Well Systems – An Introduction to Operation and Maintenance

Maryland Center for Environmental Training
301-934-7500
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www.mcet.org

Well Systems:
An Introduction to Operation and Maintenance

Eddie Cope, CET

Introductions

- Instructor
- Course Participants
  - Name
  - Where you work
  - Type of system(s) that you operate
  - Expectations of this training

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Topic to be covered

- Operator Responsibilities
- Regulations
- Water Use and the Water Cycle (Hydrology)
- Groundwater Sources and Aquifers
- Wells and Wellhead Protection
- Well Permitting and Construction
- Well Operation and Maintenance

Topics continued

- Well Rehabilitation
- Well Sampling and Testing
- Contaminants and Treatment

Regulatory Setting

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Public Water Supply Regulations

- The Safe Drinking Water Act of 1974

  Directs the EPA to establish standards and requirements necessary to protect the public from all known harmful contaminants in drinking water.

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Classification by Treatment Process (MDE)

Class of Plants	*Type of Treatment Systems*	*Typical Processes Included in the System*
1	Disinfection	Chlorination
2	Chemical Treatment	Chlorination, pH control Fluoridation
3	Simple Iron Removal	Chlorination, pH control, fluoridation, filtration, and iron removal utilizing ion exchange or contact oxidation processes.
4	Complete Treatment	Chlorination, pH control, fluoridation, aeration, coagulation, sedimentation, filtration, and complex iron removal.
5	Site Specific	Site specific - any alternative technology plant not covered under the classification system.
G	No Chemical Treatment	Well, storage tanks, UV disinfection

Well Permitting


MARYLAND DEPARTMENT OF THE ENVIRONMENT
Water Management Administration - Water Supply Program
1800 Washington Boulevard • Baltimore, Maryland 21230
(410) 537-3590 • 1-800-633-6101 • fax (410)537-3157 • http://www.mde.state.md.us

APPLICATION TO APPROPRIATE AND USE WATERS OF THE STATE

☒ New Application Change in Existing Permit Application Number AA1986G070/04

APPLICATION

Anne Arundel County - DPW - Water Operations (Owners Name) 410/222-8410 (Daytime Phone Number)

437 Maxwell Frye Road (Mailing Address) (Street) Millersville (City) MD (State) 21146 (Zip Code)

WITHDRAWAL of GROUNDWATER

Appropriate and use an annual average of 1,000,000 (Total Annual Use / 365) gallons per day, and 1,500,000 (Highest Monthly Use / 30) gallons per day during month of maximum use, from 2 wells, having a diameter of 12 (Estimate) inches, and a depth of 1,600 (Estimate) feet

PATUXENT AQUIFER

WITHDRAWAL of SURFACE WATER

Appropriate and use an annual average of ______ (Total Annual Use / 365) gallons per day, and a maximum use of ______ gallons in any one day from ______ (Name of Stream or Waterway) ______ (Exact Location of Intake)

PROJECT LOCATION

Truman Parkway west of Riva Road; ADC Map 19; Grid H-9 (STREET ADDRESS - MAP DIRECTIONS - ADC PAGE/GRID - TAX MAP PAGE/GRID/PARCEL)

County Anne Arundel Subdivision or Town Broad Creek Phone Number 410/222/8410

Name and Type of Business Anne Arundel County Department of Public Works

SUBDIVISIONS MUST INCLUDE PLAT - ALL PROJECTS MUST INCLUDE LOCATION MAP

PURPOSE

The water will be used for:
- ☒ Community Water Supply
- ☐ Non-Potable Supply (sanitary non Drinking Water)
- ☐ Potable Supply
- ☐ Cooling Water
- ☐ Irrigation
- ☐ Process Water
- ☐ Other, explain ______

WASTEWATER TREATMENT AND DISPOSAL
- ☐ Public Sewer
- ☐ Groundwater
  - ☐ Subsurface (Tilefield, Seepage Pit etc.)
  - ☐ Spray Irrigation
  - ☐ Other, Explain ______
- ☐ Surface Water ______ (Name of stream)

DISCHARGE PERMIT # ______

SIGNATURE [signature]
[handwritten name] 8/8/2014
PRINT (Name) (Title) (DATE)
Acting Asst Chief Eng/A

THIS APPLICATION WILL NOT BE PROCESSED WITHOUT A SIGNATURE AND LOCATION MAP

REVIEW BY COUNTY ENVIRONMENTAL HEALTH OR DESIGNATED AGENCY

THIS SECTION NOT TO BE COMPLETED BY APPLICANT

IS PROJECT CONSISTANT WITH THE COUNTY WATER AND SEWER PLAN AND LOCAL PLANNING AND ZONING?

☐ YES ☐ NO, Explain ______

Signature of County Representative ______ (Signature) (Title) (Date)

Form Number MDE/WMA/PER.001
Revision Date 09/09/2002
TTY Users 1-800-735-2258

Page 1 of 1
RECYCLED PAPER

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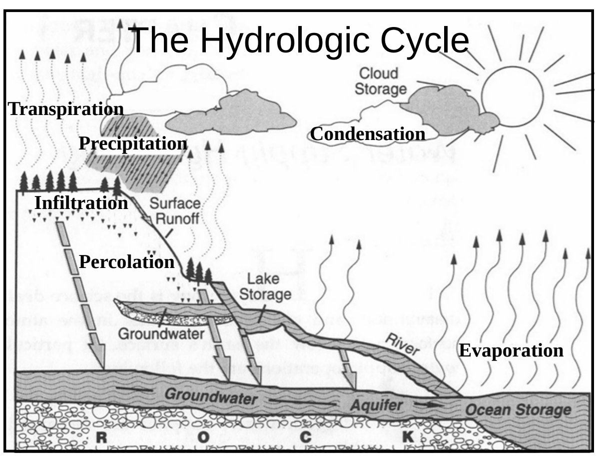
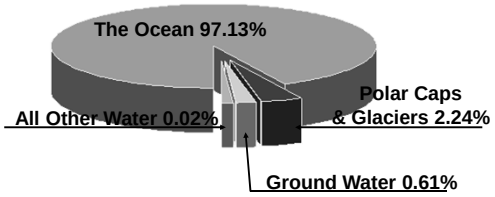
The Hydrologic Cycle



Where is the Water?



