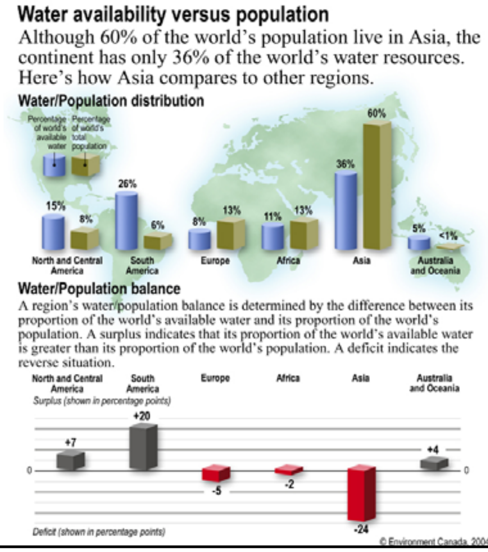
Lecture 1

Introduction to water and wastewater treatment processes

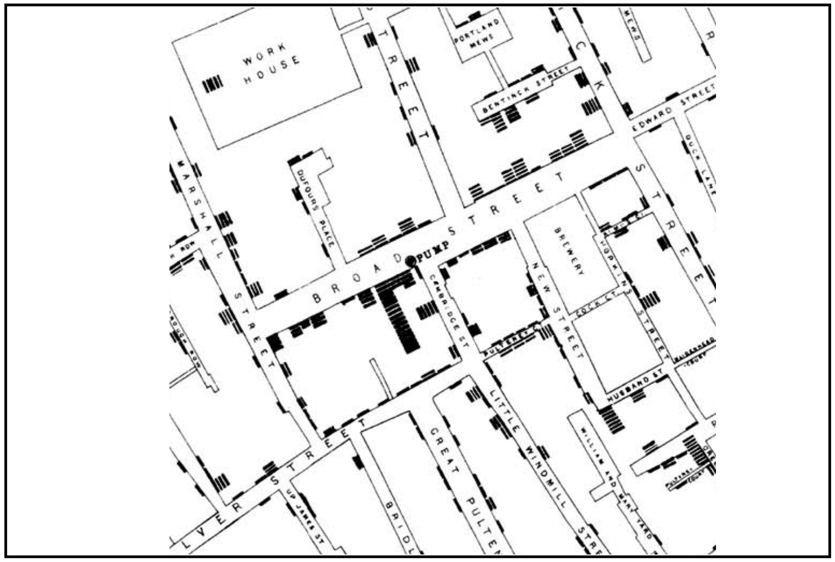


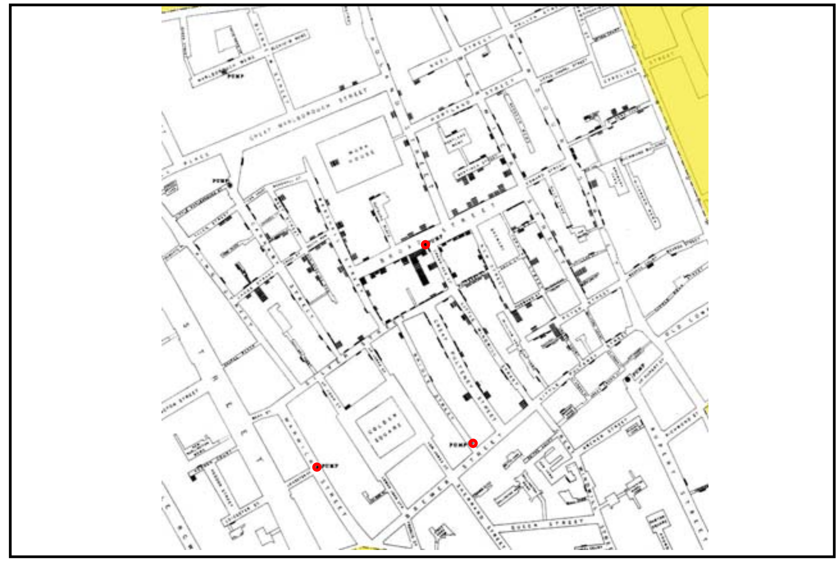
Source: Environment Canada, 2004. Water availability versus population. http://www.ec.gc.ca/water/images/info/facts/e-Water_availability.jpg. Accessed December 10, 2004.

Significant dates in public water supply

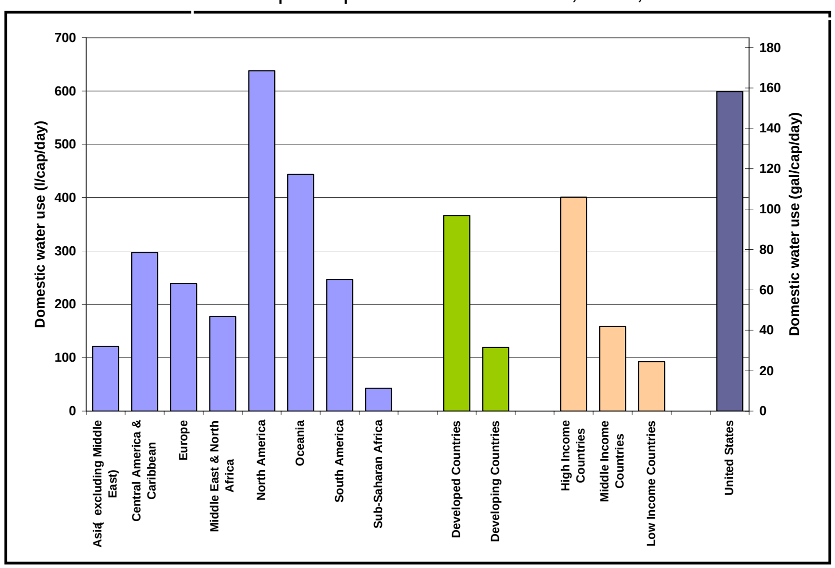
97	Inhabitants in ancient Rome use about 38 gpcd
1619	New River Company first to supply each home directly with its own water for a few hours per day
1854	John Snow establishes source of cholera epidemic in London as a contaminated supply well – first understanding of water and health
1873	Continuous supplies in general use in London
1900	Most cities have a water supply with service pipes to homes

Source: Frerichs, Ralph R., 2005. John Snow. Department of Edipdemiology, School of Public Health, University of California, Los Angeles, California. Updated January 1, 2005. Accessed January 4, 2005. http://www.ph.ucla.edu/epi/snow.html. The map is reproduced from: Snow, John, 1855. On the Mode of Communication of Cholera. John Churchill, London.

