PDHonline Course C106W (8 PDH)

Design of Small Water Systems (Live Webinar)

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DESIGN OF SMALL WATER SYSTEMS

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AGENDA

- Introduction
- Preliminary Planning and Design
- Water Quality Requirements
- Water Quantity Requirements
- Water Sources
- Water Treatment
- Pumping, Storage and Distribution

Introduction

Small Systems

- Classification of small can be based on:
  - Design flow rates of less than 100,000 gallons per day
  - Regulations based on
    - Acceptability of water source
    - Degree of treatment required
    - Monitoring requirements
  - Based on number of people served, for the time period served

Preliminary Planning and Design

Functions of water supply

- Provide water from a source
- Treat the water to render it suitable for its intended use
- Deliver the water to the user at the time and in the quantity desired

Factors affecting water systems

- Yield and quality of raw water sources
- Topography
- Geology
- Population density of areas served
- Intended uses of water

Agencies involved in water systems

- US EPA
- State and local public health agencies
- State and local pollution control agencies
- State and local planning agencies
- State and local highway agencies
- State and local recreational agencies
- Local utilities (electric, phone, natural gas, transportation)
- US Dept. of Agriculture
- US Dept. of Housing and Urban Development
- US Army Corps of Engineers

Water Quality

- Directly related to intended use
- Must meet appropriate local, state and federal standards
- Standards include:
  - Microbiological
  - Chemical
  - Radiochemical
  - Aesthetic

Water Quantity

- Reasonably accurate estimate of quantity of water to be supplied needed in early planning stage
- Average daily demand especially important
  - Used to assess the ability of available sources
  - Size raw water storage facilities
- Peak demand must be known to:
  - Size pumps,
  - Size pipelines,
  - Estimate pressure losses
  - Determine finished water storage requirements
- Smaller the system greater ratio between peak and average demand rates
- Design of small systems often driven by peak demand rather than average use

Water Sources

- Four alternative sources for small systems:
  - Direct connection to an existing system
  - Indirect connection to an existing system
  - Development of groundwater resources
  - Development of surface water resources

Factors affecting sources

- Factors include:
  - Proximity and capacity of existing systems
  - Necessary institutional arrangements for obtaining water from existing sources
  - Yield and quantity of available groundwater and surface water sources
  - Level of operation and management activity for the system being designed

Other Water Source Considerations

- Source of water is important factor in determining which environmental regulations apply
  - Groundwater
  - Groundwater under the influence of surface water
  - Surface water (lakes, rivers, streams, reservoirs)
  - Latter two generally regulated together
- Operations and maintenance considerations reflect the likelihood of connecting to an existing source
  - Might consider water hauling (especially for small recreation areas)

Water treatment

- Degree of treatment depends on the initial water quality
- Water quality can vary among sources
- Water treatment systems should be:
  - Simple in design and operation
  - Low in maintenance
  - Require minimal operator training and skills (may require licensing of operators)
  - Compatible with the available O&M resources

Pumping, storage and distribution

- Needed to deliver water to users
- All three components must work together
- Must carefully integrate the design of such systems

Cost estimating

- Natural part of any design
- Detailed estimates can only be made after design is fairly complete
- Sources of costs
  - Equipment suppliers
  - Equipment manufacturers

O & M

- Careful consideration of O&M is very important part of design
- Small systems should be designed for minimal O&M
  - Reliability of processes and equipment
  - Anticipate the types of failures
  - Provisions for dealing with as little disruption as possible
- Seek input from current or future managers and operators

O & M, Page 2

- Making system too complex is a major design error
- Must supply an O&M manual,
- Key considerations:
  - Operating the system under various scenarios
  - Preventative and routine maintenance procedures
  - Troubleshooting
  - Should be prepared as the system is designed; not afterwards
  - Use clear, unambiguous language and instructions

O & M. Page 3

- Optimum technology selected should consider residuals created
- Residuals include:
  - Sludges
  - Backwash waters
  - Spent chemicals
- Any life cycle analysis should include
  - Pollution control
  - Storage
  - Transportation
  - Personnel training
  - Disposal of residuals

O & M, Page 4

- Some technologies that are attractive for water treatment may require expensive monitoring or expensive residual disposal options
- Waste minimization should be a prime consideration
- Treatment technologies that produce potentially hazardous residuals are not favored
- Must coordinate with facility personnel to examine the feasibility and impact of residuals
- Designer must determine regulatory requirements with respect to residuals including classification, storage, transportation and disposal

Water Quality Requirements

Quality Considerations

- Dictated by highest level of intended use
  - Human Consumption
  - Commercial
  - Industrial
- For higher quality use: point of use treatment preferred

Laws and Regulations

- National Safe Drinking Water Act
- 1996 Reauthorization of SDWA

National Safe Drinking Water Act

- Assure that water supply systems meet national minimum standards
- Requires the US EPA to
  - Provide for uniform safety of drinking water
  - Provide for uniform quality of drinking water
- Roles of EPA
  - Set standards
  - Supervise state programs
  - Coordination with states

US EPA Required to

- Set standards for drinking water specifying
  - Maximum permissible levels of contamination
  - Minimum monitoring frequencies
  - Update 25 new standards every 3 years
- Protect sole sources of drinking water from contamination by federally assisted projects
- Protect underground drinking water sources from contamination by underground injection

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- Establish regulatory programs for assuring compliance with the standards
- Ensure proper implementation of regulatory program through oversight and technical assistance to states
- Provide financial assistance to the states to implement programs
- Gather pertinent information pertaining to drinking water sources and supplies

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EPA Approach

- Drinking Water Program (DWP)
- Public Water System Supervision (PWS)
- Groundwater Protection (GWP)

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DWP

- National Primary Drinking Water Standards (NPDWS)
- National Secondary Drinking Water Standards (NSDWS)

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1996 Reauthorization of SDWA

- Update the standard setting process based on
  - Occurrence
  - Relative risk
  - Cost-benefit considerations
- At least 5 new contaminants every 5 years
- States are to develop an operator certification program

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- EPA to identify technologies that are more affordable for small systems
- Set up Small System Technical Assistance Centers (National Small Flow Clearinghouse)
- States can grant compliance variances for
  - Systems serving less than 3,300 people
  - Systems serving between 3,301 and 9,999 with the concurrence of EPA

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National Primary Drinking Water Regulations

- General
  - Specify maximum permissible levels of contaminants
  - Authorize a maximum contaminant level (MCL)
    - Set for given substance
    - Set for given group of substances
  - Can consider economic feasibility as well as public health
  - Can establish treatment methodology criteria without specifying a MCL

NPDWS Definitions

Contaminant

Any physical, chemical, biological or radiological substance or matter in water

Maximum Contaminant Level (MCL)

Maximum permissible level of a contaminant in water delivered to the free flowing outlet of the ultimate user of a public water system, except for turbidity, where the level is measured at the point of entry into the distribution system

Contaminants added to the water under circumstances controlled by the user, except those resulting from corrosion of piping and plumbing, are excluded from the definition

Public Water System

System for the provision to the pubic of piped water for human consumption if the system has at least 15 service connections or regularly serves an average of at least 25 individuals at least 60 days/year.

Includes collection, pretreatment storage, treatment, storage and distribution facilities

Can be divided into community or non-community systems

Community Water System

A public water system that serves at least 15 service connections used by year-round residents or regularly serves at least 25 year round residents

Non-Community Water Systems

Any public water system that is not a community water system

Nontransient Non-Community Water System,

A public water system that is not a community water system and that regularly serves at least 25 of the same individuals at least 6 months per year.

Transient Non-Community Water System

A public water supply serving a transient population of at least 25 people at least 60 days a year.

Best Available Technologies (BAT)

The technology referenced by the US EPA to meet MCLs. MCLs must be set as close to maximum contaminant level goals (MCLGs), with the use of the best technology

Maximum Contaminant Level Goal

The MCLG for each contaminant is a nonenforceable, health-based goal set at a level at which no known or anticipated adverse effect on human health occurs. It allows for an adequate margin of safety, without regards to the cost of reaching these goals.

SDWA PWS exemptions

- Must meet all conditions:
  - The systems consists of only distribution and storage facilities
  - The system obtains all its water from a public water system to which the regulations apply
  - The system does not sell water to any individual, corporation, company, association, partnership, state, municipality, or federal agency
  - The system is not a carrier that conveys passengers in interstate commerce

MCLs

- Based on an assumed daily intake of 2 liters of water
- Designed to protect the public from potential health effects of long term exposure
- Not applicable to noncommunity systems, except for nitrates

SNARLS

- Suggested No Adverse Response Levels
- Established by the National Academy of Sciences
- Not enforceable
- Not directly related to MCLs
- Been developed for short term exposures
- Covers some potential contaminants
- Most useful in emergency situations such as chemical spills
- Continuously being reviewed and revised

MCLs for Inorganic Chemicals

- Applies to all community and non-transient noncommunity system
- For complete list see Pages 3-4 and 3-5
- For current list consult EPA website
  http://www.epa.gov/safewater/contaminants/index.html#listmcl

MCLs for Organic Chemicals

- Applies to all community and non-transient noncommunity system
- For complete list see Pages 3-5, 3-6 and 3-7
- For current list consult EPA website
  http://www.epa.gov/safewater/contaminants/index.html#listmcl

MCLs for Total Trihalomethanes and Other Disinfection Byproducts

- Applies to
  - all community systems serving a population of 10,000 or more and which add an oxidant for disinfection and
  - Community and NTNC systems obtaining water from a surface supply source
- For complete list see Pages 3-4
- Compliance is determined on the basis of the running average of quarterly samples
- For current list consult EPA website
  http://www.epa.gov/safewater/contaminants/index.html#listmcl

MCL for Turbidity

- Applies to all community and non-transient noncommunity systems using surface water sources
- Based on monthly average of all samples taken
- Set at 0.5 Turbidity Units (TU) or less, but not more than 1 TU for surface water sources and 5 TU or less but no more than 125 TU for groundwater sources
- For complete list see Page 3-4
- For current list consult EPA website
  http://www.epa.gov/safewater/contaminants/index.html#listmcl

MCL for Microbiological Contaminants

- Applies to all community and non-transient noncommunity systems
- For complete list see Page 3-4
- Compliance based on the analysis of samples taken at regular intervals and in numbers proportionate to the population served by the system
- For current list consult EPA website http://www.epa.gov/safewater/contaminants/index.html#listmcl