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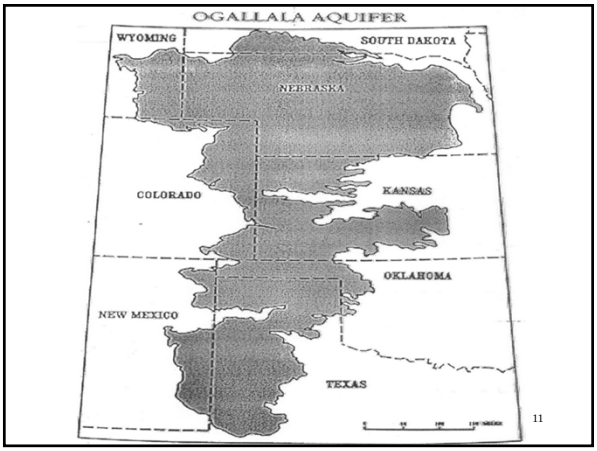

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Groundwater Sources

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Important Terms

- Aquifer
- Static Water Level
- Pumping Water Level
- Drawdown
- Residual Drawdown
- Well Yield
- Specific capacity
- Transmissivity

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Important Terms (cont.)

- Permeability
- Porosity
- Mutual Interference

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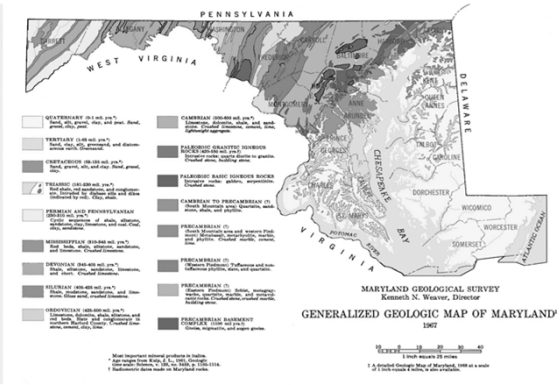
Generalized geologic map of MD



MD Geology

- 3 regions: Coastal Plain, Piedmont, and Blue Valley and Ridge and Appalachian Plateau.
- Coastal Plain: gravel, sand, silt and clay
- Piedmont: igneous and metamorphic rock
- Valley, Ridge, Plateau: Sedimentary rocks (limestone)

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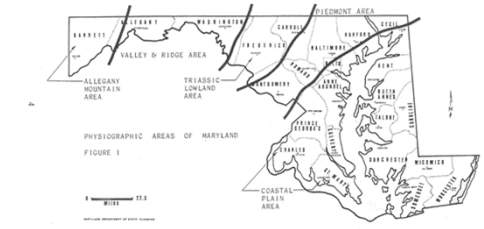
Maryland's Five Geologic Areas



Major Aquifers in MD

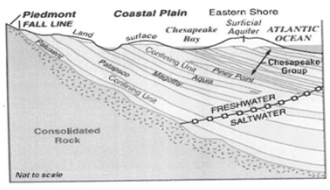
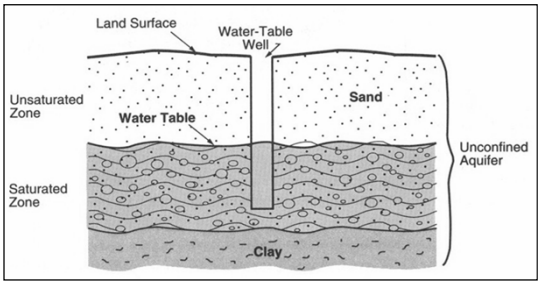


Figure 4. Schematic diagram of the Atlantic Coastal Plain aquifer system (relative thicknesses of aquifers and confining layers not to scale).

Unconfined Aquifer



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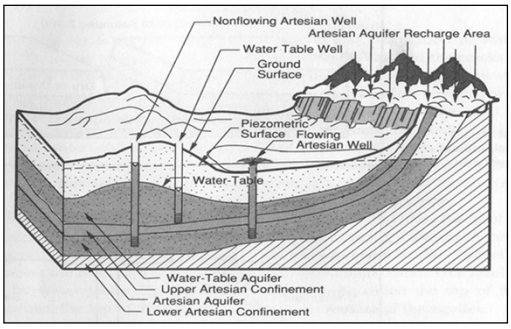
What is an Artesian Well?



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Aquifer Performance...

- Changes in an aquifer are measured by a small diameter test well called an Observation Well
- Located near an operating well

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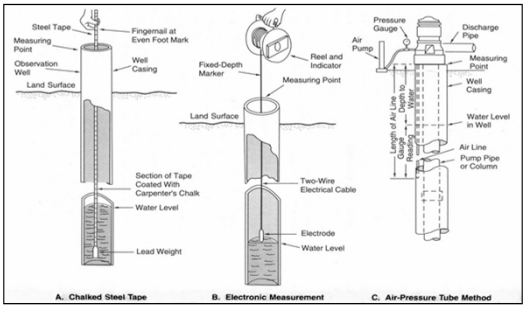
Aquifer Evaluation can be Measured Manually or Mechanically



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Well Yield- Rate of water withdrawal that a well can supply over a long period of time

- Example: Pumpage from an aquifer continuously exceeds the recharge to the aquifer, draw-down will extend and a safe yield will be reduced

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Ground Water Under the Direct Influence of Surface Water (GWUDISW)

- Definition: Any water beneath the surface of the ground with significant occurrence of:
  - insects
  - other macroorganisms,
  - algae,
  - or large diameter pathogens such as *Giardia lamblia*
  - OR

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Ground Water Under the Direct Influence of Surface Water (GWUDISW) [continued]

- Definition: Any water beneath the surface of the ground with significant and relatively rapid shifts in water characteristics such as:
  - turbidity,
  - temperature,
  - conductivity, or
  - pH

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Groundwater Under Direct Influence of Surface Water

- GWUDISW must meet same treatment technologies as surface water.
- Disinfection is mandatory.
- Filtration is mandatory, unless the system meets the filtration avoidance criteria.