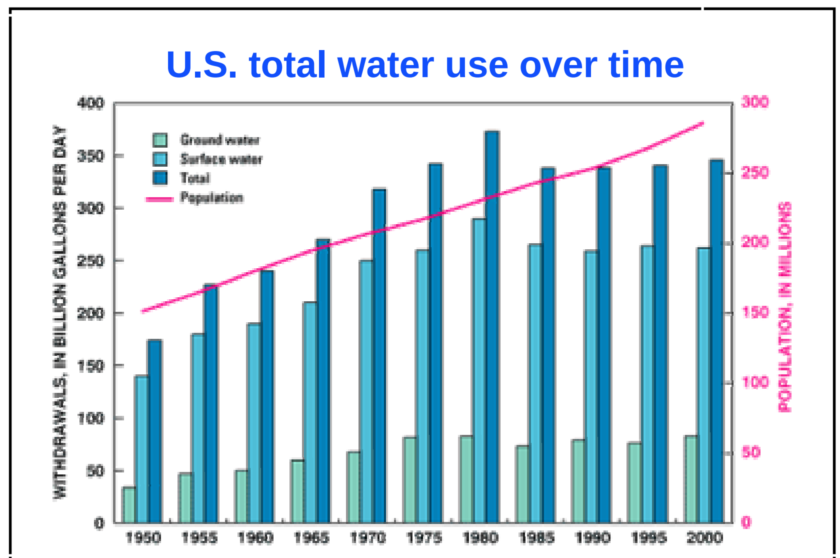




Source for both images: Frerichs, Ralph R., 2005. John Snow. Department of Edipdemiology, School of Public Health, University of California, Los Angeles, California. Updated January 1, 2005. Accessed January 4, 2005. http://www.ph.ucla.edu/epi/snow.html. The map is reproduced from: Snow, John, 1855. On the Mode of Communication of Cholera. John Churchill, London.



Based on data from: World Resources Institute, 2004. EarthTrends, The Environmental Information Portal, Water Resources and Freshwater Ecosystems, Searchable Database, http://earthtrends.wri.org/searchable_db/index.cfm?theme=2. Accessed December 10, 2004.



Source: USGS, 2004. Water Science for Schools: Trends in water use. U.S. Geological Survey, Washington, D.C. May 06, 2004. http://ga.water.usgs.gov/edu/totrendbar.html, accessed November 23, 2004. See also: Hutson, Susan S., Nancy L. Barber, Joan F. Kenny, Kristin S. Linsey, Deborah S. Lumia, and Molly A. Maupin, 2004. Estimated Use of Water in the United States in 2000. Circular 1268. U.S. Geological Survey, Reston, Virginia. May 2004. http://water.usgs.gov/pubs/circ/2004/circ1268/index.html, accessed November 23, 2004.

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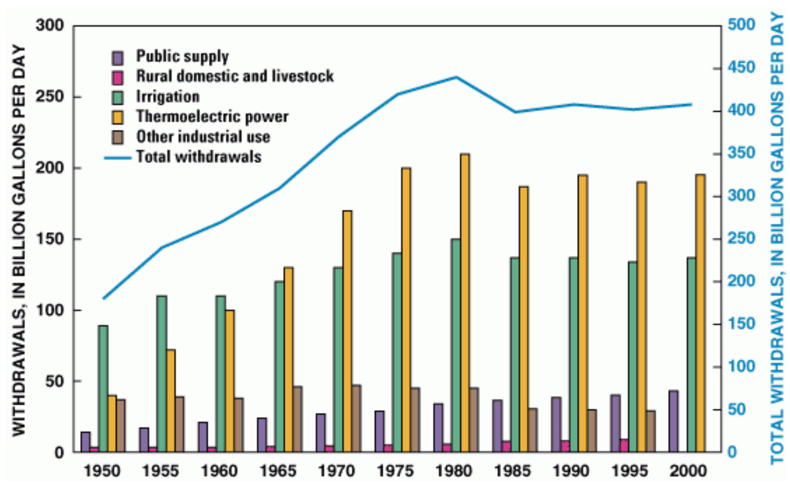
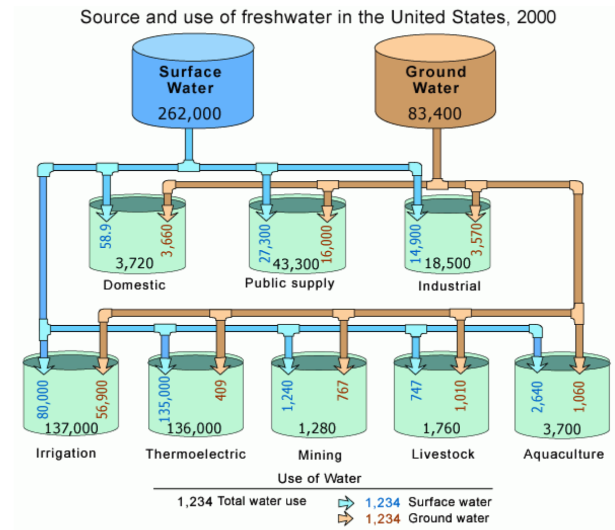
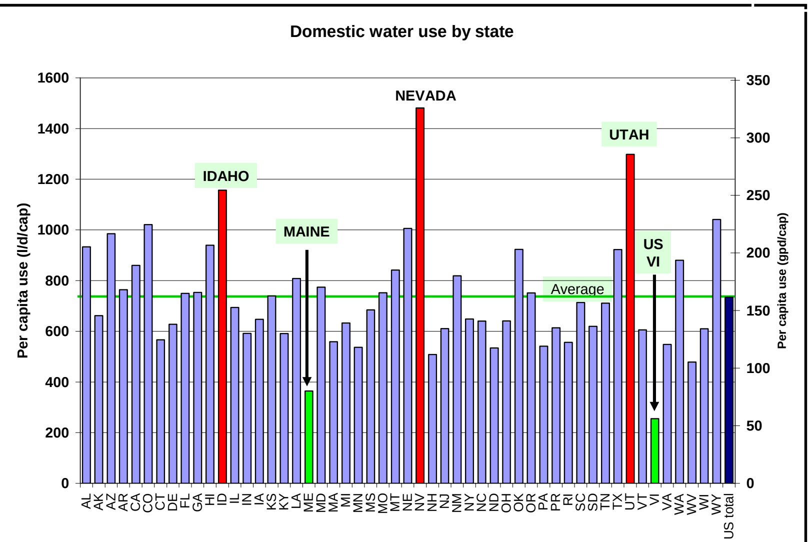
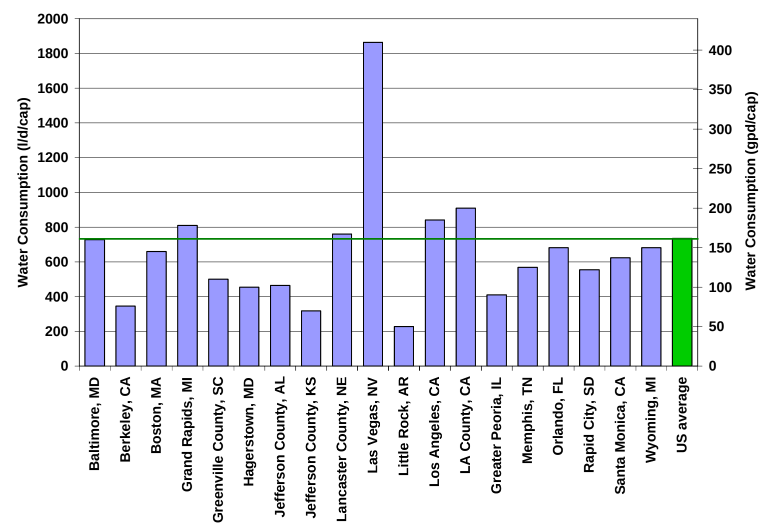




Source: USGS, 2004. Source and use of freshwater in the United States, 2000. http://ga.water.usgs.gov/edu/summary95.html. Last Modified: May 06, 2004. Accessed November 23, 2004.
See also: Hutson, Susan S., Nancy L. Barber, Joan F. Kenny, Kristin S. Linsey, Deborah S. Lumia, and Molly A. Maupin, 2004.





