Day 1: History of urban drainage and evolution of separate and combined sewer systems

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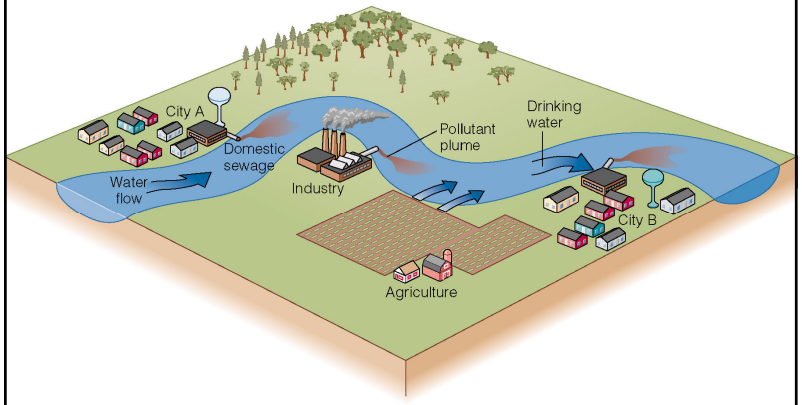
Dead Sea and Jordon

1

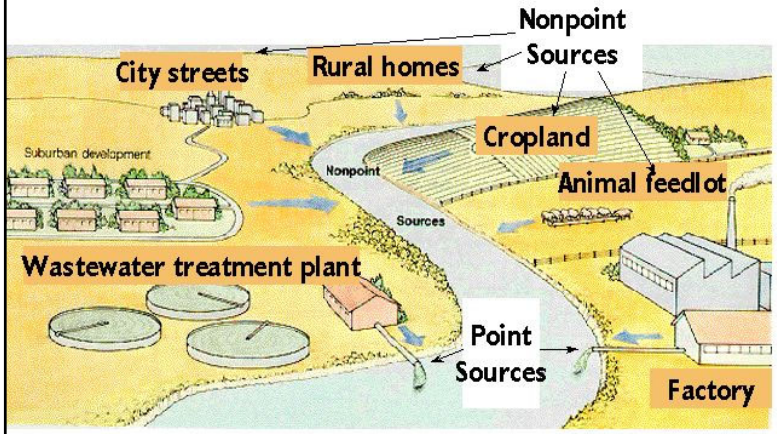
One City's Wastewater is Another City's Water Supply



McKinney and Schoch

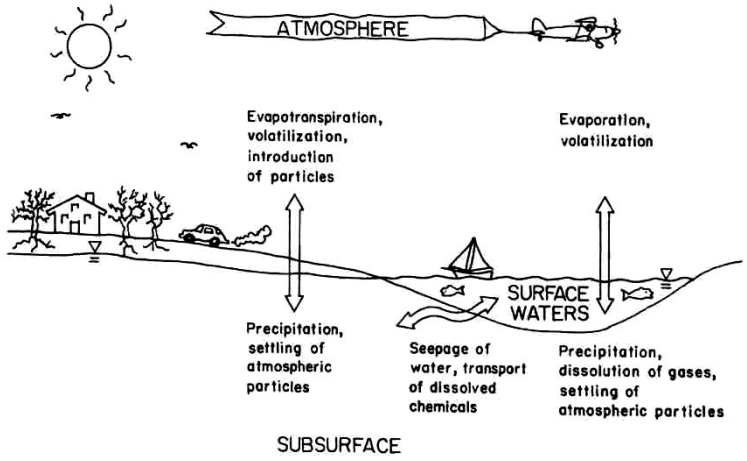
2

Point and nonpoint sources



3

Frequent and Significant Interaction between Media

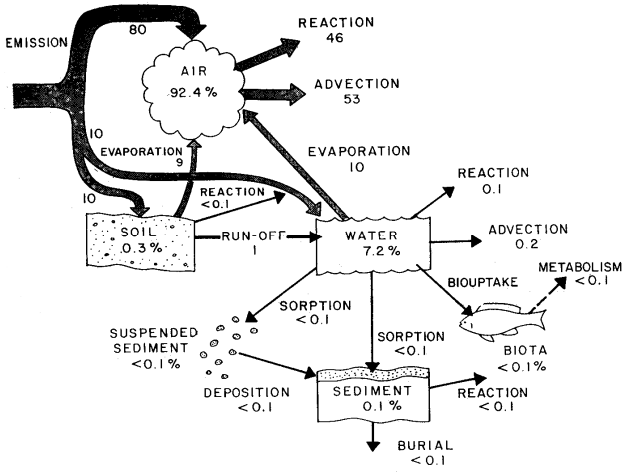


Hemond and Fechner-Levy 2000, figure 1-1

4

Where did that Chemical Go?

