RESERVOIRS AND INTAKES

CSUS – Water Treatment Plant Operation Vol. I

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OBJECTIVES

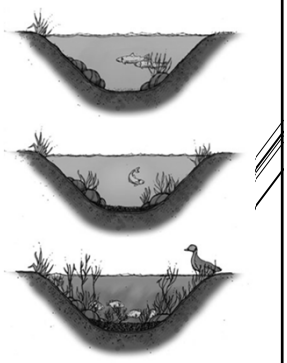
- Water Quality
  - Factors affecting
  - Causes of water quality problems
- Reservoir Management
  - Watershed management
  - Algae control
  - Reaeration/destratification
- Intake Structures

FACTORS AFFECTING WATER QUALITY

- Climate
  - Temperature, intensity and direction of wind movements, type, pattern, intensity, and duration of precipitation
- Watershed and Drainage Areas
  - Geology, topography, type and extent of vegetation, and use by native animals
- Wildfires
  - Caused by lightning
- Reservoir Area
  - Geology, land form including depth, area, and bottom topography, and surface vegetation at the time the reservoir is filled

CAUSES OF WATER QUALITY PROBLEMS

- Nutrients
  - Act as a fertilizer
    - Phosphate
    - Nitrate
    - Organic nitrogen compounds
  - Lake will become eutrophic – rich in nutrients and plant life



CAUSES OF WATER QUALITY PROBLEMS

- Algal Blooms
  - Eutrophic lakes support large populations of phytoplankton (very small plants) and zooplankton (very small animals)
  - A sudden large increase in phytoplankton is called an algal bloom
    - Can last from a few days to several weeks or months
  - Problems:
    - Taste and odor problems
    - Shortened filter runs of traditional treatment plants
    - Organic Loading
    - Increased pH**
      - Reduction in chlorine efficiency
    - Dissolved oxygen depletion after die-off**

CAUSES OF WATER QUALITY PROBLEMS

- Tastes and Odors
  - Often related to occurrence of algal blooms
  - Common taste and odors caused
    - Fishy
    - Aromatic
    - Grassy
    - Septic
    - Musty
    - Earthy
  - Odors most noticeable when hot water is in use
  - Geosmin and MIB (methyl-isoborneol) can be detected at just a few parts per trillion (ppt)

CAUSES OF WATER QUALITY PROBLEMS

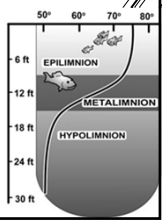
- Shortened Filter Runs
  - Clogged filters caused by diatoms and plankton in large numbers
- Increased pH
  - pH will increase during daylight
    - Photosynthesis decreases carbon dioxide in water, increasing the pH
  - pH will decrease during dark
    - Respiration increases carbon dioxide, lowering the pH

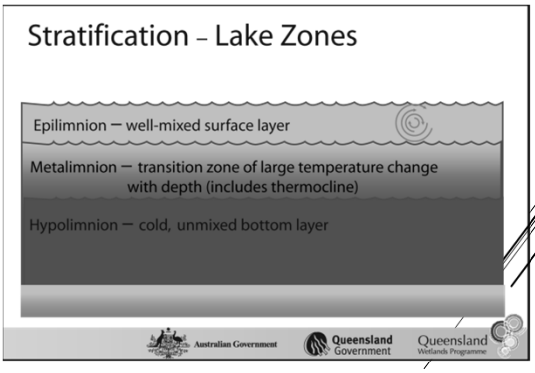
CAUSES OF WATER QUALITY PROBLEMS

- Dissolved Oxygen Depletion
  - Algal blooms increase the amount of DO as a result of photosynthesis
  - When algal cells die, bacteria decomposing the cells consume the dissolved oxygen
    - Can result in a fish kill
- Organic Loading
  - Result in color and chlorine demand increase
  - Increase disinfection by-product (DBP) precursors

