Concepts of Drinking Water Treatment

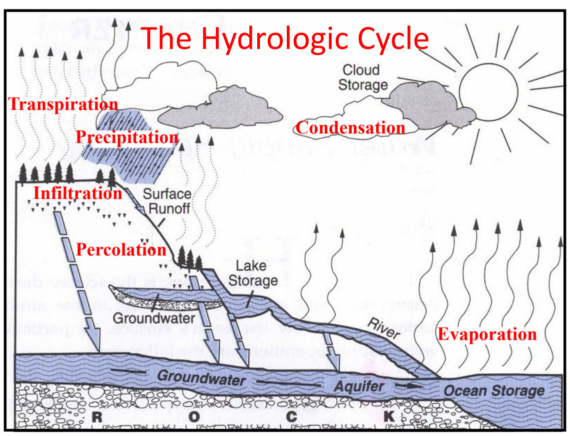
Maryland Center for Environmental Training
College of Southern Maryland
La Plata, MD

Course Description & Objectives

Concepts of Drinking Water Treatment
TRE 3819-06-07: WT All; WD (Process) 7 hours,

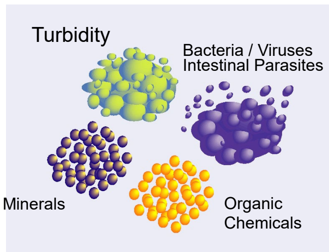
Attendee will be introduced to the Safe Drinking Water Act and how it applies to the operator. The concepts of water sources, water storage, and distribution systems will be introduced during this course. Other topics covered will include basic concepts of pumping and pressure maintenance, disinfection, storage tanks, fluoridation, corrosion control, and plant safety. Participants will further discuss the key elements of an effective safety program.

The Hydrologic Cycle



WATER TREATMENT

"The **water treatment** is the primary barrier against unsafe water…any malfunction in the treatment process could result in water quality problems."



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Source Protection

- A strategy designed to protect public drinking water supplies by managing the land surface around a well where activities might affect the quality of the water.

The best method to manage a watershed or well head is through the regulatory process.

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Public Water Systems

- 15 or more connections
- 25 or more people per day
- At least 60 days per year
- Three subcategories:
  - Community Water System
  - Two Non-Community Water Systems:
    - Transient Water System
    - Non-transient Water System

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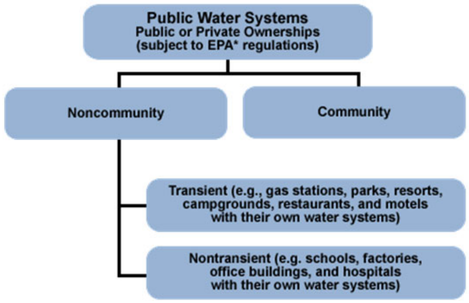
Public Water Systems



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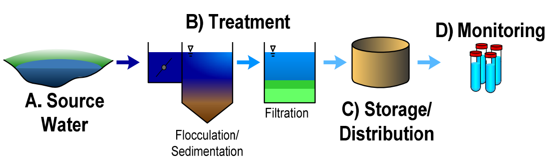
Multi-Barrier Approach



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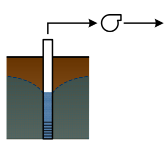
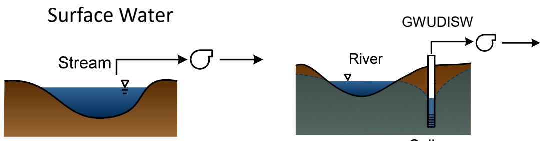
Types of Source Water

- Ground Water



- Surface Water and Ground Water under the Influence of Surface Water



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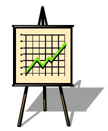
Ground Water Under the Direct Influence of Surface Water (GWUDISW) [

- Definition: Any water beneath the surface of the ground with significant and relatively rapid shifts in water characteristics that closely correlates to climatological or surface water conditions such as:
  - Turbidity,
  - Temperature,
  - Conductivity, or
  - pH



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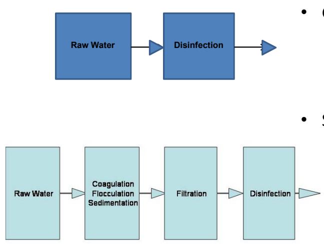
COMMON TREATMENT TECHNIQUES



- GROUNDWATER
  - pH adjustment
  - Disinfection
  - Fluoridation
  - Corrosion Control
- SURFACE WATER (& GWUDISW)
  - **Screening**
  - **Coagulation**
  - **Flocculation**
  - **Sedimentation**
  - **Filtration**
  - Disinfection
  - Fluoridation
  - Corrosion control

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Drinking Water Systems

Water Sources

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Water Sources

- Primary Sources:
  - Groundwater – Major risks are inorganic (e.g., arsenic) and organic pollutants
  - Surface Water – Major risks are microbial and organic (e.g., pesticides, wastewater-derived) pollutants
- Alternative Sources:
  - Seawater, rainwater, and treated municipal wastewater

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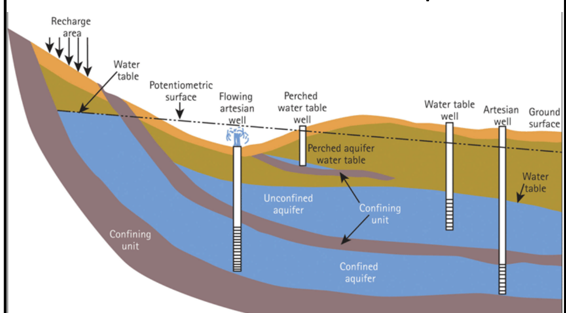
Unconfined v. Confined Aquifers



Unconfined - More vulnerable to contamination

Confined Wells more costly to drill

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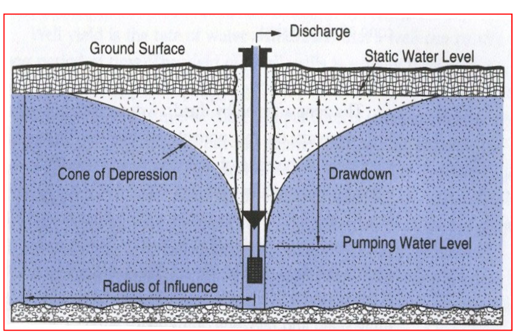
Ground Water Drawdown



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Overview

Water Treatment

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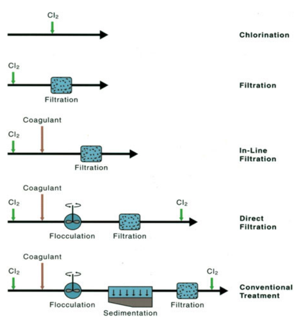
Water Treatment Process Trains

- Chlorination
- Filtration (Cartridge, sand, or coal)
- In-Line Filtration

  Coagulation to aggregate suspended solids with alum, ferric sulfate, ferric chloride, or polyelectrolytes)
- Direct Filtration

  Coagulation/flocculation before filtration w/o sedimentation
- Conventional Treatment

  With sedimentation step which is the gravitational settling of suspended particles



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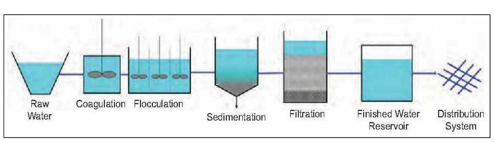
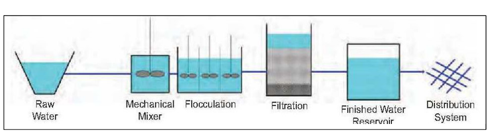
Surface Water Treatment Options



Conventional – with Sedimentation



Direct – without Sedimentation

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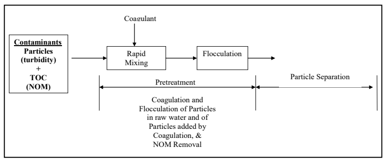
COAGULATION AND FLOCCULATION PROCESSES

•COAGULATION – chemical step involving addition of coagulants. Chemical reactions occur with these particles and chemical reactions involving phase changes may also occur with water (OH-) and Natural Organic Material (NOM) or Total Organic Carbon (TOC) .

•FLOCCULATION – physical step in which the sizes of particles are increased by collisions and attachment of smaller particles leading to larger floc particles.