Fate/mass balance analysis for trichloroethylene is needed to determine the best control strategy and to quantify the effects



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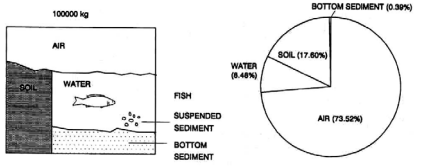
Chemical name: Naphthalene

Level I calculation: (six compartment model)



Distribution of mass

physical-chemical properties:

MW: 128.18

M.P.: 80.5°C

Fugacity ratio: 0.284

vapor pressure: 10.4 Pa

solubility: 31 mg/L

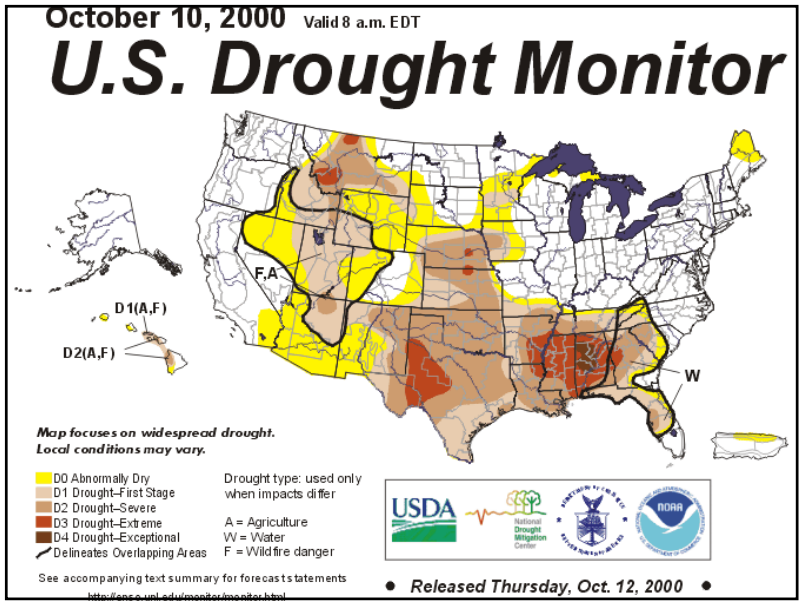
log K_{OW} : 3.37

Compartment	Z mol/m3 Pa	Concentration mol/m3	mg/L (or g/m3)	ug/g	Amount kg	Amount %
Air	4.034E-04	5.736E-09	7.352E-07	6.202E-04	73524	73.524
Water	2.325E-02	3.306E-07	4.238E-05	4.238E-05	8475.7	8.476
Soil	1.073E+00	1.525E-05	1.955E-03	8.146E-04	17596.1	17.596
Biota (fish)	2.725E+00	3.875E-05	4.967E-03	4.967E-03	0.9935	9.93E-04
Suspended sediment	6.705E+00	9.532E-05	1.222E-02	8.146E-03	12.219	1.22E-02
Bottom sediment	2.146E+00	3.050E-05	3.910E-03	1.629E-03	391.024	0.3910
	Total				100000	100

f = 1.422E-05 Pa

Mackay, *et al*. 1992, Fig 1.7

6



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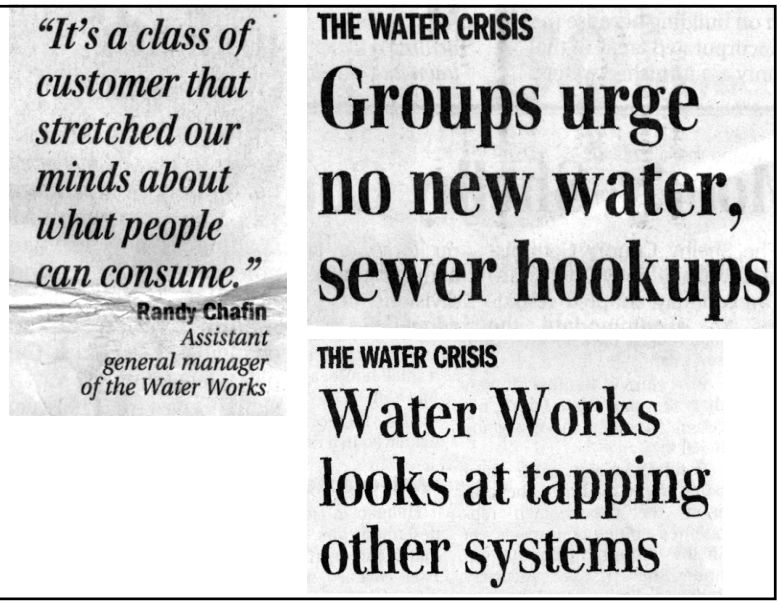
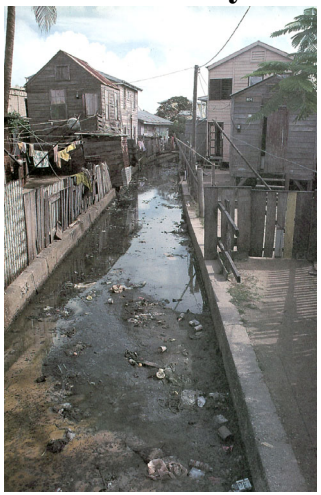


