ENVE 301
Environmental Engineering Unit Operations

Course Overview

SPRING 2014

Assist. Prof. A. Evren Tugtas

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Course Goals

- The course examines the fundamental theory of unit operations in the physical and chemical treatment of water. Coagulation and flocculation, sedimentation, filtration, and gas transfer are among topics to be considered.

Learning Outcomes

1. Learn major physical and chemical treatment processes in water and wastewater treatment
2. Gain analytical problem solving skills, which can be applied in practice
3. Be prepared for the water treatment plant design

Weekly Program

WEEK	Date	TOPICS
Week 1	12 Feb-14 Feb	Introduction to water and wastewater treatment
Week 2	19 Feb-21 Feb	Reaction Kinetics, Mass Balances, and Reactor Types
Week 3	26 Feb – 28 Feb	Reaction Kinetics, Mass Balances, and Reactor Types
Week 4	5 Mar -7 Mar	Gas Transfer
Week 5	12 Mar -14 Mar	Gas Transfer and Aeration
Week 6	19 Mar – 21 Mar	Mixing
Week 7	26 Mar – 28 Mar	Coagulation, flocculation
Week 8	9 Apr-11 Apr	Coagulation, flocculation
Week 9	16 Apr – 18 Apr	Sedimentation
Week 10	25 Apr	Sedimentation
Week 11	30 April – 2 May	Sedimentation
Week 12	7 May – 9 May	High rate settlers and solids handling
Week 13	14 May – 16 May	Filtration
Week 14	21 May – 23 May	Filtration

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Textbooks and other references

- **Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996. (Textbook)**
- Geankoplis C.J. Transport Processes and Separation Process Principles. 4th ed. New Jersey. Prentice Hall. 2003. ISBN: 0-13-101367-X
- Clark M.M. Transport Modelling for Environmental Engineers and Scientists. John Wiley&Sons, 1996 ISBN: 0-47112348X
- American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999 ISBN: 0-0070016593

Academic Honesty

- You may collaborate on understanding lectures and even homework problems.
- You may discuss your homework if you get stuck at certain points.
- <u>However, you must then do your homework yourself. Do not attempt to copy homeworks from eachother.</u>

Grading

Evaluation Tool	Quantity	Weigh in total (%)
Midterm Exam	2	30
Quizez (Short)		1
Project(s)		20
Final	1	40

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ENVE 301
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Lecture 1
Introduction to Water and Wastewater Treatment

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- Course material is prepared using following references

1) Reynolds, T. D., and P. A. Richards. Unit Operations and Processes in Environmental Engineering. 2nd ed. Boston, MA: PWS Publishing Company, 1996. (Textbook)
2) American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999 ISBN: 0-0070016593
3) McGhee TJ. Water Supply and Sewarage. 6th ed. McGraw Hill, 1991. ISBN: 0-071008233
4) Peavy HS., Rowe DR., Tchobanoglous G. Environmental Engineering. McGraw Hill, 1985. ISBN:0-071002316
5) Other sources

Fundamental Principles of Water or Wastewater Treatment

1. Physical Treatment
2. Chemical Treatment
3. Biological Treatment

Physical Treatment

- Screening
- Presedimentation
- Aeration
- Adsorption
- Grit Removal
- Flow Equalization
- Sedimentation
- Filtration
- Ammonia Stripping
- Mixing
- Membrane Processes

Chemical Treatment

- Neutralization
- Coagulation and Flocculation – Coagulant/Flocculant
- Ion Exchange
- Disinfection (Chlorine or Ozone)

Biological Treament

- Activated Sludge
- Trickling Filters and Biological Conductors
- Stabilization ponds and Lagoons
- Anaerobic or Aerobic Digestion
- Nitrification/Denitrification

Unit Operations and Processes

- ***Unit Operations:*** Physical treatment
  - Sedimentation
  - Filtration
  - Mixing

  } typically

- ***Unit Processes:*** Chemical or biological treatment
  - Coagulation
  - Adsorption
  - Ion Exchange
  - Activated Sludge
  - Aerobic or Anaerobic Digestion

Water Treatment

Water treatment is applied to:

