Water Resource and Cycle

Cunningham and Cunningham (2017)

Chapter 11

Lecture Outline

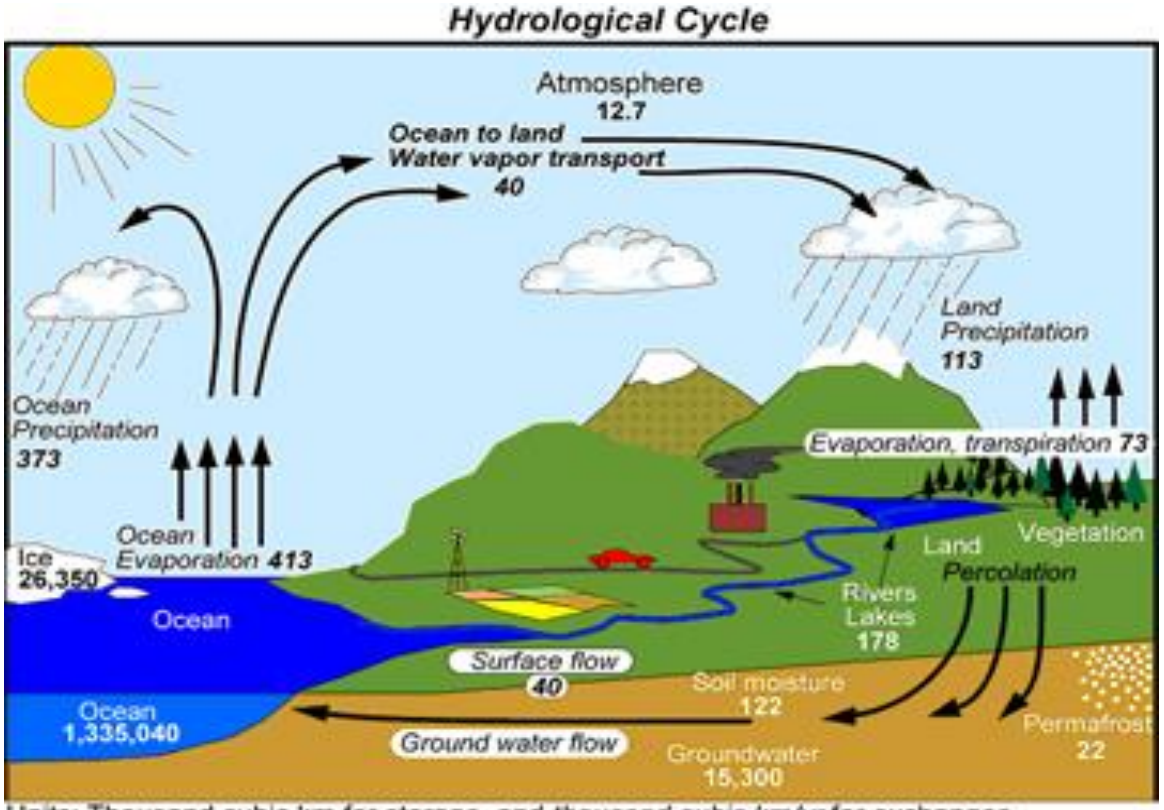
- Water cycle
- Water distribution
- Freshwater, groundwater, rivers and lakes
- Water availability and use
- Increase water supply
- Water resource management and conservation
  - Sustainable water in Singapore
  - Reclaimed water in Hong Kong

Water Facts

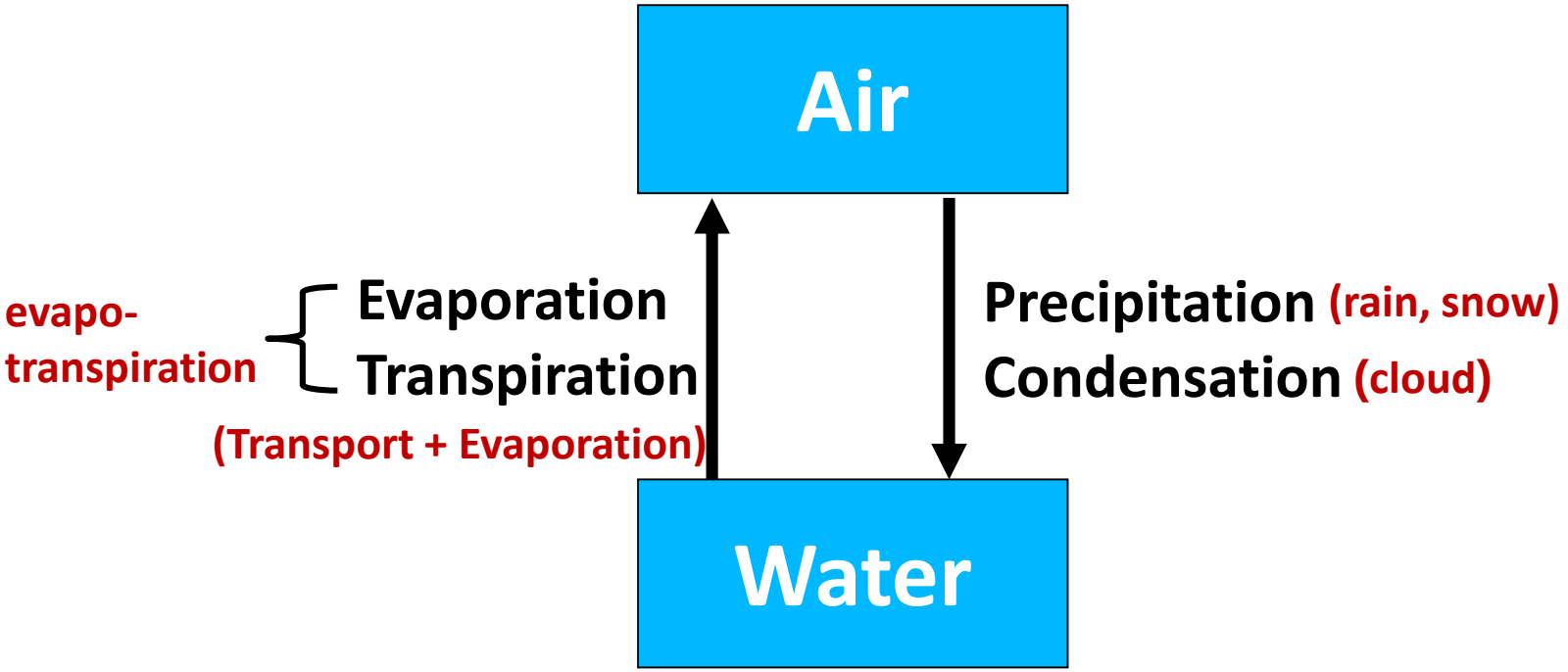
- **Essential for life (60% of our body).**
- **Survive for a few days without water.**
- **Needed for agriculture, industry, transportation.**
- **Clean freshwater is one of our most vital natural resources.**