CAUSES OF WATER QUALITY PROBLEMS

- Thermal Stratification
  - Layers of different temperature water within a lake or reservoir
  - Different temperatures result in different densities
    - Decrease in density of warmer water on top slows the vertical mixing action and forms a barrier between the upper and lower levels
  - Epilimnion – upper, warmer layer
  - Metalimnion – middle transition layer
    - Aka thermocline
  - Hypolimnion – bottom, colder layer
    - Anaerobic environment
  - As temperatures drop, the lake will destratify or "turnover"





CAUSES OF WATER QUALITY PROBLEMS

- Anaerobic conditions
  - Problems caused by reduction – removal of oxygen or sulfur when oxygen is absent
  - Noted by the presence of a rotten egg odor
  - Iron and manganese in bottom sediments pass into solution
    - Iron is changed from the oxidized ferric state into the soluble ferrous state
    - Manganese is changed from the oxidized maganic state into the soluble manganous state

RESERVOIR MANAGEMENT

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WATERSHED MANAGEMENT

- Primary purpose should be to control, minimize or eliminate any practices within the watershed area that are harmful to water quality within the domestic water supply reservoir
- Wastewater
  - Nutrient loading of the lake
  - Microbial contamination
  - Major source is septic systems
    - Two dependable solutions:
      - Replace all septic systems with sewer
      - Adopt ordinances that regulate the design and installation of septic systems

WATERSHED MANAGEMENT

- Fertilization
  - Results in large amounts of nitrogen in water
  - Cause eutrophication and algal blooms
  - Best solution is public education
- Soil Grading and Farming Practices
  - Contributes to turbidity of surface water
  - Can be controlled through regulations and ordinances
    - Limit the time of year of soil disturbance
    - Limit amount of time soil is left exposed

WATERSHED MANAGEMENT

- Livestock Grazing
  - Increase erosion, turbidity and eutrophication
- Wildfires
  - Large amounts of debris, nutrients, silt and other pollutants
  - Fire prevention and control programs are a must
- Highway Stormwater Runoff
  - Toxic metals, nutrients, bacteriological constituents, oil and grease, floating materials, trash and litter, pesticides, herbicides, and deicing salts

ALGAE CONTROL BY CHEMICAL METHODS

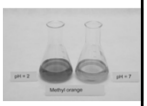
- Purpose of Chemical Methods
  - To prevent or control taste and odor problems resulting from algal blooms
  - To reduce the overall biological productivity
  - To maintain acceptable aesthetic conditions in the lake or reservoir

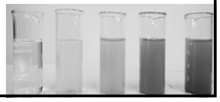
ALGAE CONTROL BY CHEMICAL METHODS

- Chemicals Available
  - Copper sulfate pentahydrate ($CuSO_4 \bullet 5\ H_2O$)
    - Aka bluestone
    - Primary algicide
    - Toxic to many species of algae but does not present health hazard to workers or consumers
    - Can be a hazard to trout
    - Must monitor copper levels in distribution system
  - Chlorine
    - Used as a bactericide or oxidizing agent, may also produce the effects of an algicide
    - High chance of producing DBPs

ALGAE CONTROL BY CHEMICAL METHODS

- Chemical Doses
  - Three major water quality indicators affect the effectiveness of copper sulfate
    - Alkalinity
      - If methyl orange alkalinity < 50, dose 0.9 lb/acre-ft
      - If methyl orange alkalinity > 50, dose 5.4 lb/acre-ft
    - Suspended Matter
      - Can reduce effectiveness by adsorbing copper sulfate
    - Temperature
      - Higher dosage feed rates required below 50°F (10°C)





ALGAE CONTROL BY CHEMICAL METHODS

- Chemical Doses
  - pH
    - The lower the pH, the more effective the copper sulfate
      - More copper ions are present making it more effective
    - The higher the pH, the less effective the copper sulfate
      - Copper more likely to precipitate out leaving none available as an algicide
  - EPA's Lead and Copper Rule limit the concentration allowed for dosing of the water
    - Copper action level = 1.3 mg/L