- Surface water (streams, lakes, man-made reservoirs, ocean)
- Ground water

Surface Water Sources

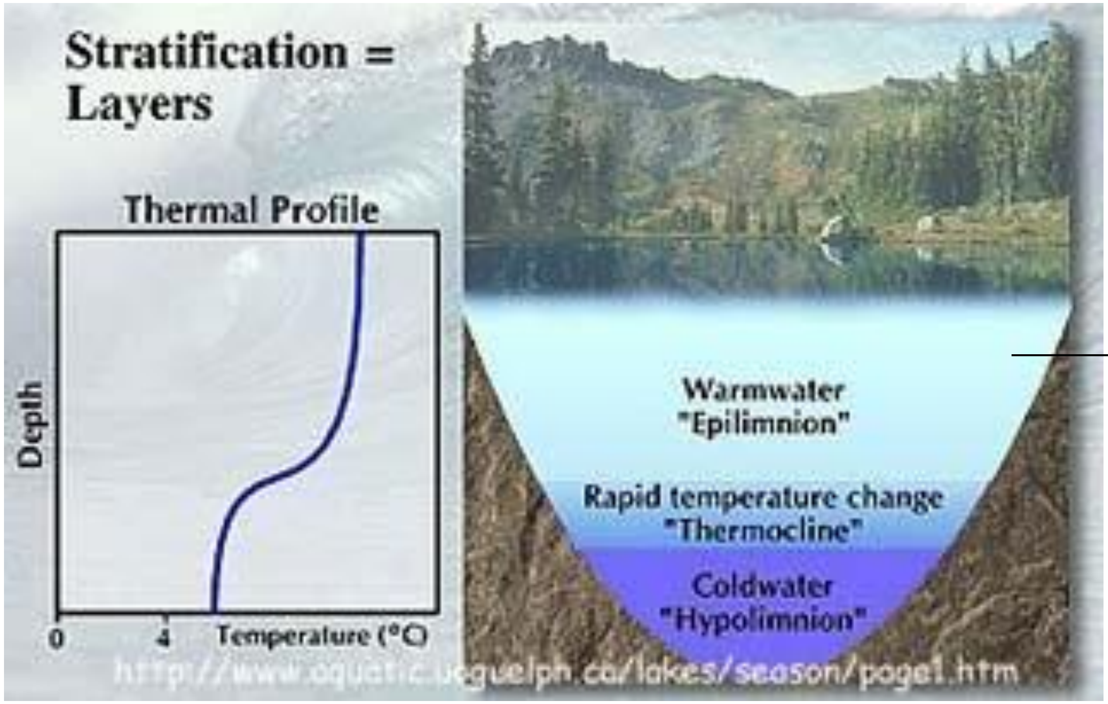
Streams or rivers

- Rapid changes in water quality
- Changes in turbidity and other constituents during heavy rains and run off
- Require flexible and reliable treatment processes

Lakes and man-made reservoirs

- Seasonal changes in water quality due to thermal stratification
- Heat transfer in reservoirs and lakes is controlled by a phenomenon known as thermal stratification
- Temperature profile changes with depth

Thermal Stratification - Summer



Warm water is less dense than cold water

Figure ref: http://www.aquatic.uoguelph.ca/lakes/season/seasnfrm.htm

Thermal Stratification - Summer

- In summer, warm water stays in the top layer and mixing due to wind occurs in the Epilimnion.
- Upper mixed layer is separated from the calm deep water.
- Algal blooms may occur at the top layer due to sufficient nutrients.
- Dead algae sinks to bottom creating anaerobic decomposition due to unsufficient mixing and thus dissolved oxygen
- Sediment will be deposited at the bottom of the lake.

Autumn Turnover

- Stratification is interrupted in autumn as the surface waters cool and begin to sink
- Wind action can cause circulation throughout the entire body of water so that turnover in the lake's strata occurs.
- Stratification disappears and the body of water reverts to uniform temperature

Peavy HS, Rowe DR, Tchobanoglous. Environmental Engineering, 1985 ,McGrawHill

Thermal Stratification – Winter and Spring

- At cold climates, surface waters freeze over as the winter sets in.
- Water beneath the ice layer allows aquatic ecosystem to survive
- In spring, the process is reversed and turnover occurs

