# Environmental Science, 15e

G. TYLER MILLER | SCOTT E. SPOOLMAN

# 11

# Water Resources and Water Pollution

# Core Case Study: The Colorado River

- Overuse of the Colorado River challenges state/federal agencies and the people who live in these regions
- Increasing population and economic development place increasing demands on this limited supply of surface water
  - How is the Colorado River used?
  - Which cities/regions would be most impaired by the loss of Colorado River water?

# The Colorado River Basin

# 11.1 Will We Have Enough Usable Water?

- By extracting water faster than nature can replace it, by wasting, polluting, and underpricing this natural resource, we are using available fresh water unsustainably
- Freshwater is not evenly distributed over the earth's surface – estimates show that one in nine people do not have access to clean, fresh water

# Fresh Water is Available But It Is Not Distributed Evenly or Managed Properly

- Globally, we have plenty of fresh water (recycled and purified by the hydrologic cycle), but pollute and overuse it faster than natural processes can replenish it
  - A global economic and health issue
  - A security issue due to terrorism
  - An environmental issue as it determines and moderates the climate, and dilutes and removes pollutants and waste

# Crucial Freshwater Resources

- Groundwater infiltrates downward through spaces in soil and rocks
  - Zone of saturation: underground areas of soil/rock where freshwater fills spaces between particles
  - Water table: the top of the groundwater zone; fluctuates up and down depending on weather, and removal/replenishment rates
- Aquifer: underground body of rock that absorbs and holds flowing water

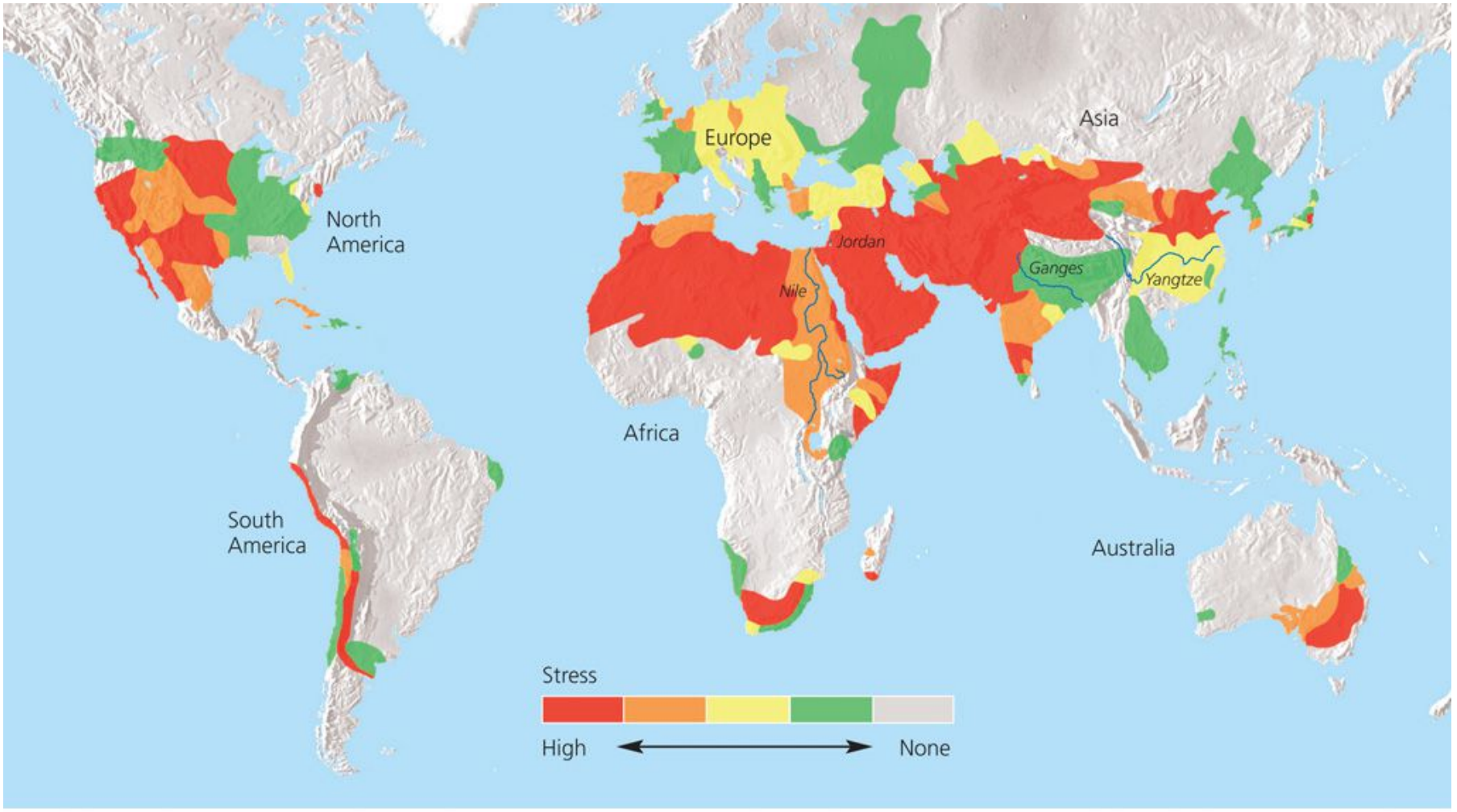
# Additional Freshwater Resources

- Surface water: the fresh water from rain and melted snow stored at the surface
  - Annually, 34% of the world's reliable surface runoff is used
    - 70% goes to irrigate crops and raise livestock, 20% is used by industry, and 10% is used by cities for drinking, cooking, etc.
- Indirect and virtual water: water used to produce food and other products – this is a large part of our water footprint