ALGAE CONTROL BY CHEMICAL METHODS

- Methods of Chemical Application
  - Drag burlap bags containing the copper material through the water using a boat
    - Simplest method
    - Very small lakes and reservoirs
  - Dump dry copper sulfate crystals into hopper mounted on a boat and fed into a broadcaster
  - Mix copper sulfate into solution and spray it onto the reservoir surface
    - Most efficient and safest method
    - Mount pipe with holes behind a boat

ALGAE CONTROL BY CHEMICAL METHODS

- Monitoring
  - Historical data can show when an algal bloom may occur
  - Monitoring should be carried out before, during and after the use of chemicals
- Recordkeeping
  - Important part of algae control program
  - Used to evaluate current and historical treatment programs
    - Designing new or revising existing programs
    - Showing compliance with regulations

ALGAE CONTROL BY CHEMICAL METHODS

- Safety
  - Follow proper procedures for handling and chemical application
    - Wear special PPE for dust
  - Follow water safety procedures

REAERATION AND DESTRATIFICATION

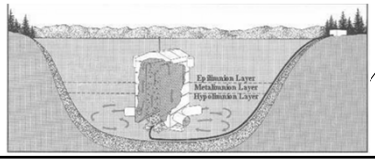
- Terminology
  - Aeration – The process of adding air to water
  - Reaeration – The introduction of air through forced air diffusers into the lower layers of the reservoirs
  - Destratification – the development of vertical mixing within a lake or reservoir to eliminate separate layers of temperature, plant or animal life
  - Reaeration-destratification – using air to destratify the reservoir

REAERATION AND DESTRATIFICATION

- Purposes of Reaeration-Destratification Programs
  - To eliminate, control, or minimize the negative effects on domestic water quality
  - To increase recreational values of the reservoirs
  - To reduce winter fish kills in water that becomes anaerobic during winter freezes

REAERATION AND DESTRATIFICATION

- Methods of Reaeration
  - Destratification
    - Alters or totally eliminates thermal stratification
  - Hypolimnetic reaeration
    - Adds dissolved oxygen directly to the hypolimnion without significantly altering the pattern of the thermal stratification



REAERATION AND DESTRATIFICATION

- Destratification
  - Accomplished by inducing vertical mixing within the reservoir
    - Mechanically by pumping hypolimnetic waters to the surface or by pumping surface waters downward
    - Through the use of diffused air
      - Diffusers release air near the bottom of the lake
      - As the bubbles rise, they carry the cold, denser water upward
      - The cold, dense water will eventually settle back to the bottom, creating vertical circulation
      - Disadvantage: deeper waters may become warmer than desired for domestic water and for certain species of fish

SURFACE WATER INTAKE STRUCTURES

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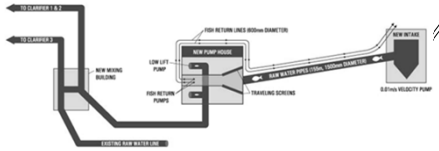
INTAKE STRUCTURES

- Purpose of Intake Structures
  - Used to deliver water to water treatment plants
  - Should be constructed on the basis of the specific function that they must serve at a give source
  - Must be capable of supplying the maximum rate or flow required for the water treatment plant
  - Should be constructed to prevent algal scums, trash, logs and fish from entering the system



INTAKE STRUCTURES

- Types of Intake-Outlet Structures
  - Single-level intakes
    - Located in the deepest portion of the stream or reservoir so that water service can still be provided even when the body of water is down to its minimum operating level
    - Most suitable in relatively shallow lakes that do not stratify significantly and have fairly uniform water from top to bottom

INTAKE STRUCTURES

- Types of Intake-Outlet Structures
  - Multilevel intakes
    - Found in vertical towers located in deeper portions of the lake and extending above the water surface
    - Each inlet is equipped with an individually operated gate or valve at the point of inlet
    - Some intakes are inclined rather than vertical
      - Commonly located on inclined face of a dam

