PHC 6937
Water Biology

Hydrogeology of watersheds, wetlands & aquifers; groundwater contamination

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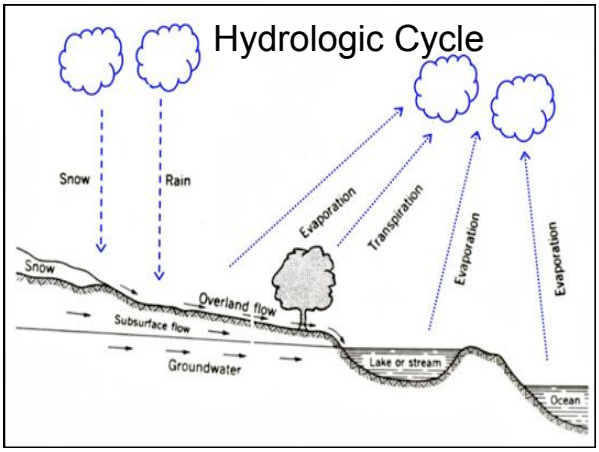
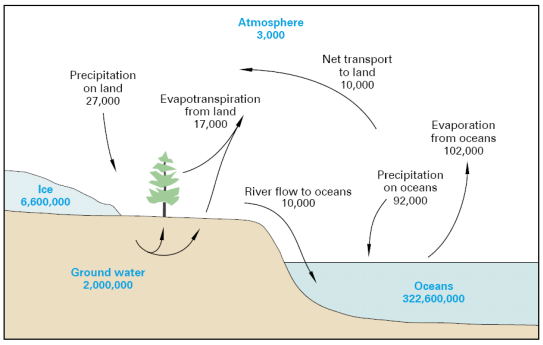
Lecture Overview & Terms

- Hydrologic vs hydraulic cycles
- Water table, vadose zone, saturated zone
- Hydraulic gradient, residence time
- Precipitation, transpiration, evaporation revisited
- Why should we care about groundwater?
- How does groundwater move about?
- Dispersion and differential advection
- Point source and non-point source contamination
- What do we do about contamination?





Pools are in cubic miles
Fluxes are in cubic miles per year

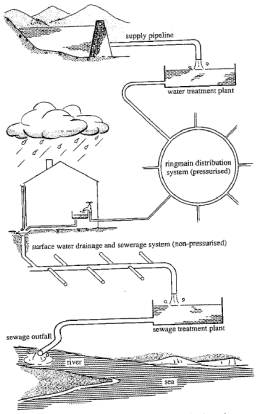
USGS Circular 1139
http://pubs.usgs.gov/circ/circ1139/pdf/circ1139.pdf

What about humans?

- We left humans out of the Earth systems above (except in the biosphere):
  - Human intervention in the hydrologic cycle defines water resources
  - Corollary to the hydrologic cycle: Hydraulic cycle
- The sum of water-related organizations, engineering works, and water use sectors. Society is not only a component of the global water system but also a significant agent of change within the system. Society is not only exposed to changes in water availability but also takes actions to mitigate or adapt to these changes.

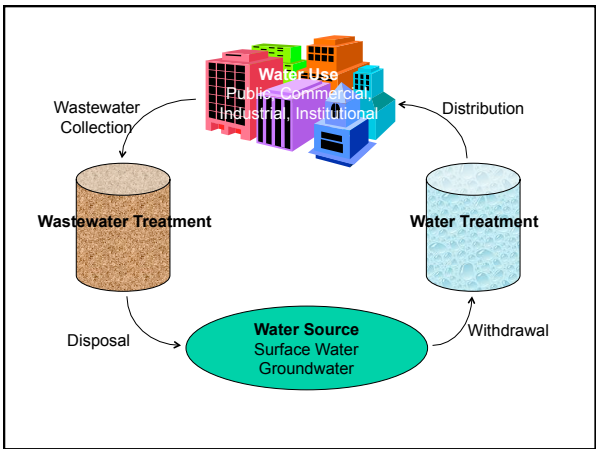
Hydraulic cycle

- Source
- Treatment
- Distribution
- Use
- Collection
- Treatment
- Disposal

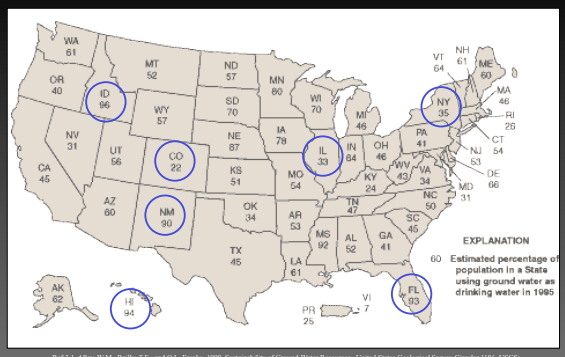


The synthetic hydrological cycle.