Thermal Stratification

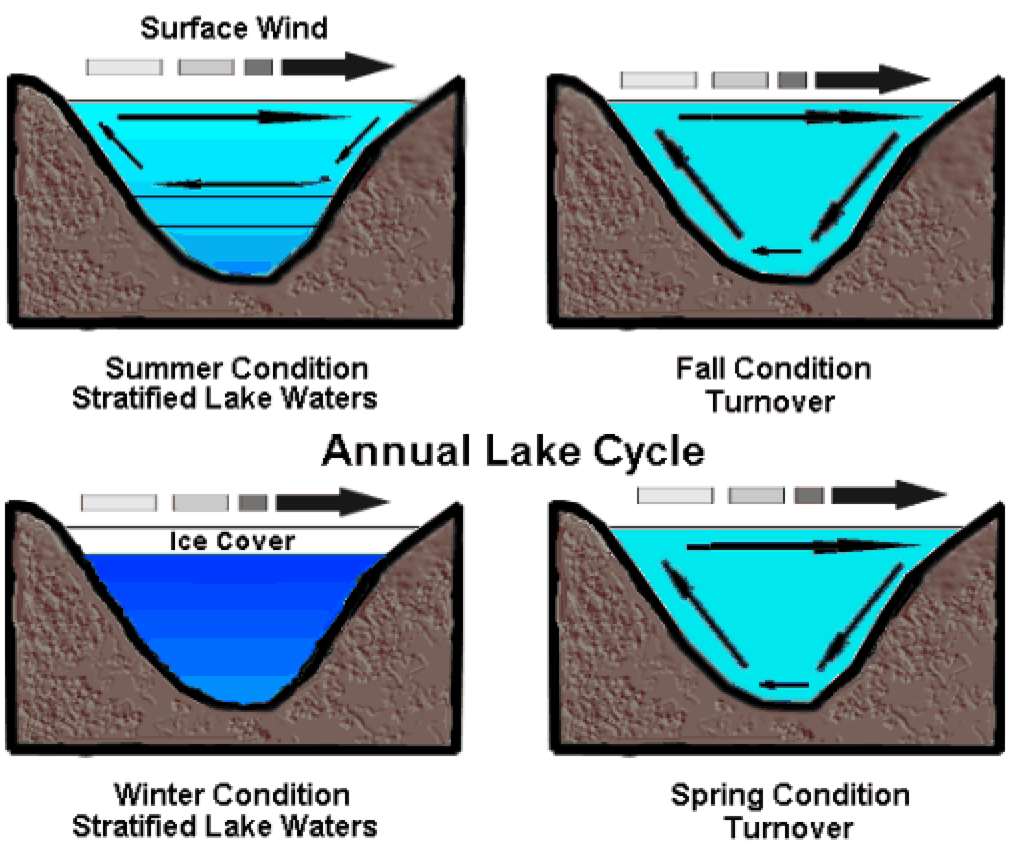


Figure ref:
http://www.islandnet.com/~see/weather/elements/turnlakes.htm

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Groundwater

- Groundwater is often superior in quality to surface waters.
- Groundwater is generally preferred as a source for municipal and industrial water supplies
- Groundwater's may be contaminated by toxic or hazardous materials leaking from landfills, waste treatment sites, accidental spills, agricultural zones etc.
- The rainfall which percolates down into the groundwater zone, dissolves minerals
- Groundwater usually contains more dissolved minerals than surface water

Groundwater

- Storage zones of groundwater are termed **Aquifers.**
- Aquifers have significant porosity and permeability.

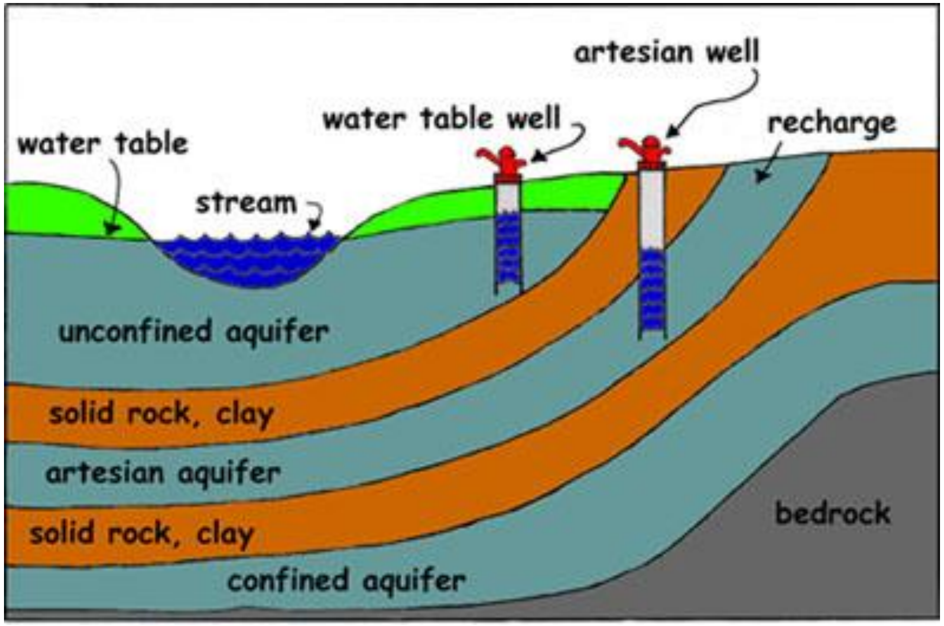

Fig ref: http://coastgis.marsci.uga.edu/summit/aquifers.htm

Motivations for Water Treatment

- Health and aesthetics are the principal motivations for water treatment.
- Late 1800s and early 1900s;
  - Acute water borne diseases such as chlorea and typhiod fever spurred development of filtration and chlorination plants

46. *Nicholas I Subduing Cholera Insurrection on Sennaia Square, St. Petersburg, 1831.* Bas-relief on Nicholas I monument by N. Ramazanov.