Hydrologic Cycle Redistributes Water

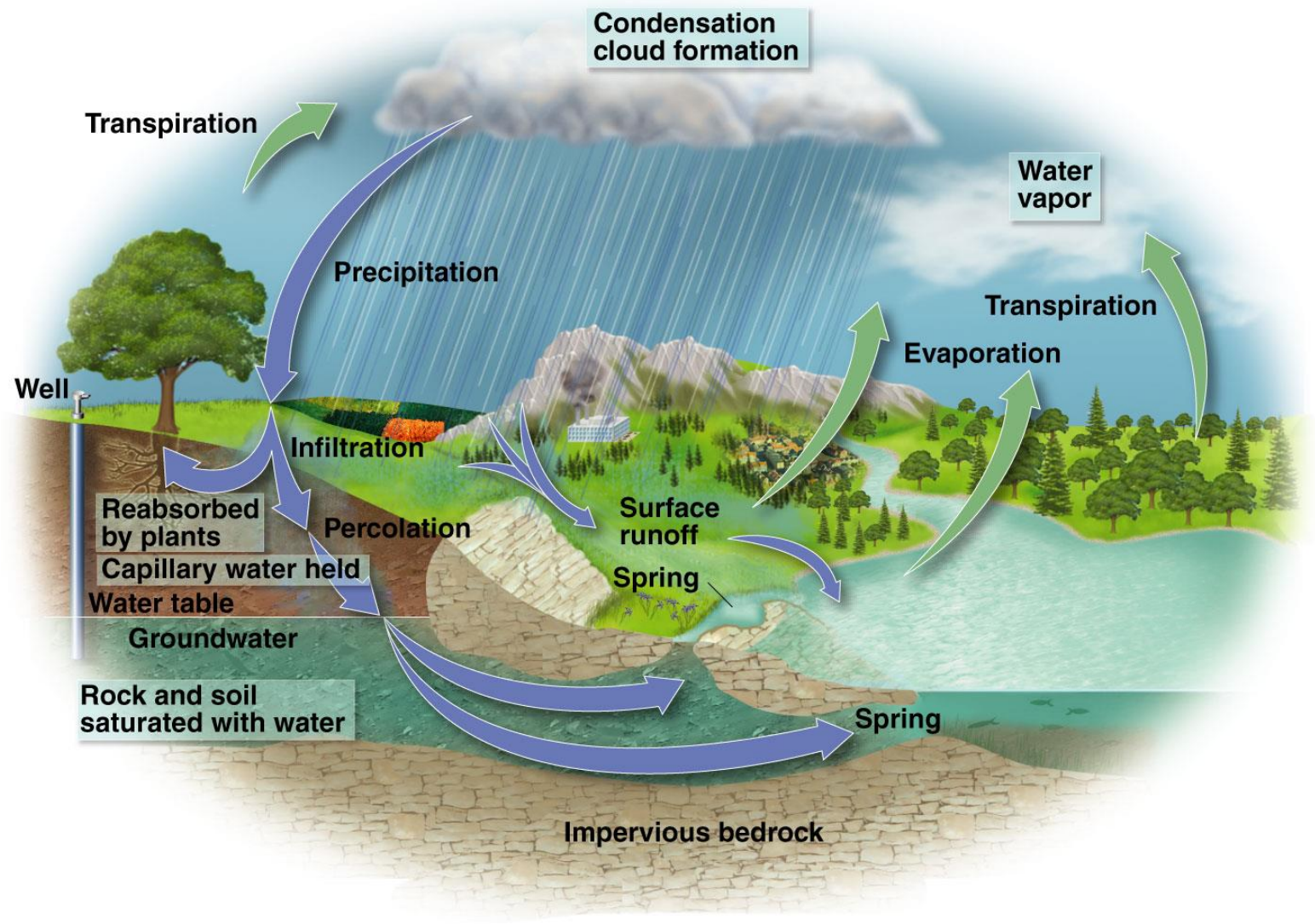
- **Water cycles constantly. Driven by solar energy.**
- **Water evaporates from moist surfaces, falls as rain or snow, and returns to the ocean.**