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Overview

Water Storage and Distribution

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Water Storage and Distribution System

- The Last Barrier(s) to Public Health Protection
- Protecting the physical barrier/infrastructure from contamination (e.g., maintaining pressure, preventing backflow, protecting storage tanks, etc.)
- Providing a disinfection barrier against contamination and water quality deterioration

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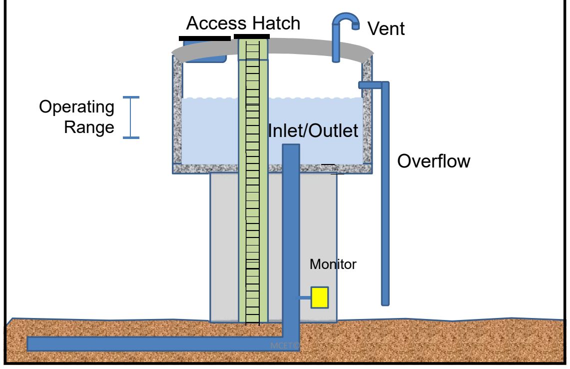
Elevated Tank



Physical Characteristics

- Storage tanks can vary by the following:
  - Size – diameter, height, volume
  - Shape – cylindrical (d>h), standpipe (h>d), rectangular, ellipsoidal, pedestal, etc.
  - Elevation – underground, ground, elevated
  - Inlet/Outlet – configuration (common or *"flow-through"*)
  - Other – baffling, pillars, mixing systems (static or mechanical)

Advantages of Gravity Storage

- Can provide fire flows
- One to five days storage
- Allows use of lower capacity wells
- Allows sizing of pumps to take advantage of load factors
- Reduces on/off pump cycling

Function of Storage Tanks

- Equalize water supply, so pumping doesn't have to equal demand:
  - Fire flows
  - Main breaks
  - Off peak pumping
- Maintain system pressure in specific range
- Important to consider tank functions when assessing potential operational changes

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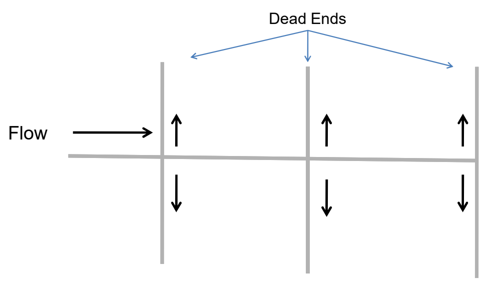
Tree Distribution System



Referred to as a Branch System

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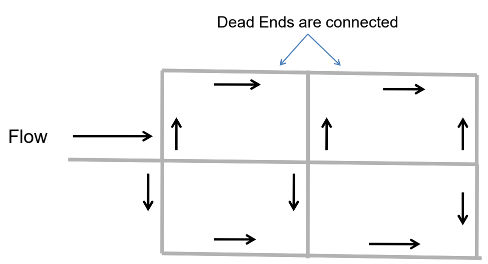
Grid Distribution System



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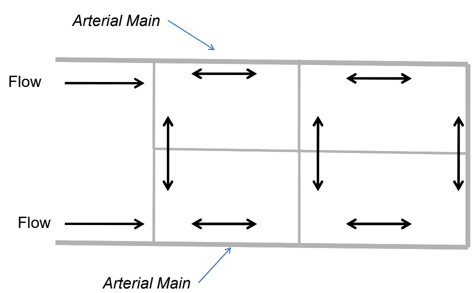
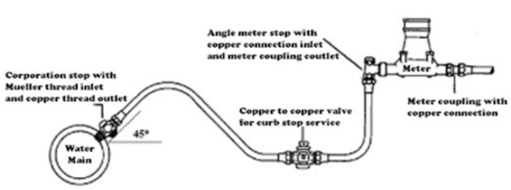
Arterial Loop System



Water System Pressure and Velocity Requirements

- Absolute minimum pressure of 20psi during fire flow conditions is required
- Desirable residential pressure is 35 – 75 psi
- Flow velocity should not exceed 4 feet per second (fps) except when flushing mains.

Typical Service Connection



. . . are the pipes and tubing that lead from a connection at the water main to the connection with the customer’s plumbing.

Water Meters

- Purpose
  - Measure and display the amount of water running through it.
- Benefits
  - Customer can be accurately billed
  - Flow rates from plants can be obtained
  - Lost water can be detected

Displacement Meter

- Small diameter (up to 6 inches)
- Commonly used for residential and commercial services
- Measures flow by counting the times the internal chamber fills and empties
  - By use of a disk or piston
- Very accurate for low flows

Velocity Meter

- Measures the water passing through the meter using a turbine, propeller, or multijet device
- Used on large diameters, up to 36 inches

Compound Meter

- Uses a combination of large and small capacity meters
  - Able to capture a wide range of flows
  - Large, cumbersome and expensive
  - Accuracy lost during low to high flow transition

Types of Fire Hydrants

- Dry-Barrel
- Wet-Barrel
- Flush Hydrants

Uses of Fire Hydrants

- Fire Fighting
- Flushing of Water Mains
- Flushing Sewers or Cleaning Streets
- Testing Water System Flow Capacity
- Provide water for Miscellaneous Use

Hydrant Operation Concerns

- Protect hydrant from backflow contamination
- Open main valve completely
- Open and close main valve slowly
- Open hydrants one at a time
- Do not stand in front of capped nozzle

Overview

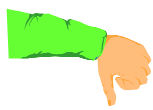
Water Quality

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)

Problems Caused by Contaminants

- Unpleasant taste
- Disease-causing organisms
- Odors
- Contaminants above recommended health related limits



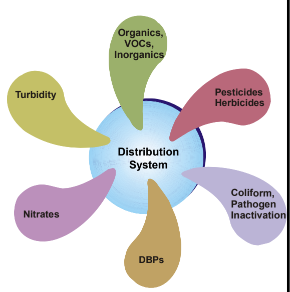
Key Regulation Facts

- **National Primary Drinking Water Regulation (NPDWR)**
  - Sets legal levels (MCL's) of specific contaminants that can adversely affect public health
  - Recommends Maximum Contaminant Level Goals (MCLG)
  - Treatment Technique (TT) in lieu of MCLs
  - Must report exceedance to state within 48 hours
  - Must certify to the state that public notification was done within 10 days.
- **National Secondary Drinking Water Regulation (NSDWR)**
  - Non-enforceable guidelines (SMCL's)
  - Covers contaminants that may cause cosmetic or aesthetic effects

Drinking Water Regulations

Primary Standards

- Affect public health
- Apply to treated water at point-of-entry to distribution system; some also apply to distribution system



Drinking Water Regulations

Secondary standards

- Affect aesthetics - color, taste, odor, hardness
- Include some inorganics - iron, manganese
- Are not mandatory but can be enforced at discretion of regulatory agency

Key Regulation Terminology

- Contaminant - Any physical, chemical, biological, or radiological substance or matter in water
- MCLG – Maximum Contaminant Level Goal; a health goal which allows an adequate margin of safety
- MCL – Maximum Contaminant Level; highest level of contaminant allowed in water; set close to MCLG

Treatment Technique (TT)

- A TT is and alternative to an MCL when it is not economically and technologically feasible to ascertain the level of the contaminant
- A TT is also an enforceable standard involving a measurable procedure or level of technological performance (e.g., “Action Level”)
- Example: Filtration and disinfection for removing and inactivating viruses and Giardia to avoidance levels

Turbidity

- Is a:
  - Regulated parameter
  - Make the water appear cloudy
  - Surrogate for microorganisms like viruses, Giardia, and Cryptosporidium
- Particles:
  - Interfere with disinfection
  - Produce residuals
  - Impact water treatment costs:
    - I. Coagulant/disinfectant demand
    - II. Filter run length
    - III. Residuals handling and disposal

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Natural Organic Matter (NOM)

- Present in all natural waters
- Consists of living organisms:
  - algae, protozoa, bacteria, viruses
- Consists of non-living material:
  - decayed vegetation, humic substances
- Usually measured as Total and Dissolved Organic Carbon (TOC & DOC)
- Largest fraction of DOC is usually humic substances
- Can only identify about 20 % of the DOC

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Stormwater Runoff – Major Source of Organic Matter

Forests and wetlands help control runoff and nutrients but ...

...contribute color and organic compounds

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NOM Removal

Why Do We Care?

- NOM (humus material) is present in all surface waters
- Exerts a disinfectant demand
- **Precursor to THMs and HAAs and other DBPs**
- Coagulant demand – NOM controls the optimum coagulant dose for most waters, *not turbidity*
- Source of color
- Can affect corrosion
- Source of tastes and odors

In most cases, maximize NOM removal

Water Quality Characteristics

- Physical
  - Color, taste, odor, turbidity
- Chemical
  - Calcium, magnesium, sodium, iron
- Biological
  - Bacteria, viruses, algae
- Radiological
  - Radium 226, radium 228 and radon

Importance of Water Quality

- The EPA (Environmental Protection Agency) sets Maximum Contaminant Levels (MCLs) for drinking water
- There are standards for numerous contaminants, two of which cause an **immediate health threat** if exceeded:
  - ***Coliform bacteria*** - because they may indicate presence of disease-causing organisms
  - ***Nitrate*** - can cause 'blue baby syndrome"— nitrates react with blood and blood can't carry as much oxygen

Source Water Quality Surface Water

Streams, rivers,& Impoundments

- Proximity to contamination
- Substances that alter water quality
  - Organic
  - Inorganic
  - Biological
  - Radiological
- Sources of impurities
- Vulnerable to contamination
  - Natural
  - Man-made

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Microbiological Contaminants of Concern

- "Heterotrophs"- heterotrophic plate count
- Total Coliforms
- Fecal Coliforms - including E. coli
  - Diseases related to or possibly present with E. coli
- Giardia Lamblia
- Cryptosporidium
- Legionella
- Viruses

"Links to Turbidity Measurements"

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Overview

Water Quality Monitoring

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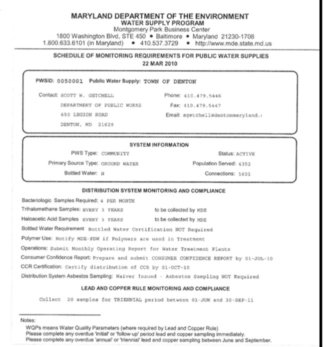
Annual Sample Schedule



MARYLAND DEPARTMENT OF THE ENVIRONMENT
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SCHEDULE OF MONITORING REQUIREMENTS FOR PUBLIC WATER SUPPLIES
22 MAR 2010

PWSID: 0050001 Public Water Supply: TOWN OF DENTON

Contact: SCOTT W. GETCHELL
DEPARTMENT OF PUBLIC WORKS
650 LEGION ROAD
DENTON, MD 21629

Phone: 410.479.5446
Fax: 410.479.5447
Email: sgetchell@dentonmaryland.