# Fresh Water Shortages

- Water scarcity is caused by dry climate, drought, overuse/inefficient use, and using water faster than it can be replenished
- Freshwater scarcity stress: a calculation that compares fresh water availability with the amount used by humans
- In 263 of the world's water basins, two or more countries share the available freshwater supplies – not always amicably

# Freshwater Scarcity Stress




Compiled by the authors using data from World Commission on Water Use for the 21st Century, UN Food and Agriculture Organization, and World Water Council.

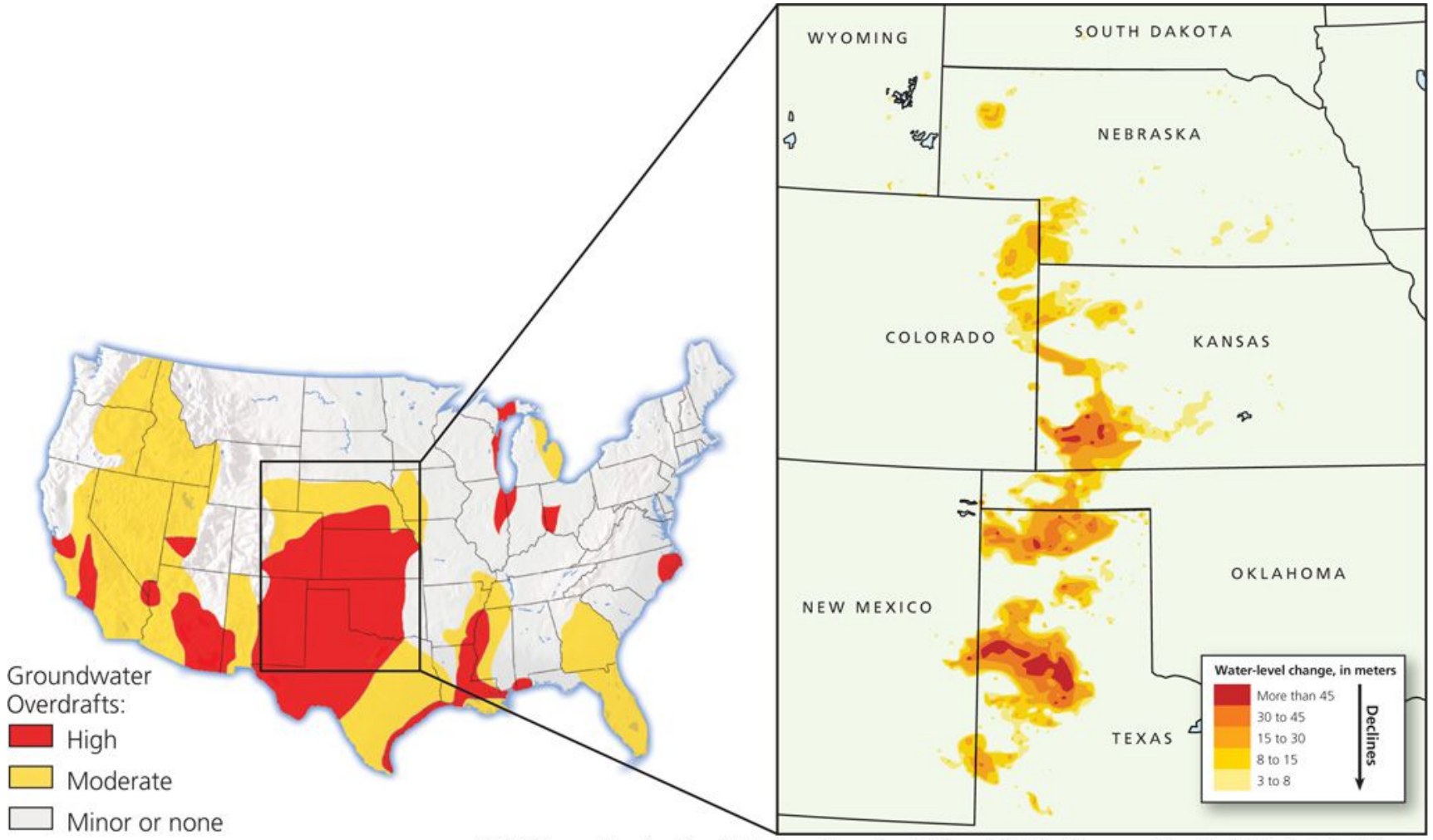
# 11.2 How Can We Increase Freshwater Supplies?