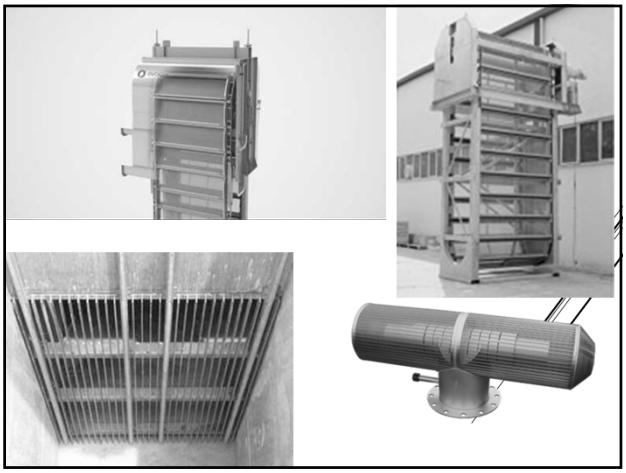
Wet intake tower

INTAKE STRUCTURES

- Types of Intake-Outlet Structures
  - Single-level intakes
    - Advantages
      - Less complicated so less costly to construct on multilevel structures
      - Easier and less costly to operate and maintain
    - Disadvantages
      - Major water quality issues due to be located in the hypolimnion
        - Water may be anaerobic, have high levels of Fe & Mn, or contain hydrogen sulfide
  - Multilevel intakes
    - Advantage: they make it possible to serve water from the depth where the best water quality is located

INTAKE STRUCTURES

- Types of Intake Gates
  - Most common are slide gates, gate valves, and butterfly valves
- Intake Screens and Trash Racks
  - Type depends on several factors
    - Depth(s) at which the inlets are located
    - Location of the intake structure in relation to where debris accumulates in the reservoir or stream
    - Frequency and intensity of algal scum or algal mass accumulations
    - Quantity and type of debris encountered
    - Size, depth, distribution, and number of fish, crayfish, and other forms of aquatic life



INTAKE STRUCTURES

- Operation and Maintenance Procedures
  - Major causes of faulty operation of gates and valves
    - Settlement or shifting of support structure, which could cause binding of gates
    - Worn, corroded, loose, or broken parts
    - Lack of use
    - Lack of lubrication
    - Vibration
    - Improper operating procedures
    - Design errors or deficiencies
    - Failure of power source or circuit failure
    - Vandalism
  - To adjust the tension on a travelling screen, turn the capstan

PRELIMINARY TREATMENT

AWWA WSO: Grade 1

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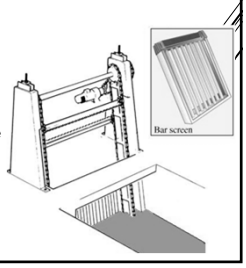
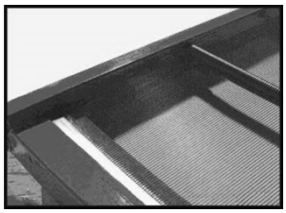
SCREENING

- Coarse screens located on intake structure to prevent clogging of the intake by removing sticks, logs, or other large debris in surface water source
  - aka trash racks or debris racks
- Bar Screens
  - Made of straight steel bars and ranked by distance between bars
    - i.e. fine, medium, coarse
  - Typically installed at 60° - 80° angle to aid in debris removal
    - As debris builds up, passing water lifts and pushes it up the slope



SCREENING

- Wire Mesh Screens
  - Woven from stainless steel or corrosion-resistant material
  - For streams and lakes with a lot of debris
  - Can be lifted out for cleaning or installed with automatic cleaning



PRESEDIMENTATION

- Removal of silt, sand, and gravel from raw water before it enters the flash mix
  - Surface waters with extensive sediment after rainfall
  - Reduces amount of coagulant needed
  - Reduces potential damage to pumps and other moving parts