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Microbiological Rules

- Surface Water Treatment Rule (SWTR)
- Enhanced Surface Water Treatment Rule (ESWTR)
- Total Coliform Rule (TCR)

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SWTR

- Provides BAT requirements for
  – Giardia lamblia
  – Heterotrophic bacteria
  – Viruses
- Instituted in June 1989

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ESWTR

- Covers Crytosporidium
- Interim 12/1998

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TCR

- Finalized January 1991
- Established treatment techniques for
  – Fecal coliforms
  – Total coliforms
  – E. coli

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MCL for Radiological Contaminants

- Applies to all community and non-transient noncommunity systems
- Basic requirements published in July 1991, except for radon
- Based on limiting the annual dose to the whole body or a single organ
- For complete list see Page 3-4
- For current list consult EPA website http://www.epa.gov/safewater/contaminants/index.html#listmcl

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National Secondary DW Regulations

- Secondary not enforceable by US EPA
- Guidelines for states
- May be adopted by states
- Primarily cover contaminants that affect drinking water aesthetics
- Some may have health effects at higher concentrations

NSDWR

- Secondary MCLs in Table 3-2 in text
- For current list consult EPA website
  http://www.epa.gov/safewater/contaminants/index.html#listmcl

Table 3-2
Secondary Maximum Contaminant Levels (USEPA)

Contaminant	SMCL
Aluminum	0.05 + 0.2 mg/L
Chloride	250 mg/L
Color	15 color units
Copper	1.0 mg/L
Corrosivity	Noncorrosive
Fluoride	2.0 mg/L
Foaming Agents	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 TON[1]
pH	6.5 - 8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids	500 mg/L
Zinc	5 mg/L

[1] Threshold odor number.

Other Regulatory Requirements

- Clean Water Act (CWA)
- Resource Conservation and Recovery Act (RCRA)
- Hazardous Materials Transportation Act (HMTA)
- Occupational Safety and Health Act (OSHA)
- National Energy Conservation Policy Act (NECA)
- River and Harbor Act of 1899
- Various State and Local Acts

Water Quality and Public Health

- Water treatment started in 1850's
- British cholera epidemics of 1845-1849 and 1853

Water Borne Diseases

- No natural water should be assumed to be free of water borne disease
- Some cause taste and odors only
- Many cause no problem unless in large numbers
- Modern treatment removal or inactivation of all disease causing organisms (disinfection) but not all life forms (sterilization)

Special Interest Organisms

- Bacteria
- Algae
- Fungi
- Molds
- Viruses

Bacteria

- Can be pathogenic
- Can lead to aesthetic issues
  - Iron bacteria
  - Producing odor and taste problems
- Controlled by disinfection

Some Bacterial Waterborne Diseases

Disease	Responsible Organism	Comment
Cholera	*Vibrio cholera*	Very serious. Organism can survive in clean or turbid water.
Salmonellosis	Several species of *Salmonella*	Range from typhoid fever to "ptomaine poisoning."
Shigellosis	Several species of *Shigella*	Common cause of acute diarrhea. *S. Dysenteriae* causes bacillary dysentery.
Leptospirosis	Several species of *Leptospira*	Comparatively uncommon, but worldwide.
Tularemia	*Francisella tularensis*	Extremely virulent organism. Can survive in water for long periods.
Tuberculosis	*Mycobacterium tuberculosis*	Very resistant to chlorination.
Montezuma's Revenge	Variants of *Esherichia coli*	Generally harmless to natives, but not visitors.
Gastroenteritis	Many bacteria, e.g., *Yersina enterocolitica.*	Survives in very cold waters. Also caused by other types of organisms.

Algae

- Nuisance organisms
- Occasionally bloom
- Cause dissolved oxygen problems in water
- Cause operational problems
  - Filter clogging
  - Undesirable odor and tastes

Viruses

- Smallest of infectious organisms
- Not consistently removed by conventional treatment
- Methods to detect and quantify difficult and unreliable
- Outbreaks not ascribed to other organisms blamed on viruses

Protozoans

- Microscopic animals
- Three species been identified
  - Entamoeba histolytica
    - Causes amoebic dysentery
  - Giardia lamblia
    - Causes a recurring form of diarrhea
  - Cryptosporidium

Protozoan Removal

- First two species large and can be removed by:
  - Coagulation
  - Flocculation
  - Sedimentation
  - Granular media filtration
- Cryptosporidium removed by direct filtration (indicated with a turbidity less than 0.1-0.2 NTU)

Indicator Organisms

- Direct measurement of all species impractical
  - Wide variety of pathogens
  - May be present in very small numbers and thus escape detection
  - Enumeration of many species difficult, unreliable, time-consuming and/or very expensive

Ideal Indicator Organisms

- Indicate the presence of pathogens in both raw and treated water
- Be somewhat more hearty than pathogens
- Be present in biologically contaminated waters in great numbers
- Be readily identifiable
  - Simple quick, inexpensive, straightforward tests
- Be such that population density is directly related to the degree of contamination

Chemical Hazards

- Increasing concern
  - Water supply industry
  - Regulatory agencies
  - Consumer advocates
  - Lawmakers
  - General public
- Better testing methods
  - PPB
  - PPT

Definitions

- Contaminant: Any physical, chemical, biological or radiological substance found in water, can be good or bad
- Pollutant: any contaminant that has deleterious effects

Occurrence

- Unlimited number of contaminants
- If found above SDWA values, should be viewed with caution
- Only a few warrant outright rejection of a water supply

Turbidity

- When optical properties that cause light to be scattered and/or absorbed rather than directly transmitted through the medium of interest
- Likely sources: Suspended matter such as clay, silt, algae, or bacteria
- Measured by nephelometers and reported in NTUs

Occurrence and removal

- Turbidity should be removed when used as a public water supply
- Most particles sizes that cause turbidity are 1-200 nm in diameter
- Particle behavior controlled by state of hydration and surface electrical charges
- Need to add coagulants and flocculants to allow them to form larger particles and then remove
- Typical coagulant is aluminum sulfate

Color

- Occurs in groundwater rather than surface water
- Results from
  - Metallic ions
  - Humic substances
  - Industrial wastes
  - Algae
- Not a public health problem
- Removal processes vary based on sources of color
- Chemical oxidation and adsorption have proven effective

Tastes and Odors

- Result from
  - Algal, bacterial or actinomycete metabolites
  - Decomposing organic matter
  - Dissolved gases
  - Industrial wastes
- Difficult to deal with
- Some people more sensitive than others
- Typical methods of treatment include:
  - Aeration
  - Chemical oxidation (potassium permanganate)
  - Activated carbon adsorption

Hardness

- Caused by the presence of divalent metal ions
- Calcium and magnesium most prevalent in natural water
- Both surface water and groundwater can exhibit it, but more likely in groundwater

- Excessive hardness causes:
  - High soap demand
  - Makes bathing difficult
  - Interferes with laundry
  - Contributes to deterioration of fabrics
  - Promotes excessive deposition of calcium carbonate and magnesium hydroxide on pipes
- Insufficient hardness
  - Interferes with rinsing
  - Promotes rapid corrosion of metallic water lines and appurtenances

Hardness Classification

mg/L as $CaCO_3$	
0-20	Soft
20-60	Slightly Hard
60-120	Moderately Hard
120-180	Hard
Above 180	Very Hard

Hardness removal

- Chemical precipitation
  - Less costly
- Ion exchange
  - Simpler
  - Preferred for small systems

Iron

- Found in both surface water and groundwater
- Surface water poses more problems
- Acceptable iron level in DW is 0.3 mg/l

Iron issues

- Problems
  - Color – yellowish, reddish or brownish
  - Taste – metallic
  - Stains plumbing fixtures
  - Interferes with laundry and cleaning
  - Bacteria that feed on iron oxidation
- Solutions
  - Use corrosion inhibitors (polyphosphates)
  - Ion exchange/adsorption
  - Oxidation/sedimentation/filtration
    - Oxidants include:
      - oxygen, chlorine, potassium permanganate

Manganese

- Colors water dark brown or black
- Manganese chemistry is complex
- Use similar removal methods as used for iron
- More likely to be present in surface waters than iron
- Acceptable DW level is 0.05 mg/l

Alkalinity

- Defined as the ability to neutralize an acid
- Reported as mg/l of $CaCO_3$
- Bicarbonate ion is responsible for most alkalinity in natural water
- Optimal amount depends on
  - pH
  - Hardness
  - Concentration of dissolved oxygen
  - Concentration of carbon dioxide
- Desirable level is 30-200 mg/l, but 500 mg/l may be acceptable

Alkalinity

- Unrelated to public health
- Very important to pH control
- pH depressed by
  - Alum
  - Gaseous chlorine
  - Other chemicals used in water treatment
- Alkalinity provides buffer capacity
- May need to add lime to increase alkalinity in water

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pH

- Most natural water has a pH range from 6.5-8.5
- Important for
  - Body chemistry
  - Effectiveness of certain water treatment processes
  - Efficiency of some water treatment processes
  - Corrosion control
- Presence of water with a pH between 4-4.5 indicates mineral acids (potential industrial waste contamination)

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Water Quantity Requirements

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Key facts

- US has an abundant supply but population is not distributed in the same pattern as water
- Have had local water shortages
- Water use projections becoming important
- Reference covers:
  - Municipal and rural communities
  - Military installations
  - Recreation areas
  - Highway rest areas

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Water use rate variation factors

Climate	Standard of living	Extent of sewerage
Extent of metering	Price of water	Season of year
Day of the week	Time of day	Special events
Firefighting requirements	Commercial developments	Industrial development
Landscape irrigation	Water quality	Alternate supply availability
Distribution system pressure	System O&M and management	Real/potential water shortages
Legal constraints		

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Types of water use rates

Average annual use	Average monthly use
Maximum monthly use	Average weekly use
Maximum weekly use	Average daily use
Maximum daily use	Maximum hourly use
Maximum instantaneous use	Maximum weekend use*
Average weekend use*	

* For specialized systems, such as recreation areas

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Average use

- Needed to
  - Determine if water source yield is sufficient to safely supply over long periods of time
  - Determine storage capacity needed to assure an adequate supply during critical periods

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Peak use

- Needed to ensure peak demand
  - Can be met without overtaxing production
  - Can be met without overtaxing treatment facilities
  - Can be met without causing excessive pressure losses

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Intermediate Use

- Used in hydraulic design of treatment facilities
- Between average and peak use rates
- May design to meet average daily flow rate but be hydraulically capable of greater flows