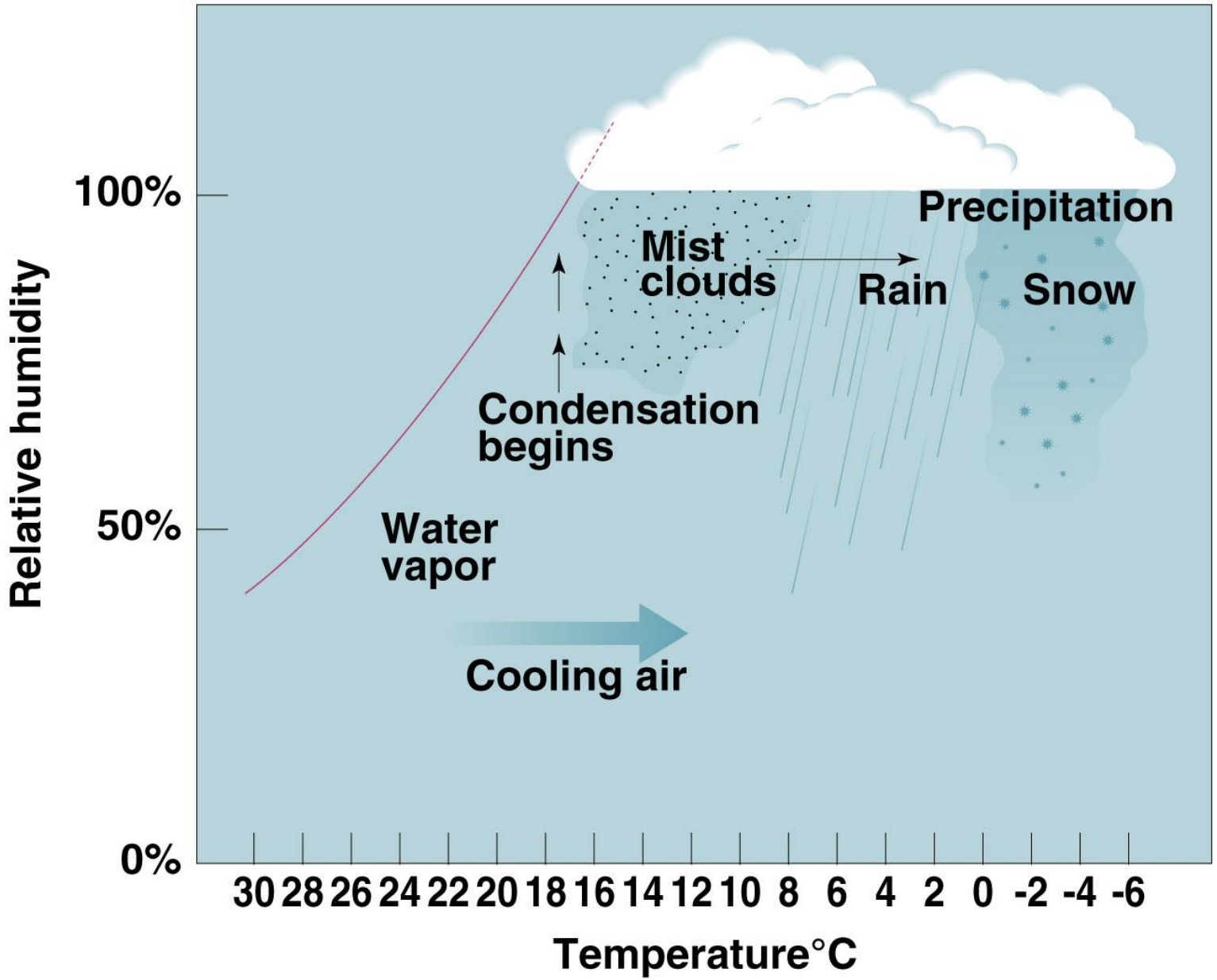
A Simple Cycle



A More Complicated Cycle

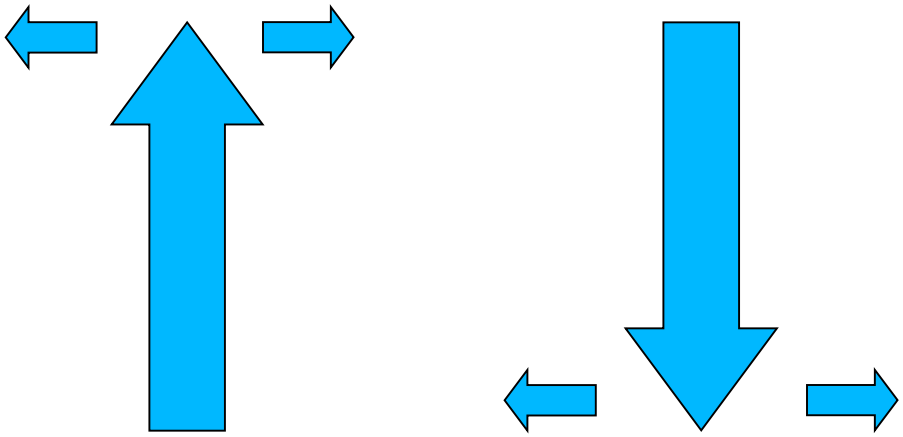


The Three Faces of H_2O