SYSTEM INFORMATION

PWS Type: COMMUNITY
Status: ACTIVE
Primary Source Type: GROUND WATER
Population Served: 4352
Bottled Water: N
Connections: 1601

DISTRIBUTION SYSTEM MONITORING AND COMPLIANCE

Bacteriologic Samples Required: 4 PER MONTH
Trihalomethane Samples: EVERY 3 YEARS to be collected by MDE
Haloacetic Acid Samples EVERY 3 YEARS to be collected by MDE
Bottled Water Requirement Bottled Water Certification NOT Required
Polymer Use: Notify MDE-PDW if Polymers are used in Treatment
Operations: Submit Monthly Operating Report for Water Treatment Plants
Consumer Confidence Report: Prepare and submit CONSUMER CONFIDENCE REPORT by 01-JUL-10
CCR Certification: Certify distribution of CCR by 01-OCT-10
Distribution System Asbestos Sampling: Waiver Issued - Asbestos Sampling NOT Required

LEAD AND COPPER RULE MONITORING AND COMPLIANCE

Collect 20 samples for TRIENNIAL period between 01-JUN and 30-SEP-11

Notes:
WQPs means Water Quality Parameters (where required by Lead and Copper Rule)
Please complete any overdue 'initial' or 'follow-up' period lead and copper sampling immediately.
Please complete any overdue 'annual' or 'triennial' lead and copper sampling between June and September.

Regulations Requiring Monitoring

- Revised Total Coliform Rule
  - Tests for coliform bacteria & Cl_2 residual
- Lead and Copper Rule
  - Tests for lead and copper at dead ends and in service connections
- Disinfectant By-Products Rule
  - Samples tested for THM, HAA and Cl_2 residual

Certified Water Sampling

- Bacteriological – specified number per month based on population served
- Lead and Copper
- Total Trihalomethane (TTHM)
- Haloacedic Acid (HAA5)
- Annual Consumer Confidence Report

Indicator Organisms

Total coliform	Some from fecal sources
Fecal coliform	Subset of total coliform Human and non-human fecal sources
Escherichia coli (E. coli)	Subset of fecal coliform Likely human source in wastewater
Enterococci	Human-specific strains of fecal streptococci, survive in marine waters

Sampling Locations

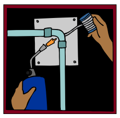
SAMPLE	LOCATION
Coliforms	Taken at points representative of conditions within the distribution system
Turbidity	Source entry points to distribution system
THM	25% collected at extreme end, 75% at representative points
Chlorine residual	Most remote locations of the system and throughout entire system
Lead & Copper	Taken at consumers taps – "first draw" sample

Collecting Coliform Samples

- Grab Sample
- Use only sterilized bottles
  - Do not handle neck or inside of bottle or cap
  - Do not rinse out bottle
- Fill bottle to ½ inch to ¼ inch of top
- Replace lid carefully
- ID and transport in ice cooler
- Positive sample requires a resample within 24 hours

Lead and Copper Rule

- Sets action levels for lead and copper that prompt corrosion control measures if exceeded
- Sets monitoring, testing, reporting requirements



Action Levels

- Principle sources: Service line & household plumbing.
- The Lead action level is 0.015 mg/L (sometimes referred to as 15 parts per billion or 15 ppb)
- The copper action level is 1.3 mg/L
- 90th percentile value

Corrosion Control – Options

- If high lead and copper results trigger control treatment, then systems choose one of the following:
  - pH and $CaCO_3$ control
  - Lead line replacement (costly; rare occasions)
  - Addition of corrosion inhibitors:
    - Phosphate-based chemicals
    - Silica-based chemicals

First Draw Sample

All tap samples must be first-draw samples, taken from a kitchen or bathroom sink cold water tap.

Water in the plumbing system should have stood motionless (stagnation period) in the pipes for at least six hours. **<u>Beginning in February 2016 (due to Flint, MI incident) EPA no longer recommends pre-stagnation flushing.</u>**

Disinfection By-products (DBPs) Rule

- By-products of reactions between disinfectant (chlorine, ozone, etc.) and natural organic matter and/or bromide present in source water

Disinfection By-products (DBPs) Rule

- **Disinfectants**
  - **Chlorine**
  - **Chloramines**
  - **Chlorine Dioxide**
- **Maximum Residual Disinfectant Level (MRDL)**
  - Level of a disinfectant added for water treatment that may not be exceeded at the consumer's tap without an unacceptable possibility of adverse health effects

Two More Rules

- Consumer Confidence Report Rule
  - Required of all CWS
  - **Annual Water Quality Report** to drinking water customers
  - Verification of customer notification to State
- Public Notification Rule
  - Requires customer notification of treatment and/or water quality violations
  - Specifies time frames based on seriousness of violation. Primary MCL exceedance 48 hrs. to notify state.
  - Notification within 10 days to the state that a PWS has complied with public notification.

Disinfection

Chlorine

Disinfection

- Goal
  - To remove, destroy, or inactivate pathogenic microorganisms including bacteria, cysts, algae, spores and viruses.
- Problem
  - Chemical disinfectants form disinfection byproducts

Methods of Disinfection

Chemical Oxidation	Physical Means
Chlorine	**Ultraviolet light**
Ozone	Heat
Chlorine dioxide	Membranes

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Disinfection

- Often the <u>most critical step</u> in protecting consumers against pathogenic microorganisms
- Pathogens are killed (or "inactivated") by reaction with various chemical oxidants
- Commonly-used disinfectants:
  - **"Free" chlorine** – Applied as $Cl_{2(g)}$ or NaOCl (HOCl is the active disinfectant in either case)
  - **Chloramines, or "Combined" chlorine** – Applied either as pre-formed NH_2Cl, or by mixing NH_3 and HOCl
  - **Ultraviolet light** – Applied via submerged UV lamps (<u>no residual</u>)

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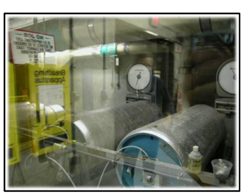
Uses of Chlorine (oxidant) in Drinking Water Treatment Plants

- Disinfection
- Oxidizes color
- Oxidizes iron and manganese
- Taste and odor control
- Controls aquatic growth in plants
- Aid to filtration (particle removal)
- Zebra mussel control



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Factors Affecting Chlorination

- Type and concentration of target organism
- Turbidity
- Temperature
- pH
- Interfering/inorganic substances
- Disinfectant species
- Concentration of disinfectant
- Contact time

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Chlorination Chemicals

- Chlorine gas
  - 100% Cl_2
  - Ton containers or cylinders
- Sodium Hypochlorite
  - NaOCl or bleach – 15% Cl_2
  - Bulk or On-Site Generated
- Calcium Hypochlorite
  - $Ca(OCl)_2$, or HTH, - 65% Cl_2
  - Tablets or powder

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Chlorine Disinfection

- Chlorine can combine with organics to form Disinfection Byproducts (DBPs)
  - Trihalomethanes (THMs) - limited to 80 ppb
  - Haloacetic Acids (HAAs) - limited to 60 ppb
  - Have proved to be carcinogens
- Detectable chlorine residual in distribution system is required by regulations (e.g., > 0.2 mg/L min. but 4.0 mg/l max.)
- Chlorine effective in inactivating bacteria, viruses; much less effective on *Crypto* and *Giardia*

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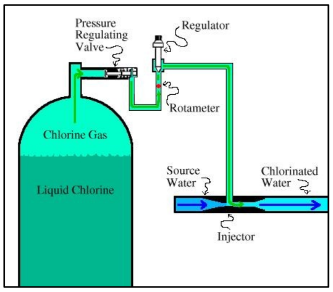
Chlorine Gas



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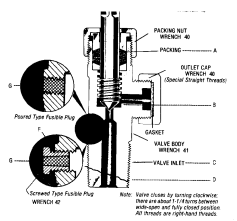
Cylinder valves are a common area for leaks.

Fusible plugs melt at 158 – 165 degrees F

Fusible plugs

150 pound cylinder: **1**
One Ton Container: **6**



TYPICAL VALVE LEAKS OCCUR THROUGH . . .

A - VALVE PACKING GLAND
B - VALVE SEAT
C - VALVE INLET THREADS
D - BROKEN OFF VALVE
E - VALVE BLOWN OUT*
F - FUSIBLE PLUG THREADS
G - FUSIBLE METAL OF PLUG
H - VALVE STEM BLOWN OUT*

Open valve 1.5 to 2 turns when feeding liquid chlorine to an evaporator

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Chlorine Characteristics

- Liquefied gas under pressure – 100 % available chlorine. A gas at normal room temperature and pressure
- Greenish – yellow Gas / 2.5 X's heavier than air
- Amber colored liquid / 1.5 X's heavier than water
- Boils @ -30 F° / freezes @ -150 F° at atmospheric pressure
- 1 volume of liquid = 460 volumes of gas
- Vapor pressure varies with the temperature
- Moisture & Chlorine = corrosive acids
- Very reactive with most elements especially with moisture present

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More Chlorine Characteristics…

- Respiratory, skin eye and mucous membrane irritant.
- A few breaths at 1,000 ppm (0.1%) will likely result in death. SCBA needed!
- Non–Flammable / Non Explosive: will support combustion
- Slightly soluble in water – 1% Max.
- Steel burns @ 483 F° in the presence of chlorine
- Reacts with some organic compounds with explosive violence
- Safe withdrawal limit for cylinders ~40ppd & ton containers ~450ppd
- Store cylinders in area where temperature is < 100 F

Hypochlorite

- Usually in the form of
  - Sodium Hypochlorite - NaOCl (12 – 15 % liquid) or
  - Calcium Hypochlorite - $Ca(OCl)_2$
- Increases pH
- Higher cost than gaseous chlorine
- Decomposition of Hypochlorite leads to the production of chlorate and perchlorate SDWA regulated disinfection by-products
- Important PPE is face/eye protection – Caustic base

Calcium Hypochlorite $Ca(OCl_2)$ HTH

- HTH – 65 % available chlorine
- White granular powder
- Used in swimming pools
- Very reactive with hydrocarbons
  - oils & paints
- Shelf life 60 – 90 days
  - if left open to high humidity loses strength faster

Sodium Hypochlorite

NaOCl (Bleach)

- Most often used instead of gas or powder
- Household Bleach 1% - 8%
- Commercial Bleach 12% - 15%
- Chlorine gas + Caustic = Sodium hypochlorite
- 15% = 1.25 lbs. Cl_2 per gallon
- Yellowish in appearance
- pH - 12 – 13 Mildly Corrosive – wear eye protection
- Short Shelf life, strength drops in 30 – 60 days
- Temperature > 85 degrees, weakens faster
- Sunlight also has an effect
- Incompatible with other chemicals

Disinfection Performance Goal

Disinfection Goal:

Maintain ≥ 0.20 mg/L free chlorine
At all monitoring sites in the distribution system, at all times.