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PRESEDIMENTATION SYSTEMS

- Impoundments
  - Basin which allows sediment to settle out before the flash mix
  - Benefit - stores water for later use
  - Problems - growth of algae and aquatic plants
  - To clean, drain, dry, and remove accumulated material

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PRESEDIMENTATION SYSTEMS

- Sand traps
  - Depression at the bottom of structure to slow water as it enters and allow the heavy solids to settle
    - e.g. bottom of a wet well
  - Installed with baffle to slow water and drain valve to flush out accumulated solids
  - Best suited for water that contains <100 mg/L sand & grit
  - Cleaned by allowing accumulations to discharge through a drain line installed at bottom
  - Hose down wet-well during draining through access cover

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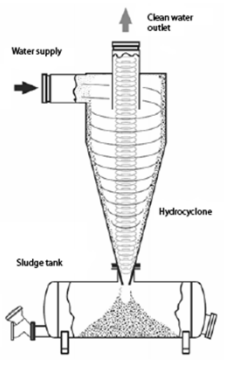
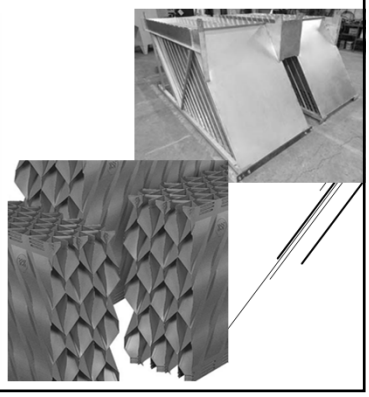
PRESEDIMENTATION SYSTEMS

- Mechanical Sand-and-Grit Removal Devices
  - Used when raw water contains large amounts of suspended solids
  - A centrifugal sand-and-grit removal device is called a *cyclone degritter*
  - Sand-laden water hits unit travelling in spiral path inside cylinder
  - Centrifugal force throws sand toward wall
  - Clean water leaves the unit with almost all sand removed
- Plate and Tube Settlers
  - Provide elevated surfaces on which solids can settle, rather than fall to the basin's bottom

PRESEDIMENTATION SYSTEMS

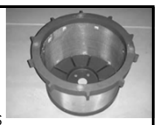




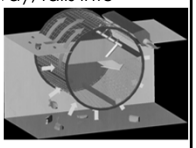
PRESEDIMENTATION

- Operation
  - Requires cleaning to prevent buildup and re-suspension of solids
  - Deposits can become anaerobic, causing taste and odors
- Record Keeping
  - Date of sampling and testing
  - Concentration of suspended solids in raw water (mg/L or mL/L)
  - Amount of suspended solids in presedimentation effluent
  - Cleaning date, time required, and estimated quantity of removed material.

MICROSTRAINING



- Removes small debris which could clog filters
- Stainless steel wire fabric
- Rotating drum – algae adheres to fabric
- High-pressure jet causes mat to break away, falls into removal trough



- Advantages
  - Removes filter-clogging material
  - Decreases chlorine demand
- Disadvantages
  - Does not remove all algae, dissolved solids, bacteria, or viruses
  - Cannot replace any treatment process

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MICROSTRAINING

- Chlorine should not be fed before the microstrainer
  - Dead algae are hard to clean off screen
  - Iron can precipitate on screen
  - Chlorine will cause corrosion
  - Chlorine reaction with algae can cause taste and odor problems

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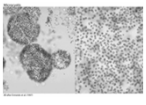
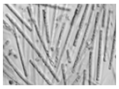
ALGAE

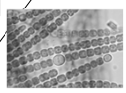
- No true leaves, stems, or roots
- Reproduce by spores, cell division, or fragmentation
- Blue-green, green, diatoms, and flagellates

ALGAE

- Need sunlight and nutrients to grow
- High levels of <u>nitrogen</u> and <u>phosphorus</u> can cause *algal blooms*
- Some species can produce powerful toxins that damage the liver and nervous system