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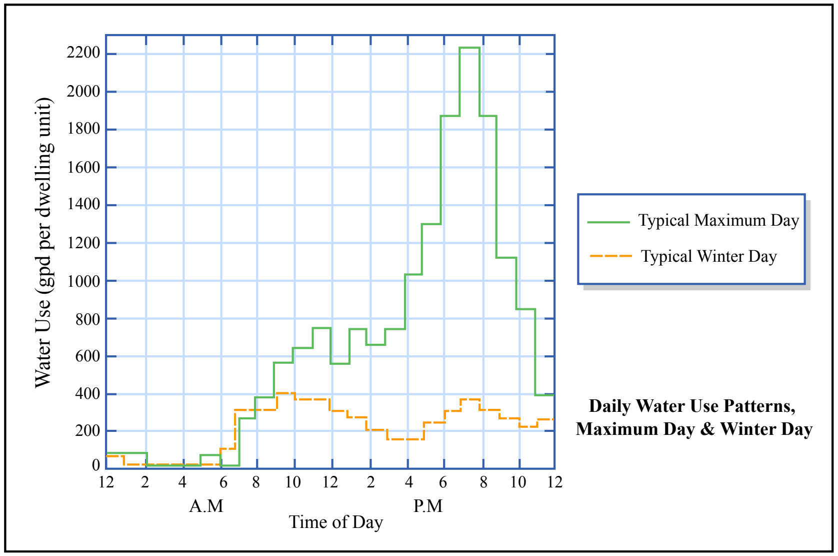
Source of data: ASCE, 1979. Design and Construction of Sanitary and Storm Sewers. American Society of Civil Engineers, New York, New York. Table 1, pp. 21-23.



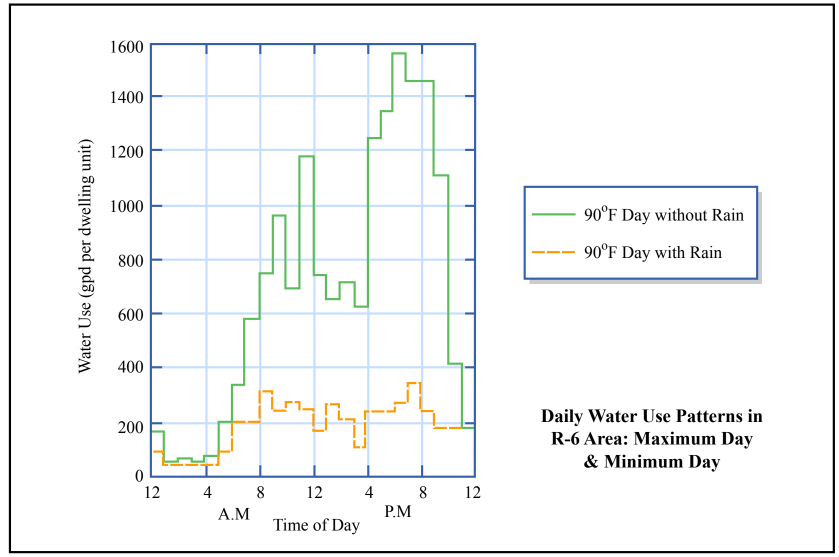


Figure by MIT OCW.

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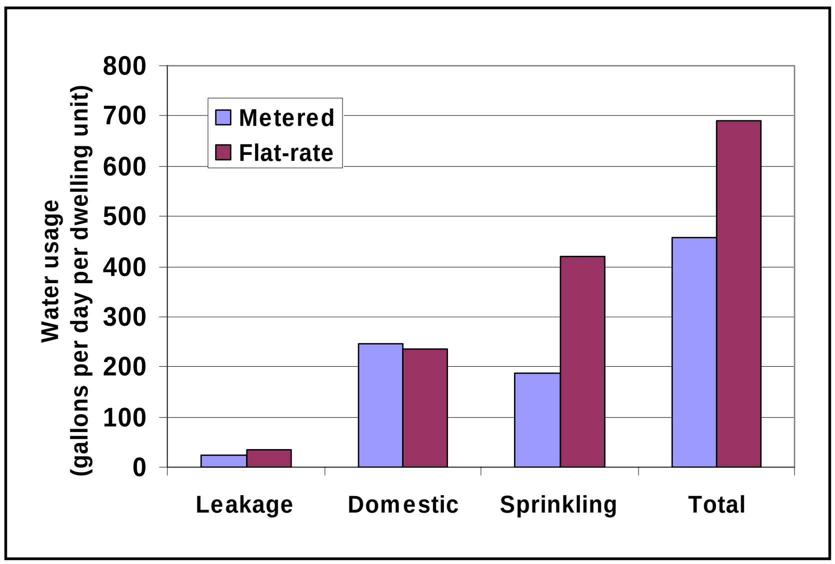
Adapted from: Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2005.



Data from: Linaweaver, F. P., Jr., J. C. Geyer, and J. B. Wolff, 1967. A Study of Residential Water Use, A Report Prepared for the Technical Studies Program of the Federal Housing Administration, Department of Housing and Urban Development. Department of Environmental Engineering Science, The Johns Hopkins University, Baltimore, Maryland.

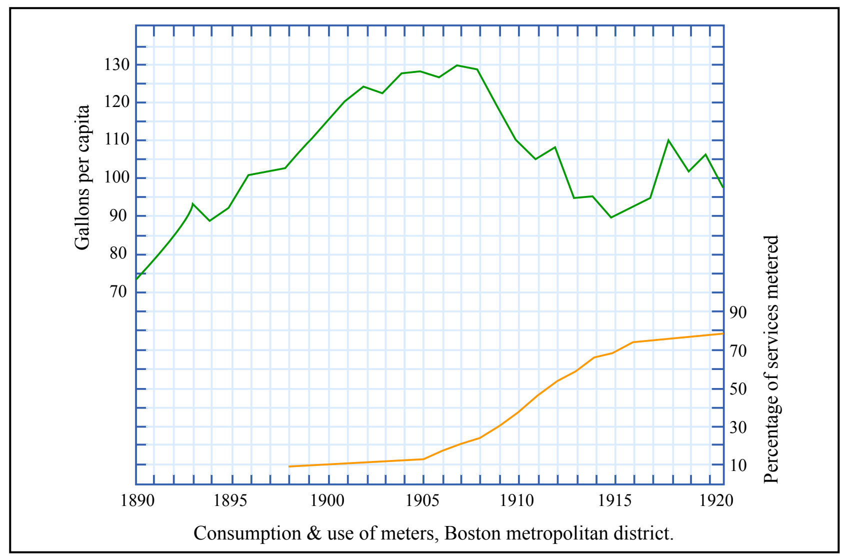


Figure by MIT OCW.