Fig. Ref
http://www.homeoint.org/books5/clarkecholera/part2.htm

Fig ref→
http://www2.cedarcrest.edu/academic/bio/hale/bioT_EID/lectures/transchol.htm

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Motivations for Water Treatment

- Identification of additional disease agents
  - Legionella, Cryptosporidium, Giardia
- And contaminants
  - Cadmium →causes calcium lost in bones
  - Lead
- Resulted in more elaborate treatment procedures to enhance filtration and disinfection
- Advanced treatment options such as activated carbon adsorption, ion exchange were applied to remove taste and odor.

Waterborne disease outbreaks

- Drinking water quality has significantly improved due to improved treatment processes.
- There are still outbreaks, however, most of the people experiencing diarrhea do not seek medical attention and therefore origin of the illness cannot be identified

Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

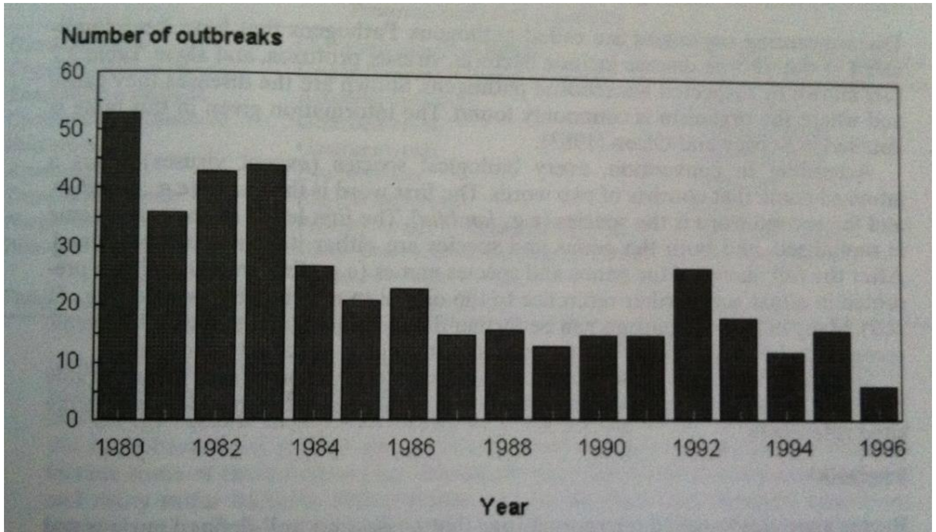

FIGURE 2.1 Waterborne disease outbreaks, 1980 to 1996.

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Pathogenic Organisms

Bacteria

- ***Salmonella*** (Typoid fever-food cont. %0.1)
- ***Shigella*** (Dysentery)
- ***Enterocolitica*** (Gastroenteritis) - Chlorine
- ***Campylobacter jejuni*** (Gastroenteritis)-Chlorine
- ***Legionella*** (pneumonia)-ozone, chlorine dioxide, UV
- ***E. Coli* (Gastroenteritis**) -
- ***Vibrio cholerae*** (Cholerae)
- ***Helicobacter pylori*** (Peptic Ulcer)-chlorine, monochloramine
- **Opportunistic pathogens**

Viruses

- Hepatitis A – coagulation, flocculation, filtration
- Norwalk Virus
- Rotaviruses – Filtration, 99%
- Enteroviruses
- Adenoviruses
- Hepatitis E (HEV)
- Astroviruses

Protozoa

- ***Giardia lambia (***giardiasis)– Cysts are 7.6-9.9 um in width – resistant to chlorine
- ***Entamoeba histolytica*** (bloody diarrhea) Cysts are 10-15um in size
- ***Cryptosporidium parvum –*** more resistant to disinfection than G. Lambia- weak immunity

Algea

- Blue-green algea---High toxin production – neurotoxins, hepatotoxins etc.

Optional Homework

Conduct a search on Giardia and Cryptosporidium.

Health Affects of Chemicals

According to health effects chemicals can be classified as;

- Toxic
- Carcinogenic
- Genotoxic
- Mutagenic
- Teratogenic

Chemicals

- Inorganic constituents
  - Aluminum, arsenic, barium, cadmium, chromium, copper, fluoride, hardness, iron, lead, manganese, mercury, molybdenum, nickel, nitrate/nitrite, selenium, sodium, sulfate, zinc
- Organic constituents
  - Benzene, chlorinated organics, methyl tert-butyl ether (MTBE), tetrachloroethylene (PCE) etc.
- Pesticides
- Organic disinfection by-products
  - Trihalomethanes etc.