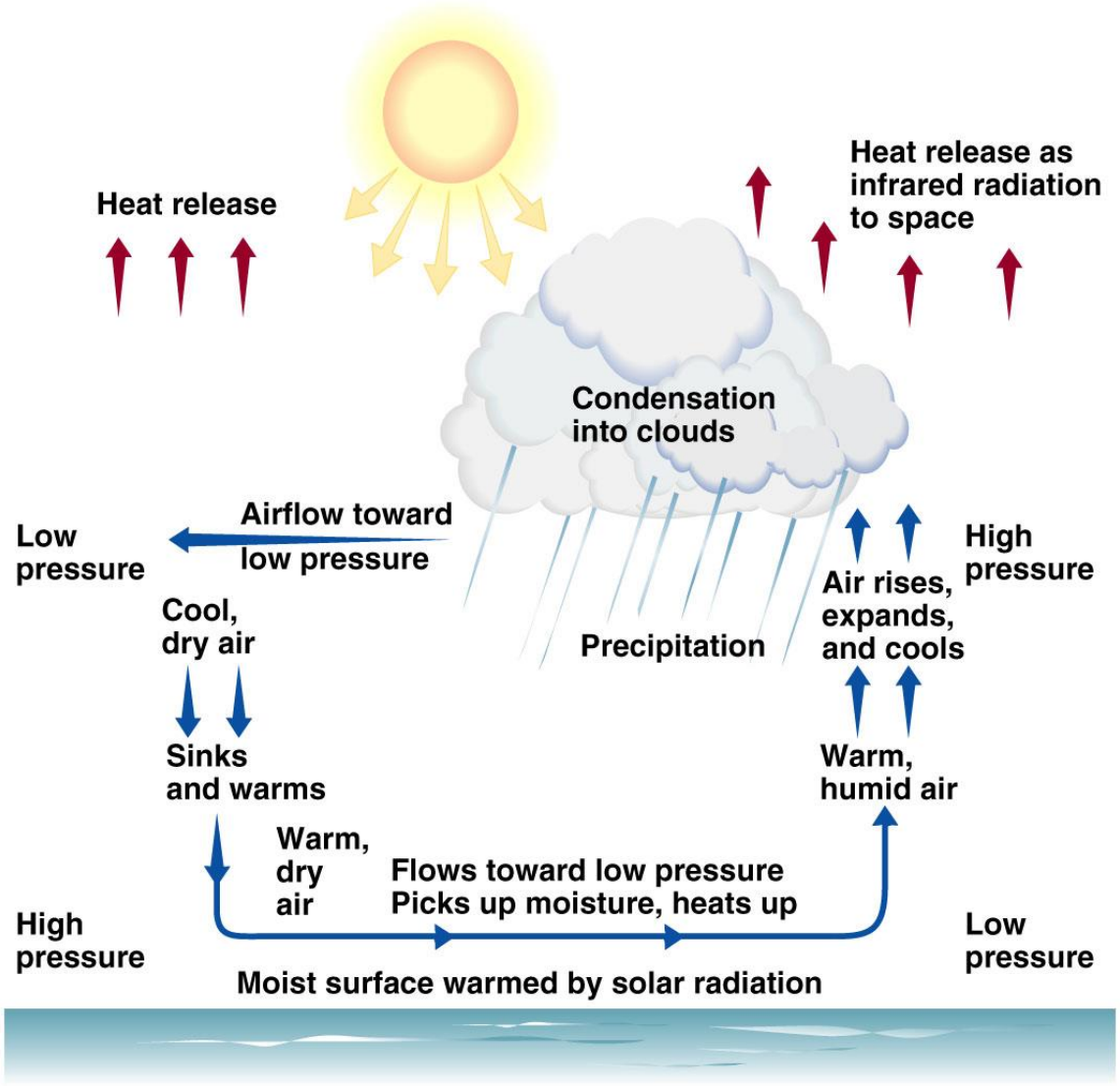


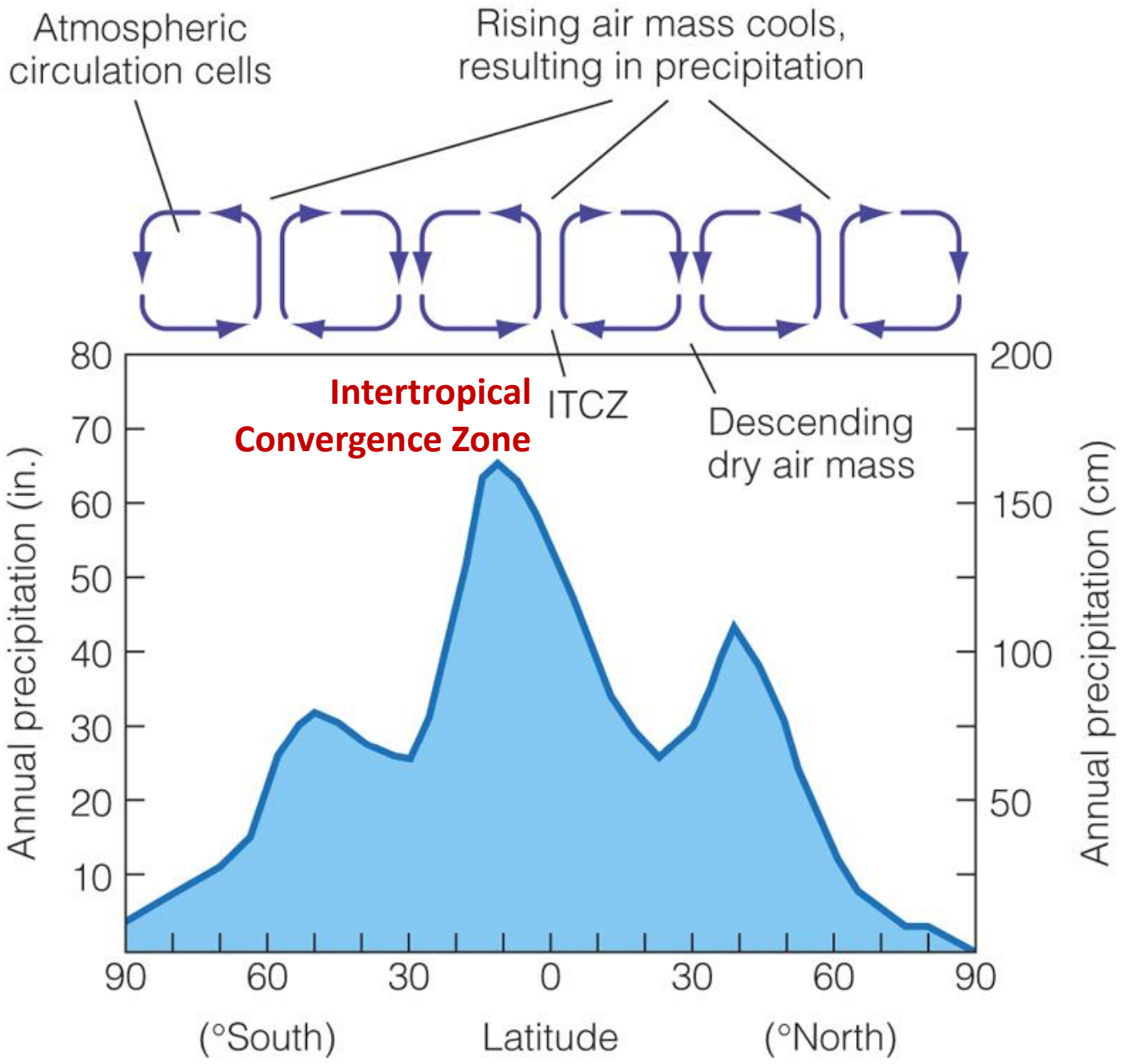
Air Currents Affect Precipitation

- **Rising air cools and condenses, then precipitates.**
- **Descending air warms, causing evaporation, dryness.**
- **Global convection currents cause rising/falling air and affect precipitation**