Chadwick and Moffett, 1998. *Hydraulics in Civil and Environmental Engineering*



Who uses groundwater?



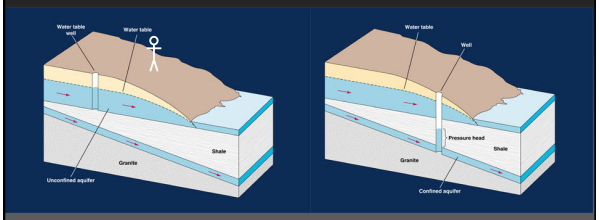
Ref 3.1, Alley, W.M., Reilly, T.E., and O.L. Franke, 1999, Sustainability of Ground-Water Resources. United States Geological Survey Circular 1186, USGS: Denver, CO. http://water.usgs.gov/pubs/circ/circ1186

Why do people use groundwater?

Aquifer: n. body of permeable rock able to hold or transmit water [Latin: *aqua* + *fer*]

- Confined aquifer
  - Wedged between layers of relatively impermeable materials and consequently under pressure.
- Unconfined aquifer
  - Water table is the upper boundary. Because the aquifer is not under pressure the water level in a well is the same as the water table outside the well. An unconfined aquifer is near the earth's surface causing it to be easily recharged locally as well as contaminated.

Unconfined vs Confined



- Contamination issues?

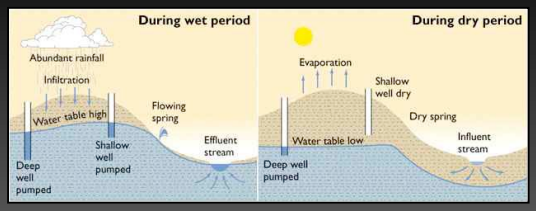
Potentiometric surface

- An imaginary surface formed by measuring the level to which water will rise in wells of a particular aquifer. For an unconfined aquifer the potentiometric surface is the water table; for a confined aquifer it is the static level of water in the wells. (Also known as the piezometric surface.)

Water table = top of the zone of saturation (where pores are saturated with water)

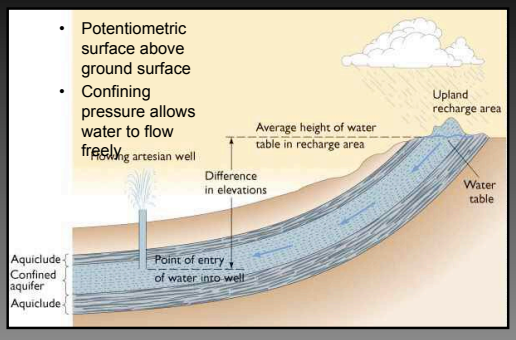
- Relationship between water table and groundwater flow?
  - Hydraulic gradient ($\Delta H/\Delta x$): slope of top of water table
- Water pressure is equal to atmospheric pressure
- Water table depth fluctuates with climate conditions on the land surface above and is *usually* gently curved and follows a subdued version of the land surface topography.

Dynamics of water table connected to near-surface processes



- Infiltration from surface vs evapotranspiration
- Influent vs effluent streams
- "saturated zone" is a dynamic definition

Artesian Groundwater Systems



Why “artesian” ?

- 1126, Artois, France
- Modena, Italy
  - Cross of St. George (patron saint)
  - What about the other bits?

Florida has 33[1] first-magnitude springs (out of 78 nationwide)

- First-magnitude springs
  - Flow > 100 cfs (> 65 MGD)
  - Biggest? [2]
- Upper Floridan – confining unit?

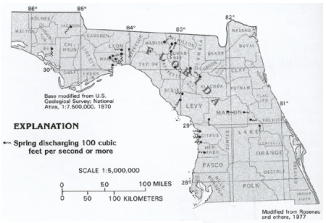


Figure 57. Large springs issue from large solution openings developed where the upper confining unit of the Floridan aquifer system is thin or absent.