Surface water contaminants

- Suspended matter;
  - silts, clays,
  - organic and inorganic colloids (color, taste and odor)
  - living organisms (pathogens and other micoorganisms)
- Dissolved matter:
  - Cations/anions (hardness ions(Ca^{2+}, Mg^{2+}); iron, manganese)
  - Dissolved gases
  - Color

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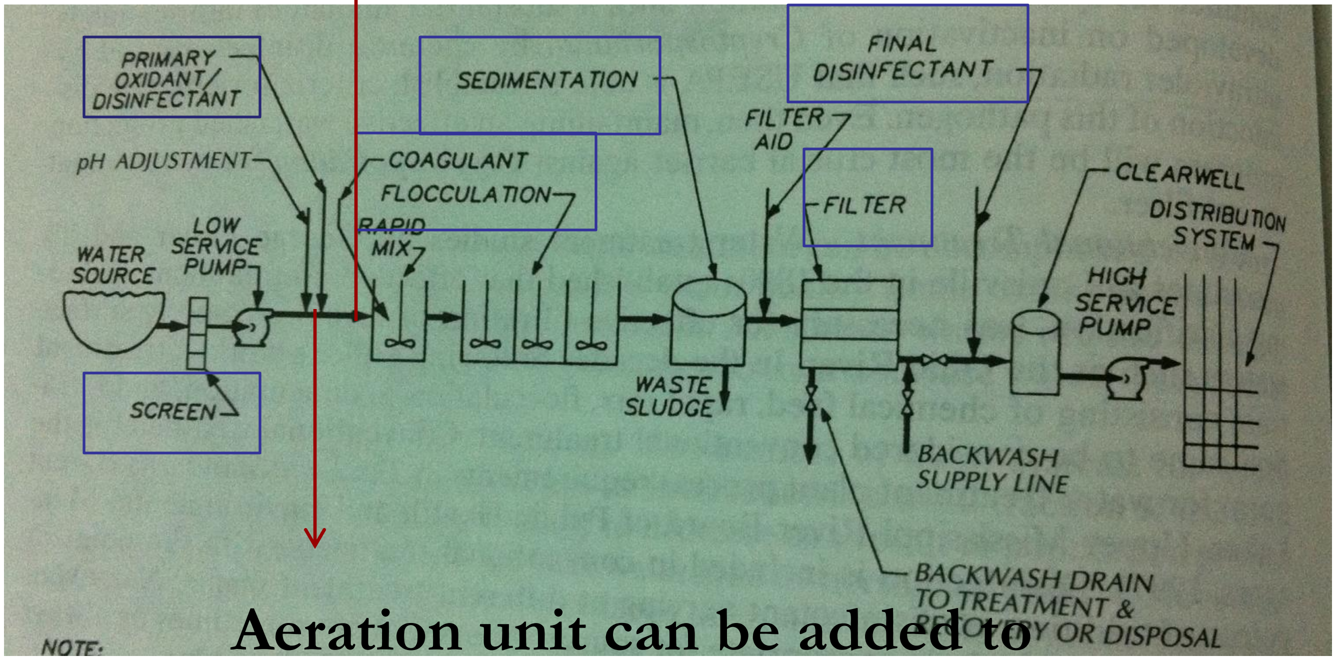
Conventional Surface Water Treatment

If water contains organics, **adsorption** process can be added following the oxidation process or prior to filtration process



Aeration unit can be added to remove volatile organics or dissolved gases (if present)