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- If designed at maximum daily use rate
  - System operates below design
    - Frequently used for rapid sand filters
  - May be able to take various treatment units offline and held in reserve
- If designed at average daily use
  - Operating only a portion of the day
  - Uneconomical for larger communities, but attractive for smaller communities

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Storage Requirements

- Raw water storage
  - General
  - Design criteria
  - Groundwater
- Finished water storage

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Different types of water storage

- Surface water impoundment
- Finished water storage at the treatment plant
  - Clear well
  - Backwash water
- Distribution storage
  - Ground tanks
  - Elevated tanks
  - Hydropneumatic tanks

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General

- May not need raw water storage
  - Small town drawing from impoundment
  - Large city drawing from large lakes
- Storage size is determined based on hydrologic information
  - Minimum dry weather flow
  - Average streamflow
  - Rainfall/runoff patterns
  - Average measure of water use
- Rippl (mass diagram) most commonly used method; references:
  - Clark, Viesmann and Hammer
  - Fair, Geyer and Okun
  - Linaweaver, Geyer and Wolff
  - Salvato
  - Steel and Mcghee
  - Metcalf and Eddy

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Design Criteria

- In eastern US reservoirs designed to refill every year
- Arid areas must store during wet years
- Based on drought conditions that occur 1 time every 20 years plus 2.5%
- May need to practice water conservation when storage is depleted
- Consider the effects of
  - Evaporation
  - Seepage
  - Siltation

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Groundwater Storage

- Does need long term raw water storage
- May need short term storage
- Especially important for low yield wells:
  - Need to have a central storage tank before pumping to system
  - Can equalize pumping rates when some or all of the water requires treatment
- Use mass diagram method for designing any storage

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Finished water storage

- Designed to
  - Meet peak demands (firefighting)
  - Allow continued service when the supply is interrupted
  - Equalize system pressures
  - Eliminate continuous pumping
  - Facilitate the use of economical pipe sizes
- Use rules of thumb, depends upon system size and type
  - ½ average daily use
  - Maximum daily use
  - 2-3 day supply
- May want to use mass diagram method as backup

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Municipal water use

1) Select the design period
2) Forecast population to be served by the end of the design period
3) Estimate the expected average water use rate at the end of the design period
4) Estimate design use rates by multiplying the average by selected factors
5) Determine the required fire demand
6) Select the applicable use rates for various system components

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Design period

- Most components 10-25 years
- Some components 25-50 years (those difficult to enlarge and/or costly)
- Higher interest rate – shorter design period
- Overdesign extends design period
- Size water lines for full development

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Population forecasts

- Based on combination of:
  - Official census data
  - Special studies made by public or private interests
  - Expansion attitudes of local people (business/political leaders)
  - Input from state, regional and local planning agencies
  - Refer to specific texts (same as water storage)

Average per capita usage

- Typically 100-175 gals/capita/day (450-800 L/capita/day)
- National average of 165 g/c/d (755 L/c/d)
- Can range from 50-500 g/c/d (227-2273 L/c/d)
- Based on knowledge of area being served
- Much lower now given water conserving equipment required by many local codes

Disaggregating water use

Residential (33-52%)
- **Single-family**
  - Interior
  - Exterior
- **Multiple-family**
  - Interior
  - Exterior

Commercial (10-18%)
- Interior
- Exterior

Industrial (16-24%)
- Process
- Cooling
- Sanitary

Public and Institutional (5-9%)
- Interior
- Exterior
- Hydrant Flow

Unaccounted-for (8-17%)
- Metering Error
- Loss

Interior water usage

Equipment	Usage (%)
Toilet	30-42
Bathing	20-37
Laundry	7-22
Dishwashing/cooking	6-25
Drinking	5-25
Misc.	2-5

Peaking factors

- Designed based on maximum hourly demand or fire flow and maximum daily demand
- Ratio of peak/average increases with decreasing system size
- Ratio of peak/average increases with increasing use of lawn watering

Typical peaking factors

- Avg. max. monthly/avg. daily 1.2-1.5
- Avg. max. weekly/avg. daily 1.4-1.48
- Max. daily/avg. daily 1.35-4.5
- Max. hourly/avg. daily 2.25-12.1

Residential water use (Linaweaver, etc.)

$Q = Q_d + 6010(a)(L_s)E_{pot} - P_{eff})$ where Q> or = Q_d

Where:

Q = expected average demand for any period (L/d)

Q_d = expected average residential use for periods of a day or longer (L/d)

a = number of dwelling units considered

L_s = average irrigable area per dwelling unit (hectares)

E_{pot} = estimated average potential evapotranspiration (mm of water/d)

P_{eff} = amount of natural precipitation reducing the need for lawn watering (mm of water/d)

Linaweaver assumptions

$Q_d = 594 + 13.1V$

Where
V = average market value of the dwelling units (1,000)

During high demand periods and negligible precipitation formula reduces to:

$Q = Q_d + 6010 (a)(L_s)(E_{pot})$

Average potential evapotranspiration is 7.11 mm/d (.28 inches/d)

Fire flows

- Annual fire flows very small compared to typical municipal flows
- Short term demands can be very high
- Based on recommendations of insurance companies
- Residential demand generally range from 30-500 L/s (500-8,000 gpm)
- CBD demand generally 760 L/s (12,000 gpm) with an additional 500 L/s (8,000 gpm)
- Duration of flows must be from 4-10 hours
- It is assumed that fire flow must be concurrent with peak demand at pressure of at lest 138 kPa (20 psi)
- Fire demand often controls distribution system design

Commercial/Industrial

- Estimate each use separately
- Broken down by individual users if possible
- Otherwise should use various references

Rural water use

- Design criteria for large systems often inappropriate
- Average per capita use is less for a small system
- Some variables include:
  - Cultural factors
  - Property values
  - Extent of lawn watering
  - Others
- Industrial or commercial users will have a greater impact

Special considerations

- Factors against using large system design approach include:
  - Diversity of customers served
  - Grid system layout of piping
  - Use of 6-8 inch diameter pipes
- Rural areas have low areal density
- Generally 2-5 service connections/mile of pipe
- Fire protection is not economical
- Pipe sizes around 2 in.

Average water use

- Many rural families are less dependent on high water use appliances
- Unit price of water is higher than urban water
- KY study
  $Q – 7.57\ P^{-0.92}$

Where Q = average monthly water use/dwelling unit
P = unit price of water, $ per 1,000 gallons

Goodwin and Doekson Formula

Q_m = 1505.73 + 954.86N + 33.85Y + 102.76E + 55.49C + 183.6H + 953.86G + 2221.92I

Where
Q_m = average monthly water use, gallons
N = number of persons/household
Y = year the house was built
E = total years of education for head of household
C = number of cattle watered
H = number of horses watered
G = garden (if garden = 1, if no garden = 0)
I = income where =1 if exceeds $40,000, =0 if $40,000 or less

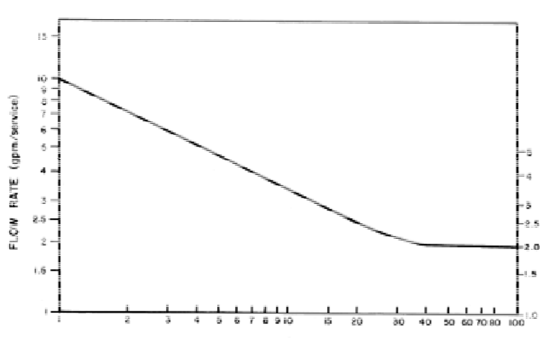
Special notes

- May not be desirable to run treatment facilities 24 hours/d
- Operating costs dominated by operator salaries
- Best to produce all treated water during 4-8 hours each day
- Groundwater treatment often only needs disinfection
- For operating part of day, must cover: raw water storage, pumping, transmission, and treatment and finished water transmission, storage and pumping facilities

Peak flows

- Don't usually consider fire flows
- Maximum instantaneous demand a function of customers served
- As number of customers served increases, unlikely that all will demand water at same time
- Peak flow may be estimated as the product of some peak use per connection
- Estimates of maximum daily rates range from 1L/min (1gpm) to 55 L/min (15 gpm),
- 2.3 L/min/connection with a peak monthly factor of 1.5(Hughes and Israelson)

Estimating Peak Flows, (Ginn, Corey and Middlebrooks)



Recreational water use

- Affected by:
  - Location
  - Type of facilities
  - Visitation rates
  - Visitation patterns
  - Season of the year
  - Day of the week
  - Special events
  - Irrigation requirements
  - Weather conditions

COE Guidance

- Min. design flows estimated as sum of
  - 110-190 L/day (30-50 gpd) per day shift employee
  - 570 L/day (150 gpd) for each dwelling
  - 20 L/day (5 gpd) for each expected visitor
  - Any additional requirements (cooling water, lawn watering)
- Other sources
  - US EPA
  - State agencies
  - Local codes

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US EPA estimates of water use

Type of Facility	Gallons per day
Bath houses (per bather)	10
Camps:	
Construction, semi-permanent (per worker)	50
Day with no meals served (per camper)	15
Luxury (per camper)	100-150
Resorts, day and night, with limited plumbing (per camper)	50
Tourist with central bath and toilet facilities (per person)	35
Laundries,	
self-serviced (gallons per washing, i.e., per customer)	50
Parks:	
Overnight, with flush toilets (per camper)	25
Trailers with individual bath units, no sewer connections (per trailer)	25
Trailers with individual bath, connected to sewer (per person)	50
Picnic:	
With bathhouses, showers, and flush toilets (per picnicker)	20
With toilet facilities only (gallons per picnicker)	10

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Peak flows

- Based on number of fixture units
- Sum all the fixture units and consult a design curve
  - Hunter
  - Salvato
  - US EPA
- Estimate any continuous demand separately and add to fixture demand

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Rest area water demand

- Similar to recreation areas
- FHA design criteria
  - 9% of vehicles passing stop
  - 25.4 L (6.7 g)/vehicle
  - 20 year design period
- 16% of daily use at midday
- 67% of daily use from 8 am – 4 pm
- Irrigation of 25mm – 76 mm (1-3 in.) per week
- Should use low water fixtures
- Minimize irrigation needs
- Need to provide storage capacity

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Water conservation

- Flow reduction devices
- Low flow fixtures
- Low flow appliances
- Many conservation devices interrelated and may be less than the sum of each separate device
- O&M costs can be reduced
- Reduce the treatment capacity of the facilities
- Need to disaggregate water uses to maximize devices