8

Spray Irrigation of Treated Wastewater at Golf Course

9

Basic Wastewater Conveyance in Sanitary Condition not Always Achieved



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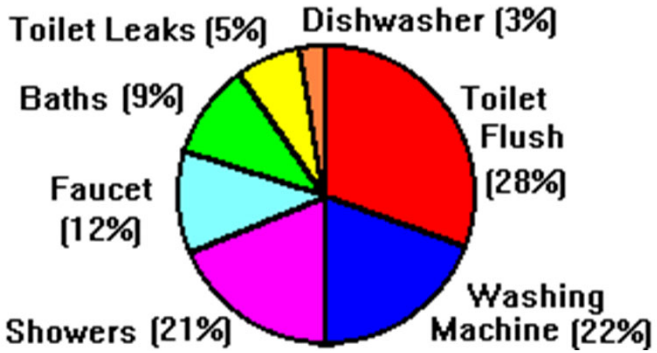
Percent Water Consumption



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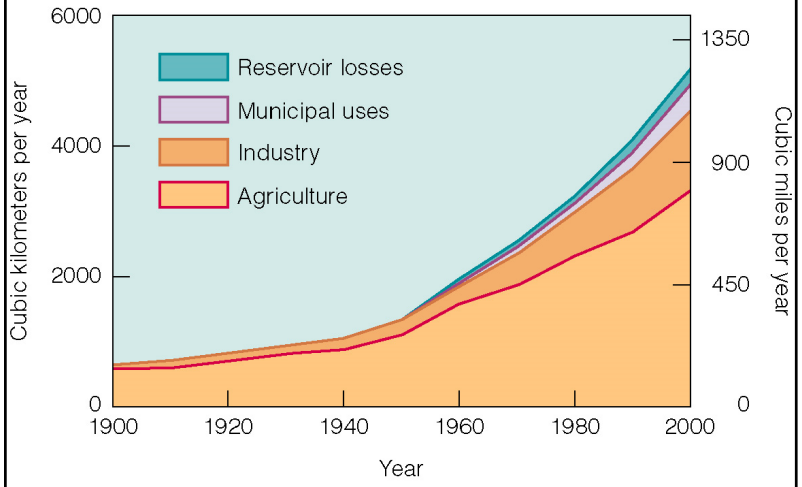
US Water Use by Sector



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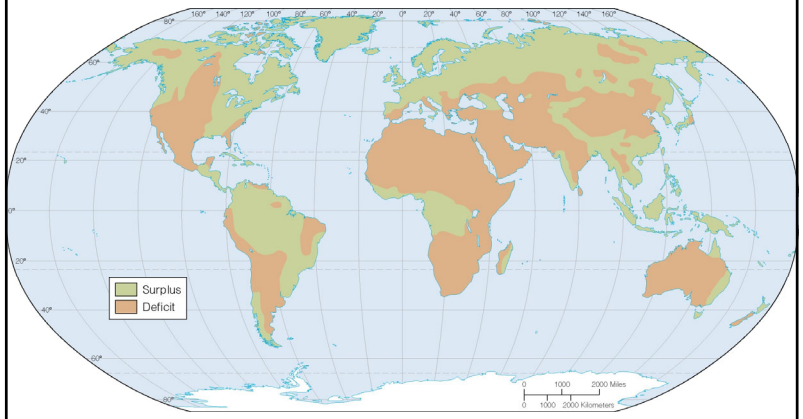
Worldwide Water Surplus and Deficit Conditions



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Water Deficits in Key Countries and Regions, Mid-1990s

Country/Region	Estimated Annual Water Deficit (billion cubic meters per year)
India	104.0
China	30.0
United States	13.6
North Africa	10.0
Saudi Arabia	6.0
Other	unknown
Minimum Global Total	163.6

14

The Historical Development of Sewers Worldwide

G. De Feo, G. Antoniou, H. F. Fardin, F. El-Gohary, X. Y. Zheng, I. Reklaityte, D. Butler, S. Yannopoulos, and A. N. Angelakis
Sustainability 6(6):3936-3974, June 2014.