- Regulatory Requirements:
  - Minimum of 0.20 mg/L free chlorine
  - Maximum of 4.0 mg/L free chlorine

DBP Performance Goals:

Individual Site LRAA Goals

Individual Site LRAA Goal:

TTHM LRAA ≤ 80 ppb
HAA5 LRAA ≤ 60 ppb
At all sample sites in the distribution system

- LRAA = Locational running annual average.
- Applies to the most recent four quarters of data (LRAA).
- Requires a minimum of four quarters of DBP data at each sample site assessed.
- **Stage 2 D/DBP Rule MCL is 80 ppb for TTHM and 60 ppb for HAA5**

Disinfection – Regulatory Goals

- EPA's regulatory framework requires systems using surface water (or groundwater "under the direct influence" of surface water) to:
  - <u>**Disinfect**</u> their water **and/or**
  - <u>**Filter**</u> their water or <u>meet criteria for avoiding filtration</u> so that the following contaminants are controlled at the following levels
    - † <u>Cryptosporidium</u> - 99 percent (2-log_{10}) removal
    - † <u>Giardia lamblia</u> - 99.9 percent (3-log_{10}) removal/inactivation
    - † <u>Viruses</u> - 99.99 percent (4-log_{10}) removal/inactivation

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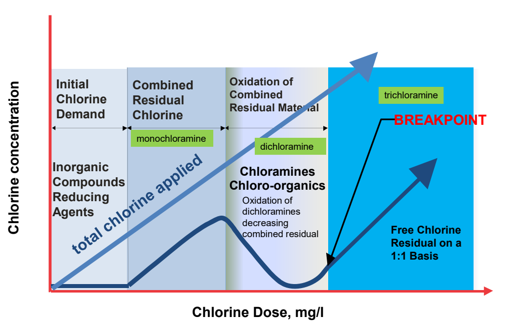
Breakpoint Chlorination



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Cl_2 Dose, Demand, and Residual

- **Dose:** **Total amount delivered**
- **Demand:** **What's consumed by constituents in the water**
- **Residual:** **What's left over**

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Cl_2 Dose, Demand, and Residual

DOSE = demand + residual

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Solve for Cl_2 Demand

Demand = DOSE - Residual

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Solve for Cl_2 Residual

Residual = DOSE - Demand

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Residual Chlorine

- Total Residual = Free + Combined
  - Free chlorine = HOCl + OCl^-
- Available chlorine = oxidizing capacity equivalent to same mg/L of Cl_2

Hypochlorous Acid and Hypochlorite

- Cl_2 + H_2O -> HOCl + HCl

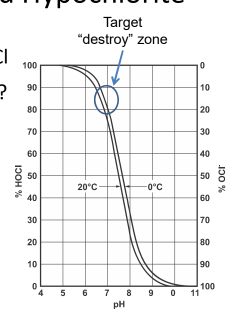
Which form destroys bacteria best?

Hypochlorous acid, HOCL …!

HOCl -> H^+ + OCl^-

0…………………7………………..14

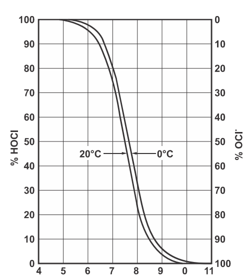
pH



How does pH effect the disinfection process ?

Hypochlorous Acid and Hypochlorite

- More HOCl at pH's below 7.5
- HOCl disinfects best
- At higher pH's, chlorine doses and contact times must increase



Chloramines

- Chloramines are formed when Cl_2 reacts with ammonia (NH_3)

$NH_3 + HOCl \leftrightarrow NH_2Cl + H_2O$ monochloramine

$NH_2Cl + HOCl \leftrightarrow NHCl_2 + H_2O$ dichloramine

$NHCl_2 + HOCl \leftrightarrow NCl_3 + H_2O$ trichloramine (nitrogen trichloride)

Chloramines

- Not effective for *Cryptosporidium* inactivation
- Used to provide a residual in the distribution system
- Persistent residual & Higher concentration
- “Halts” the formation of THMs or HAAs
- May control biofilms/regrowth better than free Cl_2
- Relatively inexpensive

“CT” Values

- Disinfection proportional to “C x T”
  - **C = concentration of disinfectant, mg/l**
  - **T = contact time, minutes**
- CT = Cl_2, mg/l x t, minutes
- CT values specific to:
  - Disinfectant
  - Target organism
  - Reduction requirements

C x T Concept

- Disinfection activity can be expressed as the product of disinfection concentration (C) and contact time (T)
- Disinfectant concentration and contact time have the same "weight" or contribution in disinfection activity and in contributing to CT
- Example: If CT = 100 mg/l-minutes, then
  - If C = 10 mg/l, T must = 10 min. for CT = 100 mg/l-min.
  - If C = 1 mg/l, then T must = 100 min. for CT = 100 mg/l-min.
  - If C = 50 mg/l, then T must = 2 min. for CT = 100 mg/l-min.

Estimated Range of CT Values

Bacteria	CT, Free Chlorine mg-min/L
2-Log (99%)	0.4-0.8
3-Log (99.9%)	1.5-3
4-Log(99.99%)	10-12

Source: Tchobanoglous in WERF Alternative Disinfectants, 2008

- Absolute CT value required will depend on water quality, pH, and temperature

Disinfection

Ultraviolet Light

99

UV Lamps

- Physical Process
- Damages genetic DNA Wavelengths between 100-400 nm
- Disrupts organism replication
- Advantage – No chemical used – contact time is seconds




Challenges with UV Lamps

- High failure rate – bulbs blow
- Lose intensity over time and bulbs have to be replaced every 8,000 hours
- Up to 100% Redundancy Required
  - Channels
  - Banks
- Lamp output degrades over time

Chlorination versus UV radiation

	Chlorine	UV
Disinfection by-products (DBPs)	Yes	No
Residual	Yes	No
Corrosive	Yes	No
Community safety risk	Yes	No
Effective against Crypto/ Giardia	No/Yes	Yes
Contact time	30 – 60 minutes	< 20 seconds
Lamp cleaning	N/A	Yes
Costs	Competitive when chlor/dechlor is required and fire codes must be met. Lamps are expensive	

Water Treatment

Coagulation

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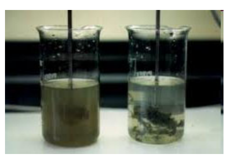
Objectives of Coagulation

- To destabilize particles
- To convert “dissolved” substances to particulate substances



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Coagulation - 2 Step Process

1. Particle Destabilization
   - Chemical Process
   - Makes particles stick together
   - Provides particle surface area to adsorb dissolved compounds.
2. Particle Transport (Flocculation)
   - Physical Process
   - Slow mixing to induce particle collisions

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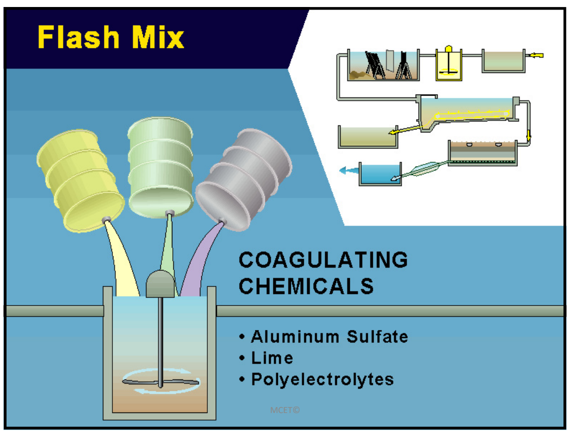
Coagulation – Process Description

- Adding and rapid mixing of chemical coagulants into the raw water.
- The process of adding a chemical or combination of chemicals to neutralize the electrostatic charges on suspended particles in raw water so that they will attract to form larger particles.