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Water Sources

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Points to consider

- Adequacy and reliability wrt providing sufficient water
- Expected water quality
- Development costs
- O&M costs
- Monitoring and health requirements

Alternative water source categories

- Connection to an existing system(s)
- Water hauling
- Development of groundwater resources
  - Wells (1 or more)
  - Underground springs
- Development of surface water resources

Sanitary Survey

- Perform for all alternative sources
- Validity dependent on investigator
- Purpose:
  - Conditions that might adversely affect the quality and adequacy of the proposed water supply
    - Discover
    - Investigate
    - Evaluate
- Gather other basic useful information in analyzing the suitability of the water source

Sampling

- Collection of samples for analysis
  - Physical
  - Chemical
  - Microscopic
  - Microbiological
- Representative samples pose a challenge
- May inadvertently contaminate samples
- Develop detailed sampling procedures
- Consult state and local health depts.
- Follow US EPA and American Public Health Assoc. guidelines and regulations

Example Analyses

Acidity	Calcium hardness	Total chloride
Alkalinity	Temperature	Total fluoride
pH	Color	Total chlorine demand
Free Carbon Dioxide	Taste	Free available chlorine
Total Residue	Odor	Total coliforms
Total volatile residue	Turbidity	Fecal coliforms
Total hardness	Nitrate Nitrogen	Organic compounds

Existing supplies

- If economical, this is the best option
- Advantages of connecting to an existing system
  - Source development costs are avoided
  - O&M is simplified (small systems don’t need qualified operators)
  - Substantial O&M costs can be avoided (small systems have limited financial resources)
  - Administrative responsibility may be greatly reduced
  - Regulatory burdens may be reduced or eliminated
  - Certain legal liabilities may be avoided

Regulatory considerations

- SDWA burden on existing system
- NPDWR do not apply to storage and distribution systems
- Considerable expense and effort avoided
- All water is obtained from a publicly owned system
- Receiving system neither sells water nor involved in conveying passengers
- Community systems often cannot utilize this option
- Rest stops and recreation areas can take advantage

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Disadvantages of tying into an existing system

- No control over management and operation of the supplying system
- Receiving system is dependent on supplying system for price of water
- May not be possible to negotiate a long term agreement
- Connecting system may need to pass along difficult terrain, experience low pressure , require booster pumps, and need substantial storage

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Existing system water quality

- Investigate during sanitary survey phase
- Look at factors that might influence future water quality
- Look at intakes, pump stations, treatment plants, storage facilities, distribution systems, and connections with other systems (industries and fire protection)
- Evaluate for actual or potential sanitary defects, such as cross connections, water main locations, or broken or leaky mains

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Evaluate the following

- An aggressive cross connection elimination program
- Good maps of the system
- Administrative attention to detail
- Good record keeping
- Adequate shop with a supply of spare parts and equipment
- Competency and dependability of O&M personnel
- Overall philosophy of system administrators

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Investigation of an existing supply

Source	Excess supply available and not already allocated	Distance from site to existing supply
Reliability	Type of treatment	Variation in pressure at the point of diversion
Quantity developed	Rates in gpm at which supply is available	Ground elevation at the point of diversion and the point of use
Ultimate quantity	Cost per thousand gallons	Existence of contaminating influences

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Groundwater

- Often a logical source when connection to an existing system not an option
- Often preferred when minimal treatment is desired
- Sources
  - Springs
  - Shallow wells
  - Deep wells (preferred)
- Springs only suitable for very small systems

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Well Sanitary Survey

Character of local geology	Thickness, location of water bearing strata	Well spacing required to prevent mutual interference
Slope of ground surface	Location, log information, yield and water quality analysis of nearby wells	Legal clearances required because of wells of others
Size of catchment area	Nature/location of sources of pollution	Drawdown data from nearby wells
Probable rate of recharge	Possibility of surface water entering the supply directly	Total seasonal and long term pumpage from the area
Nature/type of soil and underlying strata	Influence of any surface water on the quality of the well water	Permeability of the aquifer
Depth to water table	Physical, chemical, bacteriological, and radiological analyses of raw water	Velocity of the groundwater flow
Variation in depth to water table	Type of treatment required	Rainfall amount, distribution and intensity

Sources of data

- State/local health departments
- State geological agencies
- USGS
- Local water utilities
- Well drillers
- Private citizens
- Well test data
  - Pump tests

Ease of obtaining data

- Relative abundance of groundwater resources in the local area
- Nature of the subsurface materials
- Attitudes and practices of local well drillers
- Depth to water bearing strata
- Can mitigate well drilling costs by converting test wells to producing wells

Water quality

- Generally assumed that deep wells are free of contamination
- Not always true
- Exacerbated by long lag periods between application of contaminants to soil and infiltration to groundwater and slow movement of water

Well construction

- Consult US EPA or AWWA Standard A100-66
- Types
- Location
- Casings
- Screens
- Alignment
- Development
- Testing
- Preventing contamination
- Disinfection
- Number of wells
- Abandoned wells

Types of wells

- Installation methods
  - Dug
  - Bored
  - Driven
  - Jetted
  - Drilled
- Deep wells (more than 100’) are percussion or rotary drilling
- Properly drilled wells less likely to be contaminated
- Highly specialized and local
- Seek someone knowledgeable of local conditions when writing specifications and contract documents

Well location

- Located on fairly high ground to prevent contamination from surface water
- Far away from septic tanks, cesspools, privies, sewer lines, sanitary landfills, hazardous waste disposal sites, feedlots, barnyards, industries
- Maintain 100 feet between shallow wells that are less than 15 feet deep, with greater distance in Karst topography
- Hydraulically upgradient from any contamination sources
- Verify that groundwater flow in shallow aquifers parallels surface flow

Well casings

- Provide a stable, uniform opening from the surface to the aquifer
- Prevent wells from collapsing
- Prevent the entry of possibly contaminated water
- Sometimes placed as well is drilled
- Sometimes lightweight temporary casing used
- Region between outside of casing and well hole is grouted
- Casing should be large enough to accommodate equipment that must be lowered into well and strong enough to resist the forces and stresses it is exposed to
- Leakproof joints between casing segments important
- Black steel is favored, but plastic may be used in corrosion potential areas
- Casing sizes vary from 4-24 inches for wells yielding 2000-3000 gpm

Well screens

- Needed when water is removed from unconsolidated geologic formations
- Designed ideally to allow water to pass through without significant resistance while prohibiting the entrance of solid particles
- Variety of designs available
- Size depends on
  - The type of screen selected
  - Hydraulic capacity
  - Expected pumping rate
- Selection depends on expected
  - Corrosion and encrustation effects
  - Difficulty of cleaning and replacement
- Should be performed by experienced well designer

Well alignment

- Should be reasonably straight and plumbed
- Straightness is more important
  - Determines if a vertical turbine or submersible pump can be installed
- Deviations from plumb may cause excessive wear or reduction in pump performance
- Typically a well should not vary from the vertical by more than one well diameter per 100 feet of length
- Straight enough to allow a 30 foot long dummy having an outside diameter of ½ inch less than the casing diameter to move freely to the lowest pump location

Well development

- Process of removing the silt and fine grained sand, etc. from the vicinity of the well screen
- Practiced when the aquifer being tapped is in an unconsolidated formation
- Alternate direction of flow across the screen and thus flush the fines away
- Result is area around the well screen is surrounded by a highly permeable layer of well graded material to support free flow
- May need to introduce well graded gravel as an alternative by enlarging the diameter of the bottom of the well
- Method chosen with care to avoiding inadvertently clogging the well screen
- One method is to build into the contract a bonus for capacity in excess of some stated amount and a penalty for a lesser capacity

Well development methods

- Hydrojetting (preferred method)
- Bailing
- Overpumping
- Intermittent pumping
- Surging with a surge block or compressed air (preferred method)
- Backwashing

Well pump testing

- Pump test performed after development
- Determines the yield and drawdown characteristics of the well
- Can learn about the hydraulic characteristics of the aquifer
- Guidance from
  - AWWA and USGS
  - State/local health depts.
  - State geological surveys
  - Well equipment manufacturers

Pump test considerations

- Quality of information is linked to accuracy with which determinations of flow rate and pumping depth are made
- Temporary pump selected should have at least 50% in excess of planned well pump
- Select the test pump to have equal to or greater than the expected yield of the well
- The discharge of the test pump should be easily controlled to vary flow rates
- Minimum flow rate needed generally 50% of max.
- Test should be continued long enough to provide high degree of confidence in results (24-48 hours)

Preventing contamination

- Well must be effectively sealed to prevent entry of any water except from the aquifer
- Methods
  - Grout outside of well wall and casing
    - Pump from bottom up
  - Extend the top of the casing at least 1 foot above the pump house floor
  - Cover top of well with concrete sloped to divert runoff
- Better to drill a new well than to extend an old well
- Generally vent the well and extend the vent at least 2 feet above the highest known flood level

Well disinfection

- Clean well of all ropes, oil, grease, timbers, pipe dope, tools, cement
- Disinfect with chlorine to produce an initial theoretical concentration of 50 mg/l for at least 2 hours (24 hours preferred)
- Calcium hypochlorite (dry) or sodium hypochlorite (liquid) used
- Disinfect all equipment that contacts the water
- Pump out chlorine solution and the well sampled and tested for total coliforms
- Conduct physical and chemical tests of water to ensure it is suitable
- Disinfect each time the well is opened for maintenance or if excessive coliforms are detected

Number of wells

- Number a function of
  - Total need for water
  - Yields of individual wells
  - Desired operating schedule
  - Water storage facilities available
  - Regulatory requirements
  - Desired excess capacity
- Should have at least 2 wells
- Enough to meet average daily needs in less than a full days operation (typically 16 hours)

Abandoned wells

- Failure to properly seal can lead to contamination
- AWWA standard applies
- Check with state and local environmental agencies

Surface water sources

- Source of last resort
- Usually requires a substantial amount of treatment
- Requires a treatment plant that requires
  - Capital investment and
  - Substantial O&M efforts
- Surface water quality varies and requires operator attention
- Economics unfavorable for small systems

Sanitary survey

Topography	Streamflow and surface runoff patterns	Development costs
Geology	Adequacy of the supply including seasonal effects	Legal constraints
Land use	Wastewater discharges nearby	Historical water quality
Vegetative cover	Necessity for an impoundment	Potential for protection of water quality
Rainfall (amount/distribution)	Potential reservoir sites	Future plans of other users