- The use of sewers in China dates back more than 4000 years (10th–15th century BC, in the Shan dynasty), as cities were formed in the mid reach of the Yellow River.
- Need for urban drainage including wastewater from the residential areas, especially in the royal palaces.
- The earliest sewer facility was discovered in the old town Pingliangtai of Henan province. Earthenware was used to build the sewer inside the town.
- Urban drainage 800 m length from the East Gate to the palace. Inside the palace, there were branch sewers for draining of rainwater and wastewater. The underground raceway was 1.3 m in breadth and 1.4 m in height and led water from the palace and town into the moat.

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- During the 1100–221 BC period, many kingdoms in the center of China were close to the Yellow River basin and the Yangtse River lower basin.
- Urban drainage had been developed to a high level in Lingzi (then 15 km^2 with 300,000 inhabitants), the capital of Qin kingdom in today's Zibo city of Shandong Province. This is the oldest and the biggest system in ancient China discovered to date
- A complex water supply and drainage system was built combined with river, drainage channel, pipeline and moat.
- Inside the town, three raceway networks were built that linked with the supply canal to deliver the water from the river for daily use and gathered wastewater and stormwater on the way.
- The aqueduct had 15 outfalls that distributed water in three elevations in the city.
- A large drainage section, made of stone, 43 m in length and 7 m in breadth, also passed under the west town wall.

De Feo, *et al*. 2014

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- In 221 BC, the Qin Empire, the first united country in Chinese history, was founded in today's central China. The capital was Xianyang, in today's Shanxi province.
- Drainage facilities were built in the town using earthenware pipes. An example archaeological dig in the palace ruins found a drainage facility combined with 4 pools and sewers. It gathered the palace rainwater and wastewater by sewers and raceways (uncovered) to the pools and used a pipeline to drain wastewater into the river.
- A large sewer system was discovered in the old Qin Palace Efanggong in 2006, the countryside of today's Xi'an, consisting of groups of three pipes. Sewerage existed not just in the palaces but also in residential areas.

De Feo, *et al.* 2014

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- The Han Dynasty (202–220 AD) brought major advances in urban development. It's capital Chang'an, near today's Xi'an town of Shaanxi province, quickly grew to be a large town and survived as the capital for 15 dynasties until 907 AD. Chang'an town covered 35 km^2 with a population of 500,000 inhabitants.
- The ancient sewer system included four parts: (1) small sewers from the house; (2) residential sewers linked with the house sewers; (3) main sewers along the streets linked with the residential sewers; (4) drainage ditches and the rivers receiving water from the sewers.
- A sewer system was built using both ditches and sewers. The ditches were mainly built along with the main streets of the town and linked with underground sewers from the residential areas and palaces.
- Sewers made using bricks made it possible to build them longer, bigger and stronger. This technology continued during the next thousand years.

De Feo, *et al.* 2014

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- An old sewer dated from the Tang dynasty (618–907 AD) was discovered in Yangzhuo town, measuring 35 m in length, and 1.75 m in width and 1.5 m in height.
- Another main underground sewer for stormwater drainage was a brick and wooden structure, 1.8 m in width and 2.2 m in height, with 12 m of sewer opened by excavation so far.

De Feo, *et al.* 2014

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- After the Song dynasty (960–1206 AD), sewers were usually built of brick or stone blocks. The walls of the sewer were built of bricks and covered by a flagstone.
- From this period, two types of sewer construction were common. One was a raceway built underground to collect wastewater or rainwater. The other type was built along the street, usually constructed along the two sides of the street or inside the street. The walls were built of brick and covered with flagstones, still common in many cities until the 1950s. The photograph shows this example in the old town of Huai'an. Finally, the wastewater and rainwater were channeled into the river.

De Feo, *et al.* 2014

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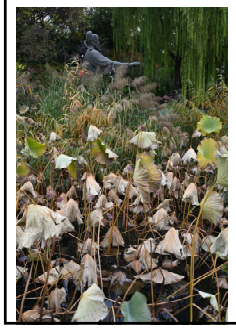
Guo Shoujing is considered to be the greatest worldwide water resources engineer during the later half of the 13th century. He presided over many water resources plans for the design and construction of the Beijing-Hangzhou Grand Canal, addressing transportation and water resources. This is now considered a great regional cultural resource that has contributed to the strengthening of the Chinese nation over the past 800 years.