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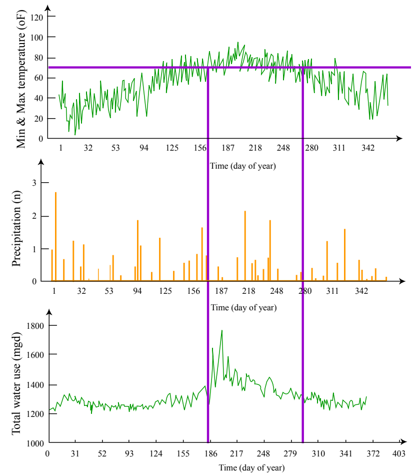
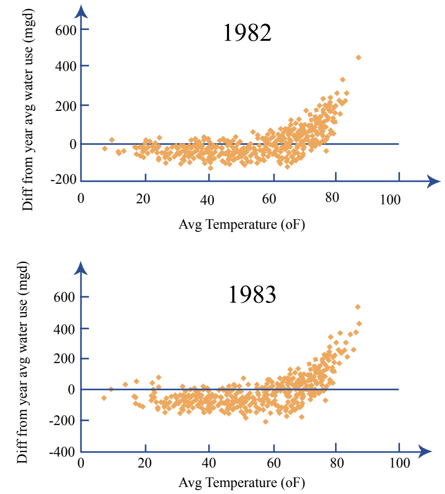


Daily min-max temperature, precipitation & water use in new york city for 1982.

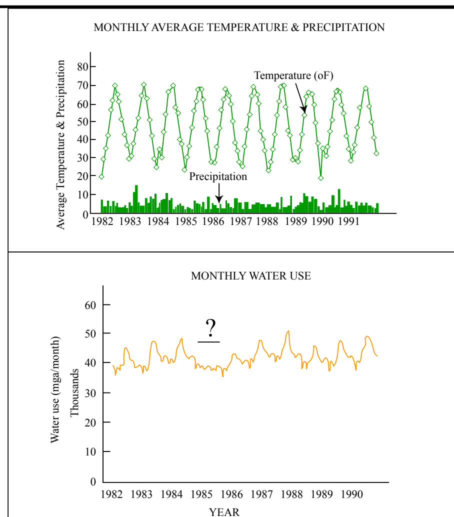
Figure by MIT OCW.



Deviations from annual average water use versus average daily temperature for 1982 & 1983

Figure by MIT OCW.

Adapted from: Protopapas, A., S. Katchamart, and A. Platonova. "Weather effects on daily water use in New York City." *Journal of Hydrologic Engineering, ASCE* 5, no. 3 (July 2000): 332-338.

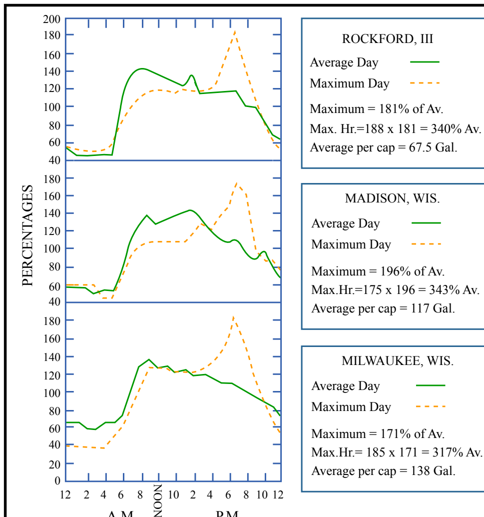


Monthly average temperature, Precipitation, & water use in new York city for 1982 to 1991

Figure by MIT OCW.

Adapted from: Protopapas, A., S. Katchamart, and A. Platonova. "Weather effects on daily water use in New York City." *Journal of Hydrologic Engineering, ASCE* 5, no. 3 (July 2000): 332-338.

Daily water use - 1940

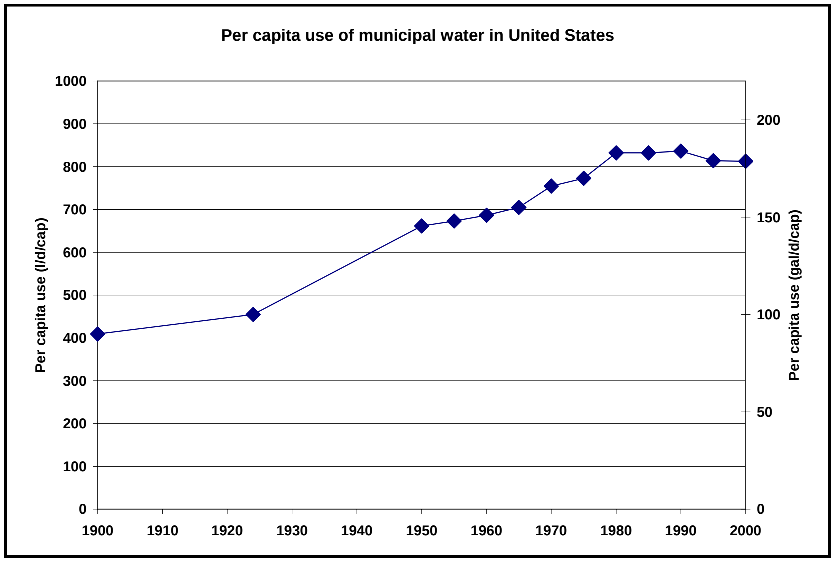


Hourly rates of consumption.

Figure by MIT OCW.

Adapted from: Turneaure, F. E., H. L. Russell, and M. S. Nichols. *Public Water Supplies: Requirements, Resources, and the Construction of Works*. New York, NY: John Wiley & Sons, 1940.

Based on U.S. Geological Survey. Estimated Use of Water in United States, Circulars 115, 398, 456, 556, 676, 765, 1001, 1004, 1081, 1200, 1268. Data for 1900 and 1924 from: Linaweaver, F. P., Jr., J. C. Geyer, and J. B. Wolff, 1967. A Study of Residential Water Use, A Report Prepared for the Technical Studies Program of the Federal Housing Administration, Department of Housing and Urban Development. Department of Environmental Engineering Science, The Johns Hopkins University, Baltimore, Maryland.