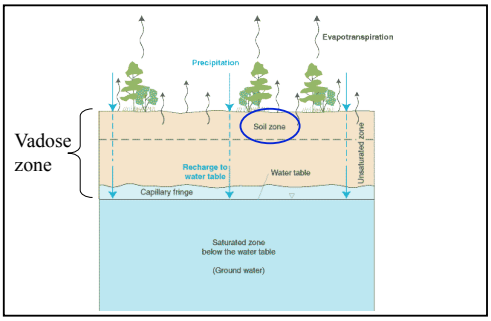
[1] 2002 revision (classifications have changed since 1970s; karst window vs spring-seep, etc)
[2] SS 820 cfs (530 MGD)

Silver Springs

Figure 58. Large springs may issue from huge solution openings in the limestone that comprises the Floridan aquifer system. These springs are major discharge points, and are a dominant control on the ground-water flow system. Some of them, such as Silver Spring shown here, form the headwaters of surface streams.

Silver River State Park

Vadose zone = between ground surface and water table



- Water pressure is less than atmospheric
- 'vadosus'

Hydraulic Gradient

- Natural groundwater flow
- Groundwater is not sitting still!
  - But is moving slowly…
  - Travel time for 10 m vs 1 km?

Definition of residence time

- The period of time that water remains in a system

$$\tau = V/Q = LA/(vA) = L/v$$

- How long does groundwater spend in an aquifer
- Turnover time is inverse of residence time

Residence time and vulnerability

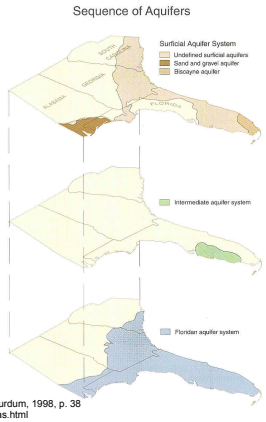
- Ocean
  - P = 92,000 mi^3/yr + Runoff = 10,000 mi^3/yr
  - V = 322,600,000 mi^3
  - Average residence time = 3,100 years (or total turnover once in that time)
    - [from 322,600,000 / 102,000]
- Similar analysis for GW
  - P = 27,000 mi^3/yr - ET = 17,000 mi^3/yr
  - Thus, roughly estimate that 10,000 mi^3 infiltrates
  - World groundwater reservoir = 2,000,000 mi^3
  - Average residence time = 200 years (or total turnover once in that time)
  - Not spatially uniform!
    - 25,000 yr old water under Saudi Arabia = Pleistocene ice age

Residence time and vulnerability

Parts of the Hydrosphere	Volume of Freshwater (km^3)	Share of Total Volume of Freshwater (percent)	Rate of Water Exchange
Ice sheets and glaciers	24,000,000	84.945	8000 years
Groundwater	4,000,000	14.158	280 years
Lakes and reservoirs	155,000	0.549	7 years
Soil moisture	83,000	0.294	1 year
Water vapor in the atmosphere	14,000	0.049	9.9 days
River water	1,200	0.004	11.3 days
Total	28,253,200	100.000	

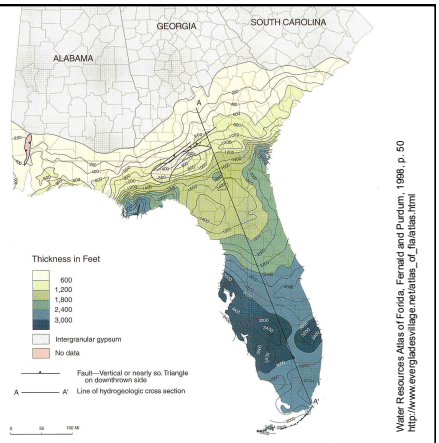
Tarbuck and Lutgens, Physical Geology

Surficial, Intermediate and Floridan aquifers



Water Resources Atlas of Forida, Fernald and Purdum, 1998, p. 38
http://www.evergladesvillage.net/atlas_of_fla/atlas.html

Floridan Aquifer System: Thickness in Feet



Discharged to the ground: land application systems (drain fields, percolation ponds, spray fields) and reuse systems

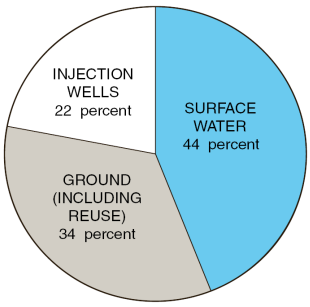
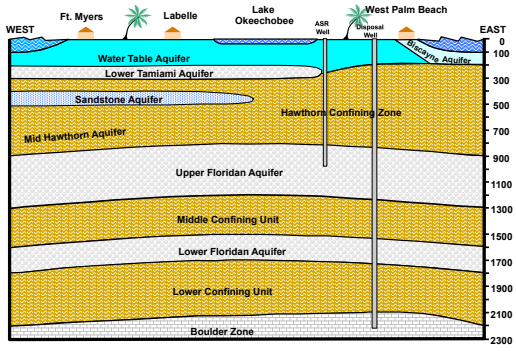