Coagulation – Rapid Mix

The process of providing rapid agitation to distribute the coagulant and other chemicals evenly throughout the water

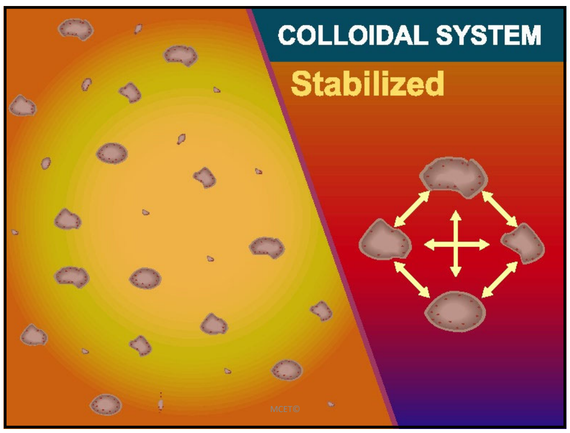
Types of Rapid Mix Devices:

- **Mechanical Mixers**
- **Static Mixers**
- **Pumps and Conduits**
- **Baffled Chambers**

Factors Affecting Rapid Mix

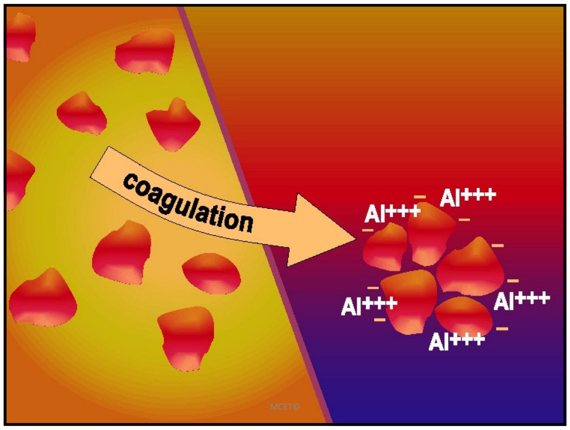
- Adequate mixing intensity is critical immediately upon addition of coagulant chemical
- Detention time typically 1 – 30 seconds
- Good process control begins with regular monitoring of the raw and settled water quality

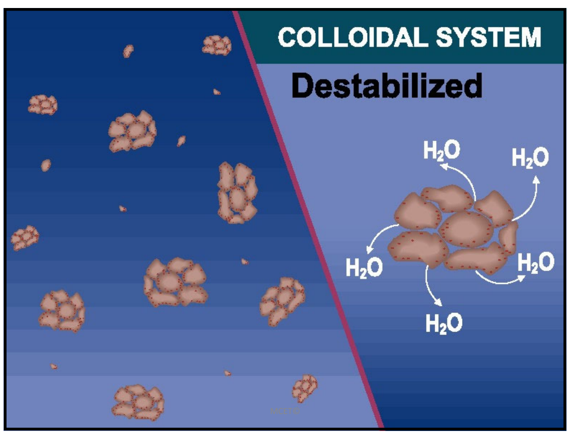
Poor mixing intensity



Chemistry of Coagulants

- Two groups of coagulants
  - metal coagulants: aluminum, iron
  - polyelectrolytes
- Alum: $Al_2(SO_4)_3 \cdot 14H_2O$
- Ferric chloride: $FeCl_3$
- Alum and ferric coagulants behave similarly





Flocculant Aids

Reasons For Using Flocculant Aids…

- to improve coagulation
- to build stronger, more settleable floc
- to overcome the effect of temperature drops which slow coagulation
- to reduce the amount of coagulant needed
- to reduce sludge production

Effects of Water Temperature on Coagulation

- Warm Water = Improved Coagulation
- Cold Water = Reduced Coagulation

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Effects of pH & Alkalinity on Coagulation

Aluminum and Ferric based coagulants.....

- react better in waters within a certain pH range and alkalinity range.
  - Alum: 5.5 – 7.5
  - Ferric: 5.0 – 8.5
- require adequate alkalinity for optimum coagulation
  - Alum: 1 mg/L converts 0.5 mg/L of $CaCO_3$
  - Ferric: 1 mg/L converts 0.75 mg/L of $CaCO_3$
- are very acidic and will reduce pH / alkalinity

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Effects of Turbidity on Coagulation

- Low turbidity
  - Sometimes difficult to form a proper floc
  - More coagulant may be needed
  - Coagulant aid / weighting agent may need to be applied
- Fluctuating turbidity
  - coagulant dose must be adjusted

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Effects of Color on Coagulation

- Color causing organics compounds react with coagulants.
- Pre-treatment with oxidants or adsorbants may be necessary

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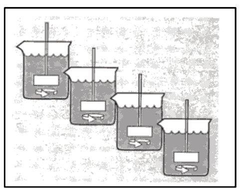
Jar Test



- Simulates C / F / S processes
- Used to evaluate…..
  - coagulant chemicals type, combination, order of application and optimum dose
  - flash mix intensity and detention time
  - flocculator speed and detention time
  - Settling velocity (for sedimentation basin)

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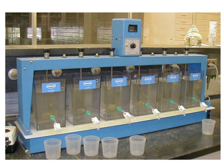
Jar Test



- Should be conducted….
  - using raw water as sample
  - whenever there are changes in raw water quality (turbidity, color, pH, alkalinity, temperature)
  - at least once per day
- Modified version of of jar test should be conducted in-plant to verify results

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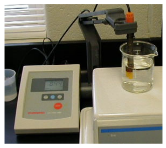
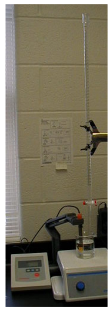
pH and Alkalinity Tests





- Typical pH of surface and ground waters 6.0 → 8.0
- Optimum pH for water treatment 7.5→ 8.5
- Should be conducted on raw water and in conjunction with jar test
- Indicates if pH / alkalinity needs to be adjusted for improved coagulation
- Requires pH meter, burette, and H_2SO_4

Water Treatment

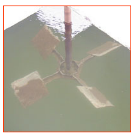
Flocculation

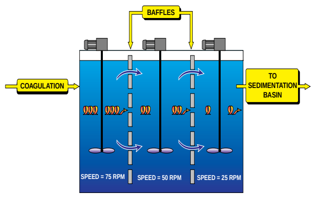
Flocculation

- Gentle stirring following rapid coagulation mix
- Promotes contact of destabilized particles to yield formation of multi-particulate “flocs”, which are larger, heavier, and much easier to separate by sedimentation and filtration

Factors Affecting Flocculation

- Coagulation Efficiency
- Detention Time
- Flocculator Speed





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Flocculation – Process Description

- Gentle stirring of the water (after coagulation has been accomplished) to bring suspended particles together so that they will form larger, more settleable clumps called floc.
- Detention time typically 10 – 30 minutes
- Flow through velocity typically 0.5 – 1.5 ft/sec

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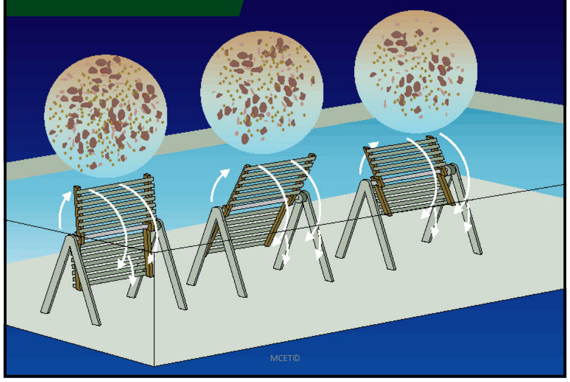
FLOC GROWTH



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Water Treatment

Sedimentation

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Sedimentation

- Objective: to separate solid material from water
- Oldest and most widely used process in water treatment
- Gravity driven
  - Sedimentation: separate particles denser than water by gravity force
  - Flotation: separate particles less dense than water via buoyancy force

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Sedimentation / Clarification – Process Description

- Reducing the velocity of water in basins so that suspended material (floc) can settle out by gravity.
  - Detention time typically 1.5 – 3.0 hours
  - Flow through velocity typically 2 – 4 ft/min
  - Surface loading rate 500 – 1,200 GPD/ft^2
- Sludge, the residue of solids and water, accumulates at the bottom of the basin and must then be pumped out of the basin for disposal.

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Factors Affecting Settling Rate

- Temperature (4° C)
  - Colder water slower particle settling
- TDS
- Particle density
- Flow-thru velocity
  - Short circuiting: inlet baffle, density currents
- Solids charge
- pH

Performance Goals - Sedimentation

- Turbidity ≤ 2 NTU 95% time when source turbidity > 10 NTU
- Turbidity ≤ 1 NTU 95% time when source turbidity ≤ 10 NTU
- Factors affecting sedimentation
  - Efficiency of C/F Processes
  - Detention Time
  - Surface Loading Rate
  - Weir Overflow
  - Temperature
  - Density Currents
  - Wind
  - Sludge Build-up

Water Treatment

Filtration

Filtration

- Process Description
  - Removal of suspended matter by passing the water through a granular porous medium such as sand, anthracite coal, or a membrane.
- Overall Goals:
  - Surface Water Treatment Rule (SWTR)
    - Surface sources must receive filtration and disinfection
    - Finished water turbidity standard of 0.5 NTU
  - Interim Enhanced Surface Water Treatment Rule (IESWTR)
    - Finished water turbidity standard of 0.3 NTU
    - Benchmarking / profiling for Cryptosporidium removal

Types of Filtration

- Granular Media Filtration
  - Most common type
  - Depth Filtration
    - Water moves through the pores between filter grains
    - Particles are smaller than pores and are deposited by colliding with the grain surface and attaching or sticking to the media
    - Filters and Rate: Slow Sand, Rapid Rate, High Rate
- Membrane Filtration
  - Particles larger than pores (removal by sieving)
  - Microfiltration and ultrafiltration
  - Nanofiltration and Reverse Osmosis

Typical Filter Design Criteria

- Surface loading rate
  - Low rate filter 2 – 4 gpm/ft^2
  - High Rate Filter 3 – 8 gpm/ft^2
- Media depth 24 inches to 80 inche
- Surface wash 2 – 5 gpm/ft^2
- Air wash 3 – 5 scfm/ft^2
- Backwash rate 10 – 20 gpm/ft^2
- Bed expansion 15 – 30%
- Gravel depth 0 – 18 inches
- Run length 12 – 72 hours
- Backwash duration ~ 30 minutes (in steps)
- Terminal head loss 8 – 9 feet max.