Surface water types

- Unregulated streams
- Impoundments
- Natural lakes

Unregulated streams

- Wide variation in streamflow and water quality
- Dry weather flow should be estimated
- If maximum demand is greater than the safe yield search for other sources
- Water quality may be an issue
- Alleviate problems using off stream raw water storage

Large lakes/impoundments

- Good sources of supply where transmission costs are not excessive
- Water quality changes seasonally
- May be able to offset by taking water from different depths
- View lakes receiving wastewater discharges
- Nutrients such as nitrogen and phosphorous can lead to algae problems

Algae problems

- Operational difficulties associated with treatment processes
- Taste and odor problems
- Produce trihalomethane precursors and can complicate disinfection or require additional treatment

Small lakes/impoundments

- Good source when the water system can own or control
- Economical yields of 75-90% of the annual streamflow can be realized

Characteristics of ideal water supply

- Clean
- Grassed
- Free of contamination
- Protected from erosion
- Protected from drainage from livestock areas
- Fenced to exclude livestock

Impoundment/lake criteria

- At least 8 feet deep at the deepest point
- Maximum possible water storage in areas more than 3 feet deep
- Able to store at least a one year supply
- Fenced
- Free of weeds, algae or floating debris

Water quality/treatment

- Treatment facilities are a significant cost
- Specific treatment processes determined by
  - Raw water quality
  - Desired finished water quality
  - Regulatory requirements
- Conventional treatment processes remove turbidity followed by disinfection
- Avoid surface waters requiring additional treatment
  - Treatment for iron, manganese, softening, taste and odor add to construction and O&M costs
- Avoid surface waters with widely varying water quality

Water intakes

- Required to remove water from the source and deliver it to the transmission facilities
- Design is highly site specific
- Most are either
  - Submerged
  - Exposed tower
  - Infiltration galleries
- Located well away from wastewater or stormwater sources

Intake factors

- Type of source
- Water depth
- Bottom conditions
- Navigation requirements
- Effects of floods, currents, and storm and bottom conditions
- Exposed structures and pipelines
- Prevalence of floating materials
- Freezing

Submerged intakes

- Applicable to lakes, streams and impoundments
- Frequently utilized by small systems
- Require very little maintenance

Common design

– Wooden crib held in place by riprap or concrete
– Ports lead directly to submerged pipelines
– Covered by wooden slats that act as a screen
– Inlet velocities low to prevent clogging
– Located where bottom materials are stable and there is no interference with navigation
– Pipelines carries water to a pumping station
– Require very little maintenance

Alternate approach

- Extend a submerged pipe with special fittings
- Fittings
  - Flared end with a strainer
  - Flared end with a section of well screen
- Can support the pipes at the desired depth
- Can hold them in place by a system of floats and anchors

Tower intake

- Used for larger flows
- May be very complex
- May have multiple inlets
- May include:
  - Automatic screen cleaning
  - Pumping stations
  - Living quarters

Infiltration galleries

- Used when bottom conditions are unstable or water surface elevations vary widely
- Perform as horizontal wells and are located at shallow depths and very near surface water sources
- Design includes well screens or perforated pipes
- Located below the lowest water surface
- Water flows through the soil from the surface source to the intakes
- Water quality similar to shallow wells
- Can result in reduced treatment plant construction costs and lower O&M costs

Water Treatment

General

- Purpose is to render raw water suitable for its intended use
- Treatment processes vary depending on raw water quality and its intended use
- Operational complexity is important for small systems
- Human consumption requires treatment to meet regulatory requirements
- Even highest quality surface water requires more treatment than groundwater
- Tastes, odors, hardness require additional treatment
- Small systems should keep treatment facilities as simple as possible
- Removal and degree of removal dependent on state and local regulations

Design basis

- Design is largely empirical and influenced by conservatism wrt to protection of public health and monetary investments
- Slow to accept new technology
- Designer must find the most economical design that satisfies the regulatory agencies
- Can model most treatment processes in lab and conduct a pilot scale plant
- Need a deeper understanding of process chemistry to reach economical and effective methods
- Consult AWWA standards

BAT for drinking water

- See Table 6-1, pages 6-2 through 6-5

Accepted Technologies

Activated alumina	Direct filtration	Precursor removal
Alterative disinfectants	Enhanced coagulation	Packed tower aeration
Aeration	Electrodialysis	Reverse osmosis
Anion exchange	Granular activated carbon	Stop prechlorination
Corrosion control	Ion exchange	Source water treatment
Coagulation/filtration	Lime softening	Slow sand filtration
Chlorination	Lead service line removal	
Disinfection	Oxidation	
Disinfection system control	Polymer addition	
Diatomaceous earth filtration	Public education	

Specific processes

- Disinfection
- Iron removal
- Manganese removal
- Hardness removal
- Taste and odor removal
- Stabilization and corrosion control
- Turbidity removal
- Total dissolved solids removal
- Color removal
- Control of organic substances
- Membrane technologies

Disinfection

- Removal, destruction or inactivation of pathogens (disease causing organisms)
- Usually only treatment process required for small systems
- Effectiveness measured in Coliform counts
  - Ideally none should be present

Disinfection methods

- Heat (pasteurization)
- Radiation (UV)
- Heavy metals (silver)
- Oxidizing agents (chlorine, iodine, hydrogen peroxide, ozone)

Selection Considerations

- Oxidizing agents favored
  - Economics
  - Public health concerns
  - Chlorine most frequently used
- Concentration times contact time muster meet minimum EPA standards
- Development of disinfection byproducts should be considered
- Consult state and local agencies

Chlorination

- Advantages
  - Relatively low cost
  - Ease of application
  - Proven reliability
  - Easy detectability
  - Residual disinfection power
  - Familiarity with its use
  - Used for other treatment purposes
- Disadvantages
  - Undesirable tastes and odors
  - Byproducts can be hazardous to human health
  - Trihalomethanes

Chlorine chemistry

- Variety of reactions (organics in water)
- Demand = amount added – amount remaining
- Product of chlorine and ammonia forms additional disinfectants called chloramines
- Combined available chlorine = chloramines
- Free available chlorine residual = chlorine that has reacted with the water itself

Required residual

- Maintain at least 1 mg/l free available chlorine residual for at least 30 minutes at pH<8
- Higher residuals or longer contact times provide increased protection
- Reductions in contact time and or high pH need a higher residual
- Keep residual of at least 0.2 mg/l in transmission system will reduce chances of recontamination
- Need to consult state and local regulators for minimum and maximum residuals

Forms of chlorine

- Gas
- Liquid
  - Sodium hypochlorite
- Dry
  - Calcium hypochlorite

Chlorine gas

- Most popular form
- Relatively inexpensive
- 150#, 1 ton cylinders, rail cars
- Poses safety and health problems
  - Separate chlorination room
  - Floor level ventilation
  - Required safety equipment
- Safety and health considerations make it unpopular for small systems

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Calcium hypochlorite

- Dry powder or granular material
- Used in home swimming pools
- Long shelf life
- Safer than gas
- Typically 60-65% by weight available chlorine
- Mix dry form with water and the inert solids are allowed to settle
- May require significant operator time to address solid issue
- Up to 6x as expensive as gas in 150# cylinders

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Sodium hypochlorite

- Best for small systems
- Available as liquid with 12-17% available chlorine
- Very small systems can use 5% bleach
- Relatively safe to use
- Requires little handling or processing since it's already a liquid
- Costs are similar to calcium hypochlorite
- Has a half life of 90 days
- Presents a chlorine gas danger if mixed with acid or ferric chloride

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Hypochlorinators

- Solution feeders
- Positive displacement pumps best for small systems
- Can be precisely adjusted
- Synchronized with water pump to ensure that when water is flowing chorine is too
- Electrically operated
- Alarms are used to indicate when solution is too low
- Chemical compatibility is important

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Chlorine dosage

- Factors
  - Chlorine demand (higher demands require more)
  - Contact time (shorter time requires more)
  - Residual
  - Temperature (lower temperatures require more)
  - pH (above 8 mg/l requires more)
- Exact dosage determined by experimentation
- Usually no more than 2-3 mg/l required

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pH Control

- Very important factor
- Chemical equilibrium between hypochlorous acid and hypochlorite ion is controlled by pH
- Ideal ph is 7.7
  - Less than 7 acid predominates
  - More than 8 ion predominates
- Acid is more effective disinfectant
- Addition of gas lowers pH
- Addition of hypochlorite raises pH
- Ideal range is 5-8
- May need to add sodium bicarbonate or sulfuric acid to adjust pH

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Superchlorination - dechlorination

- Favored when adequate contact time can not be assured
- Add more chlorine than necessary
- Remove excess chlorine
- Dechlorination methods
  - Sulfur dioxide
  - Sodium sulfite
  - Sodium bisulfite
  - Sodium thiosulfate
  - Activated carbon
- Chemical methods are difficult to control
- Better to provide additional contact time

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Chlorine - ammonia treatment

- When taste and odor are issues or production of chlorinated organic compounds
- Controlled addition of both substances together
- Does not react with phenols and does not produce chloroforms or other similar compounds
- Less effective as a disinfectant but are very persistent
- Should evaluate cost and operational complexity

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Chlorine dioxide

- A powerful oxidant
- Excellent germicidal properties
- Unaffected by pH
- Does not react with ammonia
- Used for the control of tastes and odors
- Does not react with water
- Can oxidize organic substances w/o producing halogenated hydrocarbons
- A very dangerous gas and must be produced on site
- Unknown health effects of possible byproducts
- Unlikely to be used in small systems

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Iodination

- Excellent disinfectant
- More expensive than chlorine (up to 20x)
- Has possible deleterious health effects for unborn children and individuals with thyroid problems
- Best for a transient population

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Ozonation

- Used in Europe for many years
- Does not form trihalomethanes
- Attractive for large systems
- Disadvantages
  - Unstable such that no residual can be maintained
  - Process is too complicated
  - Ozone must be generated on site
  - Simply too expensive
  - Can be a safety hazard

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UV

- Ultraviolet radiation has germicidal properties
- 250-260 nm range
- Lamps similar to fluorescent bulbs w/o coating
- Destroys cell or interferes with normal cell growth and development
- Suspended particles (turbidity) can interfere
- Iron compounds, phenols, other aromatic compounds absorb UV
- Can be designed to work automatically
- Process requires minimal contact time
- Produces no known undesirable byproducts
- Penetrating power of UV is low
- Lamps slowly lose their effectiveness
- No known residual disinfecting power
- No rapid test of effectiveness
- Efficiency is limited by factors
- Equipment is expensive
- Consumes electricity
- Limited to very small systems