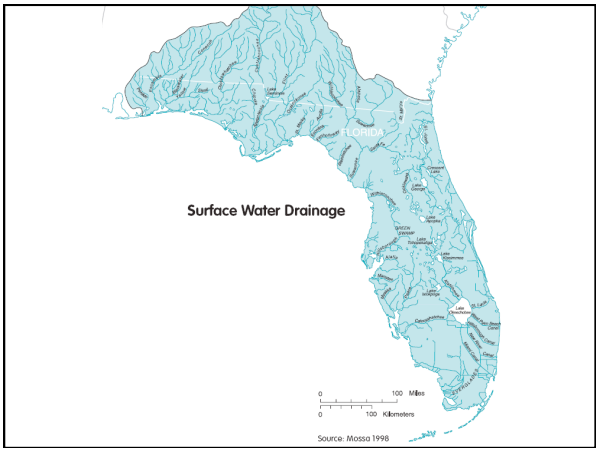
Figure 37. Treated domestic wastewater discharges in Florida by primary disposal method, 2000.

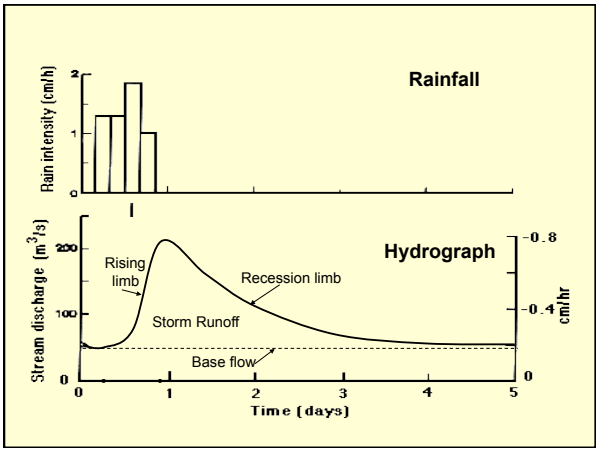
Marella, R.L., 2004, Water withdrawals, use, discharge, and trends in Florida, 2000: U.S. Geological Survey Scientific Investigations Report 2004-5151, 136 p.

Hydrogeology of South Florida

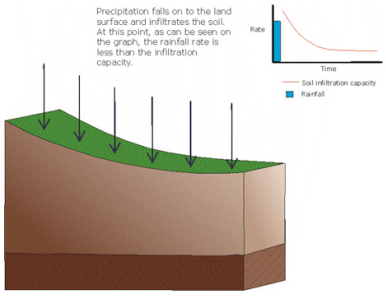


Surface water flow considerations



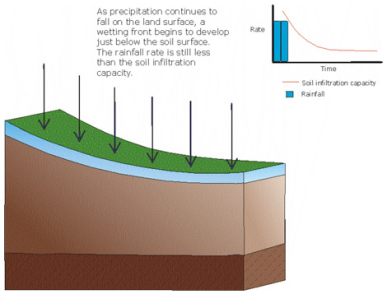


Infiltration Excess



http://soilandwater.bee.cornell.edu/research/VSA/processes/processes_infil.html

Infiltration Excess



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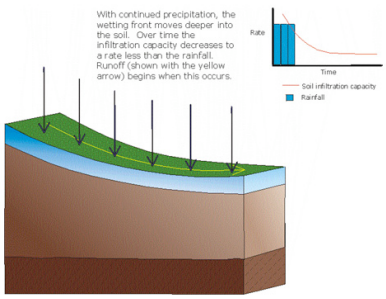

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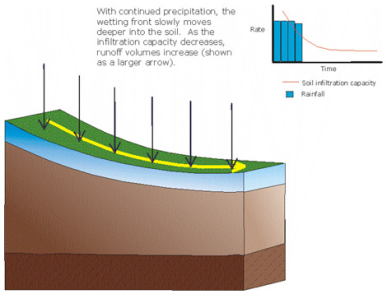

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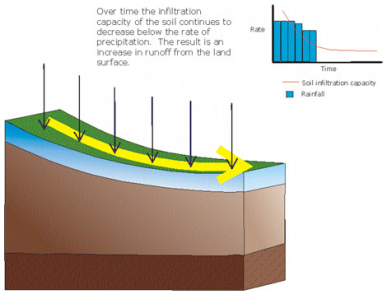