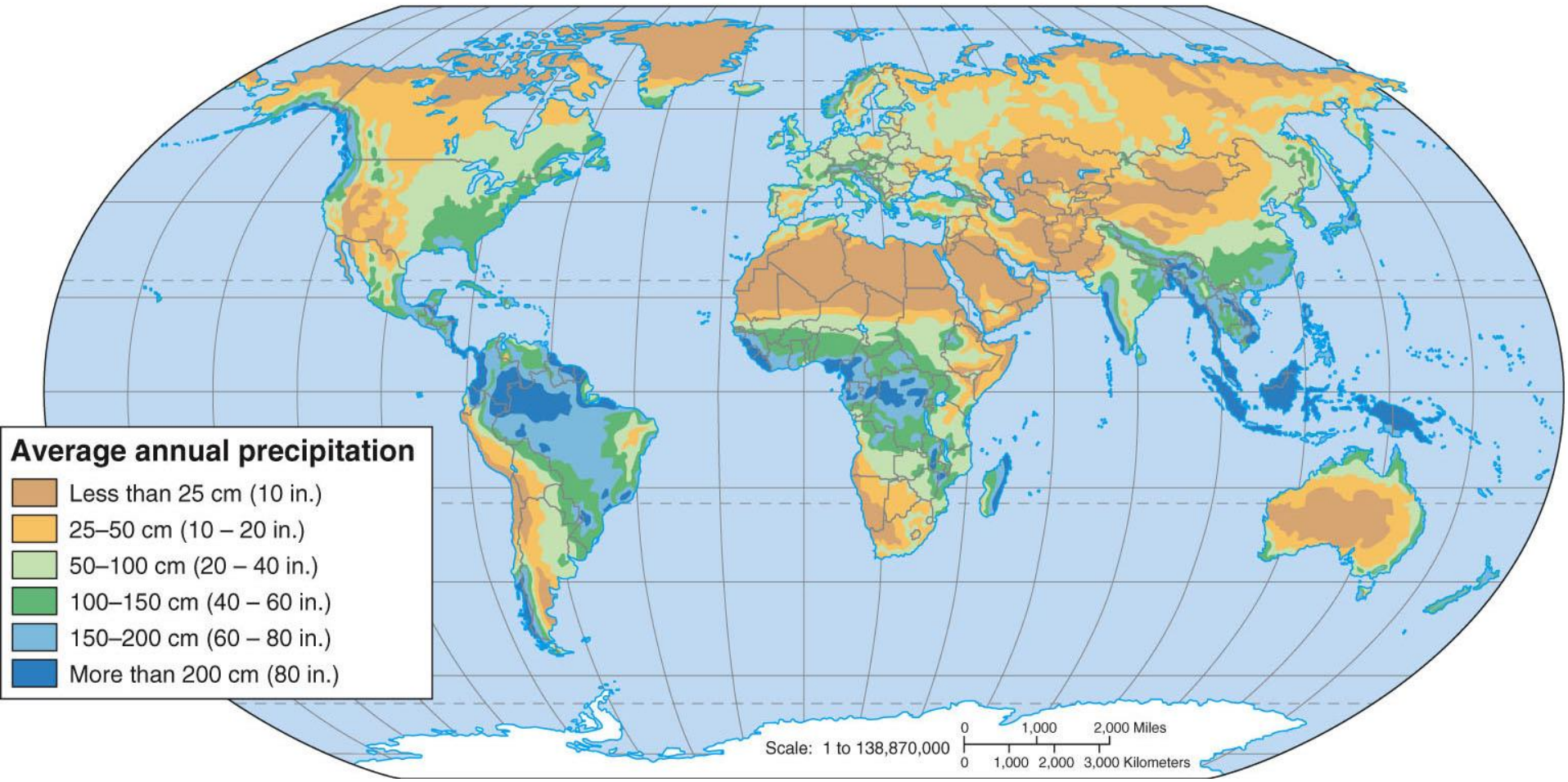


A Convection Cell

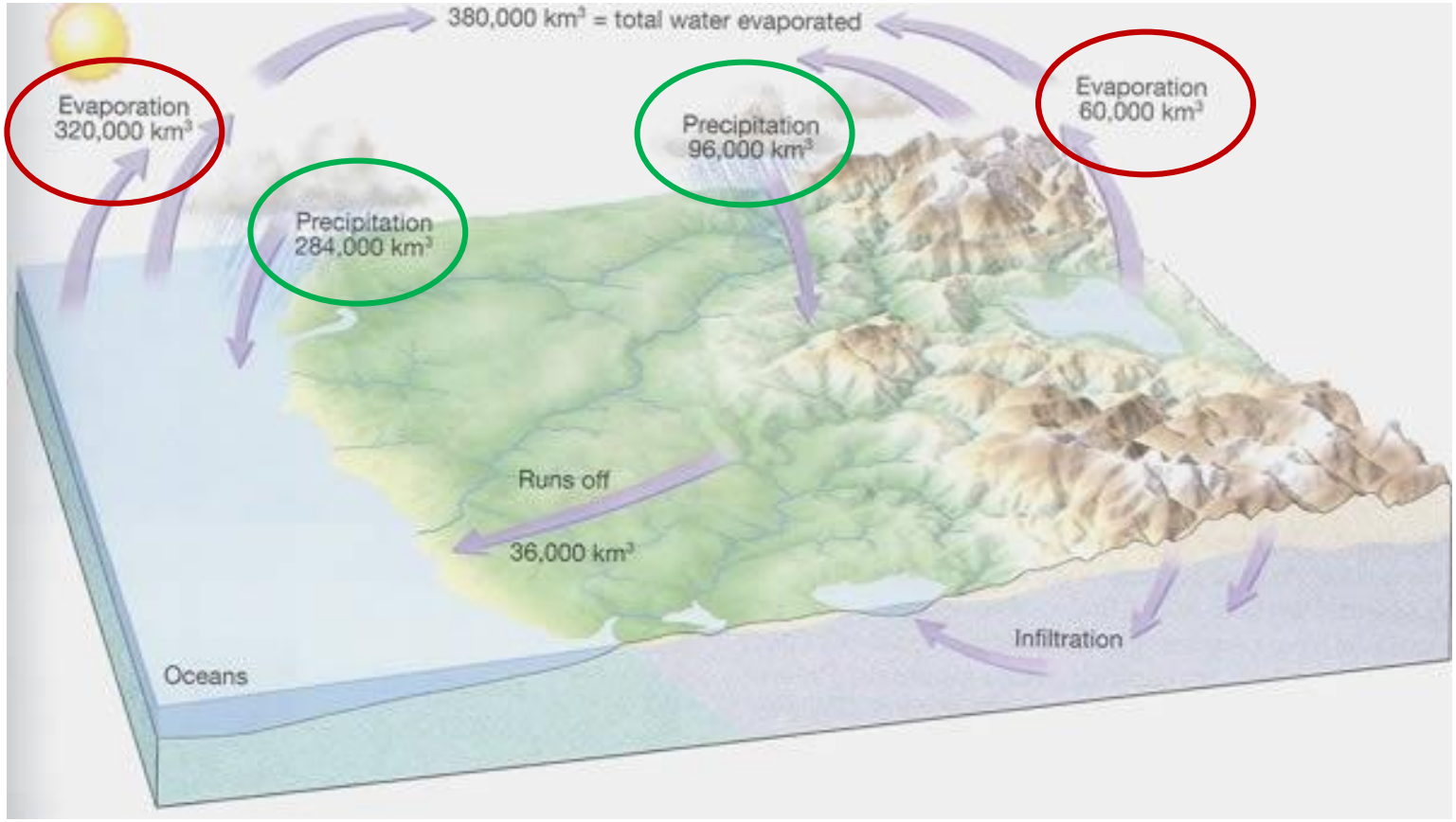




Uneven Distribution of Water Resources



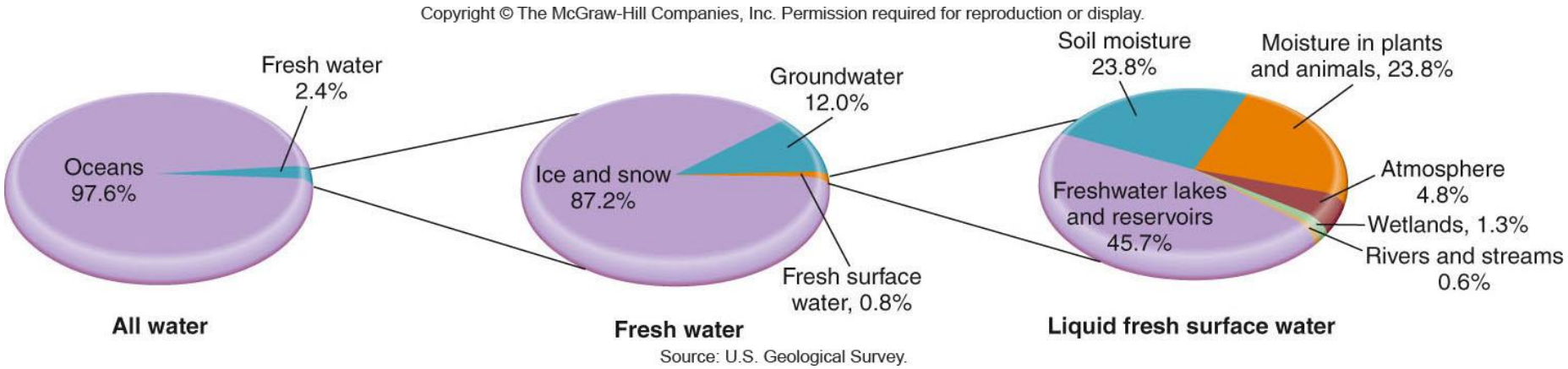
Water Balance in the Hydrologic Cycle



Total water evaporated = 320,000 + 60,000 = 380,000 km^2

Total water precipitated = 284,000 + 96,000 = 380,000 km^2

Major Water Compartments



