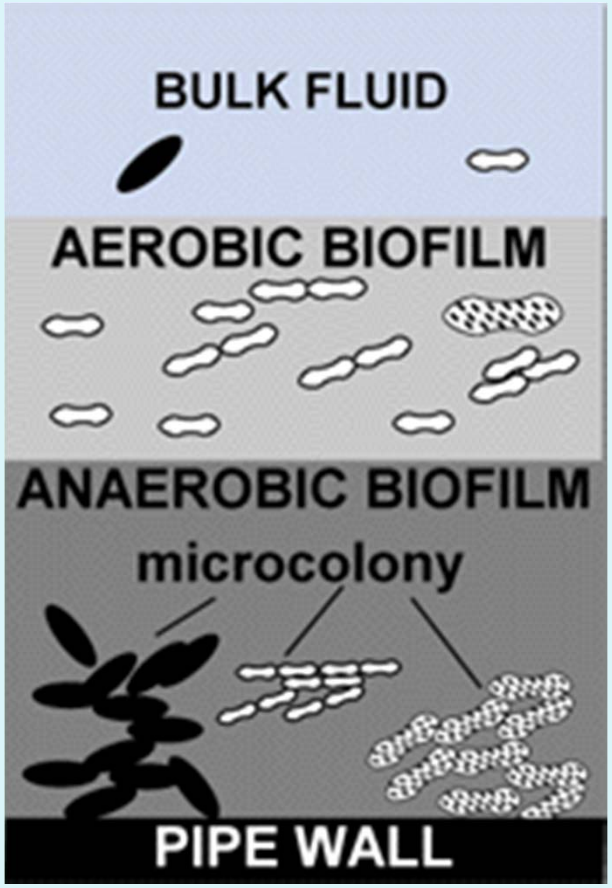
- In a pipe of flowing water, some of the planktonic (free-floating) bacteria will approach the pipe wall and become entrained within the boundary layer, where flow velocity falls to zero.
- Cells begin to form structures which may permanently adhere the cell to the surface.



Transport of bacteria cells to the conditioned surface.
(Characklis 1990)

http://www.edstrom.com/resources.cfm?doc_id=143

Biofilm Cross Section

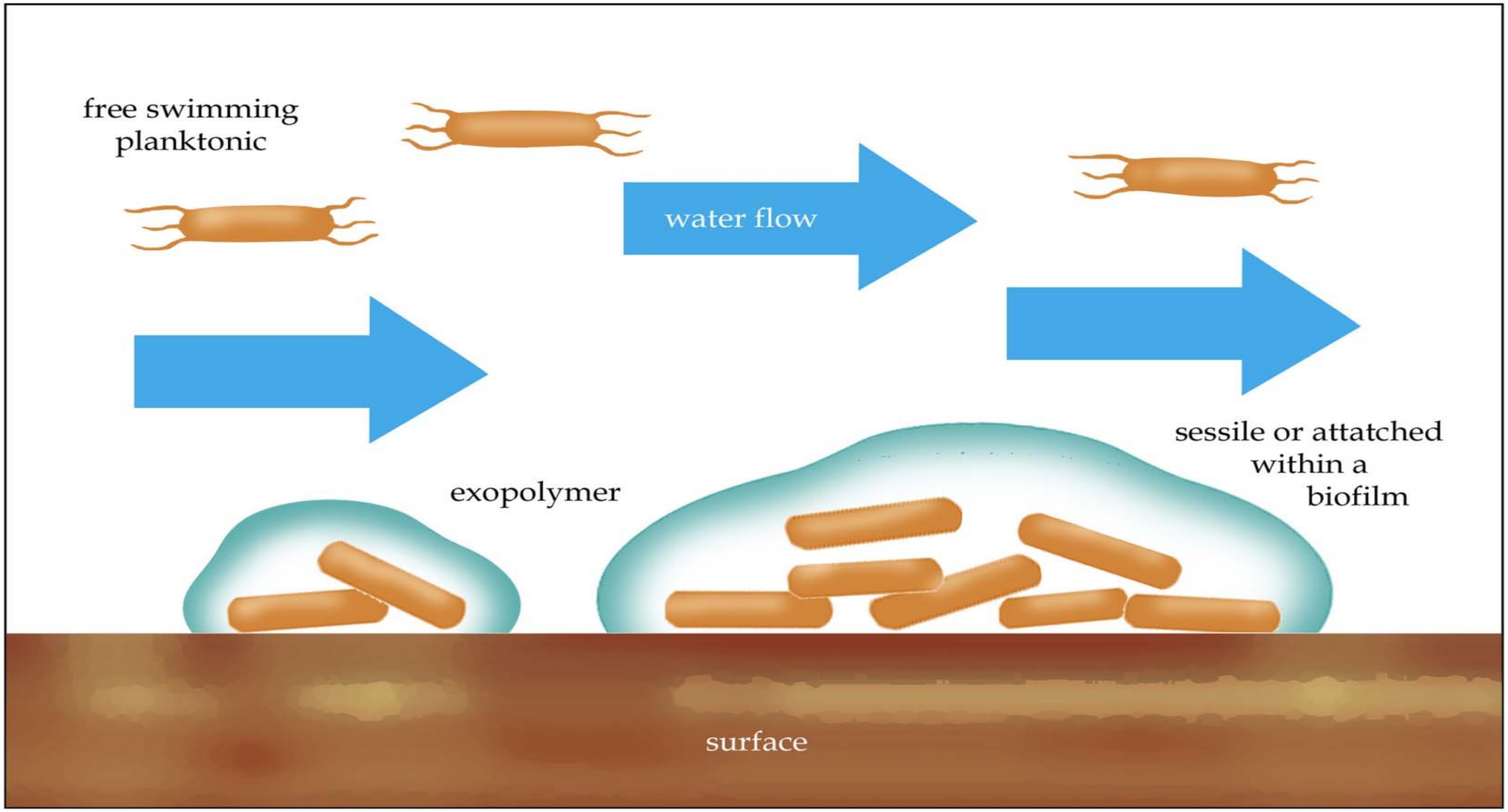


Bacteria and other microorganisms develop cooperative colonies or "consortia" within the biofilm.