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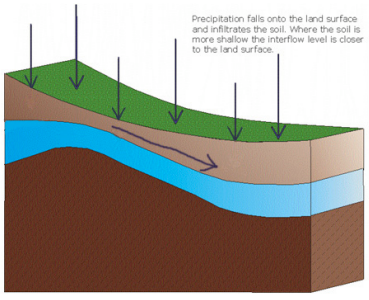
Saturation Excess



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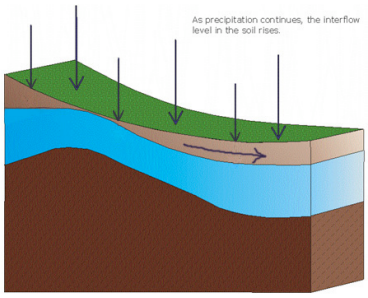

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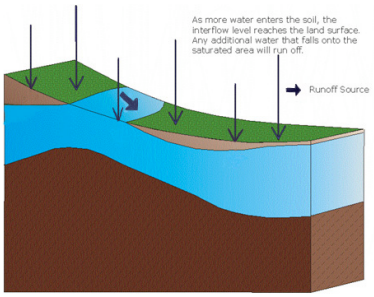

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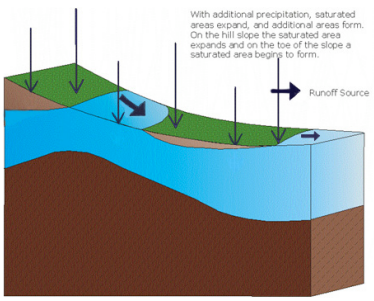

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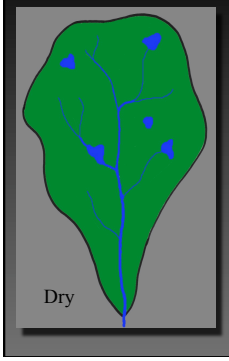
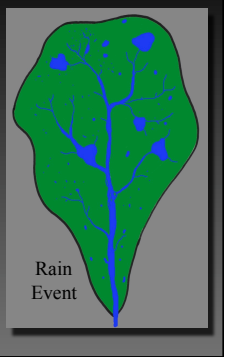
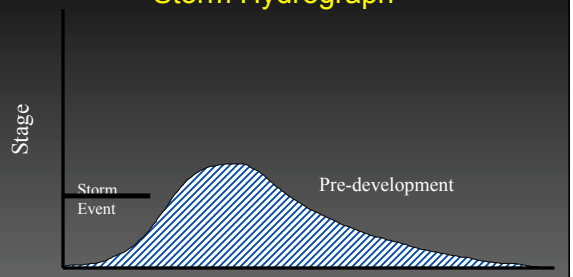
Undeveloped Watershed



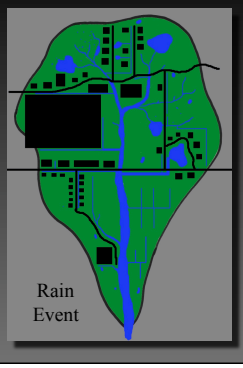
- Pervious surface
- Depressions in landscape
- Vegetated "rough" surface



Effect of Development on Storm Hydrograph

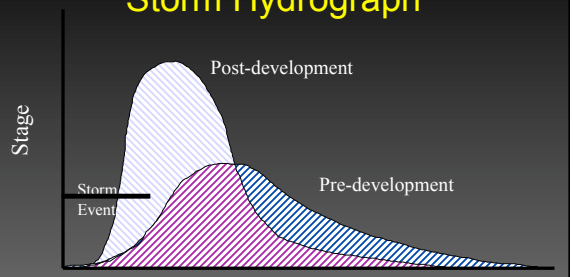


Developed Watershed



- Impervious surfaces increase
- Depressions in landscape drained
- Vegetated "rough" surfaces decrease and become smooth with quicker runoff.
- Culverts, swales, and ditches move water off the landscape quickly.

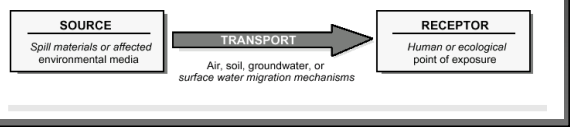
Effect of Development on Storm Hydrograph



Part III: Contamination

Risk Assessment: Three components

- Contaminant Source
  - site characterization
- Transport
  - site characterization/transport processes -> model
- Receptor
  - Exposure pathways -> water and soil standards