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Basic Rules for Wellhead Protection

- Restrict access to well
- Inspect protective zones regularly
- Slope ground away from the well
- Locate maintenance sheds and chemical storage outside of protective zone
- Site new wells carefully

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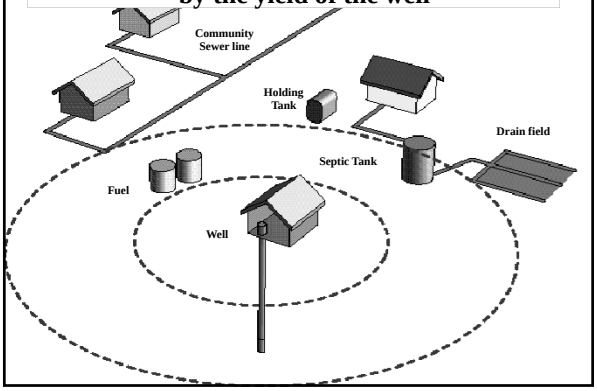
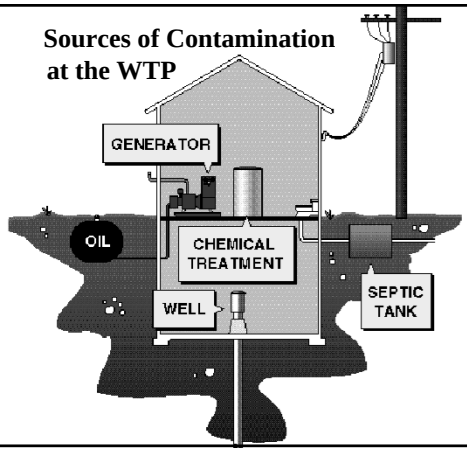
Radius of the Protection Areas is determined by the yield of the well



Sources of Contamination at the WTP



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Types of Wells...

- Dug wells
- Bored wells
- Drilled wells
- Driven wells
- Jetted wells

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Dug Wells
(found in rural areas)

- Do not penetrate much below water table
- May fail during drought conditions
- Protection from surface contamination difficult
- Only type of well **always** treated as a surface water source

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Drilled Wells Most Commonly Found In Public Water Supply

- Benefit - they can reach extreme depths and have large well diameters
  (up to 4 feet and larger)

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Well Drilling Methods

- Cable Tool
- Mud Rotary
- Reverse Circulation
- Air Rotary
- Auger
- Other

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The Well Construction Process

- Project mobilization
- Pilot hole drilling and sample collection
- Geophysical log of pilot hole
- Determination of proper well casing and screen placement
- Verification of proper material placement (casing grout, gravel pack, etc)
- Well development to remove residual materials from the drilling process

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The Well Construction Process (continued)

- Well and aquifer performance testing to determine important hydraulic parameters
- Water quality testing (physical, chemical, bacteriological)
- Pumping equipment selection, installation, and testing
- Supplemental water treatment

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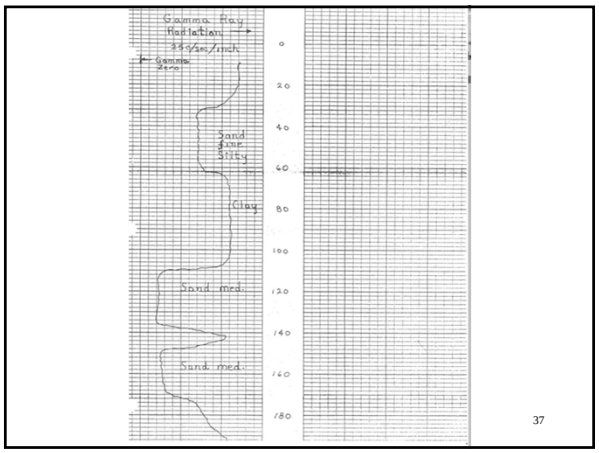
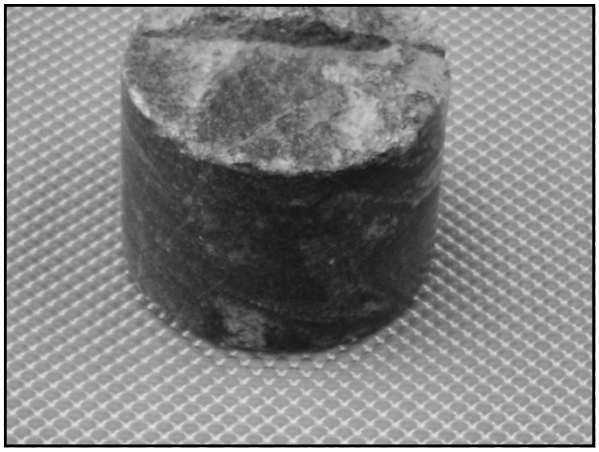
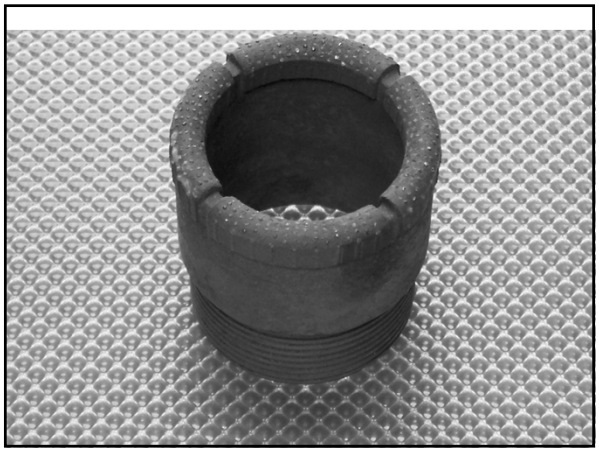
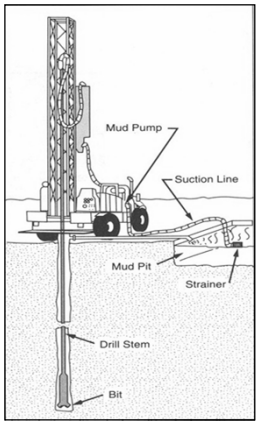