- Groundwater for food production and use by cities is being pumped from aquifers faster than it can be replenished by nature
- Although dam-and-reservoir systems and water transfer projects expand water distribution, they also disrupt ecosystems and displace people
- Freshwater supplies can be augmented by desalination of ocean water (expensive)

# Groundwater/Aquifer Usage Exceeds Replenishment Rate

- Overpumping limits food production, raises food prices, and widens the gap between the rich and the poor
  - As water tables drop, water must be pumped from lower depths (more energy and money)
  - Can cause land subsidence and sinkhole development where land above aquifers collapses – making recharge impossible
  - Can draw saltwater into freshwater aquifers – making it undrinkable/unusable for irrigation

# Natural Capital Degradation: Areas of Greatest Aquifer Depletion

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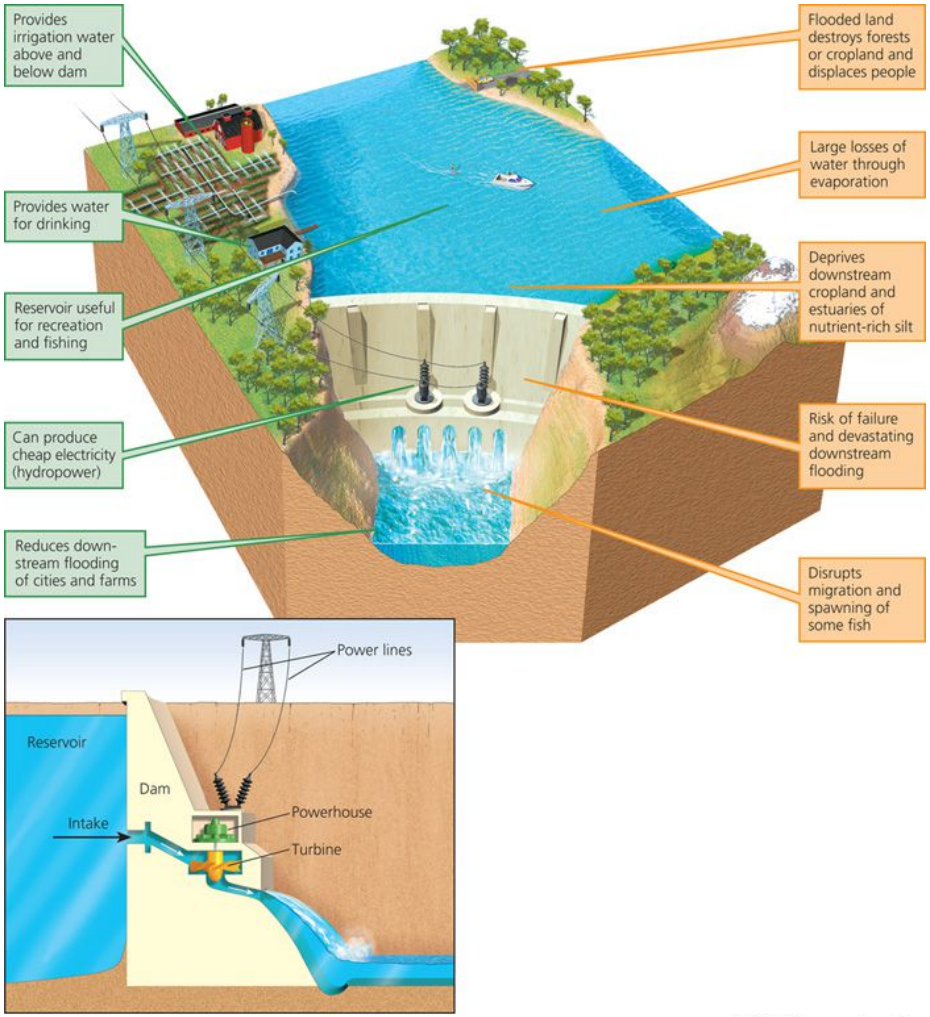
# Advantages of Large Dams and Water Transfer Projects

- Dams/reservoir systems capture and store surface runoff from a river's watershed
  - Water is released as needed to control upstream flooding, generate electricity (hydropower), supply fresh/irrigation water and provide recreational opportunities
- Water transfer projects use dams, pumps, and aqueducts to transfer water from water rich to water poor regions

# Disadvantages of Large Dams and Water Transfer Projects

- Dam/reservoirs displace millions of people, flood productive lands, impair the ecosystem services of rivers, and have a useful life expectancy of only 50 years
- Water transfer projects reduce a river's flow and flushing action (leading to pollution), and threaten fisheries and artificially cheapen costs – leading to inefficient and wasteful water use