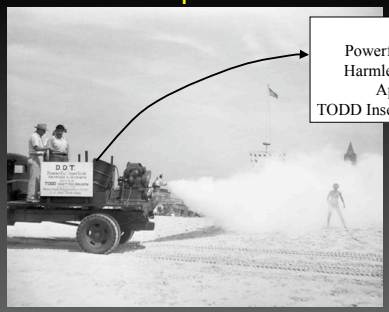
Sources of contamination

- Point source
  - Gas station
  - Dry cleaner
  - Landfill
  - Deep-well injection
  - Other spills and disposal sites
- Nonpoint source
  - Agriculture
  - Wastewater
    - Leaky sewers
    - Septic tanks
  - Other wide-area sprays… (mosquito control; Goshutes)

Point source

Agricultural surface water drainage in the Everglades Agricultural Area (EAA) – nutrients (C, N, P), pesticides (photo from SFWMD)

Non-point source

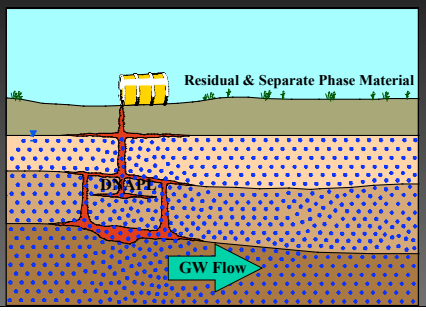


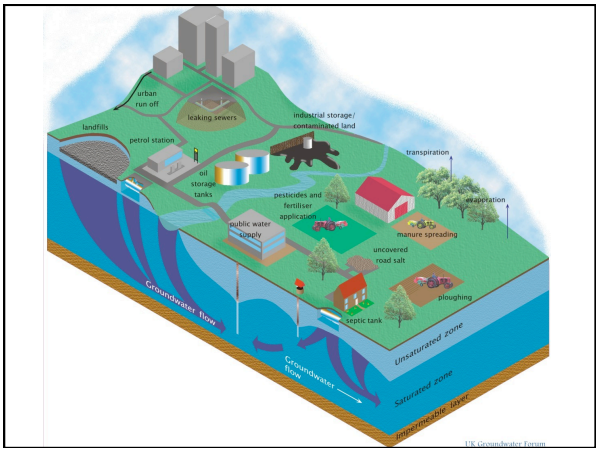
Sexton, K. et al., 2004. Human biomonitoring of environmental chemicals. American Scientist, 92 (1), p. 38. doi: 10.1511/2004.1.38

In July 1945, DDT was widely (and mistakenly) hailed as a progressive measure to eradicate disease-bearing mosquitoes without posing a risk to human health. In this photo from a beach on Long Island, New York, a new insecticide-spraying machine is tested as beachgoers play in the mist. Although this chemical contact is obvious, many other sources of environmental chemical exposure are more difficult to identify.

Contaminant Source Zone

- Nonaqueous phase liquid (NAPL) contamination of groundwater
  - immiscible with water
  - but enough dissolves to contaminate





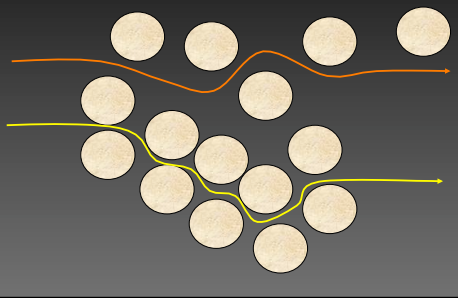
Contaminant categories

- Solutes
  - Organic
  - Inorganic
    - salt
- Others?
  - Sediment
  - Biological (bacteria, viruses)

Solute Transport in One Slide

- Advection – physical mechanism by which pollutants are transported along with the flow of subsurface water
- Dispersion – spreading caused by 'differential advection'
- Reactions
  - Sorption/desorption
  - Degradation

Dispersion conceptualized as differential advection



Chess-based alternatives for dealing with groundwater contamination

- When in check, four alternatives:
  - Check mate
  - Move the king out of check → Alternate water supply
  - Block the attack → Source management (Containment) Plume management (PAT)
  - Remove the attacker → Source removal

What is cholera?