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Iron removal

- Ferrous ion is soluble in water and causes taste problems
- Ferric ion is less soluble in water and precipitates colored material (yellow, brown or red)
  - Interfere with cleaning and washing
  - Taste
- Certain filamentous bacteria oxidize iron and exist in pipes (controlled by chlorination)

Techniques

- Polyphosphate addition
- Ion exchange
- Oxidation-filtration
  - Aeration
  - Chlorination
  - Potassium permanganate

Polyphosphate addition

- Masks the problem for ferrous less than 3 mg/l
  - Sodium hexametaphosphate
- Sequester the iron prior to precipitation
- Apply before oxidation
- Dose of 1-5 mg/l per mg/l of iron
- Simple process that requires a solution tank and a feed system
- Limited retention time of less than 24 hours and can break down to orthophosphates which act as nutrients

Ion exchange

- Remove small amounts of ferrous
- Ferric ion should not be present in order to prevent severe fouling of the exchange media
- Typically less than 1 mg/l

Oxidation - filtration

- Most popular method
- Sequence
  - Aeration
  - Chlorination or potassium permanganate addition
  - Filtration
- Larger plants use sedimentation before filtration
- Need ph of 7 or above

Filters

- Can use slow or rapid sand filters or pressure filters (small systems)
  - Filter media: greensand zeolite coated w/oxides of manganese (act as a catalyst)
- Flow rates are up to 5 gpm/ft^2
- Sustained flow rate of 8-10 gpm/ft^2 for several minutes during backwashing
- Need to provide enough treated water storage to reduce the number of on/off cycles
- If alkalinity is less than 100 mg/l manganese zeolite filtration is not recommended

Aeration

- Frequently used for surface waters
- Air applied
  - Through small bubble diffusers
  - Spraying water into the air
  - Allowing water to trickle over a multi-tray aerator
  - Spray method also removes undesirable gas such as carbon dioxide, hydrogen sulfide
- Very effective when pH >7
- Cannot overdose system, which removes the need for operator control
- Aeration can promote corrosion

Chlorination

- Affected by:
  - pH
  - Chlorine dose
  - Reaction time
  - Mixing conditions
- Much slower than permanganate oxidation
- If superchlorination is needed, need to add GAC to remove excess chlorine
  - GAC quite expensive to regenerate carbon
  - Replace carbon in small systems
- May feed chlorine by solution feeders

Permanganate

- Oxidizes ferrous to ferric
- Theoretically 1 mg/l oxidizes 1.06 mg/l of iron (may be able to use less)
- Many times faster than chlorine
- Uses same procedure to add as chlorine
- Produces a slight pink color
- pH range of 5-9
- Extra permanganate can regenerate greensand media
- Works for iron between 1.5-2.5 mg/l

Manganese removal

- Much less common than iron
- Oxidation typically requires pH around 9.5
- Treatment with 2 mg/l potassium permanganate is effective followed by oxidation filter
- Many times found along with iron problems

Hardness removal

- Composed mainly of calcium and magnesium
- Measured as calcium carbonate
- Methods
  - Chemical precipitation
  - Ion exchange
- Removal not mandatory (not a health issue)
- Not cost effective to soften less than 20 mg/l
- Some removal necessary above 300 mg/l

Ion exchange

- Packed bed of granular material
  - Polystyrene beads
    - 03.mm – 1.2 mm diameter
    - 95 % between 0.4-0.8 mm
  - Zeolite
- Removal
  - Water passed at a rate of 2-5 gpm/ft^2
  - Divalent ions (calcium, magnesium) replace monovalent ions (sodium) in medium
  - No change in the electrochemical balance
  - When surface areas full need to regenerate medium
  - Not intended as filters for suspended solids
  - Need to pretreat turbid waters (5 NTU>)
  - Can remove ferrous ions as well

Regeneration

- Passing a strong solution or soaking the medium in a solution of monovalent ions
- 10-15% sodium chloride solution is used for a sodium system
- Clean rock salt
- An acid solution can be used for a hydrogen system
- Process can take from several minutes to an hour
- Process can be automated, semi-automatic or manual
- Process selection is based on the frequency of operator checks and amount of usage

Efficiency

- Frequency of regeneration
  - Capacity of medium
  - Hardness of water
  - Flow rate
  - Efficiency of regeneration process
- May be economical to regenerate with a weaker solution and more often
- Can treat only a portion of the water such that the combined hardness is between 50-100 mg/l

Wastes

- Waste regenerate solution is produced and must be disposed of
  - Generally a small quantity only
- High sodium concentration
- May not be suitable for a septic tank system or a wastewater system

Taste/odor removal

- Variety of sources
  - Hydrogen sulfide (groundwater)
  - Metabolic effect from algae, actinomycetes or decayed vegetative matter (surface water)
  - Reactions with chlorine and other organics
  - Contamination from industrial, municipal, commercial or domestic wastes
  - Excessive iron concentrations
- Difficult to measure
  - No reliable test methods
  - Varies by individuals

Removal techniques

- Management practices
  - Develop an alternative supply
  - Manage source to minimize problems
    - Weed control such as deepening or varying the water level of reservoirs or dredging plants and debris
    - Chemical treatment of algae
    - Land use management in the watershed
      - Can protect against industrial or agricultural wastes
      - Limit nutrients entering watershed

Aeration

- Reduce or eliminate some compounds that create these
  - Algal metabolites
  - VOCs
  - Hydrogen sulfide
- Strip the water using techniques similar to those used to control iron also can promote oxidation

Adsorption

- GAC filters are often used but may require suspended solids removal before unit
- Effective against
  - Organic decay products
  - Residual chlorine
  - Chlorination byproducts
  - Pesticides
  - Dissolved gases
- Synthetic absorbents can remove hydrogen sulfide
- Bench or pilot testing is necessary
- Typical flow rates of 2-5 gpm/ft^2
- Occasionally need to backwash units
- May be able to use powdered GAC on surface waters

Oxidation

- Use agents such as chlorine and potassium permanganate
- May need to dechlorinate
- Requires an adequate detention time
- Chlorine used to control sulfides may create precipitates that can be removed by pressure filters

Stabilization and corrosion control

- Water is stable if it tends to neither deposit nor dissolve solid calcium carbonate
- Function of
  - Calcium ion concentration
  - Total alkalinity
  - pH
- Lime can adjust all three (sodium carbonate, sodium hydroxide, carbon dioxide are alternates)
- Finished water should have:
  - In excess of 40 mg/l of calcium and alkalinity concentrations each
  - pH no higher than 9-9.3
  - Potential to deposit 4-10 mg/l of calcium carbonate

- Thin layer of calcium carbonate will coat pipes and keep them from corroding
- A corrosive water dissolves calcium carbonate
- A water that deposits calcium carbonate may clog pumps and appurtenances and reduce the carrying capacity of the pipes
- Magnesium hydroxide in excess of 40 mg/l will deposit in hot water pipes and appliances

Corrosion control

- Cannot completely prevent this
- Factors affecting corrosion
  - Low pH
  - Low mineral content
  - Low alkalinity
  - High dissolved oxygen concentrations
  - High carbon dioxide concentrations

Neutralization

- Groundwater contains high concentrations of carbon dioxide
- Can strip this out by aeration
  - Has the drawback that this introduces oxygen, which is also corrosive
- Use sodium bicarbonate or sodium carbonate (soda ash)
  - Readily available
  - Do not add hardness
  - Relatively inexpensive
  - Highly soluble
  - Fairly safe to handle
- Neutralizer can be injected into the water flow or the well
- Can mix with hypochlorites to reduce costs

Additional information

- Alternate compounds to soda ash
  - Sodium hydroxide (caustic soda)
  - Calcium hydroxide (hydrated lime)
  - Calcium oxide (quick lime)
  - May add operational problems
- May pass the water over a bed of limestone chips
  - May need to replace the chips as they are used up
  - May need to backwash chips to prevent clogging
  - Requires a relatively long contact time
- Design should be based on lab studies to determine doses, contact time and solution strengths

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Turbidity removal

- Almost always required when using surface water
- Particles are very small (1-200 mm) and affected by surface chemistry and electrical phenomena more than gravity
- Neither settling nor filtration are effective
- Refer to AWWA texts for detailed discussions

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Coagulation/flocculation

- Coagulation is the process that make particles agglomeration possible
- Flocculation is the actual process of agglomeration
- Processes are often indistinguishable

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Coagulation

- Add a chemical to water
- Most popular is filter alum (aluminum sulfate)
  - Dry powder
  - Granule
  - Lump
- Need to add enough alum to precipitate aluminum hydroxide
- Need to introduce alum with intense short term mixing (about 1 min.)
- Coagulation occurs during the mixing using high speed mechanical mixers or in-line static mixers
- Can use centrifugal pumps also

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Flocculation

- Long term gentle mixing
- Time for mixing is a function of mixing intensity and the nature of the particles
- Design parameters
  - Mean velocity gradient (30-60 l/sec)
  - Mixing time (10-45 min.)
  - Factor, G*t, 10^4-10^5
- Mechanical, paddle wheel mixers used
- Coagulant dose based on jar tests

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Aids

- High molecular polymers can improve performance
  - Can improve performance
  - Reduce the alum required
  - Reduce the sludge produced
- Cationic polymers can be most effective
- Water treatment chemical manufacturers should be consulted

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Alternatives to alum

- Ferric chloride
- Ferric sulfate
- Magnesium carbonate
- Magnesium requires a Ph from 10.8-11

pH Control

- Very important when alum is used
- Alum tends to lower pH
- Alum works best with a pH 5.5-8.5
- Buffer by adding
  - Lime
  - Soda ash

Sedimentation

- Settling basins at large plants are long, narrow basins (4:1 or 5:1 ratio) with detention times of 3-6 hours
- Overflow rates 500-800 gallons/day/m^2
- Small plants use high rate settling devices such as inclined tubes or plates
- High rate systems need less space
- Less than 100% effective in removing suspended solids

Design factors

- Get the water in with minimum turbulence
- Provide an adequate settling period under quiescent flow
- Provide storage for sludge
- Provide a means to periodically remove sludge
- Add a weir for overflow
  - 20,000 gallons/day/m of weir length