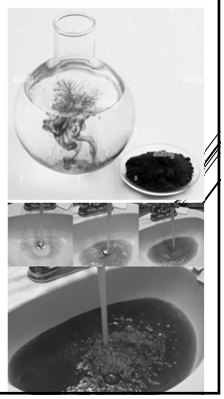


PROBLEMS CAUSED BY ALGAE

- Slime accumulation
- Taste, odor and color
- Interference with treatment processes
- Toxicity
- Filter clogging
- Corrosion
- THM precursors

POTASSIUM PERMANGANATE

- Can be used for control of algae in reservoirs by applying directly to reservoir
- Oxidant used for iron & manganese control, some organic precursor control, and taste & odor control
- Changes color at end point
  - Pink to straw or yellow
- Reactions dependent largely on pH
- Can run demand test in lab to determine dosage



POWDERED ACTIVATED CARBON (PAC)

- Fed directly to reservoir: acts to physically block light, restricting algae growth
  - Only practical for small reservoirs
- Fed to intake help control those organic compounds responsible for tastes and odors
- Acts as weighting agent in coagulation step

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POWDERED ACTIVATED CARBON (PAC)

- Application considerations:
  - Minimum 15 minutes contact time
  - PAC particles will lose adsorption ability if coated with coagulants or other chemicals
  - PAC will adsorb chlorine
    - If fed together, will result in decreased organics removal and increased chlorine demand

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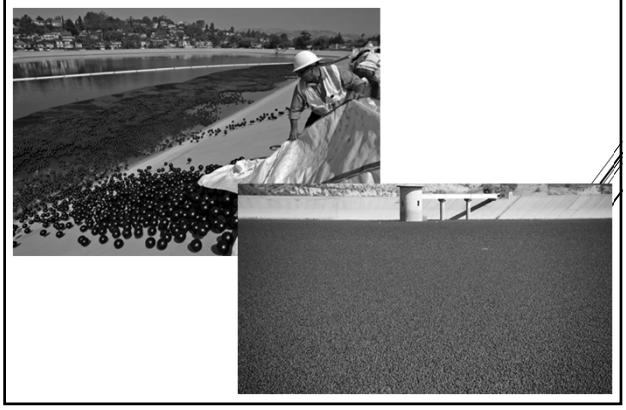
INNOVATIVE ALGAE CONTROL

- Department of Water and Power workers are emptying out bales of plastic balls in the Los Angeles reservoir.
  - About 96 million 4-inch black plastic balls were released to form a floating cover over the 175-acre reservoir.
  - The reservoir holds up to 3.3 billion gallons, enough to supply the city with drinking water for up to three weeks.

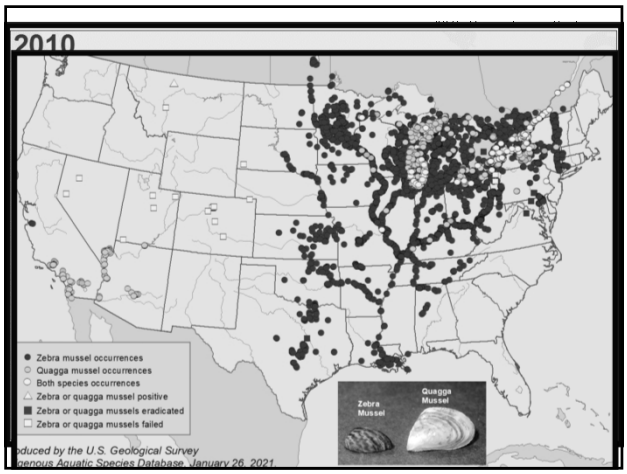
INNOVATIVE ALGAE CONTROL



ASIATIC CLAMS & ZEBRA MUSSELS

- Asiatic Clams
  - Introduced to US from Southeast Asia in 1938
  - Clams can infest raw-water intake pipelines and treatment facilities leading to low flow capacities and clogging of mechanical equipment
- Zebra Mussels
  - Freshwater shellfish that invaded the Great Lakes in the 1980's
  - Native to Black and Caspian Seas and thought to have been brought over in freighter's ballast water
  - Population is spreading to most waters of North America

Zebra Mussels



ZEBRA MUSSELS

- Attach to intakes, clog intake screens, reduce flow capacity
- Rapid die-off causes taste & odor problems
- Shells of dead mussels can clog intakes


Zebra mussels (*Dreissena polymorpha*) fouling an intake pipe.
Photo courtesy of Peter Yates.