Gamma Ray Radiation
25 c/m/inch
Gamma Zero
0
20
40
60
80
100
120
140
160
180
Sand Zone Silty
Clay
Sand med.
Sand med.
37



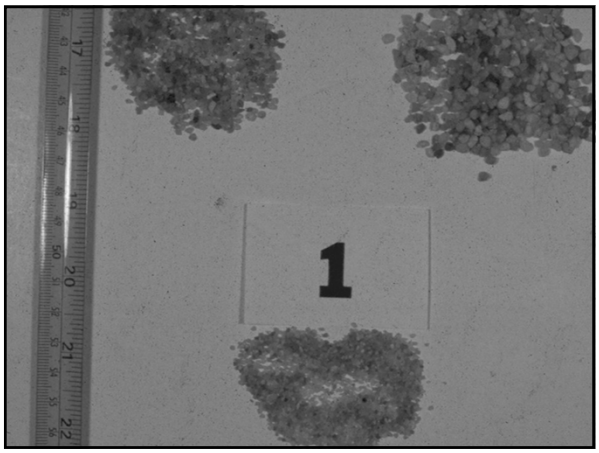


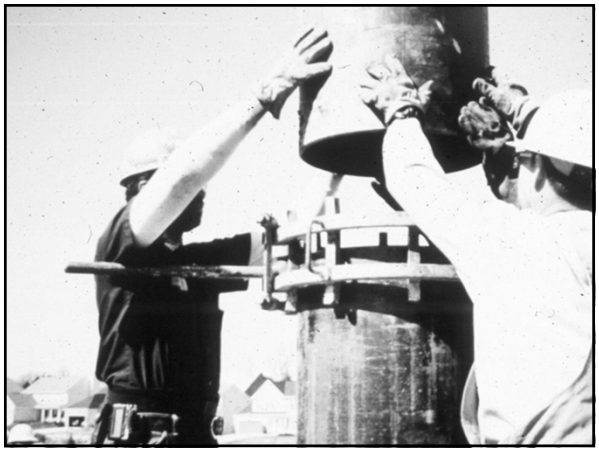
Drilling Rig



Mud Pit

40





Well Drilling Gone Wrong!

www.youtube.com/watch?v=-l4FOL_UPB0

Sampling Procedures for New Wells

- Sampling and testing required prior to placing a well in operation
- Use state-certified lab and approved methods
- Well must be fully-developed prior to sampling

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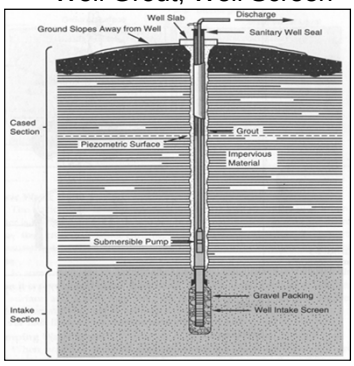
Highlight Well Casing, Well Slab, Well Grout, Well Screen



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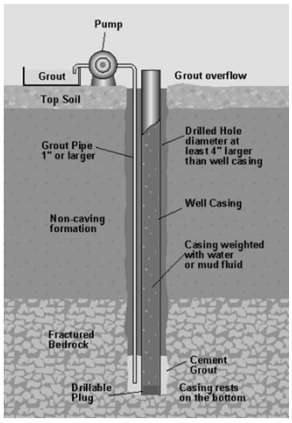
Ground Water Wells: Grouting Methods



Well casing is cemented by pumping grout through a pipe lowered into the annular space outside the casing.

Source: Ground Water and Wells, Johnson Well Screen Division, 1975

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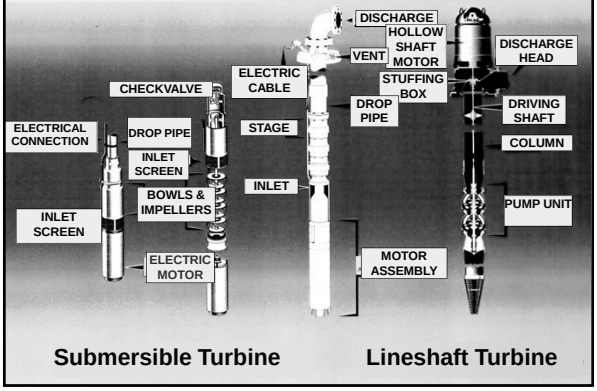
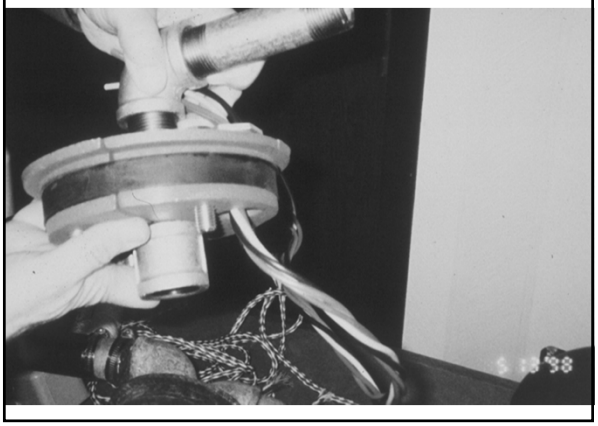
Well Pumps