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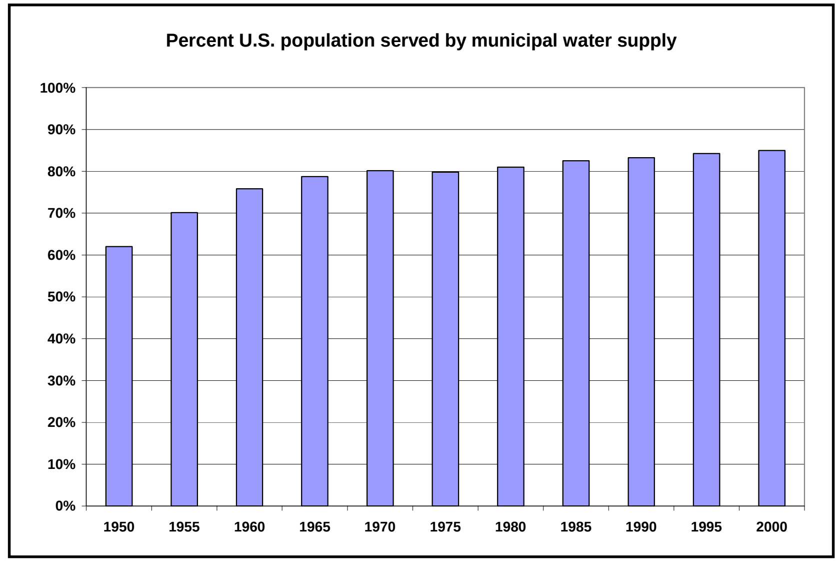
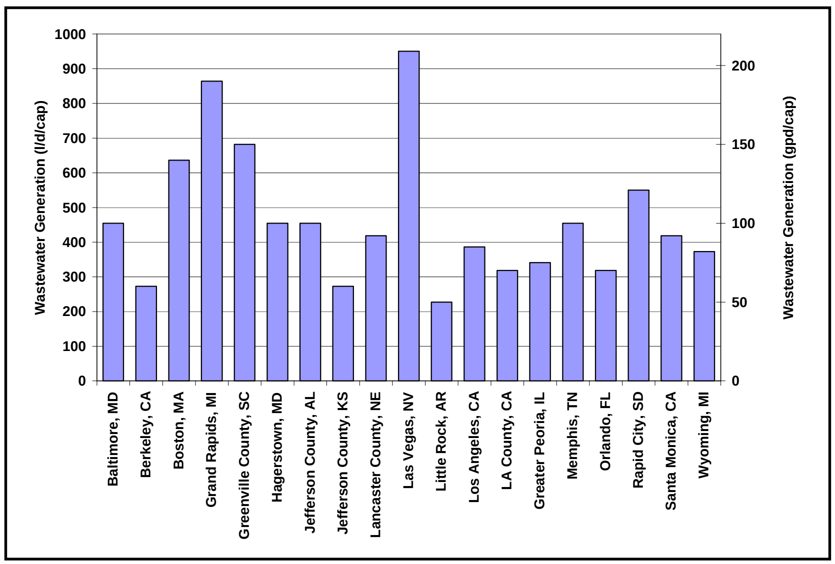
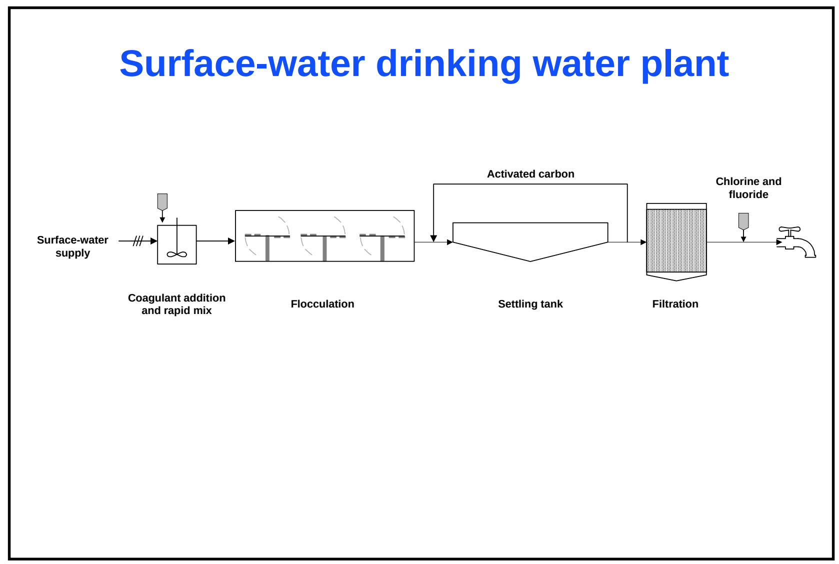




Source of data: ASCE, 1979. Design and Construction of Sanitary and Storm Sewers. American Society of Civil Engineers, New York, New York. Table 1, pp. 21-23.



Chattahoochee Water Treatment Plant – Intake Structure

Courtesy of Joe Lin. Used with permission.

Chemical Addition / Disinfection

Alum: Promote flocculation

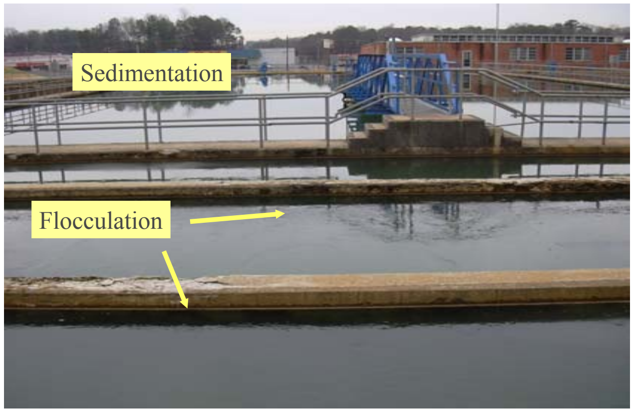
Sodium Hypochlorite: Disinfection

Courtesy of Joe Lin. Used with permission.

Chemical mixing

Courtesy of Joe Lin. Used with permission.

Flocculation / Sedimentation



Courtesy of Joe Lin. Used with permission.

Flocculation tank

Courtesy of Joe Lin. Used with permission.

Sedimentation tank (clarifier)

Courtesy of Joe Lin. Used with permission.

Sedimentation tank collection troughs

Courtesy of Joe Lin. Used with permission.

Filtration

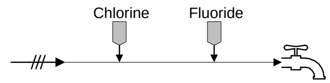
Courtesy of Joe Lin. Used with permission.

Post-Treatment Chemical Addition

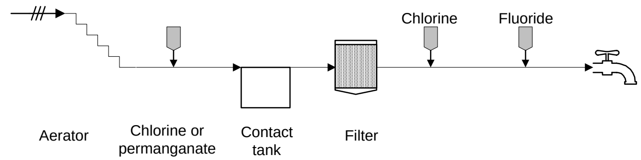
Fluoride: To prevent tooth decay
Lime: To raise the pH
Phosphoric acid: To prevent corrosion of piping in the distribution system
Sodium hypochlorite: To maintain disinfection residual in distribution system

Ground-water drinking water treatment plants

Disinfection and fluoridation

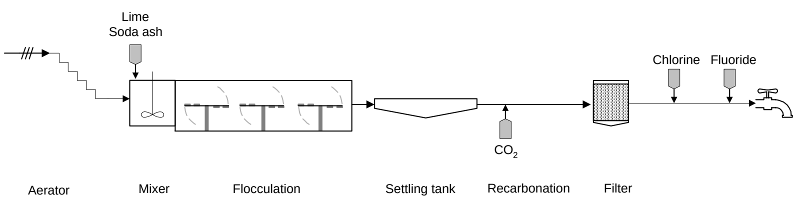


Iron and manganese removal



Ground-water drinking water treatment plants

Softening



West Bridgewater, MA water distribution system

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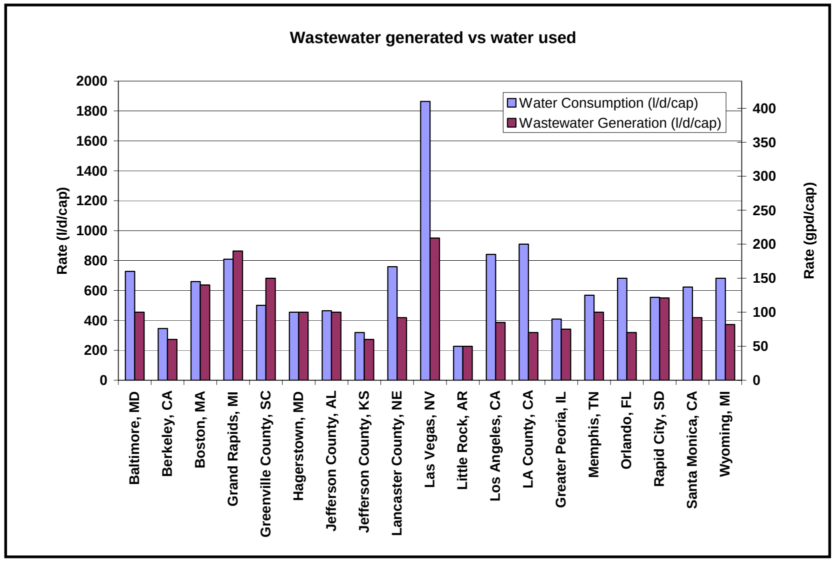