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Ancient springs at Delphi, Greece (site of Oracle)
(bronze age center of the universe)

22

Modern springs at Delphi, Greece

23


Ancient temple drains at Knossos, Crete (Minoan 2600 to 1000 BC)

24

Ancient stone pipe from reservoir at Knossos, Crete (Minoan 2600 to 1000 BC)

25

Kamiros, Rhodes (ancient Greece, 7th century BC)

26

Ancient clay pipe at Kamiros, Rhodes (ancient Greece, 7th century BC)

27

Ancient temple site at top of hill that had roof runoff cistern, Kamiros, Rhodes (ancient Greece, 7th century BC)

28

Cistern tank, Kamiros, Rhodes (ancient Greece, 7th century BC)

29

Steps alongside cistern, Kamiros, Rhodes (ancient Greece)

30

The Agora, Athens, Greece (from the Acropolis to modern Athens) (1st to 4th century BC)

31

The Agora, Athens, Greece

32

The Agora, Athens, Greece

33

Storm drainage channels at the Agora, Athens, Greece

34

Storm drainage channels at the Agora, Athens, Greece

35

Storm drainage channels at the Agora, Athens, Greece

36

Storm drainage channels at the Agora, Athens, Greece

37

House drain at the Agora, Athens, Greece

38

Waterwheel at the Agora, Athens, Greece

39

Child potty, ancient Greece (Agora Museum)

40

Pipe at Pompeii, Italy (before 79 AD)

J. Harper photo

41

Roof drain at Pompeii, Italy (destroyed Aug 24-26, 79 A.D.)

J. Harper photo

42

Water storage jugs at Pompeii, Italy (prior to 79 AD)

43

Impluvium (indoor pool and cistern for rain water storage), Pompeii, Italy (before 79 AD)

J. Harper photo

44

Swimming pool at the Baths, Pompeii, Italy (prior to 79 AD)
J. Harper photo

45

Roman community toilet, Athens, Greece (100 BC)

46

Coliseum sewage ditch, Rome (completed in 80 AD)
J. Harper photo

47

Coliseum sewage ditch, Rome J. Harper photo

48

Ancient gutter still in use, Rome (about 100 AD)

J. Harper photo

49

Excavation of ancient Roman pipes, Rome (about 100 AD)

J. Harper photo

50

Excavation of ancient Roman pipes, Rome (about 100 AD)

J. Harper photo

51

Bill James reading 1600s hydraulic manuscript at the library of the Institute of Civil Engineers, London

52

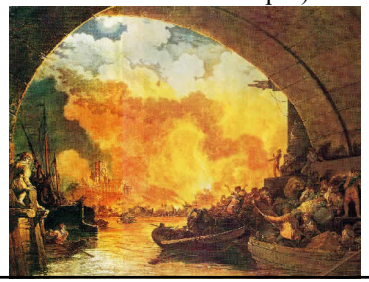
". . . the great prodigality of Paris, her marvelous fête, her Beaujon folly, her orgy, her full-handed outpouring of gold, her pageant, her luxury, her magnificence, is her sewer." (*Les Miserables*; Jean Valjean, Book II, ch1, by Victor Hugo; *The Intestine of Leviathan*)

Freely available at:
http://www.readbookonline.net/read/177/5767/

A graphic description of the sewers of Paris in the mid 1800s, and the mystery of their construction and design.

53

Charles Dickens was a satirical journalist, besides a very popular novelist, who championed improved public health. *The Water Drops, a Fairy Tale*, is a little known story graphically describing the urban water system in London in the 1800s. I transcribed it several years ago from a old copy of the book and it is posted at:
http://unix.eng.ua.edu/~rpitt/Class/Computerapplications/Module1/Dickens%20The%20Water%20Drops.PDF (or search Google for "Dickens The Water Drops")



The "Great London Fire" burned for 14 days in 1666, right after a plaque outbreak and provided an opportunity to rebuild the city's water system.

54

Clay pipe, Roman London, 43-410 AD (Key Bridge Steam Museum

55

Lead pipe, Medieval London, 1000 to 1400 (Key Bridge Steam Museum)

56

Stone pipe, Tudor London, 1500s (Key Bridge Steam Museum)

57

Wood log pipe, Georgian London, 1710 - 1830 (Key Bridge Steam Museum)

58

Cast iron pipe, Victorian London, 1840 - 1900 (Key Bridge Steam Museum)

59

Wooden water pipe, Seattle, WA (Underground Seattle Museum)