Submersible Turbine **Lineshaft Turbine**



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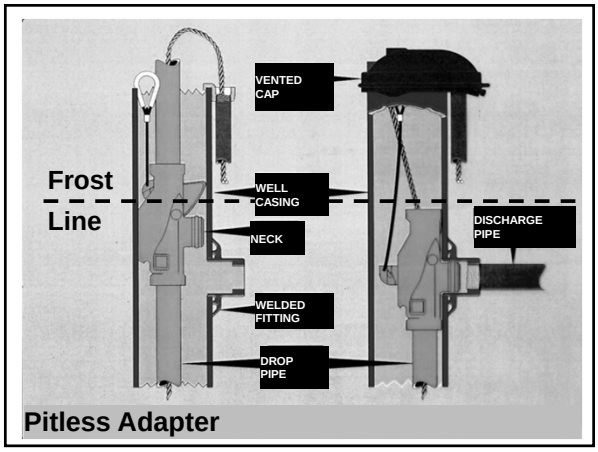
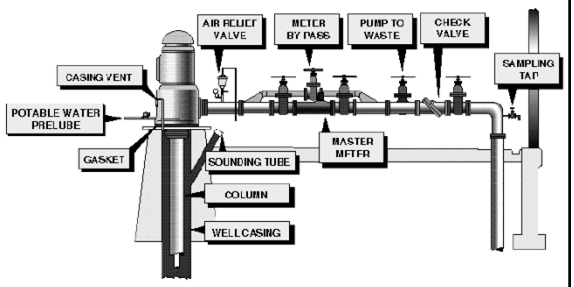
Wellhead Terminated Below Grade –
Subject to Contamination


VENTED CAP
Frost Line
WELL CASING
NECK
DISCHARGE PIPE
WELDED FITTING
DROP PIPE
Pitless Adapter


AIR RELIEF VALVE
METER BY PASS
PUMP TO WASTE
CHECK VALVE
SAMPLING TAP
CASING VENT
POTABLE WATER PRELUBE
GASKET
SOUNDING TUBE
MASTER METER
COLUMN
WELL CASING

55


01/14/2009

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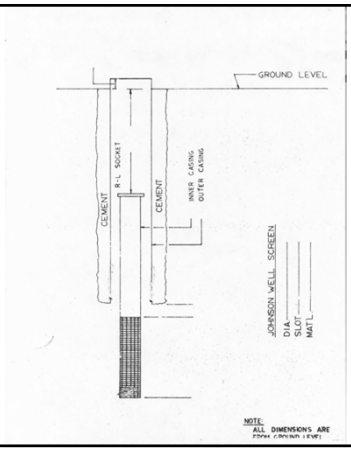
Why are some inner casings not brought to the surface?

- Advantages
  - $
  - More room for the pump
- Disadvantages
  - Access
  - Maintenance and repairs
- Relief screen
  - Expensive lessons



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Well Operation & Maintenance

60

O&M

- Measure Drawdown
- Calculate Specific Capacity
  - GPM per Foot of Drawdown
- Check for presence of sand
- Check actual pump capacity
- Verify pressure cut-in and cut-out set points
- Ensure that connections & sanitary seals are intact
- Eliminate potential sources of contamination

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O&M

- Test alarm systems
- Record daily water production and pump runtime
- Measure raw water quality
  - Watch for changes in contaminant levels
- Consult with a “Well System Professional”
  - Well Driller
  - Hydrogeologic / Engineering Firm
  - Electricians
    - Power
    - Industrial Controls

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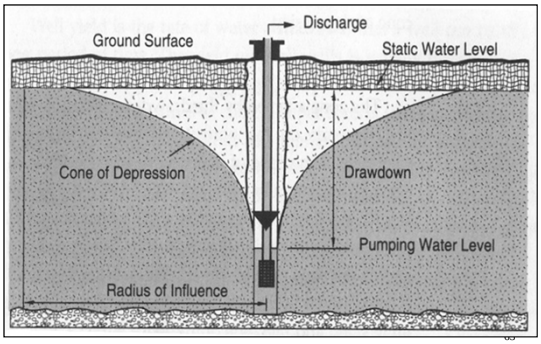
Draw-down



HOW/WHY DO WELLS CLOG UP???

- PHYSICAL PLUGGING
- CHEMICAL / MINERAL ENCRUSTATION
- BIOLOGICAL GROWTHS
- COMBINATIONS
- VELOCITY CONSIDERATIONS

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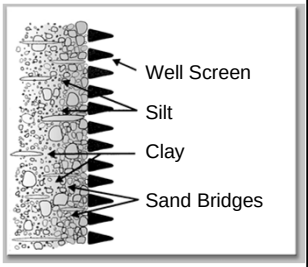
Cause: Physical Plugging

Physical and mechanical blockage that occurs when fine-ground material migrates toward the well bore accumulating in pore spaces near the well screen, gravel pack, bore hole wall, or in rock wells in fracture apertures.



Orange juice pulp

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Mineral Encrustation - Type 1

Fe^{+2} (Ferrous) → **Fe^{+3} (Ferric)**

Red or brown deposits

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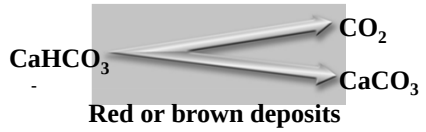
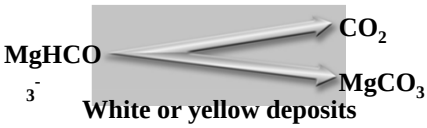
Mineral Encrustation - Type 3



Red or brown deposits



White or yellow deposits

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Biological Clogging

- Iron-related bacteria (IRB)
  - Stalks (gallionella)
  - Sheaths (crenothrix)
  - Filamentous
- Slime-forming bacteria
  - Mostly IRBs
- Sulfate-reducing bacteria
  - Microbial corrosion
  - Hydrogen sulfide gas
  - Rotten-egg odor

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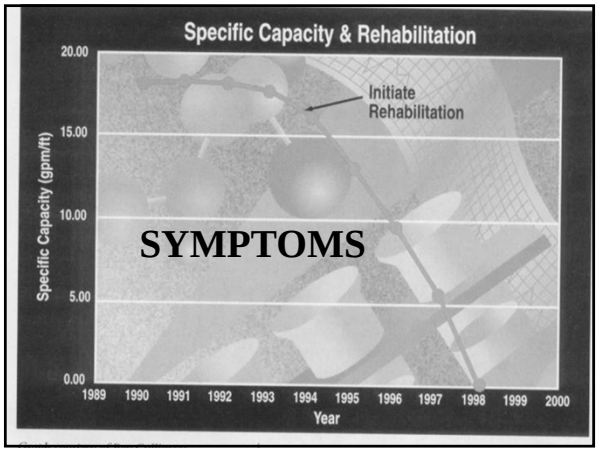

SO HOW DO WE FIX IT ???