# Tradeoffs: Use of Large Dams and Reservoirs, Advantages/Disadvantages



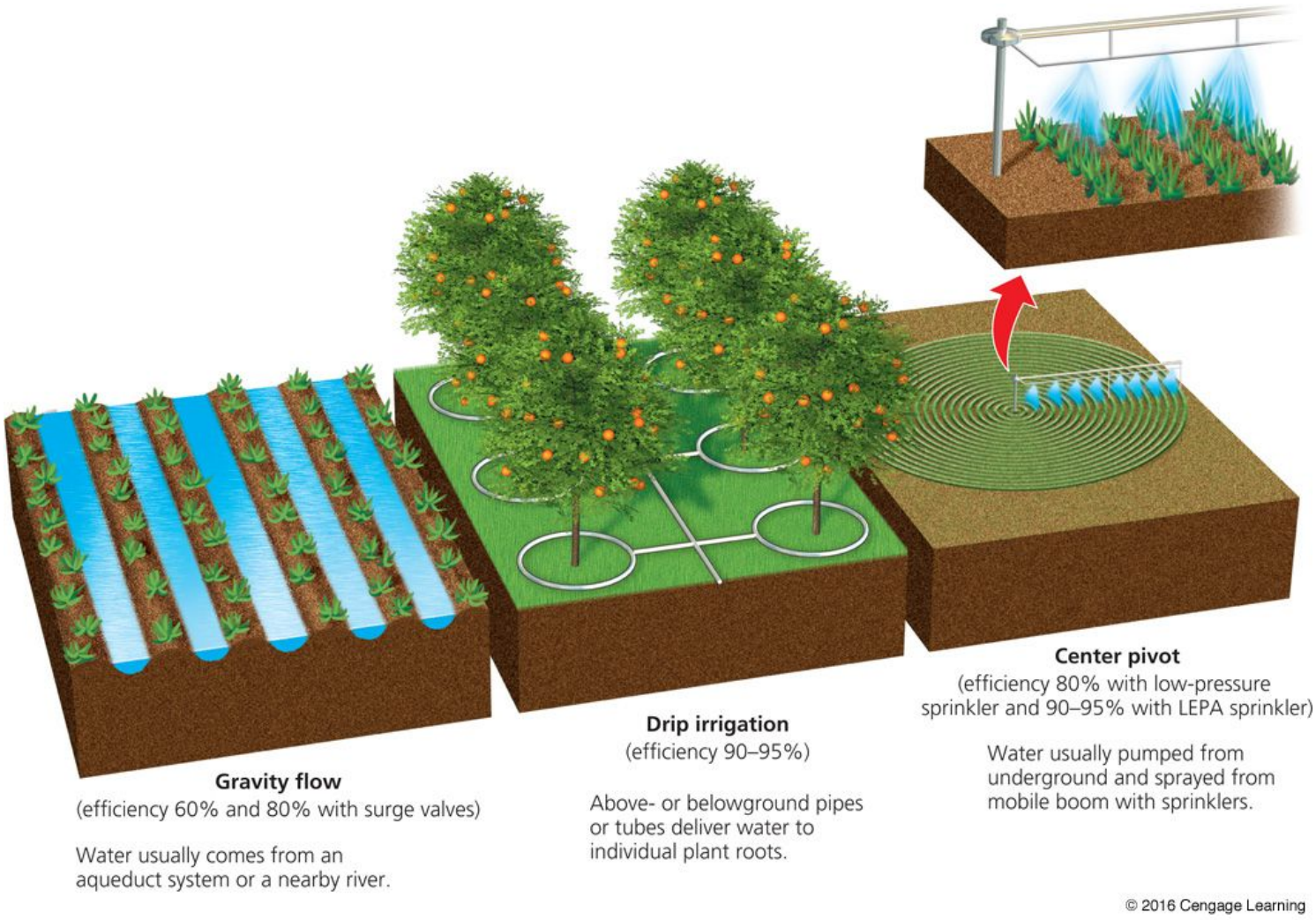
# 11.3 How Can We Use Fresh Water More Sustainably?

- By reducing wastage, raising prices, slowing population growth and protecting ecosystems that store water naturally, we can use available freshwater more sustainably

# Reducing Freshwater Losses and Improving Efficient Usage

- More than half the world's freshwater supply is lost annually due to evaporation, and inefficient use (irrigation) – Why?
  - Government subsidies and underpricing
  - Lack of subsidies for efficient water use
- Switching to modern irrigation methods (drip, central pivot etc.) will help reduce irrigation water usage by 10% – enough to supply everyone through 2025