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ZEBRA MUSSELS AND CLAMS

- Treatment should begin prior to invasion
- Treatment:
  - Chlorine, potassium permanganate, or copper sulfate applied at intake

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TASTE AND ODOR PROBLEMS

- Customers judge the quality of their water by its aesthetic properties
  - Mainly taste and odor
- To prevent or treat a problem, you must know the source of the problem
- Preventative Measures
  - Watershed protection and control of nutrients entering water source
  - Prevent stagnation
  - Physical and chemical pretreatment are an important step in improving the overall efficiency and effectiveness of the treatment process

Vocabulary

A. Adsorption
B. Aeration
C. Aerobic
D. Anaerobic
E. Coliform
F. Colloids
G. Conductivity
H. Decomposition
I. Destratification
J. Diatoms
K. Electrolyte
L. Epilimnion
M. Eutrophic
N. Eutrophication
O. Evapotranspiration
P. Hypolimnion
Q. Inorganic
R. Metalimnion
S. Organic
T. Overturn
U. Oxidation
V. Potable
W. Precipitate
X. Reduction
Y. Septic
Z. Stratification
AA. Threshold Odor Number

_____ 1. The conversion of chemically unstable materials to more stable forms by chemical or biological action.

_____ 2. The upper layer of water in a thermally stratified lake or reservoir.

_____ 3. The gathering of a gas, liquid, or dissolved substance on the surface or interface zone of another material.

_____ 4. An insoluble, finely divided substance which is a product of a chemical reaction within a liquid.

_____ 5. Substances that comes from animal or plant sources and always contain carbon.

_____ 6. The addition of oxygen, removal of hydrogen, or the removal of electrons from an element or compound.

_____ 7. The increase in the nutrient levels of a lake or other body of water.

_____ 8. A measure of the ability of a solution (water) to carry an electric current.

_____ 9. The middle layer in a thermally stratified lake or reservoir.

_____ 10. The addition of hydrogen, removal of oxygen, or addition of electrons to an element or compound.

_____ 11. The greatest dilution of a sample with odor-free water that still yields a just-detectable odor.

_____ 12. A condition in which atmospheric or dissolved molecular oxygen is present in the aquatic (water) environment.

_____ 13. The development of vertical mixing within a lake or reservoir to eliminate separate layers of temperature, plant, or animal life.

_____ 14. A condition in which atmospheric or dissolved molecular oxygen is NOT present in the aquatic (water) environment.

_____ 15. A substance which dissolves (separates) into two or more ions when it is dissolved in water .

_____ 16. Material such as sand, salt, iron, calcium salts and other minerals materials.

_____ 17. The formation of separate layers (of temperature, plant, or animal life) in a lake or reservoir.

_____ 18. Water that does not contain objectionable pollution, contamination, minerals, or infective agents and is considered satisfactory for drinking.

_____ 19. A group of bacteria found in the intestines of warm-blooded animals and also in plants, soil, air and water. Their presence is an indication that the water is polluted and may contain pathogenic (disease causing) organisms.

_____ 20. The process of adding air to water. Air can be added to water by either passing air through water or passing water through air.

_____ 21. The process by which water vapor passes into the atmosphere from living plants.

_____ 22. Very small, finely divided solids that remain dispersed in a liquid for a long time due to their small size and electrical charge.

_____ 23. Reservoirs and lakes which are rich in nutrients and very productive in terms of aquatic animal and plant life.