Note: Coliforms are facultative; they can live in anaerobic or aerobic conditions.

http://www.edstrom.com/resources.cfm?doc_id=143

Biofilm formation, free cells to attached cells



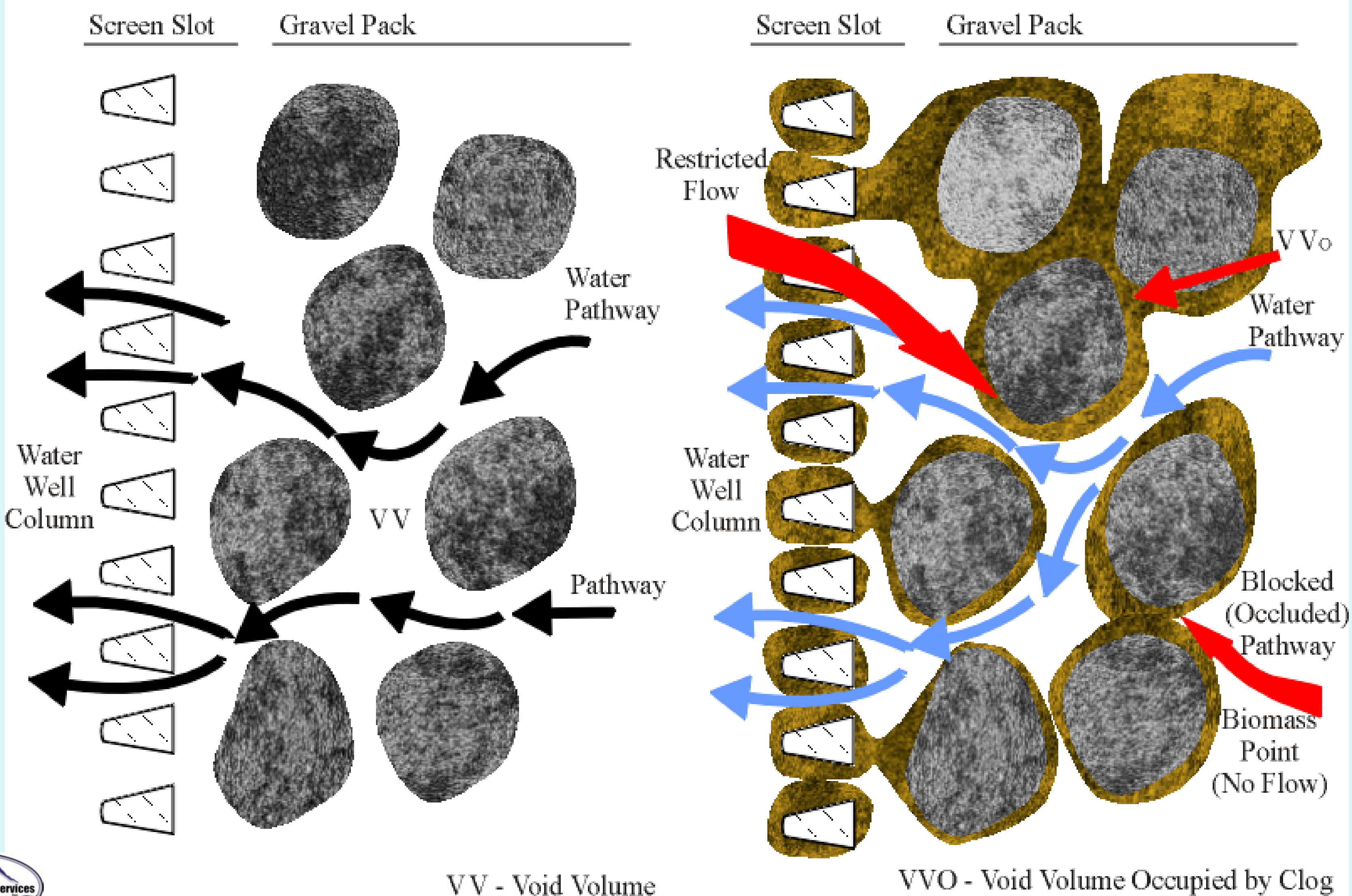
Biofilm Movement

Laboratory studies measured the rate of movement of biofouling through the fractured sand

An average rate of 4.2 mm per week was observed during a two year study

Developed Well

Biofouled Well



AmeriWest Water Services

Laboratory Services: Complete Well Profile

- One casing sample and one aquifer sample
- Includes inorganic chemistries
  - pH, alkalinity, bicarbonate, chloride, etc
- Bacterial assessment
  - Adenosine Triphosphate (ATP)
  - 2 major bacteria populations
  - Aerobic vs. anaerobic growth
  - Iron bacteria
  - Coliform bacteria

AmeriWest Water Services, Inc.

P O Box 44683
Boise ID 83711-0683

Phone/Fax: 208-658-806
Cell: 208-861-341

PROVIDE THE FOLLOWING INFORMATION FOR EACH WELL SAMPLED

Well Name (No.):______________Owner/Field:______________
Date Collected:______________Collection Point:______________
Was well idle for more than 24 hours before collection? Yes ( ) No ( )
Sample Submitted by:______________
City/State:______________Phone:______________
Fax: ______________Attn:______________

FOR CHEMICAL ESTIMATION:

Well Total Depth __________
Well Diameter __________
Borehole Diameter __________
Static Water Level __________
Total Feet of Screen/Perforations__________

Age of Well __________
Orig. GPM__________
Orig. Sp. Cap.__________
Current GPM__________
Current Sp. Cap. __________

Material of Construction of Screen and Casing __________
Does the well have a gravel pack? __________size and material:__________

OTHER INFORMATION:

Has well been treated before?______________How long ago?______________
What was used?______________
Any noticeable odors or turbidity?______________
Type of Well: ____Potable Water Well ____Recovery Well ____Injection Well
____Remediation Well ____ Other - please specify: ______________

STATEMENT OF PROBLEM: ______________

CHECK TYPE OF ANALYSIS REQUIRED:

Complete Profile:______________ (Requires a 1000 ml sample taken within one minute of startup and one 1000 ml sample taken after the well has run four hours or longer).

CHECK TYPE OF REPORT REQUIRED: (X) Complete Report with Recommendations
( ) Complete Report with Interpretation Only: ( ) Report Data Only

Send Report To:______________ **Bill To:**______________

Purchase Order #:______________

NOTE: Please **DO Not** add preservative to samples. Submit a minimum of 1-quart (1000 ml) per tightly sealed plastic container. Fill completely before sealing to minimize entrapped air. Send via UPS or Fed-Ex, overnight, (scheduled to arrive Tuesday through Thursday).