Flocculation/clarifiers

- A number of manufacturers provide combined units
  - Coagulant feed
  - Rapid mixing
  - Flocculation
  - Clarification
- Advantages
  - Reduced space
  - Reduced detention time
  - Reduced piping
- Disadvantage
  - Need regulatory agency acceptance

Filtration

- Required for any surface waters
- Pressure type most used in small systems
- Sand most commonly used filter media
- Rapid sand filters
  - 0.4-0.6 mm sand size with a 1.3-1.7 uniformity coefficient
  - 24-30 inch deep bed supported with 18-24 inch hard, rounded gravel that is 3/32 – 2-1/4 inches in diameter
  - May add GAC or anthracite coal bed (dual media)
  - Down flow motion is primary water feed
  - Most particles removed in the top layer
  - Head loss rapidly builds
  - Requires periodic backwashing
  - Typical flow rates of 2 gpm/ft^2
  - Need at least 2 filters
  - Backwashing system should deliver a flow rate of 15-20 gpm/ft^2
  - Effective backwashing is key to success
  - Most regulatory agencies have design requirements

Slow sand filters

- Not used following coagulation flocculation and settling
- Good choice for groundwater and high quality surface water
- May need special regulatory approval
- Operate by gravity
- When head loss is excessive, filter is taken offline, drained and allowed to dry
- Layer of debris is then removed
- Primary treatment area is top 1-2 inches
- Typical filter
  - 48 inch deep bed
  - Homogeneous packed sand of 0.2-0.4 mm size and a coefficient of 2.5 or less
  - Supported by a bed of 10-12 inches graded, 3/16-3 in. diameter gravel
  - Need to have a head loss gauge
  - Underdrain system
  - Cover to prevent algae growth
  - 0.08-0.09 gpm/ft^2 overflow rate
  - Water depth above sand of 4 feet
  - Requires a turbidity of 10 NTU or less
  - Not used for waters containing more than 0.3 mg/l iron or 0.05 mg/l manganese

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Direct filtration

- Mostly for low turbidity waters
- Coagulants are used, but sedimentation is omitted
- Filter is sole suspended solids removal process
- May need regulatory approval
- Most applicable when raw water turbidity is less than 10 NTU
- May only need a polymer as a coagulant
- Equipment is similar to rapid sand filters

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Package plants

- Pre-engineered and prefabricated
- Variety of sizes available from 10 gpm to several MGD
- Can be delivered to the site virtually intact, set up, connected to an electrical source and the required piping and placed into operations in a matter of days
- Technology used is proven and reliable
- Some have process control systems
- Can reduce operator time and O&M costs
- Less expensive than custom designed systems
- Most are designed for surface waters
- Typical units
  - Mechanically mixed flocculators
  - High rate settlers
  - Gravity filtration devices

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Waste disposal

- Two types of wastes
  - Filter backwash water
  - Sludge
- Principal components are suspended solid particles and coagulant precipitants
- Not very odorous
- May be able to dispose of in a sewer to a wastewater plant
- May be able to hold backwash water and sludge in a thickener and dewater

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Total dissolved solids (TDS) removal

- Most likely a problem in groundwater found in the Midwestern and Southwestern US and coastal surface water
- TDS species include:
  - Calcium
  - Magnesium
  - Sodium
  - Bicarbonate
  - Chloride
  - Sulfate
- Common complaints of excessive TDS
  - Salty taste
  - A laxative effect
- Sulfate limited to 250 mg/l and TDS 500 mg/l

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Reverse osmosis

- Process where higher TDS water is separated from fresher water by a semipermeable membrane, the natural tendency is for the fresh water to diffuse through the membrane and dilute the high TDS water
- Sufficient pressure applied to the high TDS water the process is reversed

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Typical RO units

- Commercially available in sizes from 100 to 250,000 gpm and larger
- High pressure pump (200-1500 psi)
- Membrane module
- Membrane materials include nylon, cellulose acetate
- Membranes consist of bundles of hollow fibers

RO design factors

- Cost
- O&M costs
- Feed water quality
- Temperature
- Salt rejection
- Water recovery
- Waste disposal
- Required pretreatment
  - Fouled by
    - Hardness
    - Iron
    - Manganese
    - Organic matter
    - Sulfides
    - Chlorine

RO efficiency

- Can achieve 90-99% salt rejection rates
- Nitrate removed at 50-80%
- Reject water may contain 90% of the total feed TDS
- Disposal of wastes can be serious problem
- Production rates dependent on
  - Feed water quality
  - Higher temperatures offer higher solvent recovery but a shorter membrane life
  - pH may need to be adjusted

Ion exchange

- Cationic (hydrogen form) and anionic (hydroxide form) media are used
- Cationic regenerated using a strong acid
- Anionic regenerated using a strong base
- Major problems
  - Pretreatment
  - Regeneration
  - Waste disposal
  - Limited durability of most anionic media

Color removal

- True color due to dissolved solids difficult to remove
  - May indicate industrial contamination
  - Occasionally with oxidation or adsorption
- Apparent color due to suspended substances is removed with turbidity
- Color problems can be controlled at the source

Control of organics

- Contribute to a variety of problems
  - Taste and odor
  - Color
  - Adverse health effects
- Hundreds or thousands of organics may be present
- Real environmental or public health problems unknown for most
- Most attention focused on: pesticides and trihalomethanes
- Removal is often expensive and requires skillful operation and difficult to monitor

Control of THMs

- Watershed management
  - Find a water source without THMs
  - Control land use
  - Control of the algal population
- Conventional treatment
  - Eliminate precursors
  - Coagulation
  - Flocculation
  - Settling
  - Filtration
  - Do not chlorinate water

Control part II

- Alternative disinfection
  - Use other than chlorine
  - Solves the problem of forming chlorinated organics
  - Increased cost
  - Lower residual of disinfection power
- Aeration
  - VOCs can be transferred to air
  - Packed tower systems more frequently used
  - Care not to pick up contaminants from the air
- Chemical oxidation
  - Permanganate and ozone may prove useful
- Adsorption
  - GAC used in pressure systems
  - Powdered GAC added to water and settled or filtered

Membrane technologies

- Desalting brackish water
- Filtration
- Disinfection
- Types
  - Microfiltration
  - Ultrafiltration
  - Nanofiltration

Membranes II

- Removes
  - Particles
  - Microorganisms
  - Natural and synthetic organic matter
  - Inorganic chemicals
- Treatment depends on
  - Treatment compliance criteria
  - Chemical/physical condition of the source water
  - Whether O&M personnel have been properly staffed and trained

Pumping, Storage and Distribution

Pumping

- Pumps used to
  - Remove water from its source
  - Process it
  - Deliver potable water to the users
- For small systems may only require 1 pump

Selecting pumps

- Discussed in many references
  - US COE and AWWA guidelines
  - US EPA Manual of Individual Water supply
  - Many engineering texts
- Data requirements

Information needed for pump selection

- Max. safe rate at which water is supplied
- Avg. and max. rates at which water must be delivered to the distribution and storage system
- Min. available net positive suction head
- Range of discharge heads the pump must work against
- Characteristics of the water to be pumped
- Availability of suitable electric power at the site
- Expected level of OM capability
- Desired placement of pump
- Design period
- Other site-specific information
- Search manufacturers literature for available pumps

Pump types

- Centrifugal
  - Mostly used for deep well or surface supplied water systems
  - Vertical turbines (only pumping head is submerged)
    - Easily service for maintenance or replacement
    - Require a drive shaft to connect the driver to the head
  - Submersible pumps (pumping head and driver submerged)
    - Can be installed in poorly aligned wells
- Consult EPA or AWWA manuals for more detailed discussion

Operating reliability

- Use a pump and control system that is simple, rugged, and reliable
- Constant speed units are preferred
- Selected to operate near their peak efficiencies under actual operating conditions
- Tend to reduce operating cost when maximize efficiency
- Do not over design

Over design

- Inefficiencies arise when overdesigned
- Conservative design
- Capable of delivering more water than needed
- Must consider pump characteristics and system head curves
- Work closely with pump manufacturer reps.
- Prefer pumps with fairly steep characteristic curves
- As equipment ages, head losses will increase

Pumping stations

- Should protect pumps from weather and vandalism
- Located on high ground above 100 yr flood or properly protected
- Floors should be at least 6 inches above finished grade
- Adequate interior drainage should be provided
- Should direct drainage away from wells
- Freeze protection provided
- Keep equipment fluids away from raw and finished water
- Windows should be minimized
- Use security type fencing around station
- Large enough to allow free access to equipment
- Review piping and final design with operators
- Assume every piece of equipment will need to be replaced
- May need to add chemical storage
- Consider safety issues such as confined spaces, falls, electrical, etc.

Piping and appurtenances

- Equip each pump with a pressure gauge and flowmeter on the discharge side
- Arrange piping to promote minimal head loss
- Each pump should have its own intake
- Valves should be located to isolate each pump
- Make sure pumps always draw water and not an air/water mixture or just air
- Check valves should be located based on:
  - Inlet conditions
  - Type of storage
  - Piping layout
  - Regulatory requirements
- Need to make provisions for sampling and future chemical addition

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Pump capacity

- At least 2 pumps should be provided each capable of handling the required demand
- Alternate pumps in service
- May need to meet additional requirements of providing fire protection
- For well systems, each pump should be able to meet the avg. demand over a fraction of the day (16 hours)
- Multiple pumps with complex control systems not suitable for small systems
- Use identical pumps in alternating service and meet higher rates of demand from storage or longer and/or more frequent pumping cycles

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Other considerations

- Emergency operation
  - Electricity usually provided by a gas or diesel powered generator for small systems
  - Local regulations (air) may apply
- Lightning protection
  - Seek advice of utility company
- Pump installation
  - Installed according to manufacturer's instruction
  - Ensure correct anchoring and alignment
  - Protect every part of the pump, frame, and driver from loads or stresses

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Storage

- Purpose is to ensure that an adequate supply of water is available at all times
- Careful sizing and siting can:
  - Permit the use of economical pipe sizes
  - Reduce the magnitude of pressure variations
  - Make it possible to operate production facilities at a uniform average rates
  - Allow production facilities to operate according to a convenient schedule
- Design is site specific with no simple procedure
- Must consider the water supply system as a whole
- Must be compatible with other system components
- Should result in an economical system that is capable of serving its intended purpose

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Types of storage

- Underground tanks
- Ground level tanks
- Elevated tanks
- Hydropneumatic (pressurized) tanks
- Underground/ground level tanks
  - Used for intermediate storage (after treatment, before entering distribution system)
  - Constructed of concrete or steel
  - Choice is based on economics
- Design refer to AWWA standards