- Acute, diarrheal illness caused by infection of the intestine with the bacterium *Vibrio cholerae*.
- The infection is often mild or without symptoms, but sometimes it can be severe.
- Approximately one in 20 infected persons has severe disease characterized by profuse watery diarrhea, vomiting, and leg cramps.
- In these persons, rapid loss of body fluids leads to dehydration and shock.
- Without treatment, death can occur within hours.

http://www.cdc.gov/ncidod/dbmd/diseaseinfo/cholera_g.htm

The Hall of Forgotten Presidents

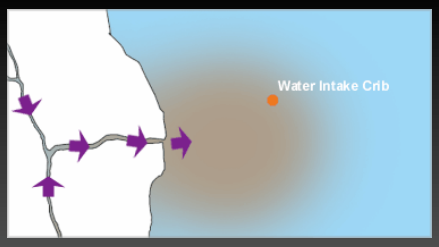
- James K. Polk, President 1845 - 1849
- "President Polk worked extremely hard during his term and at the end of it, suffering from exhaustion, decided to return to private life even though he remained popular and probably could have won a second term. He also felt he had achieved what he had set out to do, and simply didn't need to return to the office. At the age of only 53, he died at his Nashville home a mere three months after leaving office."

http://www.paulsilhan.com/hallpres.htm

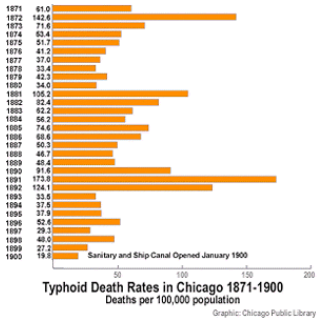
Cholera epidemic origins in early 1800s

- **1816-1826 - First pandemic: Previously restricted, the pandemic began in Bengal, then spread across India by 1820. It extended as far as China and the Caspian Sea before receding.**
- **1829-1851 - Second pandemic reached Europe**
  - London in 1832 - at least 3000 victims
  - Also in 1832 Russia, Quebec, New York
  - By 1834, the Pacific coast of North America
- **1849 - An outbreak in North America took the life of U.S. President James K. Polk**
- **1852-1860 - Third pandemic mainly affected Russia, with over a million deaths.**
- **1863-1875 - Fourth pandemic spread mostly in Europe and Africa.**
- **1866 - Outbreak in North America.**
- **1899-1923 - Sixth pandemic had little effect in Europe because of advances in public health, but Russia was badly affected again.**
- **1961-1970s - Seventh pandemic began in Indonesia, called El Tor after the strain, and reached Bangladesh in 1963, India in 1964, and the USSR in 1966. From North Africa it spread into Italy by 1973. In the late 1970s there were small outbreaks in Japan and in the South Pacific.**
- **January 1991 to September 1994 - Outbreak in South America, apparently initiated by discharged ballast water. Beginning in Peru there were 1.04 million identified cases and almost 10,000 deaths.**

http://en.wikipedia.org/wiki/Cholera

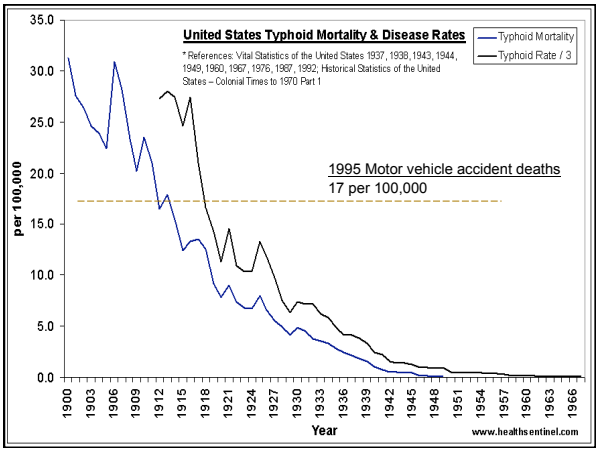


By the 1880s, Chicago's sewage flowed from the Chicago River past the Two Mile Crib, the source of Chicago's drinking water in Lake Michigan. Epidemics of typhoid and other diseases led to the establishment, in 1889, of the Sanitary District of Chicago (now Metropolitan Water Reclamation District).



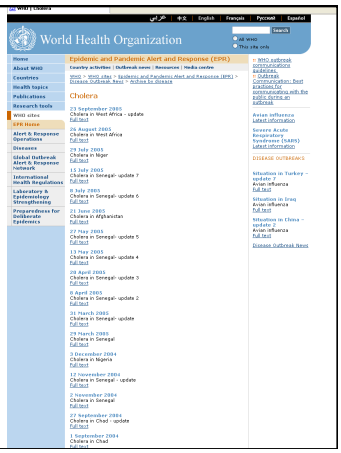
While the Sanitary and Ship Canal resulted in 91% drop in the rate of typhoid deaths in Chicago by 1908, Chicago's water supply was not truly safe until the addition of chlorine to the water in 1912. By 1917 Chicago's typhoid death rate had fallen to lowest of any major city in the nation.