# Efficient Irrigation Technologies Save Water



# Ways To Further Reduce Irrigation Water Loss

## Solutions

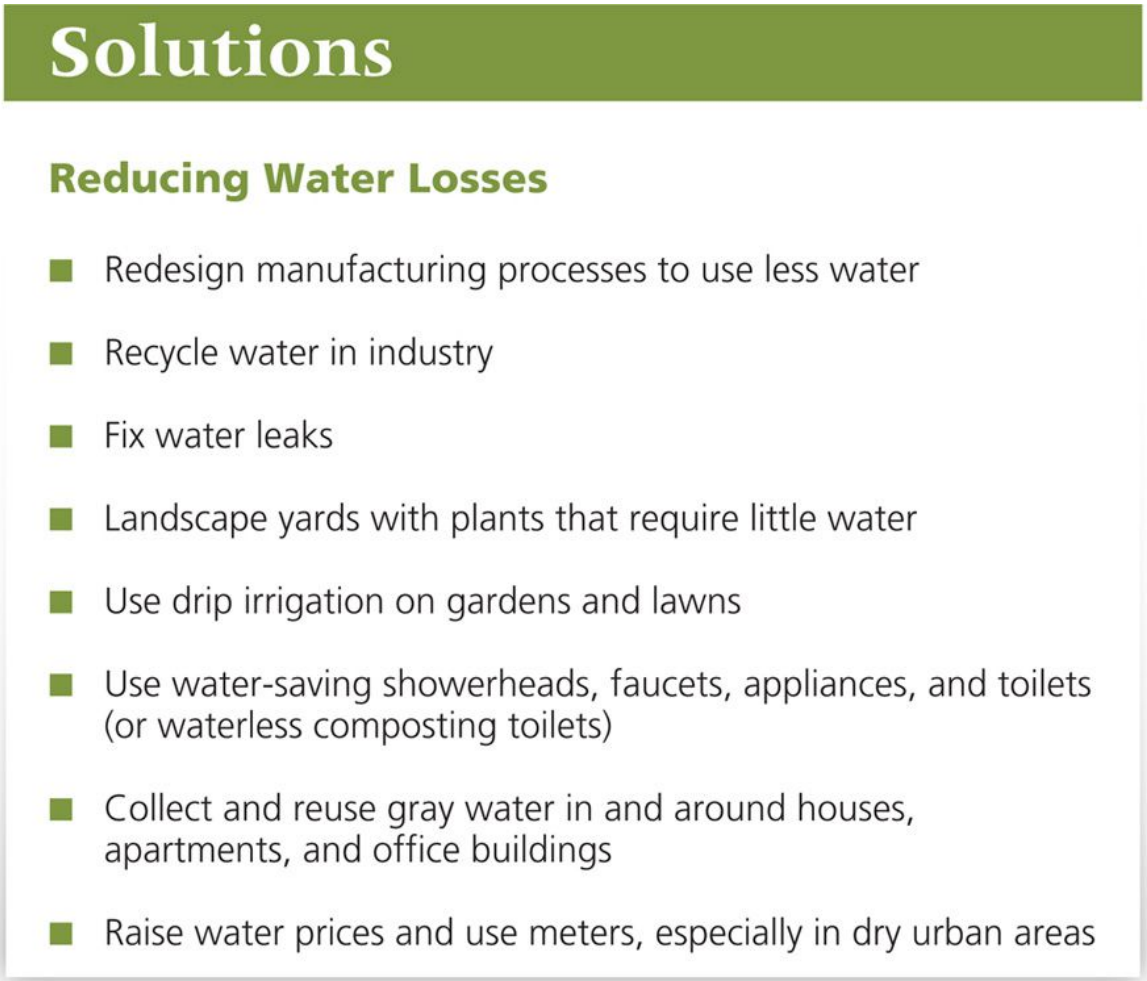
### Reducing Irrigation Water Losses

- Avoid growing thirsty crops in dry areas
- Import water-intensive crops and meat
- Encourage organic farming and polyculture to retain soil moisture
- Monitor soil moisture to add water only when necessary
- Expand use of drip irrigation and other efficient methods
- Irrigate at night to reduce evaporation
- Line canals that bring water to irrigation ditches
- Irrigate with treated wastewater

# Reducing Freshwater Losses and Improving Use in Industries and Homes

- Industries need to intensify efforts to recapture/purify/recycle the water they use
- In U.S. homes, toilet flushing is the single largest use of domestic freshwater
  - Install low-flow toilets/showerheads/faucets
  - Fix water leaks/use front-loading washers
  - Use gray water/drip/smart sprinkler systems on landscaping, or replace lawns with drought tolerant plants

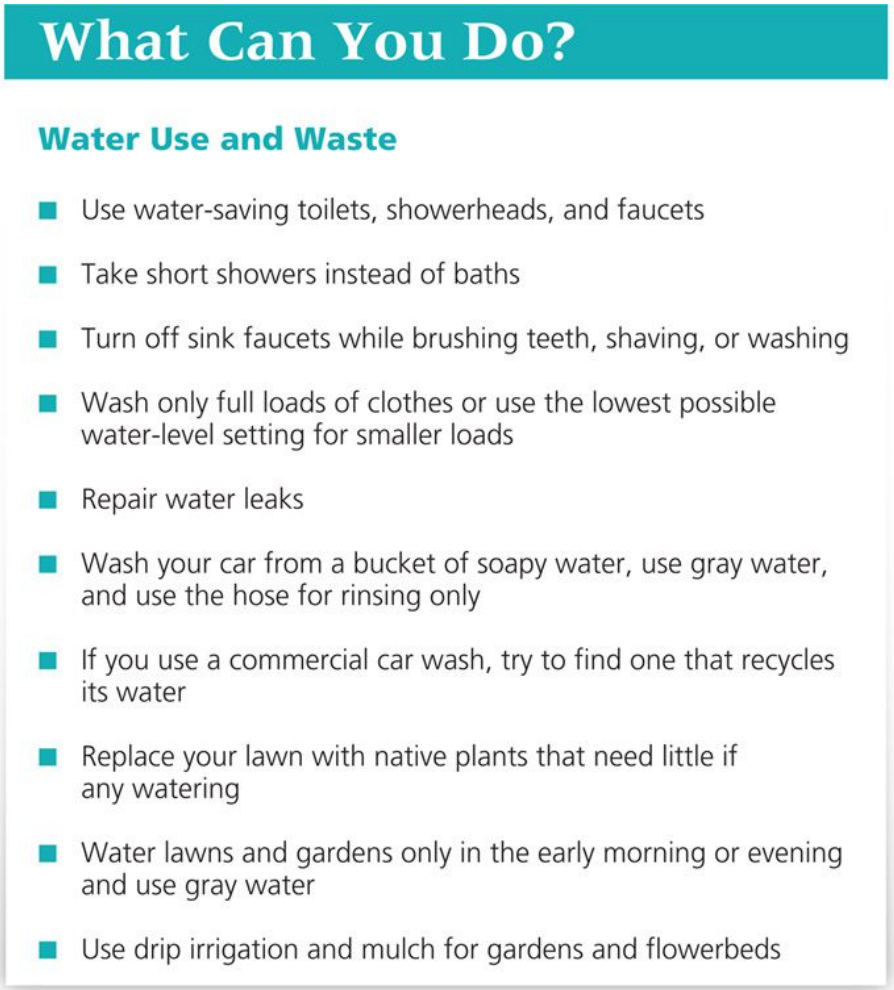
# Ways To Reduce Freshwater Losses in Industries