- WELL REDEVELOPMENT OR WELL REHABILITATION
- UNCLOG OR REOPEN THE PASSAGEWAYS
- LET THE WATER FLOW INTO THE WELL EASIER (LIKE IT USED TO)
-

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WELL REHABILITATION

- LIKE CLEANING YOUR TEETH
- BRUSHES
- CHEMICALS
- BIOFILMS
- EVERYONE HAS A FAVORITE

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Types of Chemical Treatment

- Chlorine/ Disinfectants as Biocides
- Acids to Dissolve Encrustation
- Formulated chemistries
- Aqua Freed™
- **Not Focused**
- **Disposal Considerations**

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Mechanical Redevelopment Techniques

- Over-pumping/surging
- Wire-brushing
- Solid swab
- Double (hollow) swab
- High-velocity jetting
- Hydraulic fracturing
- Air pressurization
- Sonar jetting (primer cord)
- Aqua-burst

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Surge Block

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Schultes Ultra High Pressure

- 5000 to 10,000 Psi
- Cleans casings and screens
- Removes encrustation and opens fractures
- Exposes weak Joints or other Problems
- Powerful
- Focused

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Jetting Tools

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10,000 PSI JETTING

Before cleaning

After cleaning

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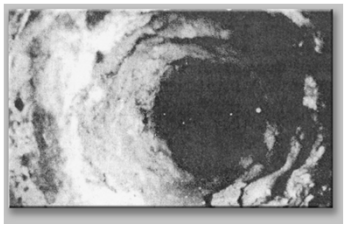
Video Log



GOOD DIAGNOSTIC TOOL

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Jetting Video

Contamination...

Any microorganisms, chemicals, wastes or wastewater in a concentration that makes the water unfit for its intended use

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Anything more than:
2 Hydrogens & 1 Oxygen
(**H_2O**), the water is contaminated.

What if you add another oxygen to H_2O ?

You would have:

H_2O_2

Hydrogen Peroxide

Contamination May Come From Natural Pollutants...

- Turbidity
- Radium 226 & 228
- Total Coliforms

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Or Manmade Chemicals...

- Synthetic organic compounds
- Volatile organic compounds

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What is the main determining factor when deciding on the type of treatment needed ?

- The characteristics of the raw water source (the contaminants that must be removed)

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Public Systems Using Groundwater...

- Previously, many systems provided acceptable quality without providing treatment
- Many more systems have turned to treatment for the following reasons:
  - Meet federal and state requirements for disinfection
  - Remove contaminants posing a threat to public health
  - Remove contaminants that reduce the aesthetic quality of the water

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Groundwater can contain…

- High hardness
- Objectionable contaminants:
  - Iron
  - Manganese
  - Hydrogen Sulfide
- Radionuclide's
- Synthetic contaminants:
  - Pesticides
  - Herbicides
  - Industrial solvents

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Groundwater Treatment Options

- All treatment must be approved by the state regulatory agency.

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GW Treatment Options

Corrosion Control:
To prevent corrosion in the distribution system and prevent leaching of lead & copper in household plumbing.

Methods:
- Feeding a pH adjustment chemical
- Feeding a corrosion inhibitor chemical

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GW Treatment Options

Iron / Manganese Removal:
To prevent iron / manganese from…

- forming deposits inside pipes and fixtures
- staining laundry
- causing taste and odor complaints

Methods:
- Feeding a chemical to sequester the iron / manganese
- Physical removal (oxidation / filtration)
- Ion Exchange

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GW Treatment Options

Calcium / Magnesium (Hardness) Removal:
To prevent calcium / magnesium from…

- forming deposits inside pipes and fixtures
- causing customer complaints
  - Hard water will not allow soap bubbles to form

Methods:
- Ion Exchange
- Lime / Soda Ash Softening

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Groundwater Treatment Options

Disinfection:
To prevent microorganisms from entering/forming in the distribution system.

Methods:
- Application of a disinfecting chemical
  - Chlorine
  - Sodium Hypochlorite
  - Calcium Hypochlorite
- Ultraviolet (UV) light

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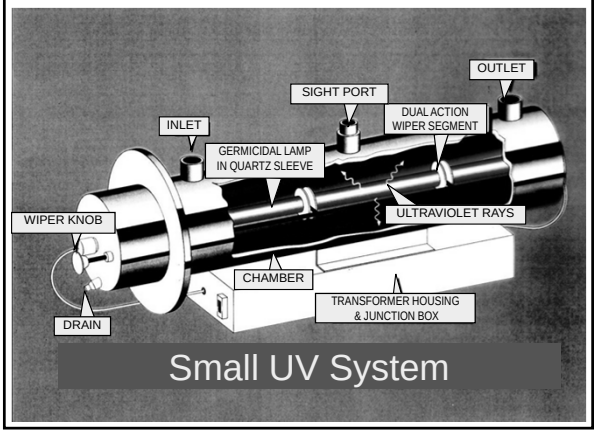

Small UV System

Groundwater Treatment Options

Organics Removal:
To prevent volatile and synthetic organics from entering the distribution system and causing chronic health problems.

Methods:
• Aeration
• GAC Contactors

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Groundwater Treatment Options

Arsenic Removal:
To prevent arsenic from entering the distribution system and causing chronic health problems.

Methods:
• Membrane Filtration
• Ion Exchange
• Lime Softening
• Oxidation / Filtration
  - May also incorporate coagulation

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In Situ Treatment…

- Chlorine, introduced into a well, is a frequently used method of removing iron bacteria from a well.