Chicago Public Library
http://www.chipublib.org/digital/sewers/history4.html



Cholera today

- Developing world
- WHO alerts (screen capture from January 2006)



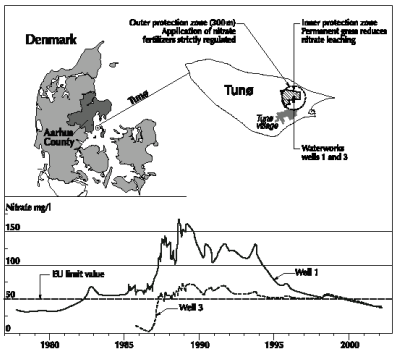


Fig. 1. The protection zones confer a beneficial effect, as illustrated.

Groundwater Protection Zone (Wellhead protection)

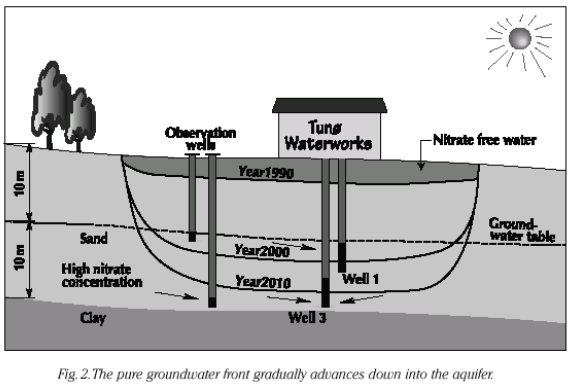


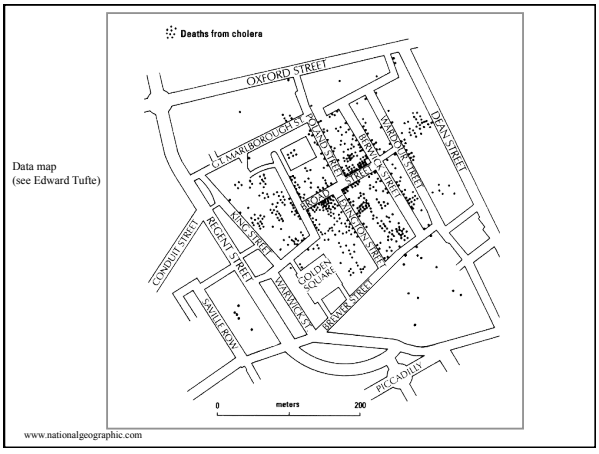
Fig. 2. The pure groundwater front gradually advances down into the aquifer.

Addenda

Dr. John Snow
Soho, London

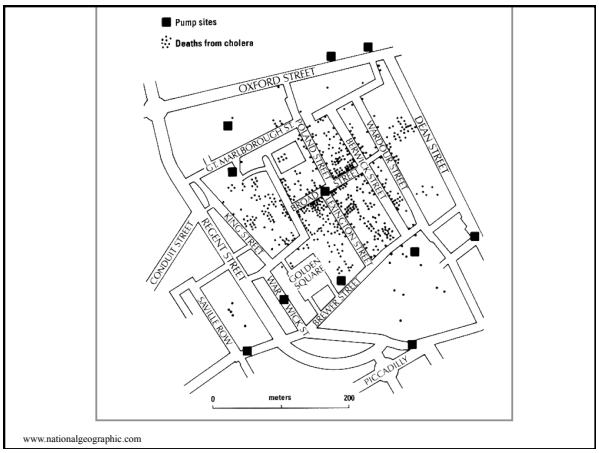
1854
860 cholera deaths

http://www.ph.ucla.edu/epi/snow/snowpub.html

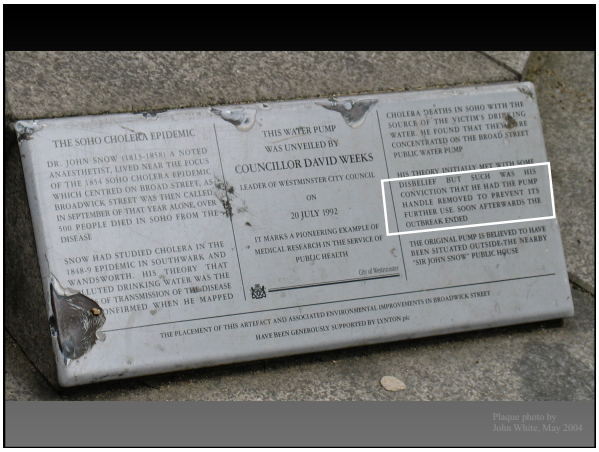


Data map
(see Edward Tufte)

www.nationalgeographic.com



www.nationalgeographic.com



Plaque photo by John White, May 2004