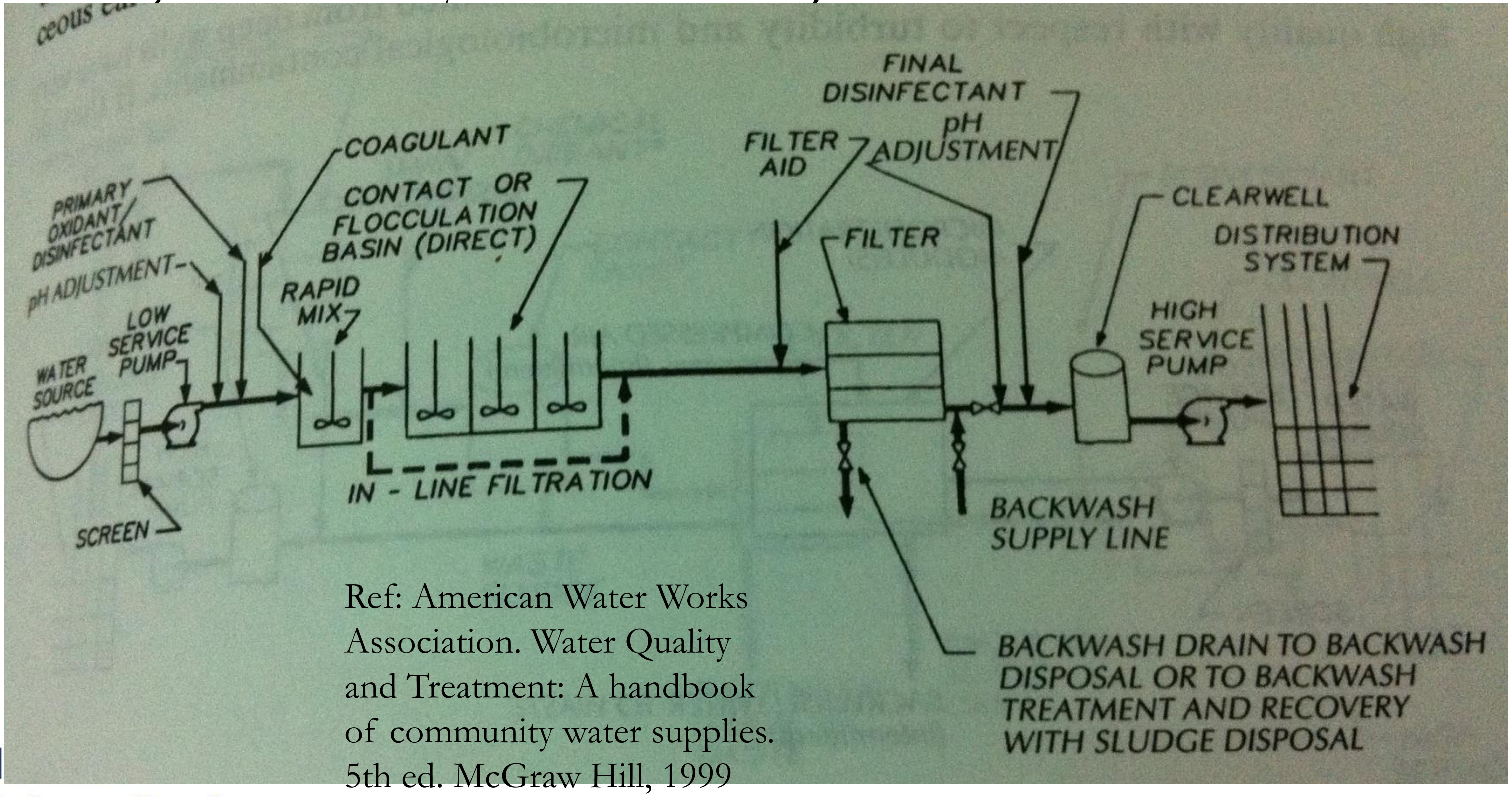
Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

Conventional Surface Water Treatment

- Screening – Prevents the entry of small debris such as sticks, leaves, fish, etc.
- Aeration – Removes unwanted gases, oxidizes iron and manganese, removes volatile organic chemicals
- Primary oxidation/disinfection – oxidation of iron and manganese, prevention of algal growth, removes compounds causing odor and taste
- Coagulation/flocculation – removes slow settling suspended solids and colloidal solids

Direct Filtration

- Treatment of clean source waters can be accomplished via direct filtration (if color<40 CU, turbidity < 5 NTU)

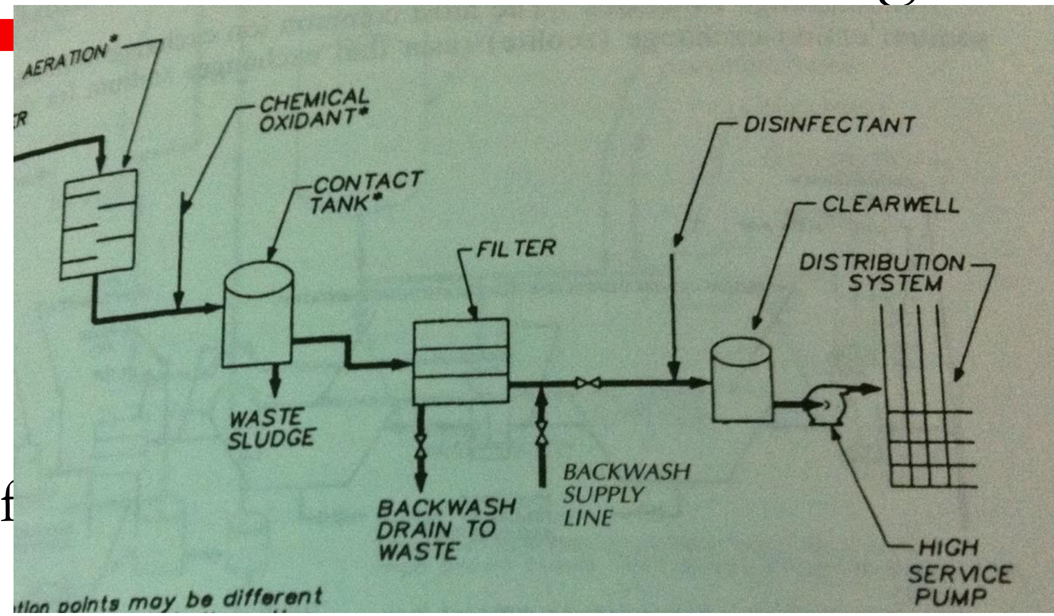


Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

Groundwater Contaminants

- Suspended matter;
  - Suspended matter in gw is negligable due to natural filtration in soil
- Dissolved matter:
  - Cations/anions (hardness ions(Ca^{2+}, Mg^{2+}); iron, manganese)
  - Dissolved gases (H_2S, CO_2)
  - Volatile, non-volatile organics