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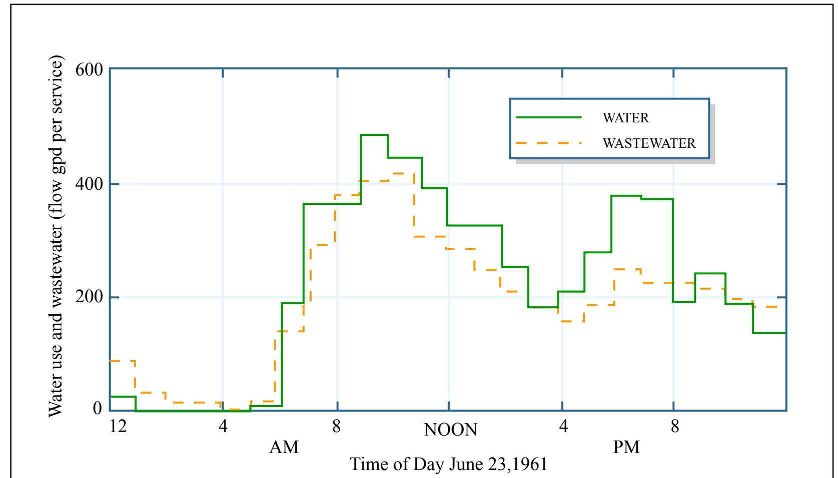
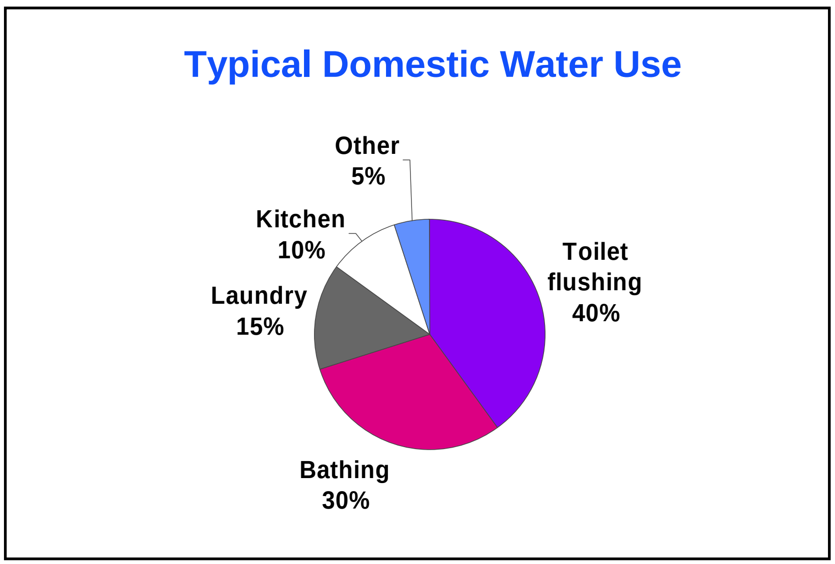


Comparison of water use (solid line) & wastewater flow (dashed lines) on days when little sprinkling occurred.

Figure by MIT OCW.

Adapted from: Viessman, W., Jr., and M. J. Hammer. *Water Supply and Pollution Control*. 7th ed. Upper Saddle River, NJ: Pearson Education, Inc., 2005.



Data from: Droste, R. L., 1997. *Theory and Practice of Water and Wastewater Treatment.* John Wiley & Sons, Hoboken, New Jersey.

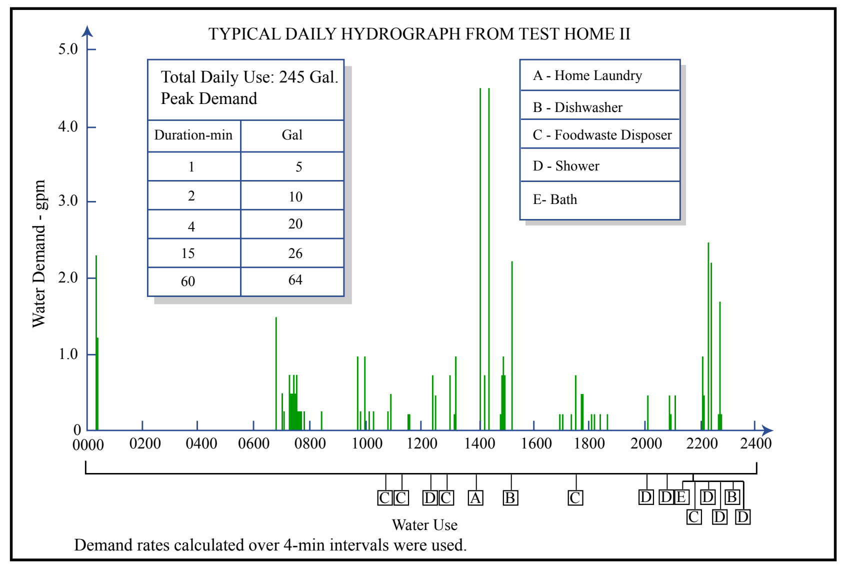


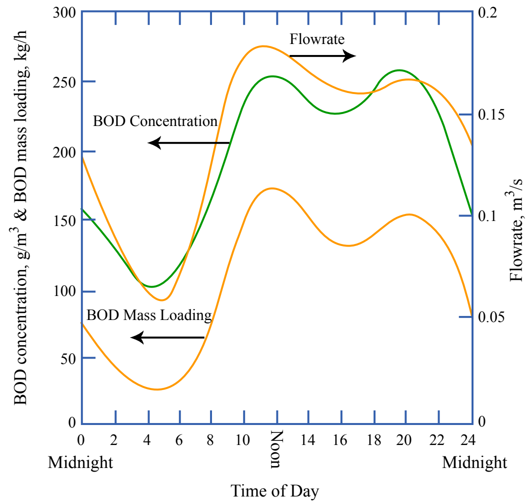
Figure by MIT OCW.

Adapted from: Anderson, J. S., and K. S. Watson. "Patterns of household usage." *Journal American Water Works Association* 59, no. 10 (October 1967): 1228-1237.

Pollutants in domestic wastewater

	High strength	Medium strength	Low strength
TSS, Total suspended solids (mg/L)	120	210	400
BOD, 5-day biochemical oxygen demand (mg/L)	110	190	350
Ammonia nitrogen (mg/L as N)	12	25	45
Organic nitrogen (mg/L as N)	8	15	25
Total phosphorus (mg/L)	4	7	12
Oil and grease (mg/L)	50	90	100
Total coliform bacteria (number/100 ml)	$10^6 – 10^8$	$10^7 – 10^9$	$10^7 - 10^{10}$
Fecal coliform bacteria (number/100 ml)	$10^3 – 10^5$	$10^4 – 10^6$	$10^5 - 10^8$
Cryptosporidium oocysts (number/100 ml)	0.1 - 1	0.1 - 10	0.1 – 100
Giardia lamblia cysts (number/100 ml)	0.1 – 10	0.1 - 100	0.1 - 1000

Based on Metcalf & Eddy Inc., G. Tchobanoglous, F. L. Burton, and H. D. Stensel, editors, 2003. Wastewater Engineering: Treatment and Reuse, Fourth Edition. McGraw-Hill, New York. Table 3-15, pg. 186.