- **Nearly all the world's water is in the oceans.**
- **Only about 0.02% of the world's water is in a form accessible to us and to other organisms.**

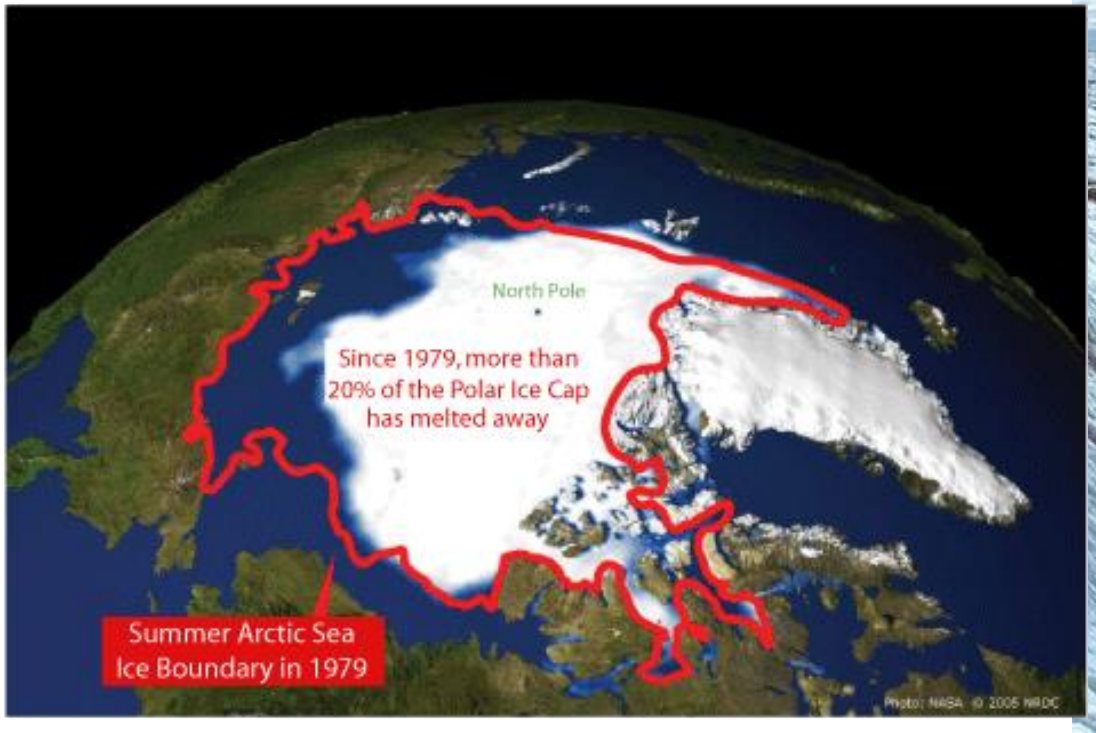
Freshwater: Glaciers, Ice and Snow

- **Of the 2.4% of all freshwater, most are in glaciers, ice caps, and snowfields.**
- **Alpine glaciers and snowfields supply water to billions of people.**