Send sample to: AmeriWest Water Services, Inc.
c/o Lab-Water Systems Engineering Inc.
3201 Labette Terrace
Ottawa, Kansas 66067

Monitor Wells with History of Slime Bacteria

- Difficult to remove from system
- Water samples to lab
- Measure of effectiveness
- Monitor fouling before significant levels occur

Effective Treatment Includes

- Identification
- Treatment
- Monitoring

Coliforms and Disinfection: A History

- Coliforms are a group of bacteria used as indicators of possible waste or fecal contamination
- Originally thought to be found only in the gut of warm-blooded animals and man.
- Discovered that they can live outside the gut of animals and are found naturally in the environment
- Colilert test in the 90's allowed testing for coliforms and E. coli in the same test.
- Too much emphasis on coliforms and not enough on E. coli

What do we know about coliforms?

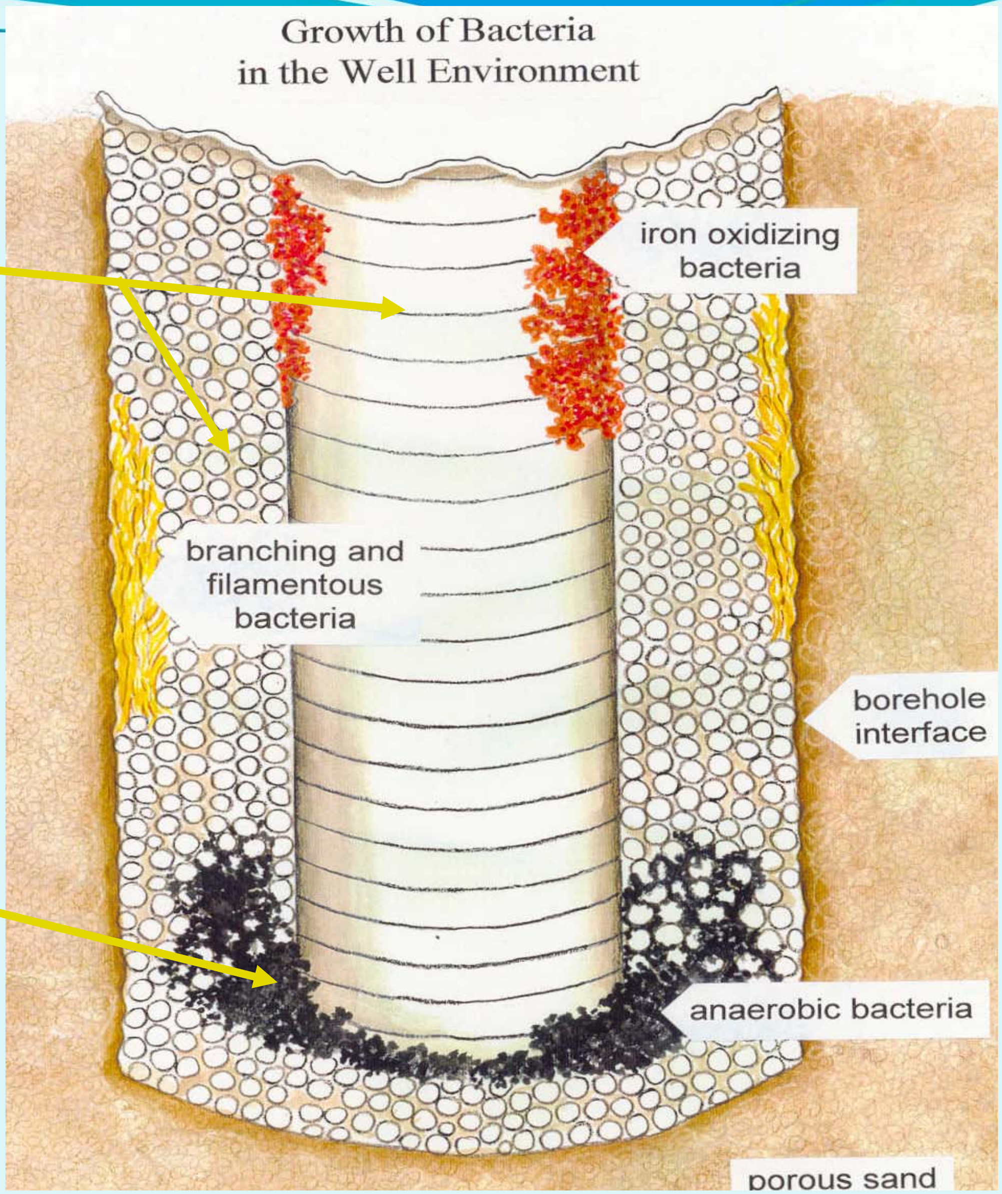
1. They can indicate contamination
2. They are persistent.
3. If they are free swimming, chlorine will kill them.
4. They are naturally occurring in the environment.
5. They often inhabit and grow in wells.

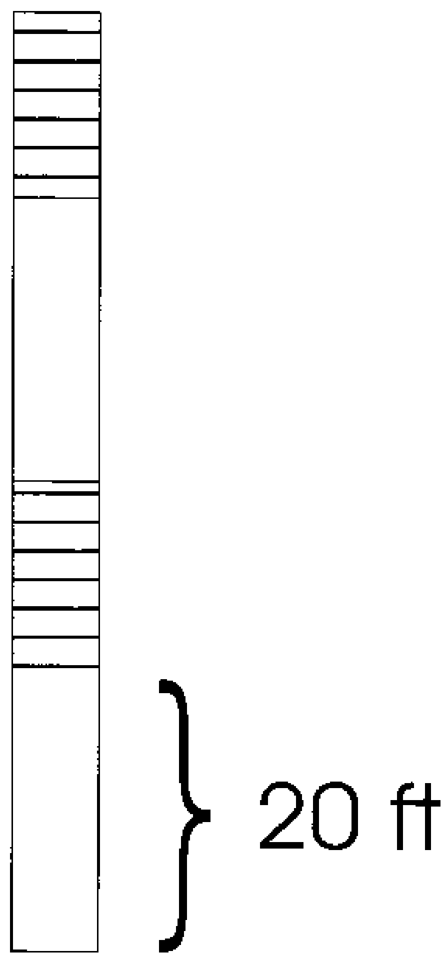
What else do we know about coliforms?