Groundwater Treatment – Removal of iron/manganese



- If minerals in the aquifer contain iron or manganese, these constituents may be found in groundwater.
- Presence of organics in water may impair removal of iron or manganese
- Iron can be oxidized via aeration at pH>8 in the absence of NOM
- Chlorine, potassium permanganate, chlorine dioxide, or ozone can be used to remove iron and manganese
- Manganese is more difficult to remove and potassium permanganate is used in conjunction with greensand (absorbs excess permanganate)

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Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

Groundwater Treatment – Removal of iron/manganese

- O_2 used as oxidant

$$4Fe^{2+} + O_2 + 10H_2O \rightarrow 4Fe(OH)_3 + 8H^+$$

$$2Mn^{2+} + O_2 + 2H_2O \rightarrow 2MnO_2 + 4H^+$$

- Cl_2 used as oxidant

$$2Fe^{2+} + Cl_2 + 6H_2O \rightarrow 2Fe(OH)_3 + 2Cl^- + 6H^+$$

$$2Mn^{2+} + Cl_2 + 2H_2O \rightarrow MnO_2 + 2Cl^- + 4H^+$$

- $KMnO_4$ used as oxidant

$$3Fe^{2+} + KMnO_4 + 7H_2O \rightarrow 3Fe(OH)_3 + MnO_2 + K^+ + 5H^+$$

$$3Mn^{2+} + KMnO_4 + 2H_2O \rightarrow 5MnO_2 + 2Cl^- + 2K^+ + 4H^+$$

Groundwater Treatment – Removal of hardness

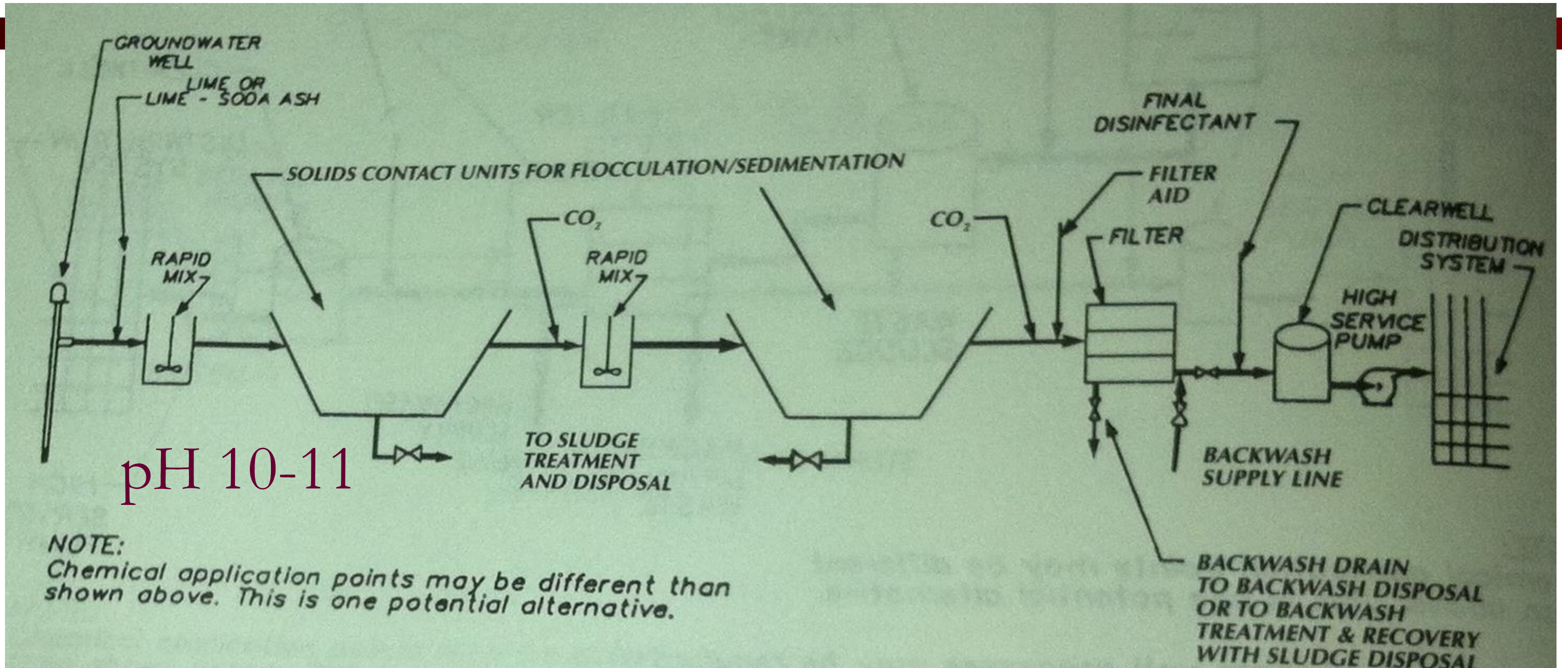

FIGURE 3.6 Two-stage excess lime softening treatment, groundwater.