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Elevated tanks

- Usually constructed from steel
- Used primarily for distribution and may be used for backwash
- Supply water by gravity flow
- Properly located pipeline friction losses can be minimized
- Can provide an uninterrupted supply from the tank
- Can provide water from the tank and pumps in any combination

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Pressurized tanks

- Commonly used in small systems
- Used especially when groundwater is involved
- Some pressure is derived from pumps others use air compressors
- Typically 10-40% of the tank contains water
- Pump provides water to the tank based on signals from a control system
- Tank may become waterlogged or air bound
- May have a flexible divider between air and water side
- Often set up as 3 parallel tanks
- Pump must be sized to meet peak demand
- Never use with an elevated tank, but can use with underground or ground level tanks

Tank sizing

- Use mass diagram method if inflow and outflow rates are known
- Determined from a combination of factors
  - Supply interruptions
  - Reliability of system components
  - Expected repair frequency of system components
  - Expected time to make repairs
  - Availability of emergency backup equipment or water supply
  - Regulatory requirements
  - Economics
  - Inflow/outflow analysis

Storage tank sizing

- Nonpressurized
  - 2 or 3 day supply is required
- Pressurized
  - 10 times the feeder pump capacity per minute

Formula

$V = QT/(1-(P_{min}/P_{max}))$ where

V = required tank volume (liter)

Q = design flow rate (l/min)

T = desired storage time at flow rate Q (15-20 mins)

P_{min} = min. desired absolute operating pressure (kPa)

P_{max} = max. desired absolute operating pressure (kPa)

Storage tank design

- AWWA standards
- Keep away from contamination
  - Precipitation
  - Surface runoff
  - Flooding
  - Groundwater intrusion
  - Discharges from storm drains or sewers
- Avoid single wall separation from treated and untreated water
- Tanks should be covered with all vents and access points covered or screened to exclude birds, animals, insect, airborne dust, etc.
- Provide overflow pipes for nonpressurized tanks
- Nonpressurized tanks should be vented
- All metal should be protected
- Finished water storage tanks should be disinfected prior to use
  - Check with local public health agency for requirements

Ground level and elevated tank design

- Provide
  - Interior and exterior ladder
  - Water level indicators
  - Sampling ports
  - Freeze protection
  - Sturdy security fence at least 6’ high with a securable gate
  - Overflow to restrict max. hydrostatic pressure to 80 psi
  - So that water surface working elevation varies no more than 20-25 ft.
  - Capability to isolate valves and drained without loss of pressure in the distribution system

Pressurized tank design

- Usually cylindrical with the long axis either horizontal or vertical
- Provided with
  - Bypass piping
  - Pressure gauge
  - Sight glass
  - Automatic blow-off valve
  - Mechanical means for adding air
  - Drain
  - Pump/pressure/water level control system
- Keep system indoors
- Keep system heated and ventilated

Distribution

- Purpose is to deliver water of a suitable quality to individual users in an adequate amount at a satisfactory pressure
- References include AWWA, ASTM
- May need to consult with state and local regulatory agencies
- May need to obtain rights of way
- Design is often based on conservative assumptions

Design flows/pressures

- Capable of delivering max. instantaneous flows at a satisfactory pressure
- Typical min. pressure is 20 psi
- Under fire conditions, 10 psi is acceptable
- Unnecessarily high pressures are wasteful both in equipment and energy
- Most small systems max. pressure is 60-70 psi at the peak hourly flow rate

Pipe sizes

- Pipe sizes selected to keep flow rates at 2-5 fps
- For fire protection, min. pipe size is 6 in.
- No fire protection, min. size is 2 in.
- Based on a hydraulic analysis of the system and regulatory requirements

System layout

- Usually laid out in grid pattern with pipes interconnected every 300-1200 feet
  - Feeder mains should be looped
  - Allows water to be supplied from any direction
  - Results in lower head losses and allows for min. inconvenience when repairs or maintenance conducted
- For small systems, use branching layout
  - Good practice to loop or interconnected lines
- Locate pipes along streets, roads or utility strips
- Minimize locating pipes under paved areas
- Design approach:
  - Sketch lines on a map
  - Determine tentative sizes based on AWWA
  - Using computer programs being more common

Hydraulic analysis

- Two equations typically used to determine friction head losses
  - Hazen-Williams
  - Darcy-Weisbach
- Movement of water through pipes has a resistance to flow
- Darcy-Weisbach best, most reliable method
  - Requires knowledge of the roughness of the pipe, which is difficult to determine

Hazen-Williams formula

$V = 0.85(C)(R)^{0.63}(S)^{0.54}$

Where:

V = flow velocity in meters/sec

C = coefficient depending on the smoothness of the pipe

R = hydraulic radius of the pipe in m

S = dimensionless slope of the energy grade line

Additional formulae

R (ft.) = D/48 for circular pipes flowing full
Where D = pipe diameter in inches

S = h/L
Where h = frictional head loss in the pipe and L = length of the pipe

(note h and L must be in the same dimensional units)

Typical friction factors

C, the friction factor for various pipes

100	20 year old cast iron pipe
130	Asbestos cement pipe
140	Plastic pipe

Other considerations

- Complex systems
  - Use Hardy Cross method
- Minor losses
  - Negligible for long pipe runs
  - Friction losses due to pipe bends, elbows, tees, valves, hydrants and other fittings
  - More important at treatment plants and pump stations

Water hammer

- Sudden change in velocity of flow in a pipe creates a surge pressure
- As system returns to normal, potential energy is converted to kinetic energy
- Occurs when valves are opened or closed suddenly or when pumps are started or stopped
- Usually not a problem because flow velocities are low

Pipe material

- Most common are:
  - Wrought or ductile iron
  - Asbestos-cement
  - Plastic
  - Galvanized steel
  - Copper
  - Polyethylene
- Choice is based on:
  - Cost
  - Local availability
  - Bedding conditions
  - Maintenance requirements
  - Ease of installation
  - Regulatory requirements

Distribution pipes

- Historically cast iron used
- PVC is gaining in popularity
  - Lower cost
  - Lightweight
  - Ease of installation
  - Virtual immunity from corrosion
- Service lines
  - Copper and galvanized steel
  - Plastic tubes (polyethylene) have become popular
    - Low cost
    - Corrosion immunity
    - Ease of installation

Valves

- Four types
  - Isolating
  - Air and vacuum relief
  - Flushing
  - Pressure reducing
- All valve locations should be clearly marked on as built drawing
- All valves should be located in valve boxes
- All located so that they are not affected by normal street or highway maintenance operations

Isolating valves

- Needed to isolate sections of the system to allow for repair or maintenance
- Double disk gate vales used most often
  - Low in cost
  - Create very little head loss when fully open
  - Widely available
  - Seat dependably
  - Effectively stop low
  - Placed at all pipe intersections and branches
  - Spaced no more than 1 mile apart
- Butterfly valves
  - Used to control or throttle flow

Air relief and vacuum valves

- Relieve air that accumulates in high points in the line
- Placed at all high points
- Most are automatically operated
- Vacuum valves are used to protect pipes as they are being emptied
- Can be a combination valve

Flushing valves

- Needed at the ends of all dead end lines
- Release air as the lines are filled
- Allow occasional flushing to remove sediment that accumulates in lines
- Consist of a gate valve with a short end of pipe attached which directs flow to avoid excessive erosion
- Manually operated valves are preferred

Pressure reducing valves

- Useful in areas where low-lying regions result in excessive pressure
- Operate automatically to throttle flow to maintain downstream pressure as long as the upstream pressure is sufficient
- Frequently used on individual water service lines to protect house plumbing and appliances

Other considerations

- Fire hydrants
  - AWWA standard applies
  - Not located on mains less than 6 inches
  - Connected by a short run of 6 in. pipe
  - Must be only installed on lines that have adequate flow
- Water meter
  - Several types available, consult AWWA

Thrust blocking

- Used to prevent the movement of pipes and appurtenances
- Needed at changes of alignment
- Wherever reducers are used
- At stops and dead ends
- Valves and hydrants
- Usually designed using methods similar to foundation and footing design
- Design factors include
  - Pipe of appurtenance size
  - Max. operating pressure
  - Type of fitting or appurtenance
  - Pipeline profile
  - Soil bearing capacity

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Loads on pipes

- Two types
  - Earth loads
  - Live loads
- Earth loads
  - Based on theories proposed by Anson Marston
- Live loads
  - From vehicular traffic
  - Insignificant compared to earth loads
  - Exceptions when pipes are shallow (4 ft. for highways, 10 ft. for railroads)
  - Check with local regulatory or transportation agencies for requirements

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Boring and casing

- Use steel pipe casings when water lines cross highways and railroads
- Casings protect roadbed from damage during construction or when failures occur
- Casings are installed by boring or jacking
- Check with local agencies for requirements
- Casings generally 4-8 in. diameter

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Pipe laying

- Referred to references in book
- Ensure pipes are aligned, both vertically and horizontally
- Follow safe excavation and trenching practices (OHSA)
- Keep trenches as narrow as possible
- A minimum cover of 3-4 ft. in cold areas
- All pipes should be bedded so that uniform longitudinal support is provided
- Ensure all pipe is properly installed and not damaged
- Provide adequate thrust blocking
- Ensure trench is properly backfilled
- Follow all local regulatory requirements
- Disinfect the entire system before placing in service
  - Flush with clean water, chlorinate for 24 hours, and flush again with clean water

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Testing

- Test new lines to ensure they will hold the specified pressure and not leak more than a specified amount
- Follow AWWA standard
- Testing should occur after thrust blocks have been installed and allowed to set (7 days) but before the trench is backfilled
- Some backfilling may be needed to hold the pipe in place

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Test procedure

- Gradually fill pipe with clean water
- Expel all air
- Cap, plug or close valves on the test section
- Connect test section to a pump capable of maintaining 5 psi
- Run test for 2 hours
- Carefully inspect all pipe and appurtenances
- Repair any visible leaks
- Measure leakage based on the formula
- Test pressure should be greater than 150% of working pressure at the test location or 125% of the working pressure at the highest elevation along the section being tested

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Leak volume

$L = (N)(D)(P)^{0.5}/7400$

Where
L = max. allowable leakage in gph
N = number of joints in the length of pipe being tested
D = nominal diameter for pipe, inches
P = avg. test pressure (gauge) in psi

End