They are facultative! They can live in both the aerobic and the anaerobic zones of the well.

Aerobic bacteria are higher up in the well or water flow

Anaerobic & facultative bacteria are located in the lower regions of the well





Anaerobic conditions affect water quality

Sulfate related bacteria and other anaerobes thrive in uncirculated water at the well bottom (sump).

Control of Microbial Growth: Definitions

Disinfection: Reducing the number of pathogenic microorganisms to the point where they no longer cause diseases. Usually involves the removal of **vegetative** or **non-endospore** **forming** pathogens.

- **Disinfectant**: Applied to inanimate objects.
- **Antiseptic**: Applied to living tissue (***antisepsis***).
- **Degerming**: Mechanical removal of most microbes in a limited area. Example: Alcohol swab on skin.
- **Sanitization**: Use of chemical agent on food-handling equipment to meet public health standards and minimize chances of disease transmission. E.g: Hot soap & water.

Testing for coliforms

So the P/A test hit Positive…

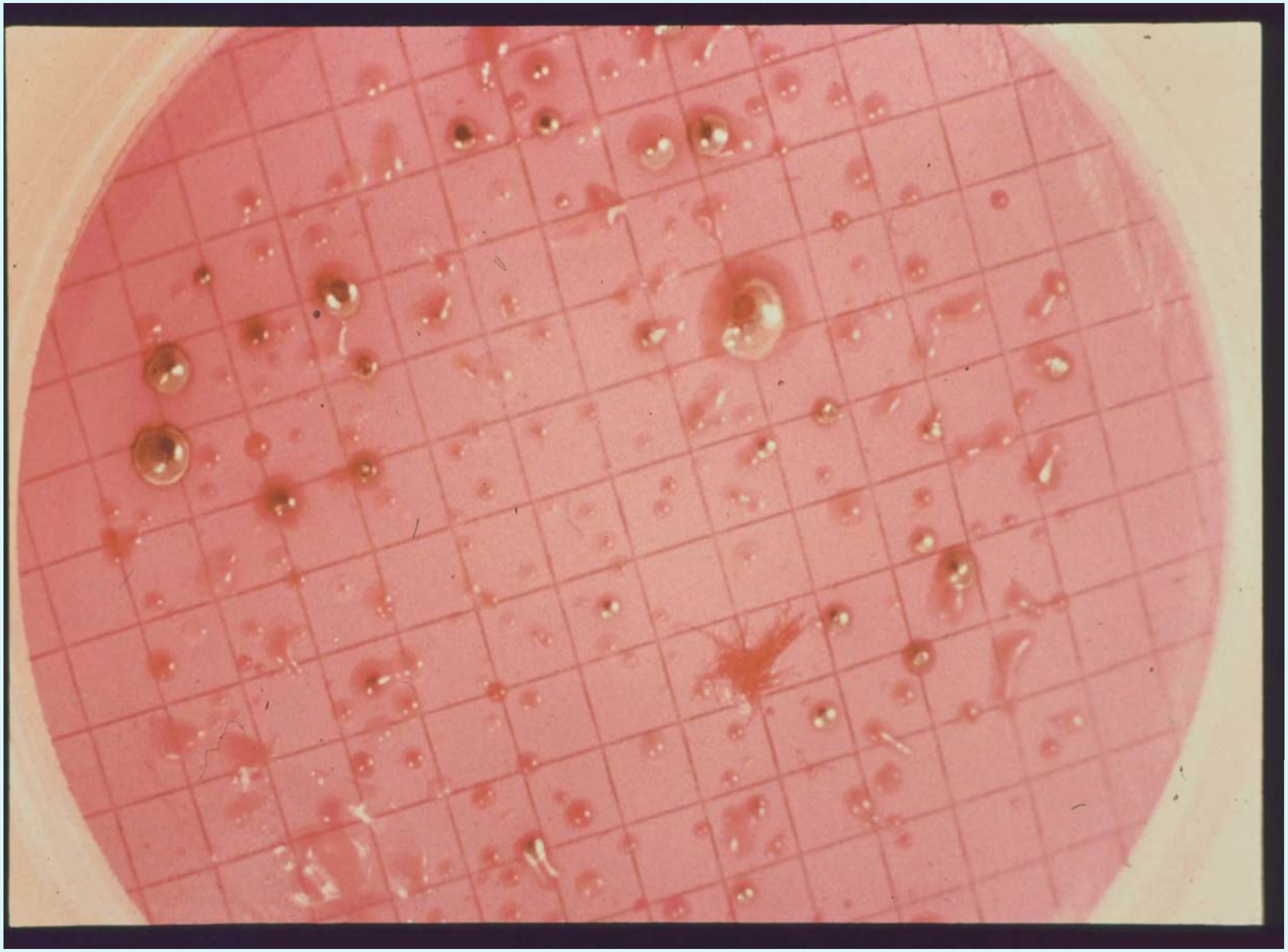
Classify the organism

ID the organism

Enumerate the occurrence

Evaluate the community

Investigate the Well



Wells with coliforms have been inaccurately labeled as "contaminated wells"

Politicians and regulators have pointed to the rise in positive coliform detection as "wide spread water contamination"

- It has resulted in unprecedented pressure to rechlorinate and super- chlorinate these wells

Classify, ID, and Enumerate the Organism

Were fecal coliforms present?

What is the coliform and what are the likely sources?

How many are present?

How does this information tie in with the Well site?

What else is occurring with the Well?