Filter Operation Cycle – 4 Stages

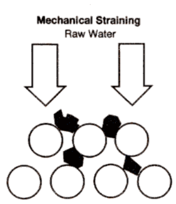
- Start-up
  - Filter ripening
  - Filter to waste
  - < 0.1 NTU before going online
- Operation
- Ending the Filter Run
  - Head loss
  - Turbidity breakthrough
  - Preset filter runs according to SOP
- Backwash – to clean filter for next cycle

Filter Operation

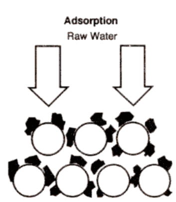
- The water above the filter provides the hydraulic pressure (head) for the process
- The filter media is above a larger gravel, rock, or other media for support
- Below the rock is usually an underdrain support of some type
- The water flows through the filter and support media, exiting from a pipe below.

The Filtration Process

Particle Attachment – Major Role



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



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

Filter Flow Control Equipment

- Loss-of-Head Indicator
- Rate-of-Flow Controller
- On-line Turbidimeter

What is Filter Backwash Water?

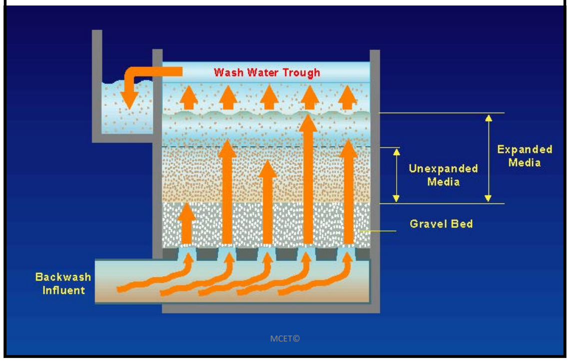
- Resulting water pushed back through the filter in the cleaning process
- Filter backwashing is an integral part of treatment plant operation

- Bed Expansion
- Scouring
- No “Boiling” or “Dead” Zones
- Avoid Air Charging and Water Hammer

Filter Backwash Operation

- Backwash
  - ➢ Fluidizes (expands) bed by reversing flow
  - ➢ Removes entrapped solids
- Backwash rates
  - ➢ Range from 10-35 GPM/ft^2 for adequate cleaning
  - ➢ Some standards require a minimum of 15 GPM/ft^2 or 50 percent bed expansion
  - ➢ Typically use 2 - 4% of the water filtered

Filter Bed Expansion



Filter Operating Problems

- Ineffective/improper backwashing
  - Mud ball formation
  - Filter media cracking and separation from filter walls (could result from mud ball formations) causing short circuiting of flow through the media
  - Supporting gravel disruption caused by backwash valve opening too quickly or uneven distribution of backwash water due to plugged under drain
    - "Boiling" occurs
    - Media will wash out into under drain

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Filter Operating Problems

- Ineffective/improper backwashing
  - Air binding; not common; pressure in the filter becomes negative during operation
    - Air dissolved in the water comes out of solution and becomes trapped in the filter
    - Creates high head conditions and short filter runs
    - Generally occurs when:
      - Water level is less than 5 feet above filter bed
      - Water is cold and super-saturated with air
    - Operate filters greater than 5 feet above filter bed or backwash more frequently

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Types of Membrane Processes

Removal of colloids / particles
- Microfiltration
  - Particle (> ~0.1 μm) removal (cyst removal)
- Ultrafiltration
  - Macromolecule & particle removal

Removal of dissolved material
- Nanofiltration (NF)
  - Softening (Ca, Mg); NOM removal
- Reverse Osmosis (RO)
  - Demineralization: membrane passes water and rejects ions and larger size molecules

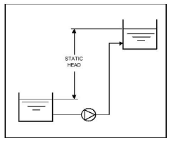
Membrane Filter Technology

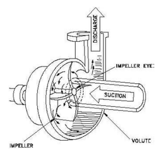
Filter type	Symbol	Pore Size, μm	Operating Pressure, psi	Types of Materials Removed
Microfilter	**MF**	**1.0-0.01**	**<30**	**Clay, bacteria, large viruses, suspended solids**
Ultrafilter	**UF**	**0.01-0.001**	**20-100**	**Viruses, proteins, starches, colloids, silica, organics, dye, fat**
Nanofilter	**NF**	**0.001-0.0001**	**50-300**	**Sugar, pesticides, herbicides, divalent anions**
Reverse Osmosis	**RO**	**< 0.0001**	**225-1,000**	**Monovalent salts**

Pumping Systems

Pumping

- Moving fluid requires pumps
- Pumps and motors need to overcome discharge head
- Motor horsepower depends on:
  - Total Dynamic Head
  - Pump efficiency
  - Motor efficiency





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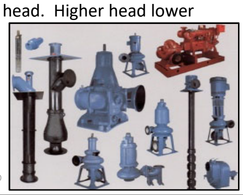
Types of Pumps

- Positive Displacement (PD) – constant flow regardless of the head or pressure.
  - Good for chemical feed . Precise
  - Piston / Diaphragm – Reciprocating
  - Hose / Peristaltic
  - Gear / Lobe - Rotating
  - Progressing Cavity (like a screw) – Rotating
- Centrifugal: flow varies with the head. Higher head lower flow & vice versa
  - Most Common
  - Single Stage
  - Multi-stage
  - Very high speed



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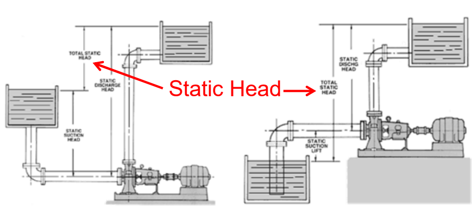
Total Static Head



- Vertical distance between the free levels of supply source and discharge liquid

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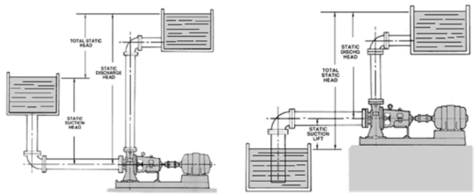
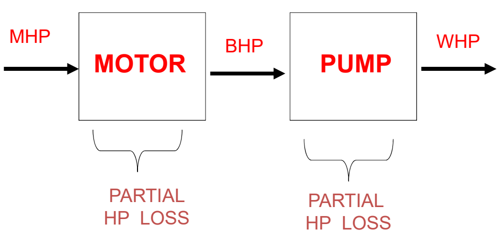
Total Dynamic Head (TDH)



- TDH = Static Head + friction losses
- Friction losses due to piping and velocity
- Pumps create the head to move water to higher elevations

WHP, BHP, and MHP



WHP, BHP, and MHP

1. **WHP =** $\mathbf{\dfrac{Flow\ (gpm) \times Head\ (Ft)}{3960}}$

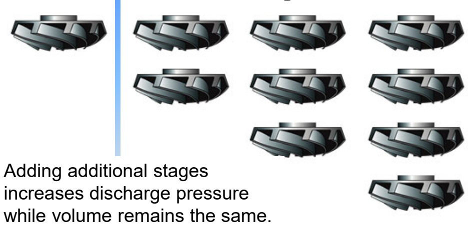
2. **BHP =** $\mathbf{\dfrac{Flow\ (gpm) \times Head\ (ft)}{3960 \times eff_{pump}}}$

3. **MHP =** $\mathbf{\dfrac{Flow\ (gpm) \times Head\ (ft)}{3960 \times eff_{motor} \times eff_{pump}}}$

Multi-stage Pumps

Single Stage

Multiple Stages



Adding additional stages increases discharge pressure while volume remains the same.

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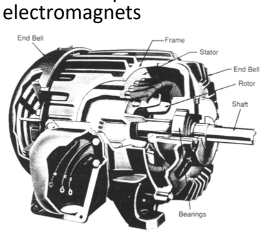
Construction

- Three basic parts of an AC induction motor: rotor, stator, and enclosure
- Stator and the rotor are electrical circuits that perform as electromagnets



Most common is the "squirrel cage" motor

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Instrumentation is a collection of devices such as sensors and controllers used to measure, display and adjust controlled variables.

Control systems - maintain <u>controlled variables</u> at a <u>set point</u> value by utilizing operators, instruments and <u>final control elements</u> to counteract the effects of process disturbances.
<u>Control is concentrating on the present.</u>

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Why is Control Necessary?

Main reasons for Control:

- To maintain the "measured variable" at its "desired value" when "disturbances" occur.
- To respond to changes in the "desired value" setpoint. Desired values are determined by control objectives.