# Flushing Away Industrial, Animal and Household Wastes

- Flushing away industrial/household waste with freshwater causes pollution and is unsustainable
- Gray water and industrial waste water from sewage treatment plants can be used to clean equipment, flush away waste, water lawns, and irrigate non-food crops

# You Can Reduce Your Use and Waste of Freshwater



# 11.4 How Can We Deal with Water Pollution?

- Humans can use natural methods to treat sewage, cut resource use and waste, reduce poverty, and slow population growth to reduce water pollution – but the best way to reduce water pollution is to prevent it

# Point/Non-Point Sources of Water Pollution

- In streams/lakes/reservoirs/groundwater
  - Water pollution: water quality changes that harm living organisms or make water unfit for drinking/ irrigation/recreation
  - Point sources: specific identifiable locations
  - Non-point sources: diffuse areas
    - Difficult to identify/control, expensive to manage
  - The leading causes of water pollution are agriculture activity/industrial facilities/mining

# Major Pollutants and Their Sources

**TABLE 11.1** Major Water Pollutants and Their Sources

| Type/*Effects* | Examples | Major Sources |
|---|---|---|
| Infectious agents (pathogens)<br>*Cause diseases* | Bacteria, viruses, protozoa, and parasites | Human and animal wastes |
| Oxygen-demanding wastes<br>*Deplete dissolved oxygen needed by aquatic species* | Biodegradable animal wastes and plant debris | Sewage, animal feedlots, food-processing facilities, paper mills |
| Plant nutrients<br>*Cause excessive growth of algae and other species* | Nitrates ($NO_3^-$) and phosphates ($PO_4^{3-}$) | Sewage, animal wastes, inorganic fertilizers |
| Organic chemicals<br>*Add toxins to aquatic systems* | Oil, gasoline, plastics, pesticides, cleaning solvents | Industry, farms, households |
| Inorganic chemicals<br>*Add toxins to aquatic systems* | Acids, bases, salts, and metal compounds | Industry, households, surface runoff |
| Sediments<br>*Disrupt photosynthesis, food webs, and other processes* | Soil, silt | Land erosion |
| Heavy metals<br>*Cause cancer, disrupt immune and endocrine systems* | Lead, mercury, arsenic | Unlined landfills, household chemicals, mining refuse, and industrial discharges |
| Thermal<br>*Make some species vulnerable to disease* | Heat | Electric power and industrial plants |