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Water Treatment Chemicals

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Disinfection Chemicals

- Chlorine
- Calcium Hypochlorite
- Sodium Hypochlorite
- Ozone
- Ultraviolet

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Chemicals Used to Prevent Corrosion...

- Calcium Hydroxide....(lime)
- Calcium Oxide……....(quicklime)
- Sodium Hydroxide…..(caustic soda)
- Sodium Carbonate…...(soda ash)
- Sodium Bicarbonate….(baking soda)
- Phosphates

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Chemicals Used to Prevent Scaling...

- Carbon Dioxide
- Sulfuric Acid
- Phosphates

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All Chemicals Added to Drinking Water

- MUST be approved by the National Sanitation Foundation (NSF)

Chemical Feed Systems at Small Water Systems

- Gas Feed Systems
- Liquid Chemical Feed Systems
- Dry Chemical Feed Systems

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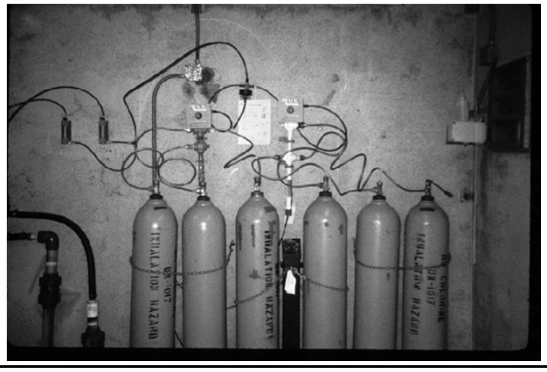
Pressurized System (pigtails)



Simple vacuum controlled chlorinator

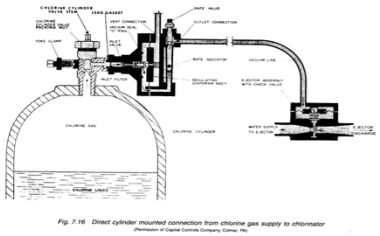
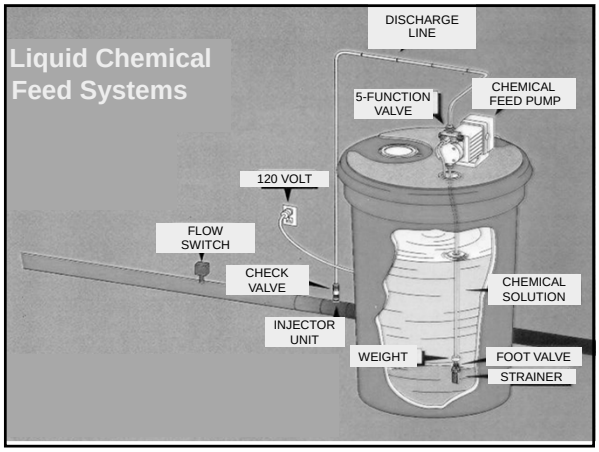


Fig. 7.16 Direct cylinder mounted connection from chlorine gas supply to chlorinator



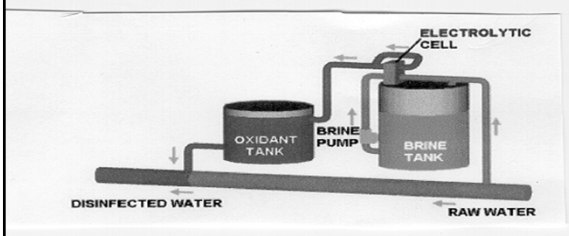
Diaphragm-Type Metering Pump

109

Peristaltic Pump

110

Sodium Hypochlorite Produced On-site



Calcium Hypochlorite Tablet Feeder

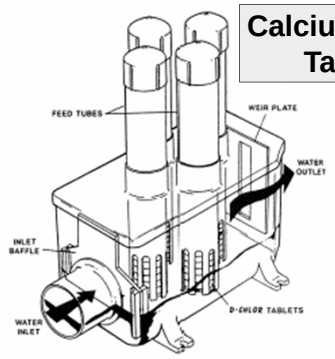


Fig. 10.22 Tablet dechlorination unit
(Permission of ELTECH International Corporation)

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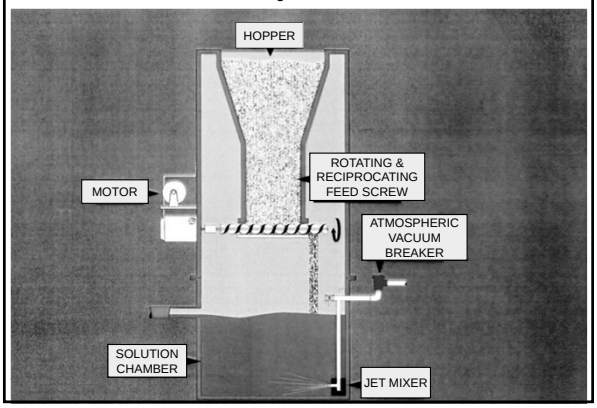
Volumetric Dry Chemical Feeder



Treatment Processes

- Disinfection
- Corrosion / Scaling Control
- Iron & Manganese Removal
- Organics Removal
- Arsenic Removal

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Disinfection !

The one process that we can't do without.

Gastroenteritis
Typhoid
Dysentery
Cholera
Hepatitis

Coliform Bacteria is tested for by the presence or absence method….

Important Terms

Dosage : The amount of chlorine added mg/l or ppm

Demand : The amount of chlorine required to react with the organic and inorganic substances.

Residual : Dose (-) Demand = Residual

The amount remaining after contact time.

Free Residual : Exists as Hypochlorous acid or hypochlorite

Combined Residual : Chlorine which has combined with ammonia to form Chloramines.