- Hard water contains excessive concentrations Ca^{2+} and Mg^{2+}
- Slaked/hydrated lime ($Ca(OH)_2$) is added to remove Ca^{2+} and Mg^{2+}
- Soda-ash (Na_2CO_3) is added to remove noncarbonate hardness
- Excess lime is removed with CO_2

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Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

Hardness

- Removal of carbonate hardness

$$Ca^{2+} + 2HCO_3^- + Ca(OH)_2 \rightarrow 2CaCO_3 + 2H_2 0$$

$$Mg^{2+} + 2HCO_3^- + Ca(OH)_2 \rightarrow 2CaCO_3 + Mg(OH)_2 + H_2 0$$

- Removal of non-carbonate hardness

$$Mg^{2+} + \begin{bmatrix} SO_4^{2-} \\ 2Cl^- \\ 2NO_3^- \end{bmatrix} + Ca(OH)_2 \rightarrow Ca^{2+} + \begin{bmatrix} SO_4^{2-} \\ 2Cl^- \\ 2NO_3^- \end{bmatrix} + Mg(OH)_2$$

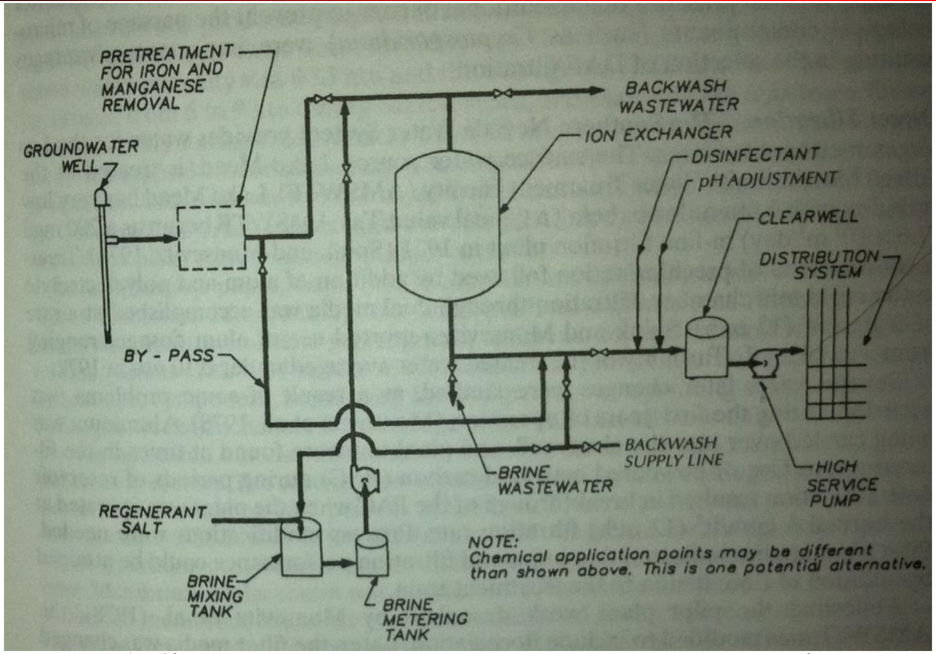
$$Ca^{2+} + \begin{bmatrix} SO_4^{2-} \\ 2Cl^- \\ 2NO_3^- \end{bmatrix} + Na_2CO_3 \rightarrow CaCO_3 + \begin{bmatrix} SO_4^{2-} \\ 2Cl^- \\ 2NO_3^- \end{bmatrix} + 2Na$$

Hardness

- Carbondioxide addition before rapid mixing is to decrease to pH. CO_2 should not be added in excess → would increase lime consumption → excess CO_2 needs to be removed via aeration
- Carbondioxide addition after the sedimentation unit is to remove the excess lime

$$Excess\ Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2 0$$

Ion exchange - Softening



Ref: American Water Works Association. Water Quality and Treatment: A handbook of community water supplies. 5th ed. McGraw Hill, 1999

- The most common ion exchange resin is a sodium cation exchange (zeolite) resin →exchanges sodium for divalent ions
- Anion exchange resin can also be used to remove anions
- Ion exchange is appropriate for water low in particulate matter, organics, iron and manganese
- High concentrations of NOM can foul some resins

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- Drinking water standards

Optional Homework

What is MCL and SMCL?

Find MCL and SMCL values for iron and manganese.