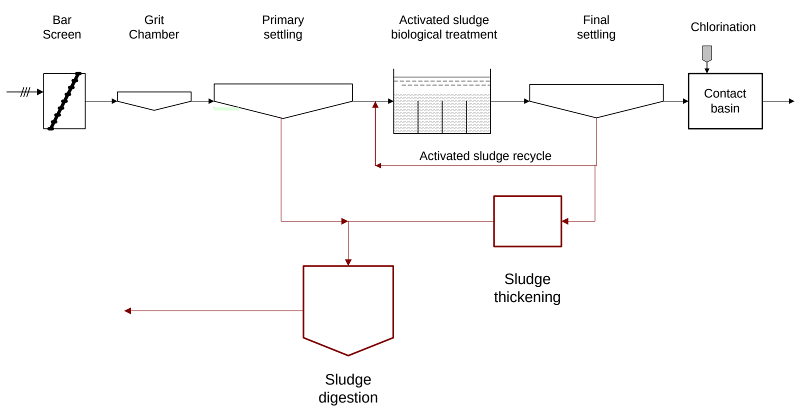


Typical hourly variations in flow & strength of domestic wastewater.

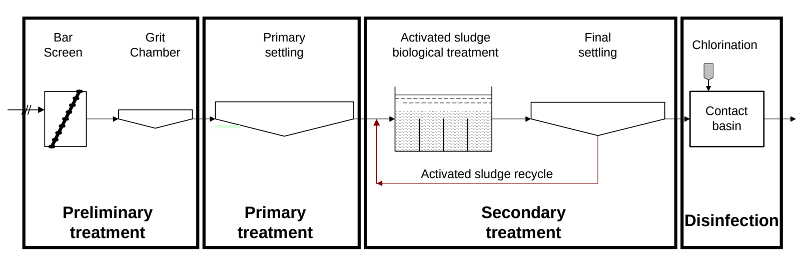
Figure by MIT OCW.

Adapted from: G. Tchobanoglous, F. L. Burton, and H. D. Stensel. *Wastewater Engineering: Treatment and Reuse*. 4th ed. Metcalf & Eddy Inc., New York, NY: McGraw-Hill, 2003.

Typical wastewater treatment plant

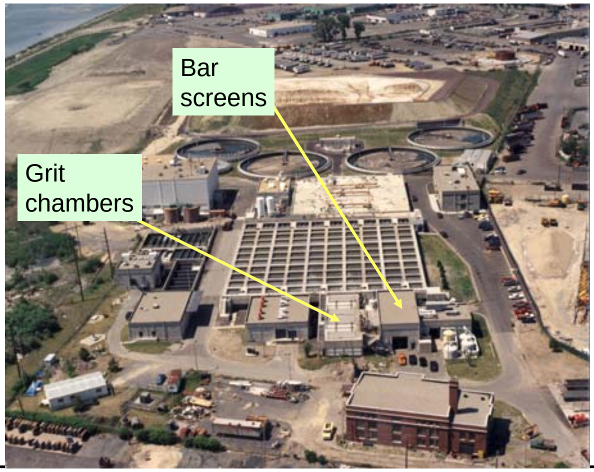


Typical wastewater treatment plant



Can also have tertiary treatment to remove nutrients and other pollutants

Lynn, MA wastewater treatment plant



Bar screens

Bar screens

Traveling screen

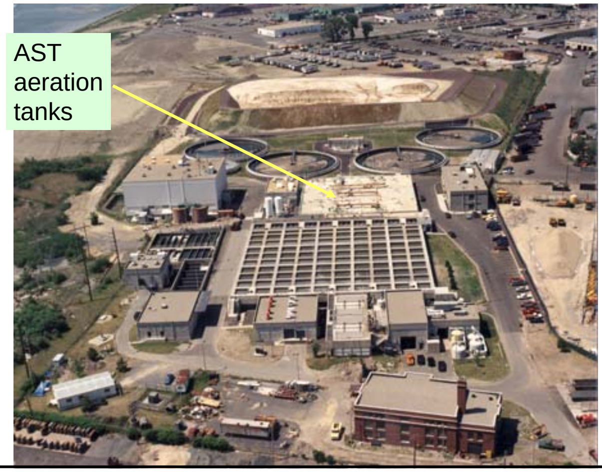
Lynn, MA wastewater treatment plant

Primary clarifiers

Primary clarifiers – sludge scrapers

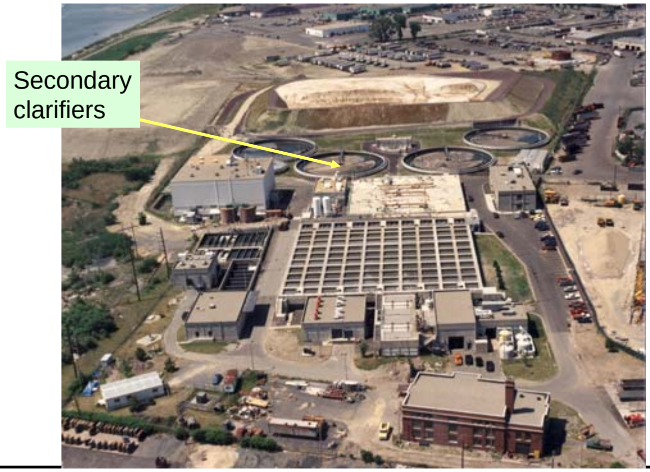
Primary clarifiers – effluent wier

Lynn, MA wastewater treatment plant



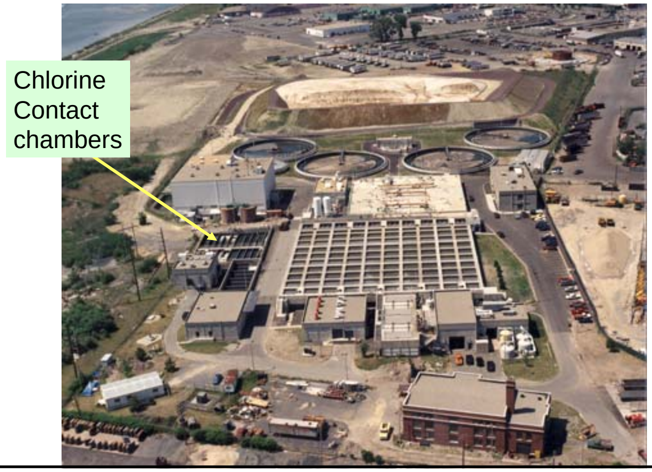
Activated sludge aeration tank

Lynn, MA wastewater treatment plant



Secondary clarifiers

Lynn, MA wastewater treatment plant



Chlorine contract chambers

Virtual tours of wastewater plants

Englewood, Colorado –
http://www.englewoodgov.org/wwtp/

Lynn, Massachusetts –
http://members.aol.com/erikschiff/prelim.htm

Lexington, Kentucky –
http://www.lfucg.com/sewers/TBTour.asp

LECTURE 1
INTRODUCTION TO WATER QUALITY AND TREATMENT, OVERVIEW OF WASTEWATER AND TREATMENT PROCESSES

Water supply

Slide 2 - Volumetric water use in the United States

US is in a relatively water-rich part of the world, although there are obviously local exceptions

Slide 3 - Per capita use for domestic water supply

US is one of largest water users – using 600 l/cap/day = 160 gal/cap/day

Slide 4 – Significant events in history of water supply

Most of the world still does not have centralized water supply with connections to individual households

According to the World Health Organization roughly 1 billion of the world's 6 billion people do not have access to an improved water supply.