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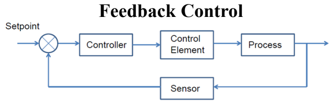
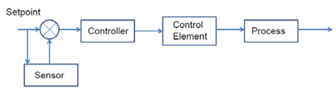
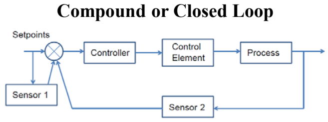
Feedback Control



Feedforward Control



Compound or Closed Loop



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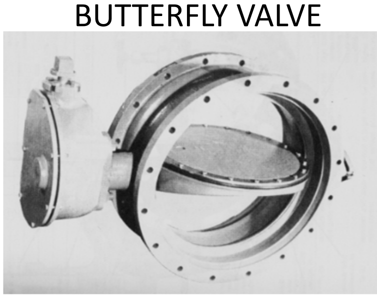
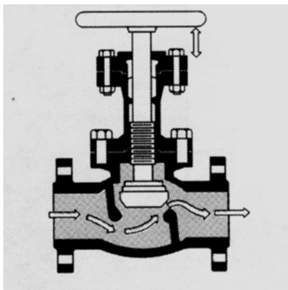
BUTTERFLY VALVE



OFTEN USED FOR LARGE DIAMETER ISOLATION

SOME ENERGY LOSS THROUGH VALVE

GLOBE VALVE



BEST FOR THROTTLING

HIGH ENERGY LOSS – GOOD FOR PRESSURE REGULATION

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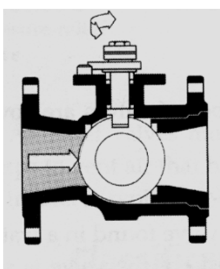
PLUG & BALL VALVES



GOOD FOR THROTTLING AND ON-OFF

LOW ENERGY LOSS BUT ¼ TURN = WATER HAMMER

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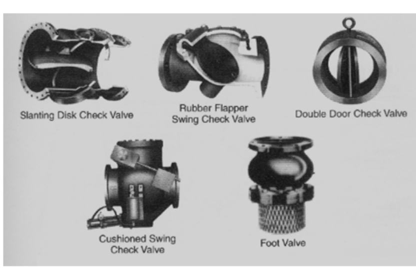
CHECK VALVES



ALLOWS FLOW IN ONE DIRECTION, prevents water from flowing back thru pump when off and at shutdown.

CAN CAUSE WATER HAMMER

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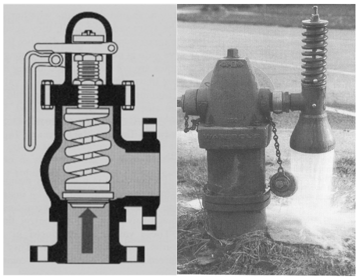
PRESSURE RELIEF VALVES



USUALLY A SPRING LOADED GLOBE VALVE

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AIR-VACUUM RELIEF VALVE

- Located at pipeline high points
- Vents accumulated air or allows air in when dewatering main

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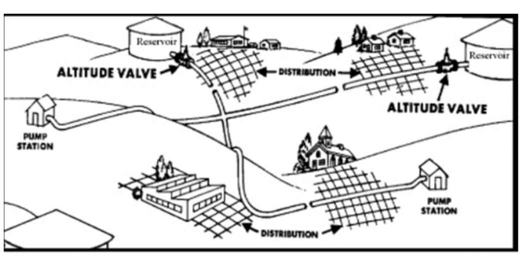
ALTITUDE VALVE



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Corrosion

What is Corrosion?

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What is Corrosion?

- Corrosion is a deterioration of metal materials by ***electrochemical*** interaction with their environment
- Metal pipe can corrode ***externally*** (due to piping arrangements and soil conditions) and ***internally*** (due to water quality)
- The gradual decomposition or destruction of a material (e.g., metal pipe or cement lining) as it reacts with oxygen and water
- Severity and type of corrosion depend on the chemical and physical characteristics of the water and the pipe material

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Galvanic Corrosion

Definition:

"Corrosion damage that occurs when two different metals are in electrical contact in an electrolyte (e.g. water), where the more noble metal is protected (cathode) and the more active metal tends to corrode (anode)"

	Location of Corrosion
Magnesium	Active (Anode)
Zinc	
Galvanized Steel	
Aluminum	
Mild Steel	
Cast Iron	
Lead	
Brass	
Copper	
Bronze	
Monel	
Nickel (passive)	
Stainless Steel 304 (passive)	
Stainless Steel 316 (passive)	
Silver	
Titanium	
Gold	
Graphite	
Platinum	Noble (Cathode)

Protected from Corrosion

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Erosion Corrosion

- The major contributing factors of erosion corrosion include:
  - Water velocities exceeding 4 fps
  - Pipe flow turbulence
  - Installation of undersized distribution lines
  - Multiple or abrupt changes in the direction of the pipe
  - Burrs on the inside of the pipe
  - Improper soldered joints

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Preventing Corrossion

- Corrosion Control
  - Promoting chemical scaling
  - Altering water chemistry
- Methods
  - Use of passivating agents
  - Improving pH stability - Alkalinity
  - Monitoring corrosion potential
  - Optimizing treatment with corrosion in mind

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Passivation

- A protective film in oxidizing atmospheres
- Protective layer adheres to parent metal
  - Barrier against further damage
  - Self-healing if scratched
- Sensitive to environmental conditions
  - Passivated metals may have high corrosion rates

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Passivating Agents

- **Orthophosphates**
  - Form inert complexes with metals - “passivating layer’
  - Effectiveness depends on pH, alkalinity, PO_4 concentration
  - Most effective pH: 7.2-7.8
  - Dosage: 1 to 3 mg/L
  - Application need to be upstream of oxidation chemicals or processes

***Orthophosphates** bond to lead pipes*

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Water Stability/Saturation

- Important to provide “stable” water to drinking water system to prevent metal release:
  - Stability refers to “degree of saturation” for:
    - Alkalinity – $CaCO_3$
    - Water Hardness – Ca^{+2}
  - Water can be over or under-saturated; and may cause problems under either condition
  - Low water pH/alkalinity causes metal release

Corrosion and Scaling Control

- Chemical treatment to control corrosion and scale formation is called “stabilization”
- Corrosion control is more prevalent because of **<u>lead and copper</u>** concerns

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Degree of Saturation

- Water can hold only so much chemical (e.g., $CaCO_3$) in solution
- If more is added, the chemical will precipitate rather than dissolve
- The point at which no more of the chemical can be dissolved is called the saturation point
- The saturation point of $CaCO_3$ depends primarily on pH; any change in pH has a great impact on LSI

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Measuring Corrosiveness of Water

Langalier Saturation Index (LSI)

- Corrosivity is MUCH more complex than just pH!
- The LSI is calculated based on various water quality results
- The LSI measures water ability to dissolve (corrode) or deposit (scale) calcium carbonate
- Negative value indicates corrosive water.
- Positive value indicates scaling water.

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Water Quality Objectives

Water Quality Parameter	Target Levels
Alkalinity (mg/L as $CaCO_3$)	As high as possible
pH	>8.5 (Prevent Copper/Lead release)
	>7.5 (Phosphate passivation)
	±0.1 pH enter distribution system
	±0.3 pH within distribution system
Water Hardness	80 to 120 mg/L as $CaCO_3$
LSI	> 0
PO_4 (mg/l)	1.0 to 3.0 mg/L as H_3PO_4

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pH and Alkalinity

- Corrosion in a water system can be reduced by:
  - Adjusting pH and alkalinity
  - Softening water with lime
  - Changing dissolved oxygen level (although this is not a common method of control)
- Any corrosion adjustment program should include monitoring for dosage modification as water characteristics change over time

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Corrosion and Scaling Control

- **Corrosion control** depends on formation of a protective film on inner pipe surfaces
- **Scaling control** depends on the avoidance of excess scale (e.g., $CaCO_3$) buildup on inner water system surfaces
- There are two ways to inhibit, or slow down, corrosion:
  - Adjusting the pH
  - Adding a corrosion inhibitor.
- Sometimes, both are used

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Chemicals for Adjusting pH and Alkalinity

Application	Chemical Name
Reduce pH and Alkalinity	Sulfuric Acid
	Hydrochloric Acid
	Carbon Dioxide
Increase pH and Alkalinity	Lime - Quicklime
	Lime - Hydrated Lime
	Soda Ash
	Sodium Hydroxide

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Scaling Control

Water Hardness

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Calcium and Magnesium Removal

Purposes - To prevent calcium/magnesium hardness 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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Water Hardness Classifications

Classification (USGS)	As $CaCO_3$	
	mg/L	Grains/Gal[1]
Soft	< 60	< 3
Moderately hard	60 – 120	3 - 7
Hard	120 – 180	7 - 10
Very hard	180 – 250	10 - 15
Extremely Hard	> 250	> 15

1. One grain/gallon = 17.1 mg/L

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Methods of Softening

Chemical Precipitation

- Lime-Soda Ash Softening

Membrane Softening

- Nanofiltration (NF)
- Low pressure reverse osmosis (RO)

Ion Exchange

- Zeolite softening

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Water Distribution Systems

Cross Connections

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The Cross-Connection

- Any connection between a potable water system and any source of contamination through which contaminated water *could* enter the potable water system.

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A Cross-Connection can be either...