60

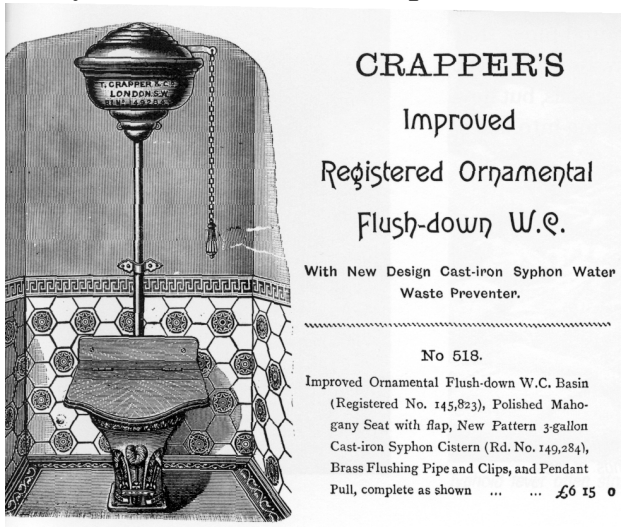
One Early Method of Getting Rid of Wastewater

Wastewater treatment has only been around since the late 1800s. People dumped wastes into gutters, ditches, and out open windows, with the expectations that rain or pigs would take care of it.

Sewer is from the old English for seaward.

61

Early Flush Toilet Vast Improvement in Sanitation



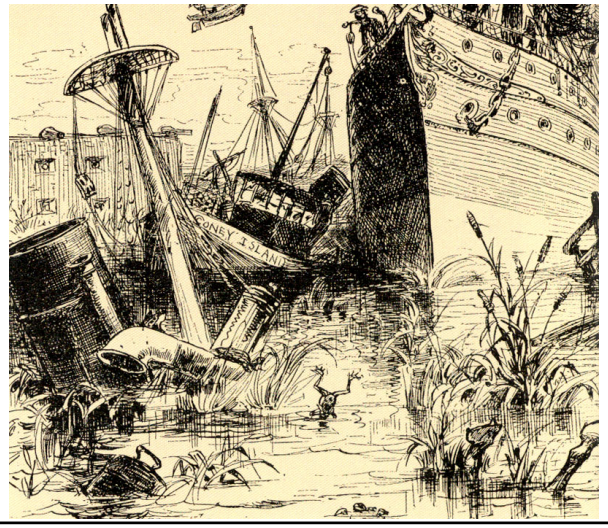
More people were able to have a flush toilet, not just the rich. First US treatment plant built in NYC in 1886 to protect Coney Island beaches from vast increases in wastewater volume.

62

Coney Island, NY, summer 1940 by Weegee

63

Polluted New York Harbor in 1883



64

Polluted New York Harbor (Coney Island Creek) in 2000

65

Thomas Crapper's Toilet Tank and "Valveless Waste Preventer" (Underground Seattle Museum)

66

Elevated toilet to keep above hydraulic grade line during high tides, Seattle, WA (Underground Seattle Museum)

67

After years of a bad sewage system and several fires, Seattle finally decided to build a new sewage system where the streets were raised anywhere from 8 to 36 feet. However, it was years before they actually raised the sidewalks, requiring climbing up a ladder (sometimes 36 feet high) to cross the street and then climbing back down on the other side.

68

The anticontagionist, or miasmic, disease etiology belief held that putrefying organic matter in sewers exuded noxious disease causing gases; separate-sewer systems were advocated as the appropriate means to rapidly remove (< 2 or 3 days) human wastes from cities

Slide by Steve Burion, Univ. of Utah

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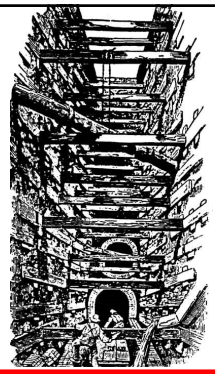

In response to frequent disease outbreaks most large cities undertook massive sewer (both combined and separate) construction projects – the largest public works projects of the time period

Slide by Steve Burion, Univ. of Utah

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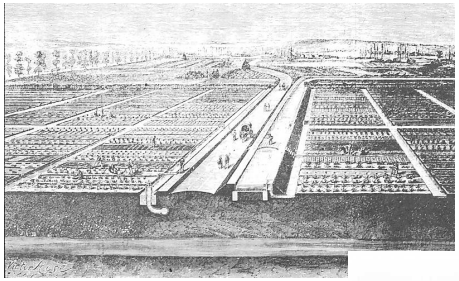

Several European cities transported wastewater to agricultural areas for fertilizer

At a later time in the USA, transporting wastewater to sewage farms was less common, but still practiced by some cities

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Major Receiving Water Beneficial Uses

- Stormwater Conveyance (flood prevention)
- Recreation (non-water contact) Uses
- Biological Uses (Warm water fishery, aquatic life use, biological integrity, etc.)
- Human Health Related Uses (Swimming, Fishing, and Water Supply)