Most coliform occurrences are tied with fouled wells and/or wells that have been idle and out of service for an extended period

Common Bacterial Indicators:

- Wells exhibiting anaerobic occurrence greater than 20%
- Wells exhibiting large bacterial populations
- Presence of slime forming bacteria and/or Sulfate Reducing Bacteria

Objective

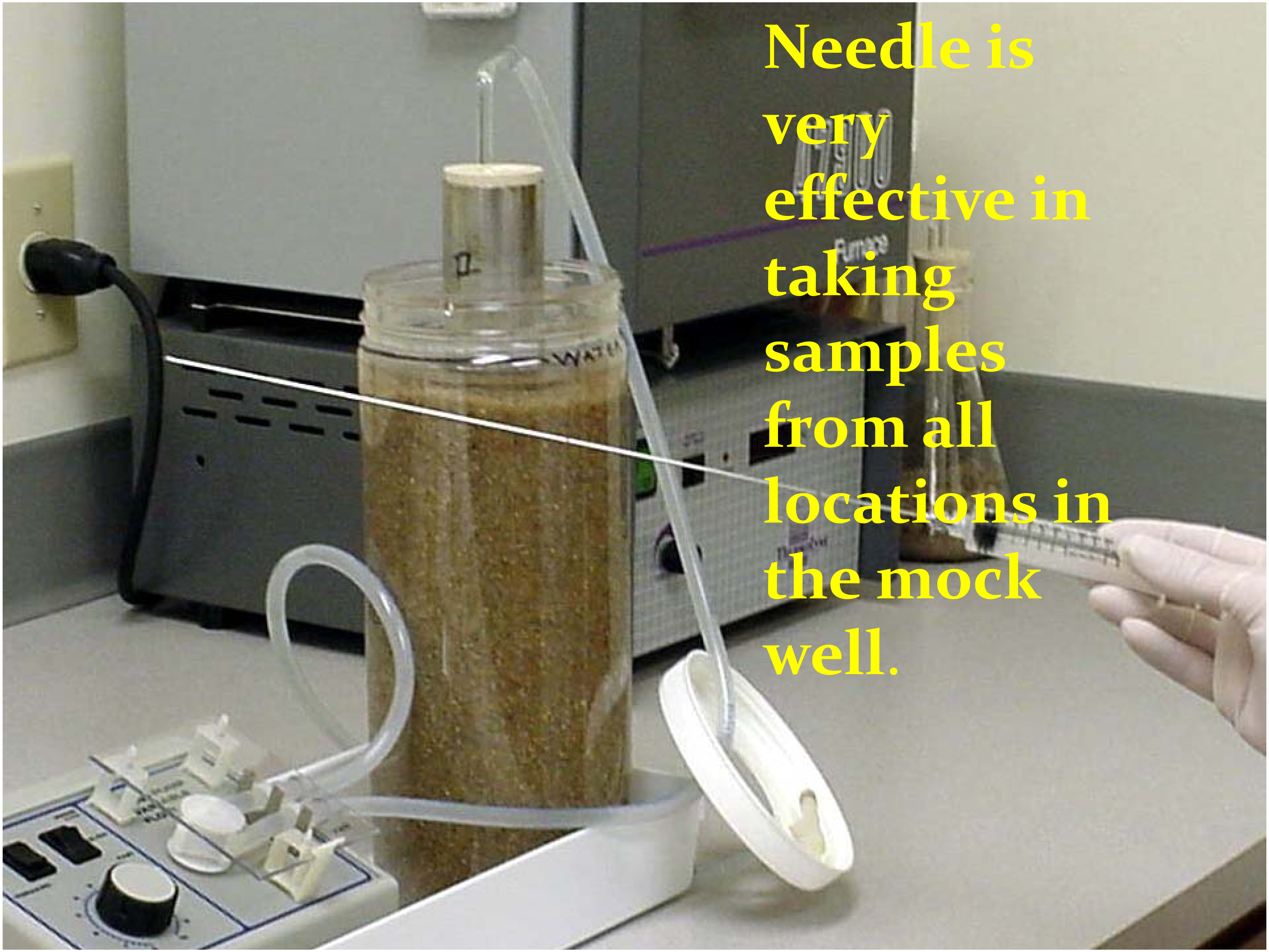
Sponsored by the Michigan DEQ to reduce the number of failures during rechlorination of wells

Workshops were held around the state to give out the results of the lab work and gather information on the most successful practices.

Laboratory study: Researched…

“Effective levels of chlorination”

Biofilms are grown on silica sand and seeded with coliform bacteria. They are then tested to see how different levels of chlorine affect the removal of coliforms.


Needle is very effective in taking samples from all locations in the mock well.

Chlorine treatment levels:

20 mg/l   50 mg/l

100 mg/l   200 mg/l   500 mg/l

The hypochlorite remained in the test unit overnight or a minimum of 10 hours.

Super chlorination levels:

1000 mg/l

2000 mg/l

5000 mg/l

Shock Chlorination

An industry response when using chlorine:

“*a little chlorine is good, MORE is BETTER*”

Shock Chlorination typically indicates a treatment of 1000 ppm or greater

All levels of super chlorination failed as measured by coliforms found in the discharge from the mock wells!

Most effective levels were the 50 mg/l and the 200 mg/l of chlorine

500 mg/l failed about 50% of the time

Effectiveness was measured as a function of zero coliforms in the discharged water

Why Did Chlorine Fail at the Higher Dosages?

- **High concentrations are very oxidative**
- **Higher levels can be greater than pH 10**
- **High pH promotes mineral precipitation**
- **Strong oxidation changes the polysaccharide…**

…which hardens the biofilm covering

AmeriWest Water Services

In over 90% of the cases that coliforms were found in the discharge of our mock wells the extracted samples were also positive for anaerobic bacteria.

What is the significance?