Total Residual : Is the sum of free and combined residual

Factors Influencing Disinfection

- pH
- Temperature
- Turbidity
- Organic Matter
- Inorganic Matter
- Reducing Agents
  - Soluble iron & manganese
  - Nitrite
  - Hydrogen sulfide
- Microorganisms

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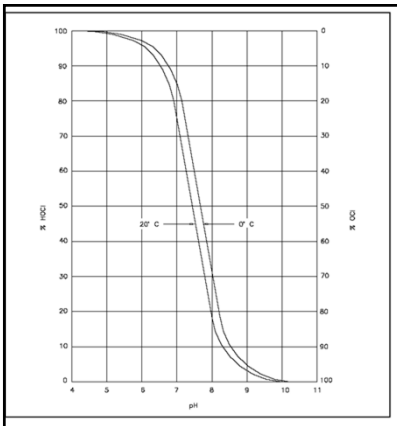

Figure 1 - Distribution of HOCl and OCl- In Water at Various pH Levels

Effects of pH

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Why Corrosion and Scaling Control?

- Protect public health
- Improve water quality
- Extend life of plumbing equipment
- Meet state and federal regulations

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Stabilization…

- Controlling of damaging corrosion or deposit scaling on pipelines due to source water

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pH Scale

0 1 2 3 4 5 6 7 8 9 10 11 12 13 14

Acid (N) Base

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Protecting Public Health...

- Corrosion can raise toxic metal levels in the water
  - example - lead and copper
- Corrosion can cause tubercles
  - Tubercles can protect bacteria from disinfection

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Meeting Regulations...

- Meeting Lead and Copper regulations enacted in 1991
- Corrosion control when levels reach Action Levels

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Water Quality...

- **Taste** - Metallic taste from corrosion of copper
- **Odor** - Dissolved iron from corrosion acts as a food source for iron bacteria which can cause taste and odor problems
- **Color** - Corrosion can cause stains such as red, blue or green

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Corrosion Can be in Two Categories...

- Localized
- Uniform

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Scale Formation...

- Small amount of scale on the inside of pipes can protect against corrosion
- Too much scale can reduce the carrying capacity of pipe or system

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What is Hard Water?

- Water having high concentrations of calcium and magnesium ions

0-60 mg/l $CaCO_3$ – Soft Water
61-120 mg/l $CaCO_3$ – Moderately Hard Water
121-180 mg/l $CaCO_3$ – Hard Water
>180 mg/l $CaCO_3$ – Very Hard Water

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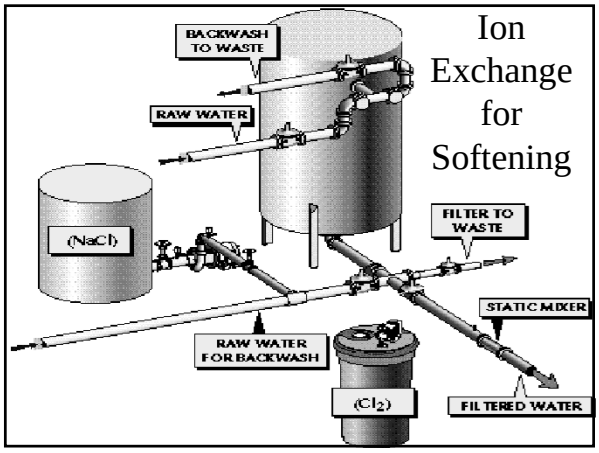

Ion Exchange for Softening

The Problem with Iron

- Iron exists in groundwater in ferrous iron and is in the soluble form (Fe^{2+})
- When soluble iron comes into contact with oxygen (or oxidizing compound), insoluble precipitate (ferric iron) is formed (Fe^{3+})
- Ferric iron stains plumbing fixtures, laundry, etc.
- Iron supports the growth of iron reducing bacteria which causes a biofilm (slime) to form inside pipes.
- Also, iron can cause encrustation inside water mains

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Iron and Manganese Removal

- Iron and manganese in surface water and ground water
- Treatment Processes
  - Oxidation and filtration
  - Oxidation, clarification, and filtration
  - Manganese greensand filtration
  - Ion exchange
  - Sequestering

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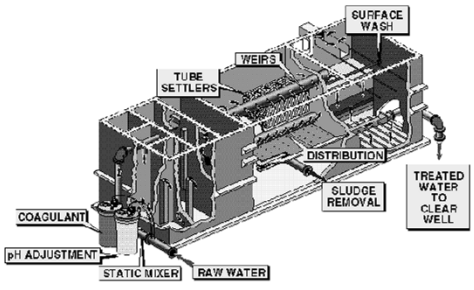
Package Treatment Plants



Conventional Treatment - Package Plant

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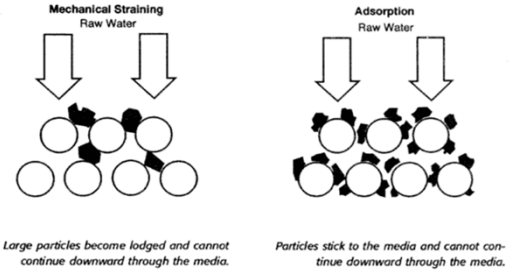
The Filtration Process



Large particles become lodged and cannot continue downward through the media.

Particles stick to the media and cannot continue downward through the media.

Figure 6-1

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Arsenic Removal

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Regulatory Issues

- SDWA identifies Arsenic as a Primary Contaminant
- Chronic health effects
- MCL
  - 10 parts per billion (0.01 mg/L)

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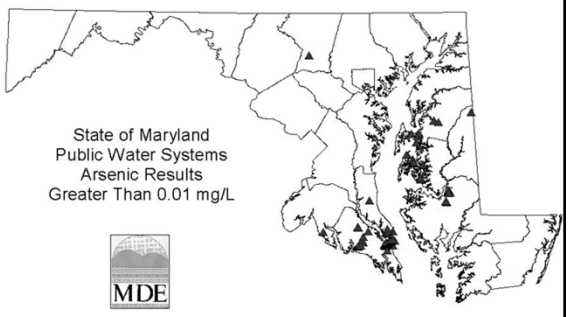

Arsenic Removal Processes

- Ion Exchange
- Reverse Osmosis / Nanofiltration
- Lime Softening
- Oxidation / Filtration
  - Conversion of As (III) to As (V)
  - Conventional Fe / Mn treatment systems are effective
  - Activated Alumina for coagulation

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