- Direct – An actual connection to the source of contamination

Or

- Indirect – A connection that occurs when hydraulic conditions create a flow reversal allowing contaminates to enter the system

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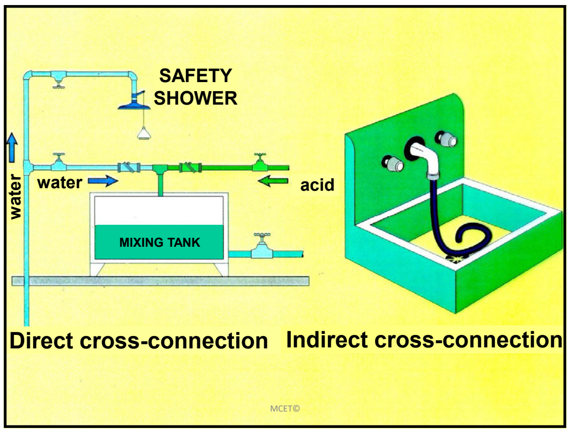

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Backflow

- The flow of any water, foreign liquids, gases and other substances back into a potable water system
- There are two conditions that can cause backflow: backpressure and backsiphonage

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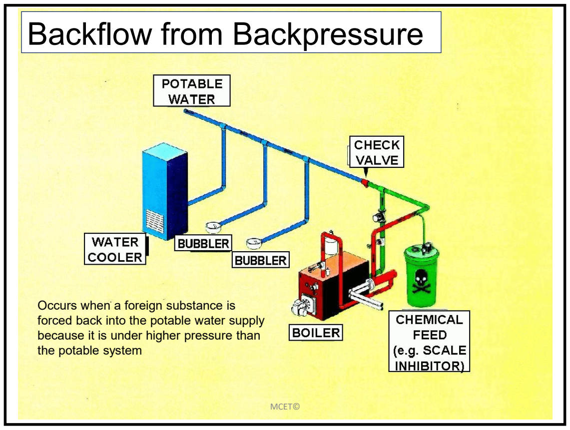

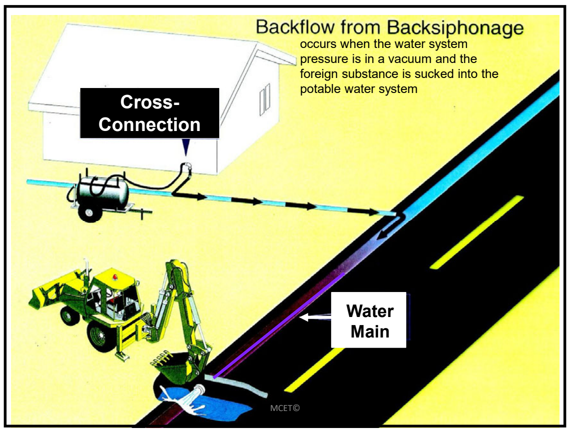

Common Protective Devices

- Air Gap
- Atmospheric Vacuum Breaker
  - Hose Bib Vacuum Breaker
- Pressure Vacuum Breaker
- Double-check
- Reduced Pressure Zone Device

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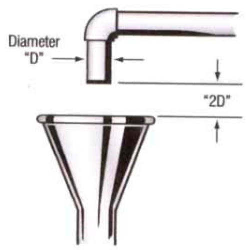
Air Gap

- Non-mechanical backflow preventer.
- Most effective of all devices.
- The air gap must be twice the supply pipe diameter but never less than one inch.



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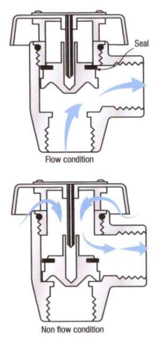
Atmospheric Vacuum Breaker

- One of the simplest and least expensive
- Provides excellent protection from backsiphonage
- Must be installed properly



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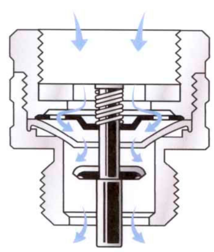
Hose Bib Vacuum Breaker

- Protect from backsiphonage through garden hoses, etc.
- Should not be used for backpressure situations



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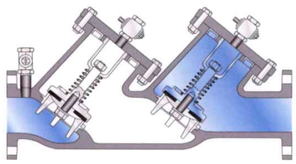
Double-Check Valve

- Two single, spring loaded check valves in a common body
- Test cocks to check operation
- Protects against low hazard backpressure and back siphonage



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Reduced Pressure Zone (RPZ) Backflow Preventer

- Maximum backflow protection in pressure conditions
- Modified double check with atmospheric vent between checks

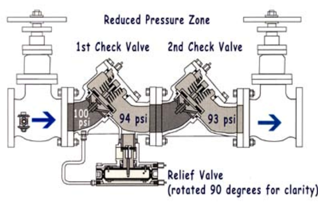

FIGURE 2 - Reduced Pressure Principle Backflow Preventer

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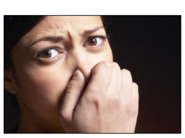
Taste & Odor

Most common water quality complaints:

Taste & Odor



Color

People lose confidence that water is safe

Taste & Odor

Natural Causes:

Biological Growth

- Can occur anywhere source to destination
- Microbes produce metabolic by-products
- Microbes release cellular material

Environmental Conditions

- Eutrophication
- Photosynthesis
- Human Activities

- The first step in determining the cause of T & O should be to locate where the problem originates
- Study plant records to anticipate changes that might lead to T & O problems

Taste & Odor

Treatment/Control: 2 categories

Removal

- Optimum Coagulation / Flocculation / Sedimentation
- Degasification
- Adsorption

Destruction

- Oxidation Chemicals

Fluoridation

Fluoride is an Ion naturally found in nature.

- Small amounts of fluoride is essential in a diet for proper tooth and bone formation.
- Discovered through comparisons of the teeth of children from areas that have different concentrations of natural fluoride in their drinking water.

Each individual State Health Department uses this information to establish optimal fluoride levels.

Annual Average of Maximum Daily Air Temperature,* °F	(°C)	Recommended Control Limits of Fluoride Concentration, *mg/L* Lower	Optimal	Upper
53.7 and below	(12.0 and below)	0.9	1.2	1.7
53.8–58.3	(12.1–14.6)	0.8	1.1	1.5
58.4–63.8	(14.7–17.6)	0.8	1.0	1.3
63.9–70.6	(17.7–21.4)	0.7	0.9	1.2
70.7–79.2	(21.5–26.2)	0.7	0.8	1.0
79.3–90.5	(26.3–32.5)	0.6	0.7	0.8

Secondary MCL – 2.0 mg/l – causes dental fluorosis

Primary MCL – 4.0 mg/l – causes skeletal fluorosis

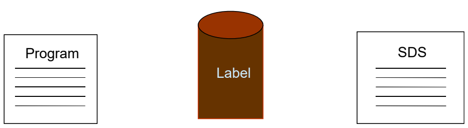
Item	Sodium Fluoride, NaF	Sodium Fluorosilicate, Na_2SiF_6	Fluorosilicic Acid, H_2SiF_6
Form	Powder or crystal	Powder or very fine crystal	Liquid
Molecular weight	42.00	118.1	144.08
Commercial purity, %	97–98	98–99	20–30
Fluoride ion, % (100% pure material)	42.25	60.7	79.2
Pounds required per mil gal for 1.0 ppm F at indicated purity	18.8, 98%	14.0, 98.5%	35.2, 30%
pH of saturated solution	7.0	3.5–4.0	1.2 (1% solution)
Sodium ion contributed at 1.0 ppm F, ppm	1.17	0.40	0.00
F ion storage space, ft^3/100 lb	22–34	23–30	54–73
Solubility at 77°F, g/100 mL water	4.0	0.762	Infinite
Weight, lb/ft^3	65–90	85–95	10.5 lb/gal, 30%
Shipping containers	100-lb bags, 125–400-lb fiber drums, bulk	100-lb bags, 125–400-lb fiber drums, bulk	13-gal carboys, 55-gal drums, bulk

Hazard Communication

Personal Protective Equipment

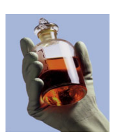
Lockout/Tagout

Purpose of OSHA's Hazard Communication Standard



How Must Chemicals be Labeled?

Each container of hazardous chemicals entering the workplace must be labeled or marked with:

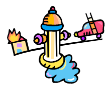


- Identity of the chemical
- Appropriate hazard warnings
- Name and address of the responsible party

Safety Data Sheets

Prepared by the chemical manufacturer or importer and describe:

- Physical hazards, such as fire and explosion
- Health hazards, such as signs of exposure
- Routes of exposure
- Precautions for safe handling and use
- Emergency and first-aid procedures
- Control measures



Training

Training is required for employees who are exposed to hazardous chemicals in their work area:

- At the time of initial assignment
- Whenever a new hazard is introduced into their work area

Personal Protective Equipment Hazard Assessments

Selecting Personal Protective Equipment

- 29 CRF 1910.132 Personal Protective Equipment
- Item (d), Hazard Assessment and Equipment Selection

"The employer shall assess the workplace to determine if hazards are present, or are likely to be present, which necessitate the use of personal protective equipment."

Control of Hazardous Energy

What is considered Hazardous Energy?

- Contact with a moving or energized part of the machine
- Struck or caught between a falling part of the machine
- Any exposure to physical hazards :

  - Electrical
  - Heat
  - Chemical
  - Pneumatic
  - Hydraulic
  - Steam
  - Kinetic

Potentially Hazardous Energy….

- Kinetic Energy is energy in motion
  - Spinning flywheels
  - Moving fan belts
  - Moving armatures
  - Electrical circuits
  - Moving fluids
- Potential Energy is stored energy
  - Coiled springs
  - Air brakes/hydraulic/pneumatic
  - Raised loads

Lockout/Tagout

- LOTO is required during servicing or maintenance operations:
  - When guards must be removed
  - When body is placed in contact with machine
  - When body is in danger zone
  - When setting up or adjusting equipment

Confined Space Safety

- Confined space is any space that has
  - Limited means of entry or exit
  - Is large enough for an employee to enter and perform work
  - Is not designed for continuous occupancy
- Confined spaces are either
  - Permit-required
  - Non permit-required

Equipment for Confined Space Entry

- Testing and monitoring equipment
- Ventilation equipment
- Communications equipment
- Lighting equipment
- Barriers and shield
- Ladders and other access equipment
- Rescue and emergency equipment

Trench Safety

- All trenches 5 feet or greater in depth must be protected from cave-in by sloping, shoring or shielding
- A ladder or other means for egress must be within 25 ft of trench workers
- A competent person must inspect the trench daily, before start of work and after any hazard increasing occurrence