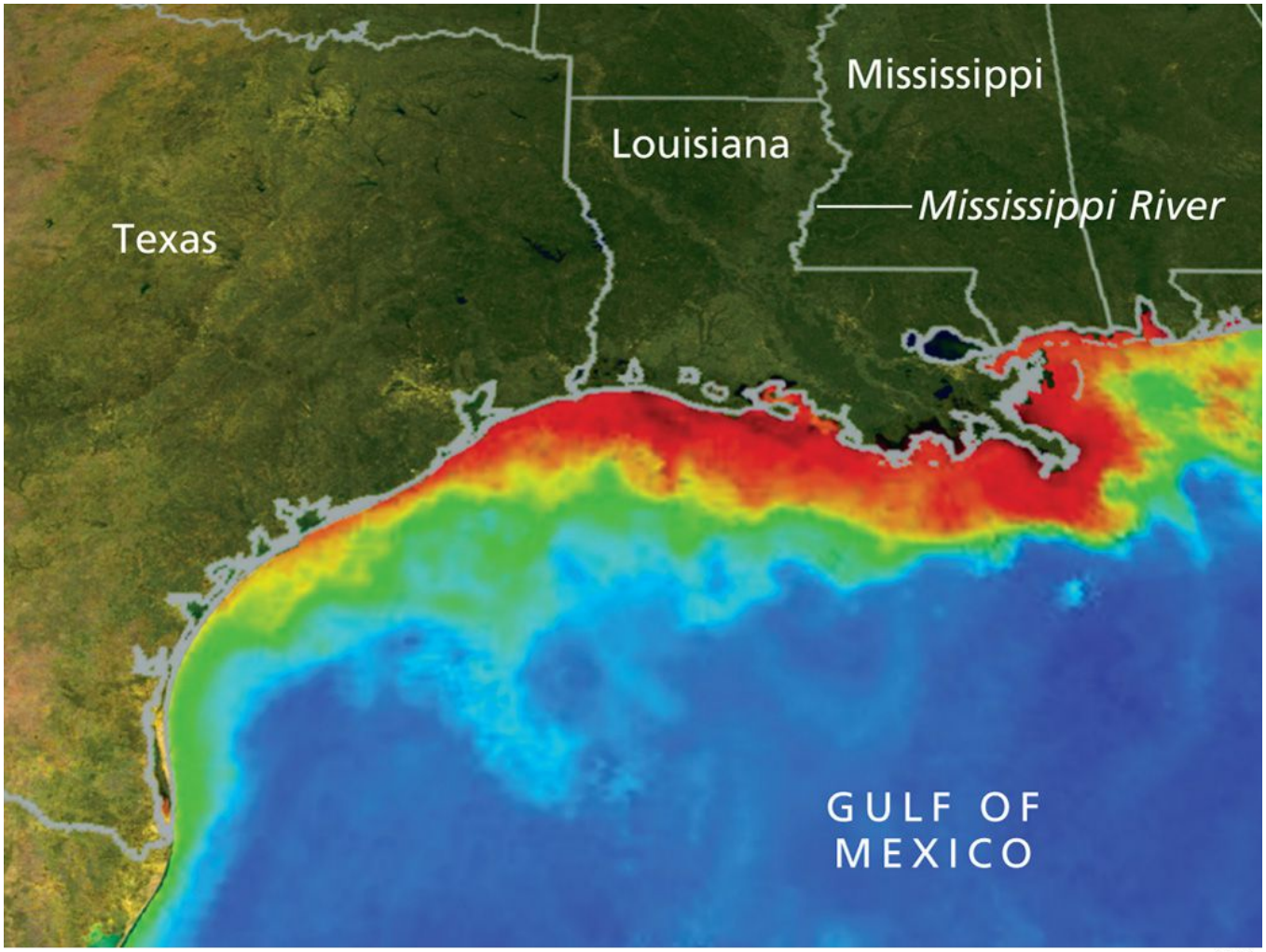
# Stream and River Pollution

- Flowing streams and rivers use a combination of dilution and bacterial biodegradation to naturally eliminate waste
  - Does not work when overloaded with pollutants (historically from industrial waste water discharge) or when flow is reduced by drought, damming, or diversion
    - Bacterial decomposition depletes dissolved oxygen – eliminating populations of high-oxygen using organisms until the stream is cleansed

# Lake and Reservoir Pollution

- Lakes/reservoirs have lower flow rates and are less effective at self-cleansing, as they typically have stratified layers
  - Near urban and agricultural areas chemical runoff cause nutrient enrichment of lakes and the mouths of rivers (cultural eutrophication)
    - Nutrient overload produces algal/bacteria overgrowth, which depletes dissolved oxygen and kills off fish and marine organisms in bottom waters (dead zones)

# Dead Zones




NOAA

# Groundwater Pollution

- Groundwater cannot cleanse itself of degradable wastes as quickly as flowing surface water
  - Can take up to thousands of years for polluted groundwater to cleanse itself of slowly degradable waste because:
    - Groundwater has lower concentrations of dissolved oxygen/smaller populations of decomposing bacteria
    - Cold temperatures reduce chemical reaction rates

# Groundwater Pollution Solutions

## Solutions

### Groundwater Pollution

#### Prevention

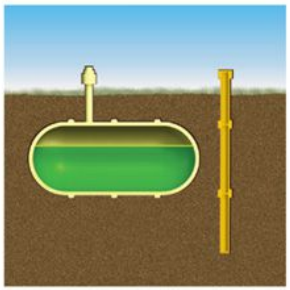
Find substitutes for toxic chemicals

Keep toxic chemicals out of the environment

Require leak detectors on underground tanks

Ban hazardous waste disposal in landfills and injection wells

Store harmful liquids in aboveground tanks with leak detection and collection systems




#### Cleanup

Pump to surface, clean, and return to aquifer (very expensive)

Inject microorganisms to clean up contamination (less expensive but still costly)

Pump nanoparticles of inorganic compounds to remove pollutants (still being developed)

# Purifying Drinking Water

- Temporarily store water in reservoirs
- Protect forests/wetlands in watersheds that flow into reservoirs
- Convert sewer water to drinking water
  - Microfiltration
  - Reverse osmosis
  - Hydrogen peroxide/ultraviolet light

# Ocean Pollution

- Many humans treat the ocean as a dumping site
  - 80% of marine pollution originates on land
  - 80-90% of municipal sewage from the coastal areas of less developed countries is dumped into the ocean without any treatment
  - May be safer to dump wastes and degradable pollutants into the deep ocean, where it can be diluted/dispersed/degraded

# Contaminants in the Ocean

- Viruses in raw sewage and from sewage treatment plants
- Toxic chemicals, garbage, sewage, and waste oil from cruise ships
- Nitrates/phosphates and sewage from agricultural waste
- Crude and refined petroleum
  - Biomagnified into sea birds
- Urban and industrial runoff

# Reducing Water Pollution

- Ways to reduce non-point sources of surface water pollution
  - Reduce soil erosion by keeping crop land covered with vegetation, and by using conservation tillage
  - Use slow release fertilizer – and no fertilizer on steeply sloped land
  - Plant vegetative buffer zones between cultivated fields and nearby surface waters
  - Encourage organic farming