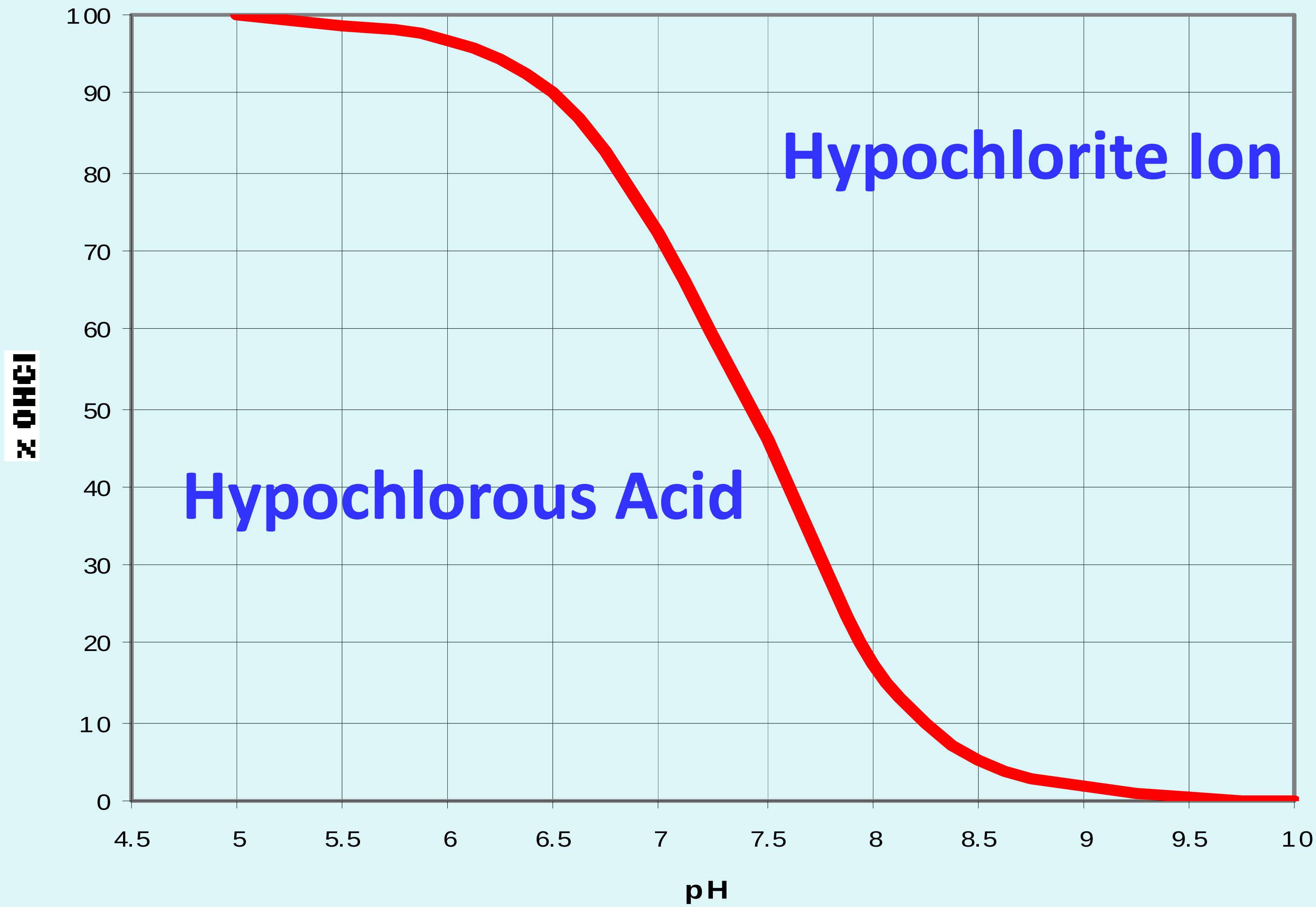
1. Coliform bacteria which are facultative use the anaerobic slime or biofilm as a protective home against the chlorine.

2. Disinfection must provide a means for chlorine to reach the anaerobic area. (well bottom)

What Interferes With the Disinfection Process?

- High pH
- Low water temperature
- Turbidity
- Insufficient mixing and poor placement in the well
- Presence of chlorine-demanding compounds, such as ammonia, organics, iron or manganese

Effects of pH on Hypochlorite Ion



Oxidative Chlorine
vs
Biocidal Chlorine

Biocidal Chlorine	Oxidative Chlorine
Kill is instant, upon contact.	Kill takes up to 48 hours.
Total solution dedicated to bacteria.	Very little percentage dedicated.
Doesn't oxidize minerals in solution.	oxidizes minerals in solution.
Non-corrosive.	Very corrosive.
Very little odor.	Excessive odor, very dangerous.

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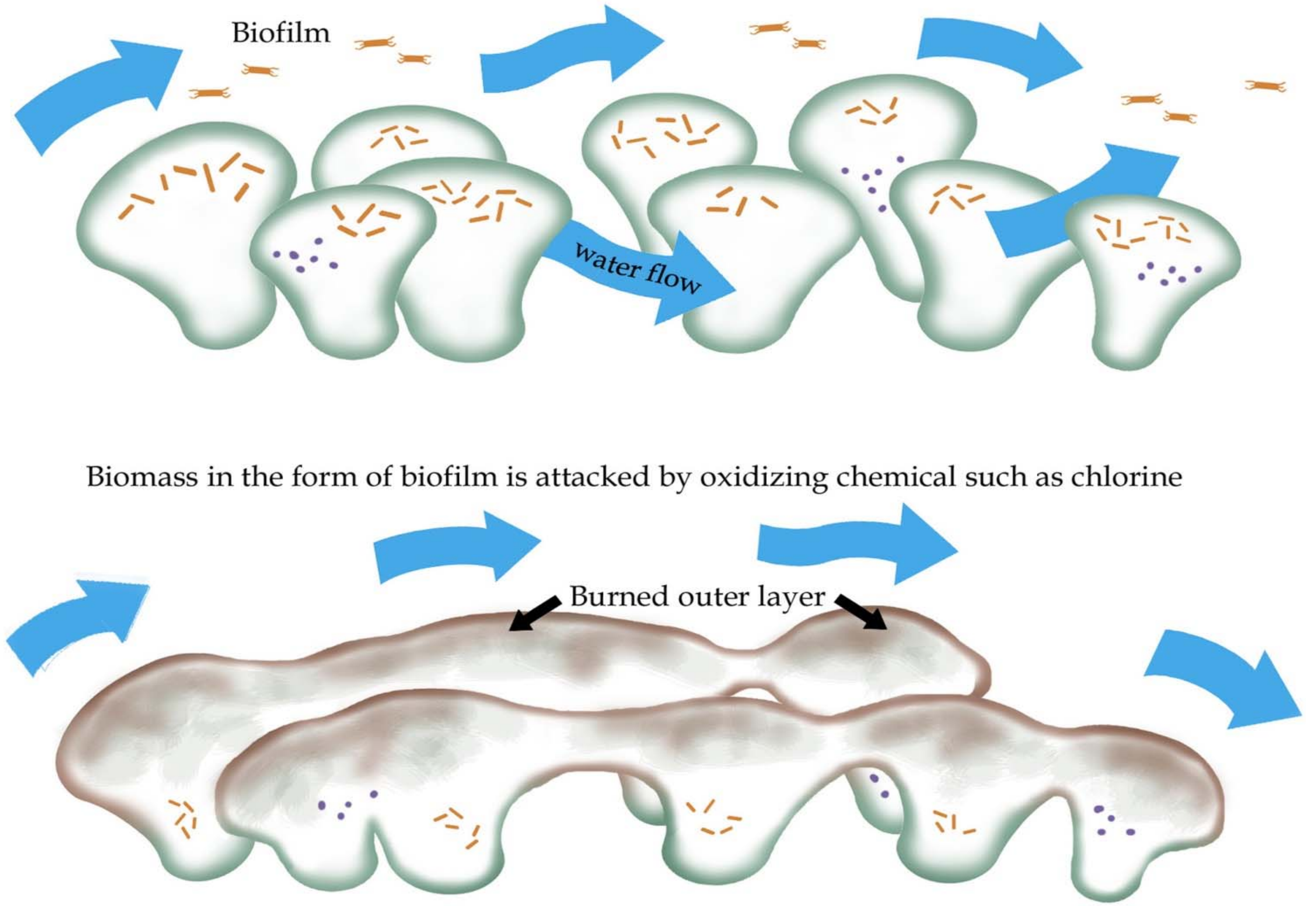
Expert Water Quality Solutions