JMC, 2000. Global Water Supply and Sanitation Assessment 2000 Report. WHO and UNICEF Joint Monitoring Programme for Water Supply and Sanitation, World Health Organization and United Nations Children's Fund, http://www.who.int/docstore/water_sanitation_health/Globassessment/Global2.1.htm. Accessed January 4, 2005.

Access to water-supply services is defined as the availability of at least 20 litres per person per day from an "improved" source within 1 kilometre of the user's dwelling. An "improved" source is one that is likely to provide "safe" water, such as a household connection, a borehole, etc.

JMC, 2004. The Joint Monitoring Programme : definitions. WHO and UNICEF Joint Monitoring Programme for Water Supply and Sanitation, World Health Organization and United Nations Children's Fund, http://www.wssinfo.org/en/122_definitions.html. Accessed January 4, 2005.

An improved water supply is defined as:

- Household connection
- Public standpipe
- Borehole
- Protected dug well
- Protected spring
- Rainwater collection

JMC, 2000. Global Water Supply and Sanitation Assessment 2000 Report. WHO and UNICEF Joint Monitoring Programme for Water Supply and Sanitation, World Health Organization and United Nations Children's Fund, http://www.who.int/docstore/water_sanitation_health/Globassessment/Global2.1.htm. Accessed January 4, 2005.

Only 48% of the world's population is connected at the household level.

JMC, 2004. Water supply data at global level. WHO and UNICEF Joint Monitoring Programme for Water Supply and Sanitation, World Health Organization and United Nations Children's Fund, http://www.wssinfo.org/en/22_wat_global.html. Accessed January 4, 2005.

Slides 5, 6, & 7 – Dr. John Snow's analysis of cholera deaths in London in 1854.

First study to show connection between contaminated water and impaired public health

Slides 8 & 9 - Patterns of water use

- Total US water use increased steadily until 1980s, but largely due to cooling water use for electric power
- Rate of increase exceeded rate of population increase
- Since 1980s water use has leveled off despite population increase
- Slide 9 – increase of public water supply has been slower but unabated

Slide 10 - Sources of drinking water in US

- Ratio of 3:1 surface water:ground water for overall use but heavier reliance on ground water for public water supply

Slides 11 & 12 – Large geographical variation within US

- Greater domestic water use in arid areas – mostly for landscaping
- Note low use in Virgin Islands – established practice of conservation: "In this land of fun and sun, we don't flush for number 1"
- Maine - ???
- Slide 12 – large variation also holds true for cities – Las Vegas has high water use for outdoor watering, not hotels as one might expect (Carmen Roberts, Vegas heading for 'dry future'. BBC News, July 29, 2005. http://news.bbc.co.uk/1/hi/sci/tech/4719473.stm)

Slides 13, 14, & 15 – Johns Hopkins study of water use

- Classic study completed in 1960s by Johns Hopkins University
  - Conducted 1961-66
  - Continuous monitoring of water use by 41 homogenous residential areas with 44 to 410 dwelling units and several apartment areas
  - Covered: 16 different water supply utilities, 11 metropolitan areas; 6 different climatic regions
- Slide 13
  - Winter graph shows household usage – morning and early evening peaks
  - Summer graph shows potentially profound effect of sprinkling
- Slide 14 shows summer usage with and without rainfall
- Factors affecting water use:
  - Income – rich people use more water
  - Climate – more water is used in dry climates (for watering lawns)
  - Season – less water is used in winter than summer
  - Metering – metered customers used less water for watering lawns than those on flat rates
- Slide 15 shows effect of metering on water use: little effect on household use but major effect on sprinkling

Slide 16 – Relation of water use to metering is not a new story – this graph is from textbook dated 1940

- After the change in economic systems in eastern Europe, there was concern about how to bring wastewater treatment systems up to western standards. Many were highly overloaded before the change, but once the authorities started to charge for water, usage went down, wastewater went down, and overloaded plants were no longer overloaded

Slides 17, 18, & 19 – Study of effect of weather on New York City supply

- Slide 17 – use during 1982 shows fairly constant use until it gets hot – above 72ºF water use increases linearly with temperature
- Slide 18 – shows same pattern in 1983

Slide 19 – pattern is absent in 1985 – why? Mandatory water conservation measures imposed by city

Slide 20 – pattern of daily water use has not changed appreciably over the years – curve for 1940 shows morning and afternoon peaks in usage

Slide 21 – shows that total usage increased, at least until around 1980

Slide 22 – despite prevalence of public water supply systems, about 20 percent of the US population is self supplied – usually by a ground-water well. This fraction has not changed appreciably for many decades.

Slides 24-33 - Walk-through of typical water treatment process

Slides 34&35 – Ground-water systems

Slide 34a – often minimal treatment is required

Slide 34b – Ground waters often high in iron and manganese (particularly in New England)

Removed by oxidizing to insoluble iron oxide (rust) or manganese oxide, which precipitate and can be removed by filtration

If not removed in treatment plant, iron and manganese precipitate in distribution system and cause staining of laundry, fixtures, etc.

Slide 35 – Deep, old ground waters are often highly mineralized and “hard” (high concentrations of Ca and Mg)

Water is softened by adding lime ($Ca(OH)_2$) and soda ash (Na_2CO_3)

Recarbonation removes excess lime and prevents scaling of equipment and pipes

Slide 36 – Water distribution systems brings treated water to homes and businesses – not covered in this course

Wastewater

Slides 37 and 38 – water supply begets wastewater generation, usually with a pretty close correlation

Slide 37 – Exceptions are:

water supply > wastewater when sprinkling use is great (e.g., Las Vegas, Los Angeles) and/or exfiltration from sewers is high

water supply < wastewater when infiltration into sewers is high (perhaps Greenville County?)

Slide 38 – Johns Hopkins study confirms this on day with little sprinkling

Slide 39 – Most water used in the household becomes wastewater via various routes

Consumption (drinking, cooking) is pretty negligible

Toilets use the most, hence low-flow toilets are a good water conservation measure

Slide 40 – Daily flow curves are averages over many households – the flow from individual household is very episodic

Under some circumstances, flow from individual homes can be coordinated: wastewater treatment plant workers in New York City claim to be able to tell the popularity of TV shows by the wastewater surge seen during commercials

Slide 41 – Wastewater quality

BOD, TSS – for short-term effect on receiving water

N, P – for long-term effect (eutrophication) on receiving water
Oil and grease – for short-term effect
Pathogens – for effects on human health

Slide 42 – Variation in flow also causes variation in strength of wastewater – Why?

At low flow, solids settle, reducing BOD concentration
At high flow, solids get scoured from pipes, increasing BOD concentration

Slides 43-49 – Walk-through of typical wastewater treatment process

Slide 50 – Virtual tours of WWTPs: (really should be "scratch and sniff")

Englewood, Colorado – http://www.englewoodgov.org/wwtp/
Lynn, Massachusetts – http://members.aol.com/erikschiff/prelim.htm
Lexington, Kentucky – http://www.lfucg.com/sewers/TBTour.asp