Urban Water is a Multidisciplinary Field

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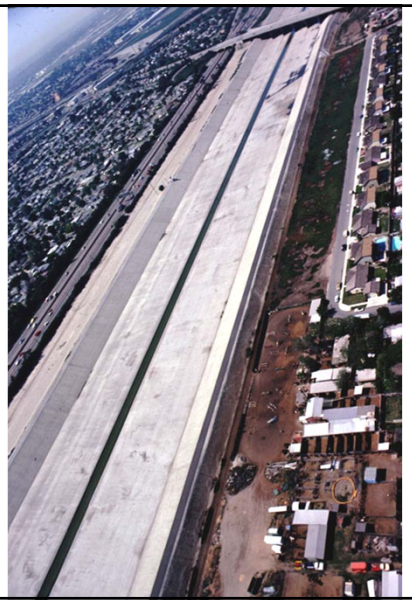
Urbanization causes extremes in flows; extended dry periods and short periods of higher flows

73

Increased high flows have lead to unusual solutions



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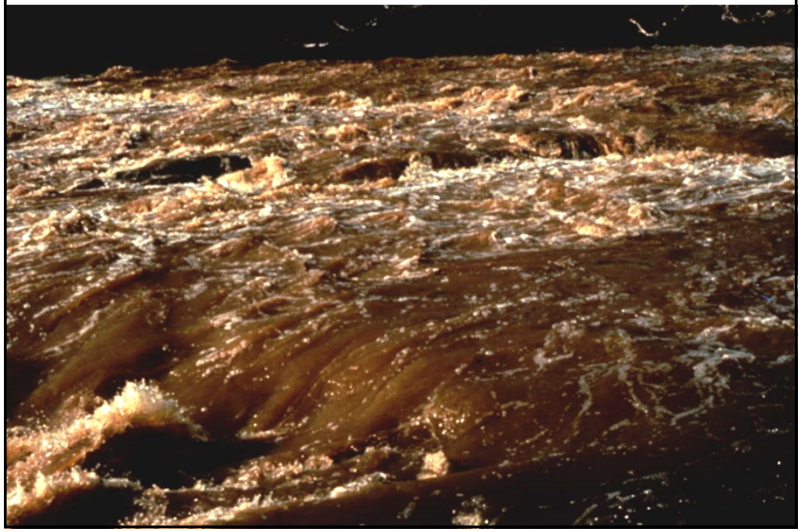
Urbanization has also caused increased pollutant discharges



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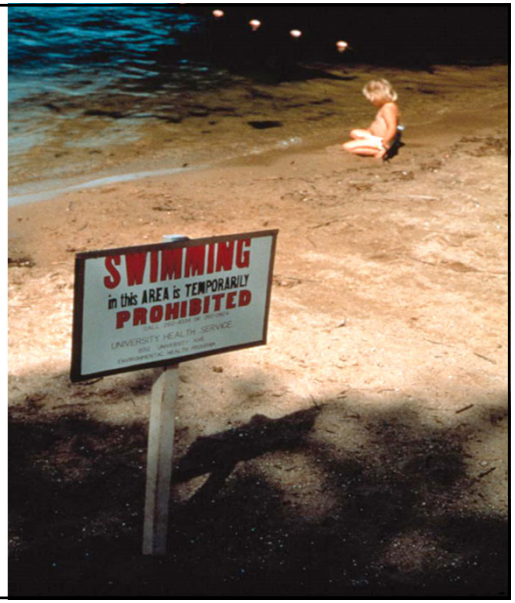
Numerous beach closures at community swimming beaches due to bacteria from urban runoff discharges

WI DNR photo



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Beach Closings in the US in 1994

Sanitary Sewer Overflows (SSOs)	584 (43%)
Stormwater Runoff	345 (25%)
Combined Sewer Overflows (CSOs)	194 (14%)
Agricultural Runoff	136 (10%)
Wastewater Treatment Plant Malfunctions	106 (7.8%)

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However, kids still play in urban creeks and swim near outfalls

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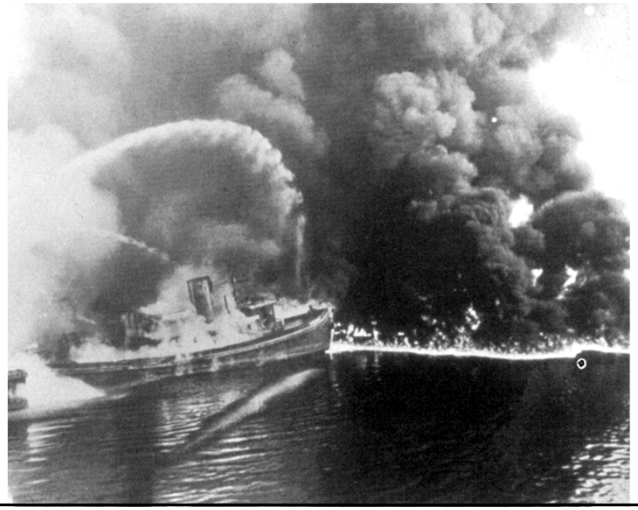
Cuyahoga River in Cleveland often Caught on Fire Between 1952 and 1969