Effect of excessive Chlorine use



Field study:

“Survey of disinfection practices”

Michigan's DEQ and Water Systems Engineering Joint study: Involved a lab study and over 300 well contractors studying their coliform successes and failures

- Led to better understanding of how coliforms reside in wells in a biofilm environment and
- What steps can be used to increase the effectiveness of chlorination and the over all process of disinfection
- Almost all wells with chlorine levels above 1000 mg/L proved positive for coliforms after one week
- The anaerobic protected zones of biofilm contained viable coliforms after chlorination

Workshops were designed to disseminate this information:

1. 50 mg/l to 200 mg/l most effective level.
2. pH control improves chlorination.
3. Disinfection must include mechanical activity to reach anaerobic zones.
4. Sodium hypochlorite is more soluble.

Techniques learned from the most successful contractors

1. **Well development and additional pumping**

2. **Cleanout or evacuation of debris**

3. **Well flooding reaches outer area (treatment volume 4 time well volume)**

4. **Good surging or mechanical activity**

After One Year

Recommendations for chlorine concentrations and application were sent throughout the state and even became law through legislative action.

Results of Implementing Recommended Changes

1. A drop of over 80% in the number of rechlorinations

2. pH control has been very effective

3. Of 100 wells cleaned and pumped for 24 to 48 hours, 60% were coliform negative without treatment.

What We Have Learned About Chlorine Disinfection

- Ph control is critical to your success during special disinfection projects
- Levels below 50 mg/L or above 200mg/L
  can be less effective
- Placement next to the biofilm is necessary
- It requires strong physical agitation

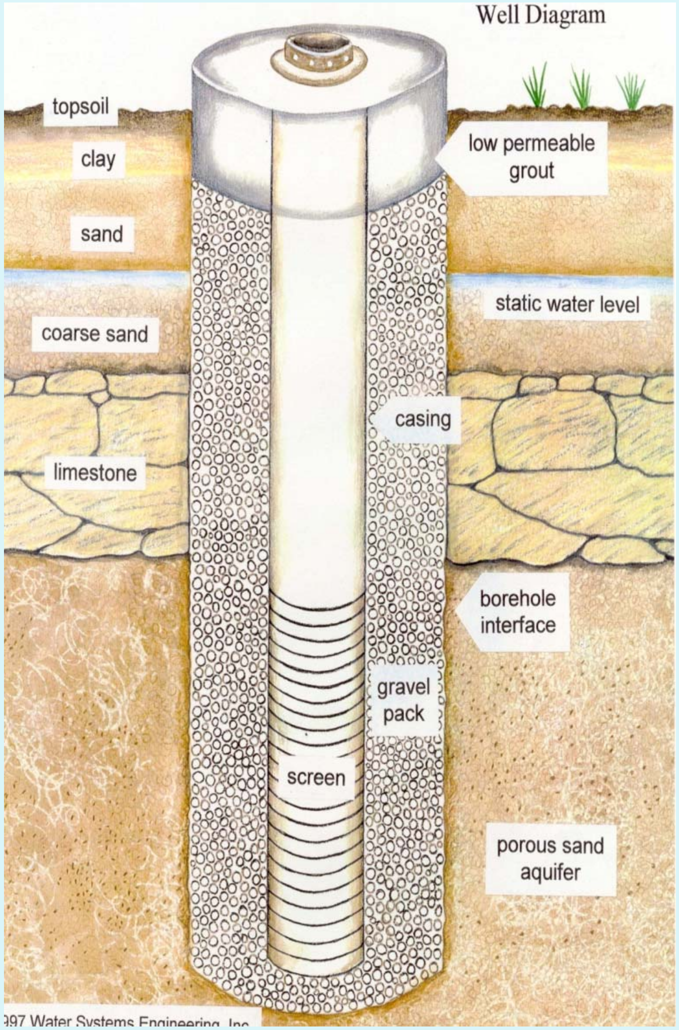
The Positive Aspects of Disinfection With Chlorine

- Broadly active
- Maintains a residual
- Penetrates cells
- Mostly stable
- Easy to work with
- Not dangerous in dilute concentrations

What to do if coliform positive?

1. **Rule out** contamination from a waste water source.

2. **Rule out** con-tamination from poor construction or structural failure.



3. **Incorporate** cleaning pro-cedures as part of the disinfection process. **You must remove** the biofilm and other debris from the sump or well bottom.

How Do We Respond?

ID the Problem

Pump the Well

Clean the Well if Necessary

Chlorinate Correctly

Keep the Well Active

Pump the Well

- Purge the stagnant water column
- Evacuate the bottom of the well

- Clean out debris that may be influencing the coliform occurrence and/or reducing the effectiveness of our treatment

Clean the Well? For Coliforms?

- Laboratory studies have shown that most environmental coliform occurrences are a result of a dirty well

- Biomass and scale accumulations provide hiding places for coliforms and reduce the effectiveness of treatment efforts

Cleaning the Well

- When Coliforms are present, cleaning the well should incorporate a combined chemical and mechanical cleaning

- Including removal of the pump and cleaning of all associated parts

Chlorination for Disinfection

- Myth of “shock chlorination”
- Choosing the right Chlorine
- Controlling the pH
- Targeted Treatment Area
- Contact Time

Improving Chlorination for Disinfection

- Control the pH
- Flood the Well Improving Dispersal of the Chlorine
- Sufficient Contact Time
- Monitor the Reaction

How do I adjust the pH?

There are a number of commercial products available that bring additional benefits such as improved penetration of the chlorine solution and control of the excess hardness in the water.