_____ 24. The most spontaneous mixing of all layers of water in a reservoir or lake when the water temperature becomes similar from top to bottom.

_____ 25. A condition produced by bacteria when all oxygen supplies are depleted.

_____ 26. The lowest layer in a thermally stratified late or reservoir.

_____ 27. Unicellular (single cell), microscopic algae with a rigid internal structure consisting mainly of silica.

1. H
2. L
3. A
4. W
5. S
6. U
7. N
8. G
9. R
10. X
11. AA
12. C
13. I
14. D
15. K
16. Q
17. Z
18. V
19. E
20. B
21. O
22. F
23. M
24. T
25. Y
26. P
27. J

Reservoirs and Intakes

Review Questions

1. Large quantities of what nutrients are undesirable in a water supply reservoir?

2. What is an “algal bloom”?

3. What types of tastes and odors are produced by algae?

4. What problems do algae cause on filters?

5. What is the influence of algal blooms on pH?

6. What is the influence of algal blooms on dissolved oxygen?

7. Increased organic loadings from algal blooms can cause what kind of water quality problems?

8. When a lake warms in the spring or summer, how does the decrease in density of the warmer surface water influence mixing action within the lake?

9. What problems are caused by anaerobic conditions in reservoirs?

10. What should be the primary purpose of a watershed management program?

11. What problems can be caused in reservoirs from raw wastewater contamination?

12. How can the adverse impacts of soil disturbances from farming, logging, and construction be minimized?

13. What problems can be created as a result of a wildfire?

14. Why are chemicals used in domestic water supply reservoirs to prevent or control attached and floating aquatic growths?

15. What chemical other than copper sulfate may be used as an algicide?

16. How does suspended particulate matter in a reservoir reduce the effectiveness of copper as and algicide?

17. What is the major factor limiting the maximum rate of application of copper sulfate in the sources of a domestic water supply?

18. What safety precautions should be taken by a person applying copper sulfate in the dry form?

19. What is the primary purpose of reaeration-destratification programs in domestic water supply reservoirs?

20. What are the most common types of intake gates?

21. List the factors that influence the type of screen needed in a specific reservoir.

Reservoirs and Intakes
Review Questions Answers

1. Phosphate, nitrate, and organic nitrogen compounds

2. Very large increase in plankton (algae) population over a very short period of time

3. fishy, aromatic, grassy, septic, musty, and earthy

4. clog filters reducing filter rates and run times

5. fluctuations in pH from day to night

6. increases DO during the bloom; decreases DO when algae dies

7. decreased oxygen levels, increase color and chlorine demand; increase DBP precursors

8. The decrease in density of the warmer water reduces the mixing action within the lake and a barrier is formed between the upper and lower layers

9. Causes the release of hydrogen sulfide and cause iron and manganese in bottom sediments to go into solution into the water

10. To control, minimize, or eliminate practices within the watershed of a domestic water supply reservoir that would lower water quality

11. Nutrient loading and microbial contamination

12. Ordinances that limit such activities to those times of the year when the danger of erosion from surface runoff is at a minimum

13. During the runoff period, large quantities of debris, nutrients, silt, and other pollutants may enter a water supply reservoir

14. to prevent or control taste and odor problems resulting from algal blooms

15. chlorine

16. reduces the effectiveness of copper as an algicide by providing sites or masses other than algal bodies where the copper is adsorbed

17. regulations limiting the concentration of copper in potable water

18. special clothing, gloves, and breathing apparatus, personal flotation advice

19. to eliminate, control, or minimize the negative effects on domestic water quality that occur during periods of thermal stratification and dissolved oxygen depletion

20. slide gates, gate valves, and butterfly valves

21. depth(s) at which the inlets are located, location of the intake structure in relation to where debris accumulates in the reservoir or stream, frequency and intensity of algal scum or algal mass accumulations, quantity and type of debris encountered, size, depth, distribution, and number of fish, crayfish, and other forms of aquatic life