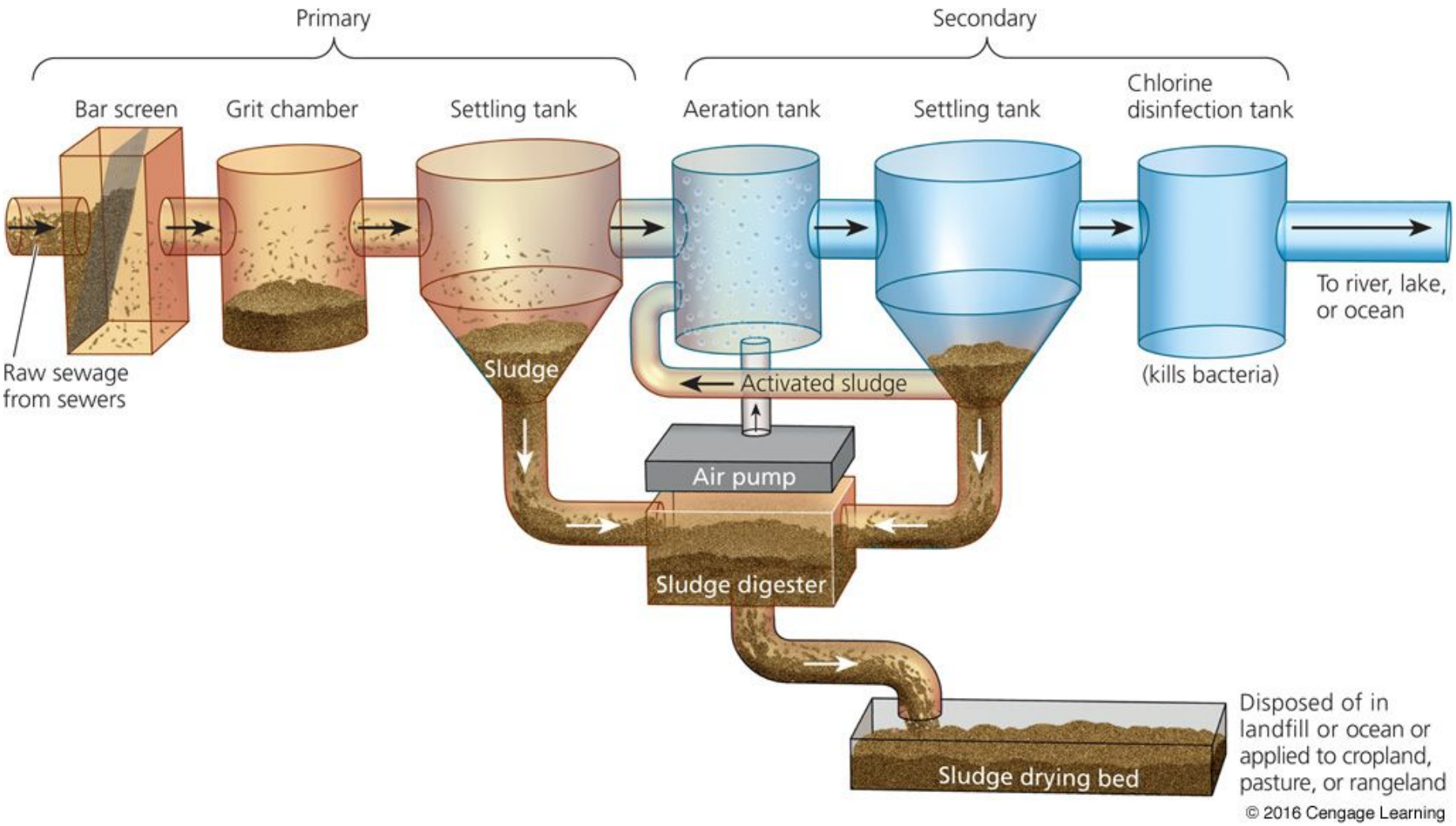
# Household Sewage Treatment

- Rural and suburban areas in the U.S. usually discharge household sewage to a septic tank where bacteria help to decompose waste – partially treated waste water ends up in gravel or crushed stone deposits below the soil surface
  - Water percolates down through the gravel and the soil filters out potential pollutants and decomposes biodegradable materials

# Sewage Treatment Plants

- Waterborne wastes in urban areas from homes, businesses, and storm runoff flow through pipes to sewage treatment plants
  - Primary sewage treatment: a physical/mechanical process
  - Secondary sewage treatment: a biological process

# Primary and Secondary Sewage Treatment



# Sustainable Ways To Reduce and Prevent Water Pollution: Solutions

- Find substitutes for toxic pollutants
- Remove hazardous waste before it reaches sewage treatment facilities
- Use natural sewage treatment methods
- Reduce non-point runoff
- Slow population growth/reduce poverty
- Eliminate air pollution
- Encourage recycling/reuse of resources

# Additional Case Study: NYC Drinking Water/Tour of a Water Treatment Plant

- Some of cleanest, unfiltered drinking water in the country is delivered to people living in New York City and surrounding counties, mainly from two sub-regions of the Lower Hudson watershed

# Additional Case Study: NYC Drinking Water

- Almost a billion and a half gallons fed daily through more than 6,000 miles of pipes, shafts and aqueducts
- Encountered/rectified nonpoint contamination in the Catskill/Delaware Watershed and continues to deliver clean drinking water to NYC
  - How is freshwater fed to NYC?
  - Is it filtered? Why or why not?

# Additional Case Study Continued: Tour of a Water Treatment Plant

- What happens to freshwater after it has been used? (see the EPA virtual tour)
  - Why does surface water generally need more treatment than groundwater?
  - What are the six steps of water treatment?
  - How is water supplied where you live?

# NYC Drinking Water, Water Treatment Plants, and the Three Big Ideas

- Strong protection of NYC's source water sheds assures the city a plentiful supply of clean drinking water
- Clean freshwater is supplied to most U.S. towns and cities by modern water treatment facilities – which clean water efficiently
- Water treatment plants and our own efforts can help reduce water pollution and waste