Only products which are dosed according to the alkalinity of the water, the level of hypochlorite used, and the volume to be adjusted should be considered.

Chlorination Step

- Water's pH is lowered to a pH of 4.5
- Chlorine is added
- pH comes up to 6.5 and stops

AmeriWest Water Services

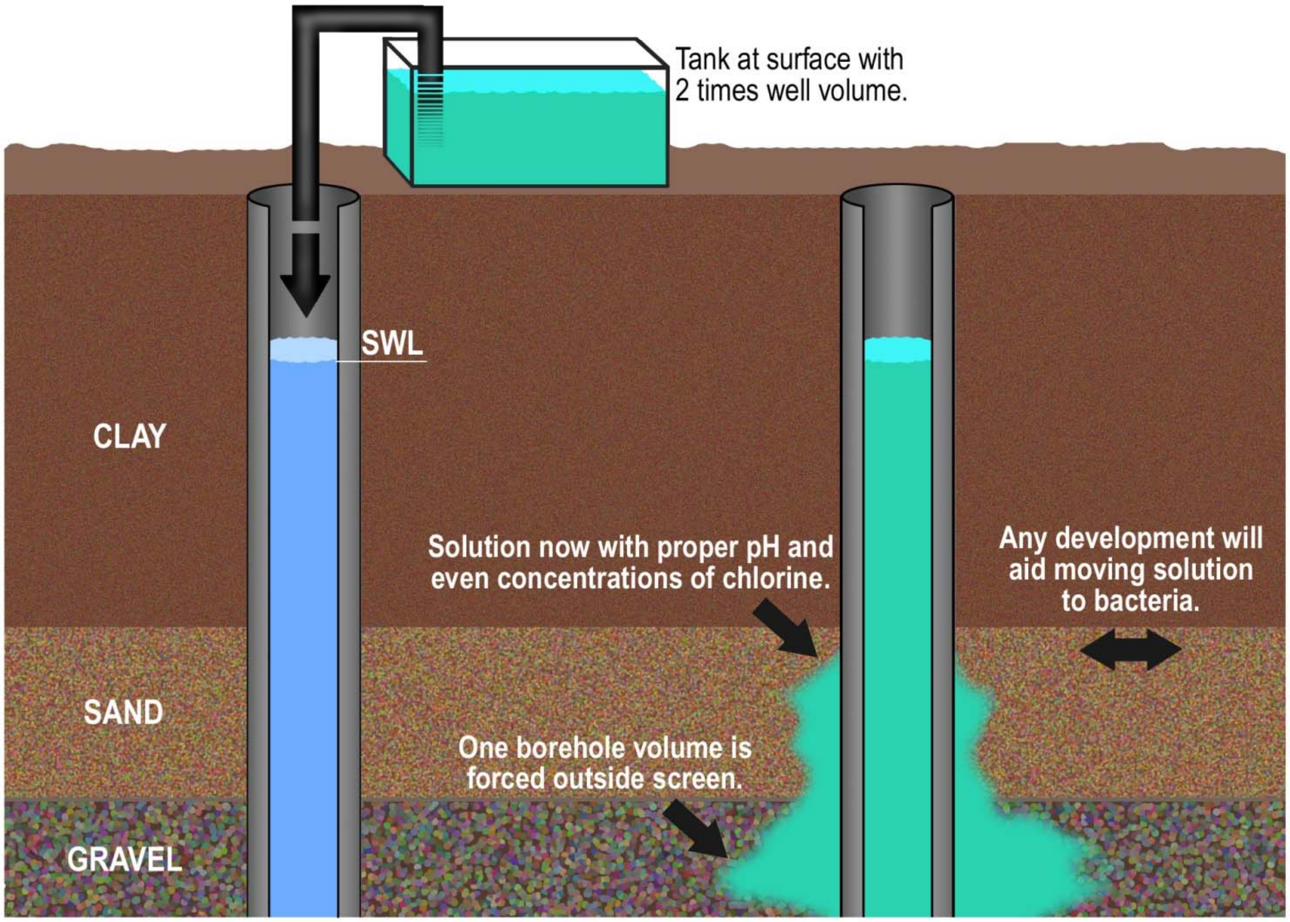
Large Scale Chemical Treatment

Large Scale Chemical Treatment

Acid reacting in the well and foaming up to the surface

Proper Chlorination

Step 1: Calculate 2 times volume of well.
Step 2: Monitor and adjust pH, if necessary.
Step 3: Use proper concentration of chlorine and mix thoroughly. Pump or pour into well. Surge. let set overnight. Pump til pH returns to normal. Take sample.



12 Step Disinfection Protocol

1. Id the problem, Investigate Well, Pump the Well
2. After pumping the well, remove pump and swab or brush the well. Clean if necessary.
3. Evacuate all the debris from the well.
4. Prepare a chlorine solution in a tank large enough to contain 4 well volumes.
5. To the tank of water add a pH buffering solution.

12 Step Disinfection Protocol

6. After mixing add the sodium hypochlorite to achieve 50 to 200 ppm.

7. Mix the hypochlorite solution.

8. First wash down the exposed casing by adding 20% to the top of the well.

9. Tremie 20% into the area between the static and the top of the screen. Place 20% at the top of the screen, 20%midway in the screen zone and 20% at the well bottom.

WATER SYSTEMS ENGINEERING

12 Step Disinfection Protocol

10. Swab or surge the well spending at least ½ to 1 minute per foot of casing. Swab the screen area for at least 3 minutes per foot.

11. Let stand overnight or at least sufficient time to achieve 1000 contact units. Repeat swabbing at ½ time and evacuate the well. Pump a minimum of 20 well volumes.


dBL
77.5

12 Step Disinfection Protocol

12. All associated piping, pump, etc. should be washed with the chlorine solution.

Open borehole wells should be treated as if the open borehole is the screened zone. Pressure jetting should be used to prevent damage to the borehole wall from a swab or surge block. Evacuation of debris is of utmost importance.

Summary

- Chlorine comes closest to being the "ideal" disinfectant
- Chlorine has saved millions of lives around the world
- Chlorine can be used at the source for disinfection in addition to maintaining residuals in the distribution system
- All water has microorganisms but not all are Pathogenic
- Chlorine without pH control and proper concentrations can be very ineffective
- Biofilm is present in all water environments
- More is not always better

We never know
the worth of water
until the well is dry.

English Proverb

Any Questions?