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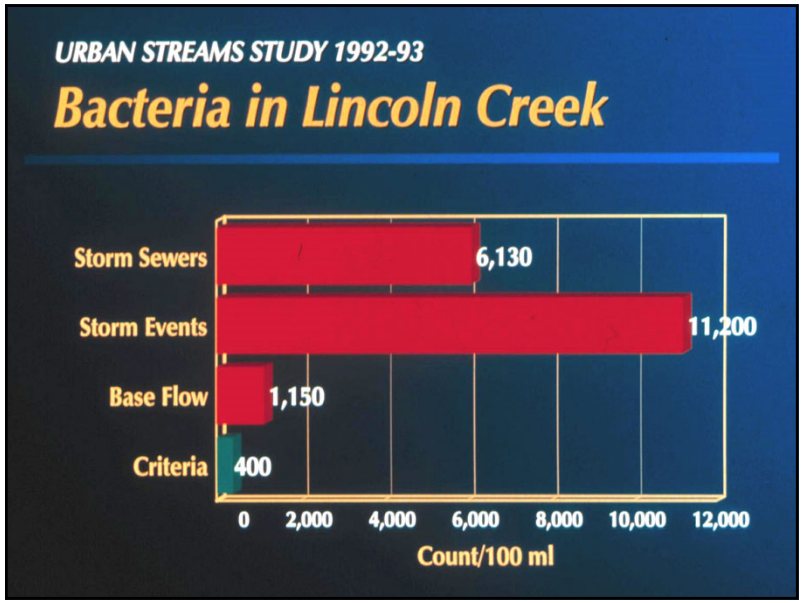
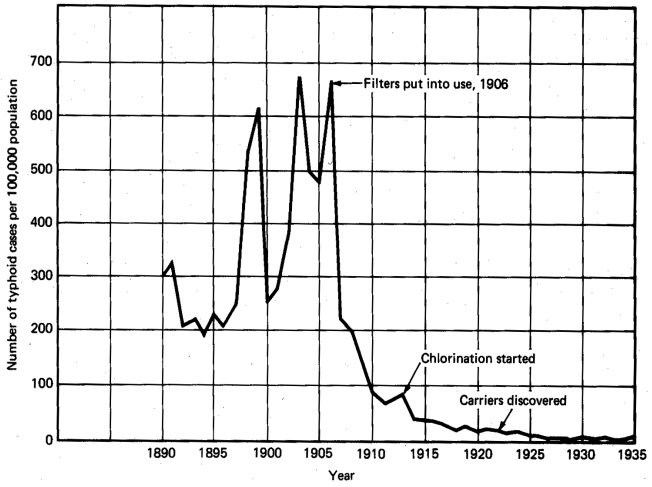
Fire from 200,000 gallons of spilled gasoline into an urban creek, Bellingham, Washington, 2000.

81



82

Typhoid cases in Philadelphia, Pennsylvania, showing rapid decrease concurrent with water filtration, and further decreases with chlorination.



http://www.p2pays.org/ref/20/images/Nf505.jpg

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Sanitary Sewer Overflow, 5-Mile Creek, Birmingham, AL

84

Continuous, low volume sanitary sewage leakage at 5-Mile Creek study area, Birmingham

85

Upwelling sewage from broken sewer in backyard, Birmingham

86

Discharge of sanitary sewage leak into Village Creek, Birmingham

87

Captured floatable debris from combined sewer outfalls at Brooklyn, NY, study area.

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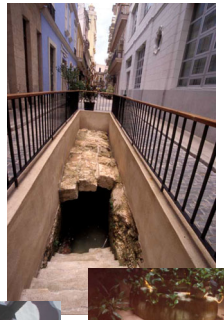
Aqueduct in Havana, Cuba, 1565



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Private Water Delivery in Havana, Cuba, 2003

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Summary of the History of Urban Drainage

- Stormwater drainage was an early public works activity as cities developed. It was necessary to mitigate flooding issues to allow basic urban activities.
- Sanitary wastewater became an issue later as the population density increased and casual disposal of wastes lead to nuisance and public health problems.
- Therefore, the earliest drainage systems for stormwater were converted to combined sewers as water transported sanitary wastewaters were discharged to these existing drainage systems.
- As receiving waters became grossly polluted with the raw sewage discharges, treatment facilities were used to treat the dry weather flows. However, the increased flows during wet weather over-whelmed the treatment capacity, resulting in untreated/poorly treated combined sewer overflows.

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