© William P. Cunningham

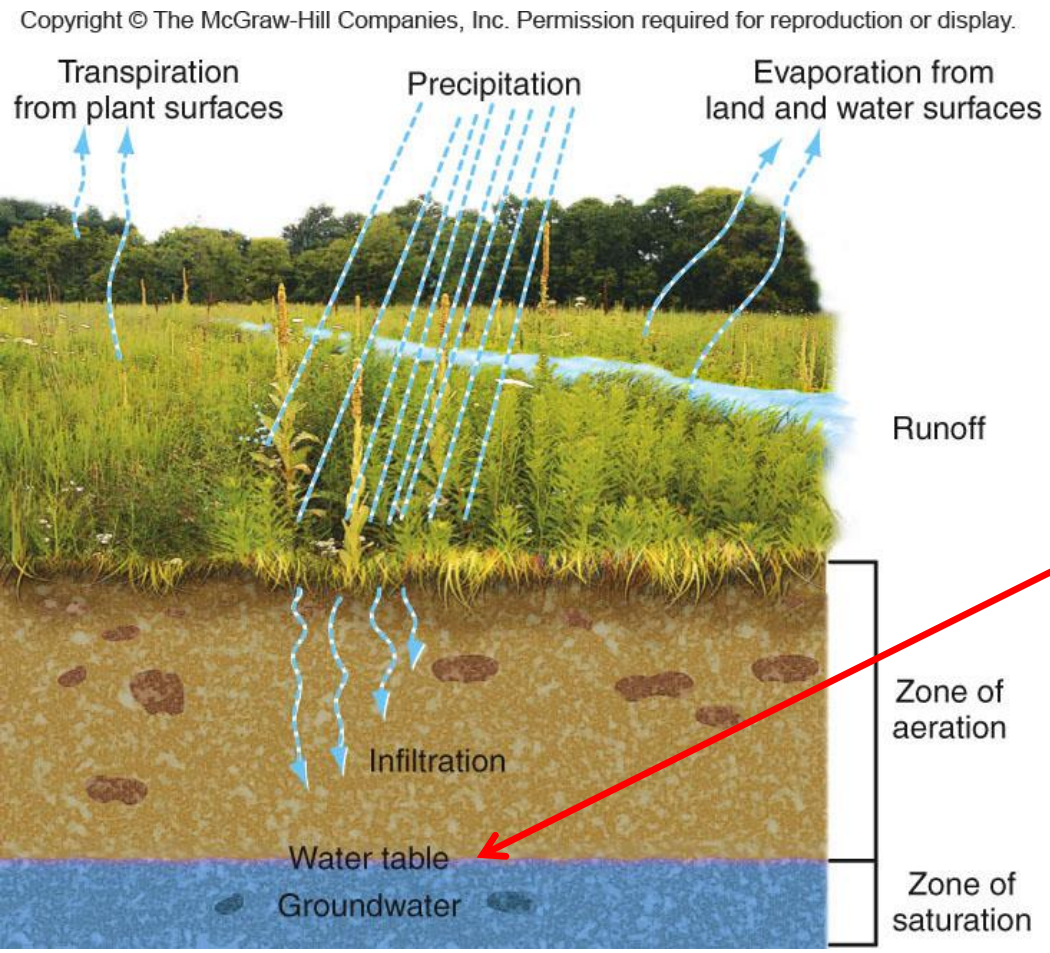
Sea Ice Melting

Summer Arctic Sea Ice Decline



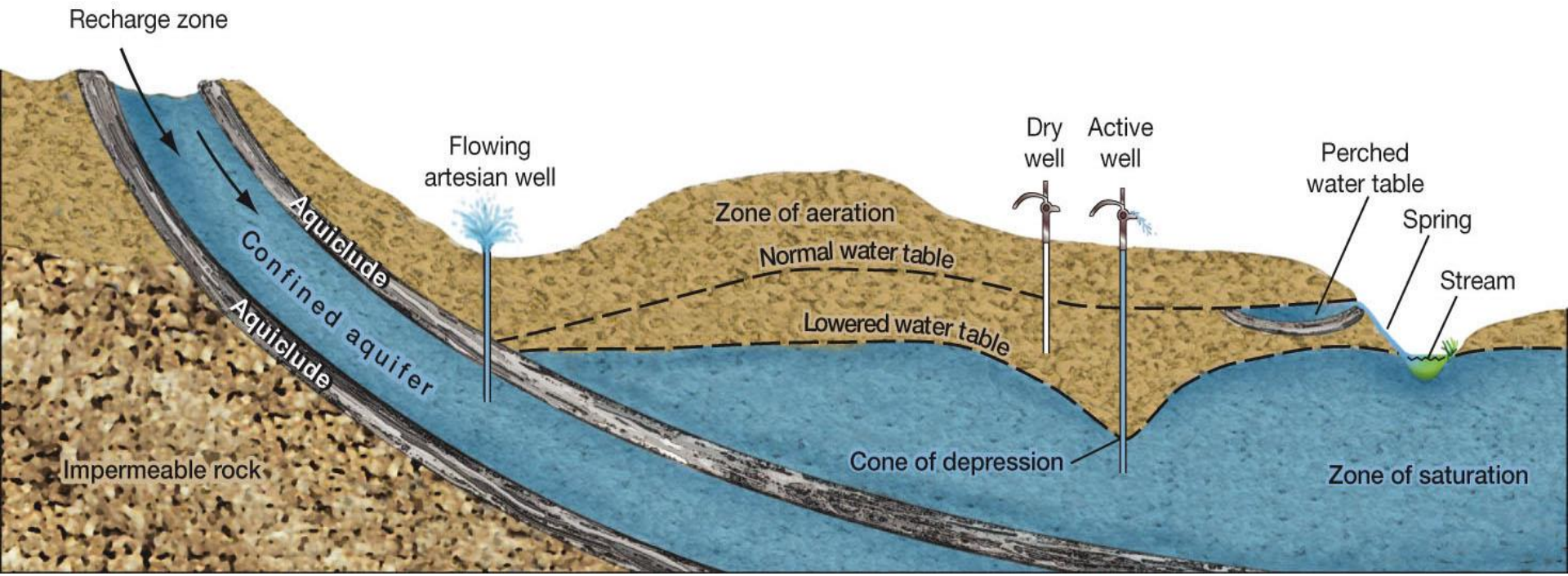
Source: NASA & Natural Resources Defense Council

Groundwater: Storage of Water



- **Zone of aeration: shallow soil containing air and water.**
- **Zone of saturation: lower soil with pores filled with water.**
- **Water table: top zone of saturation supplying most wells.**

Aquifers: Geological Layers with Water



- **Aquifers consist of porous layers of sand or gravel or porous rock. Below an aquifer, relatively impermeable layers.**

Rivers and Lakes

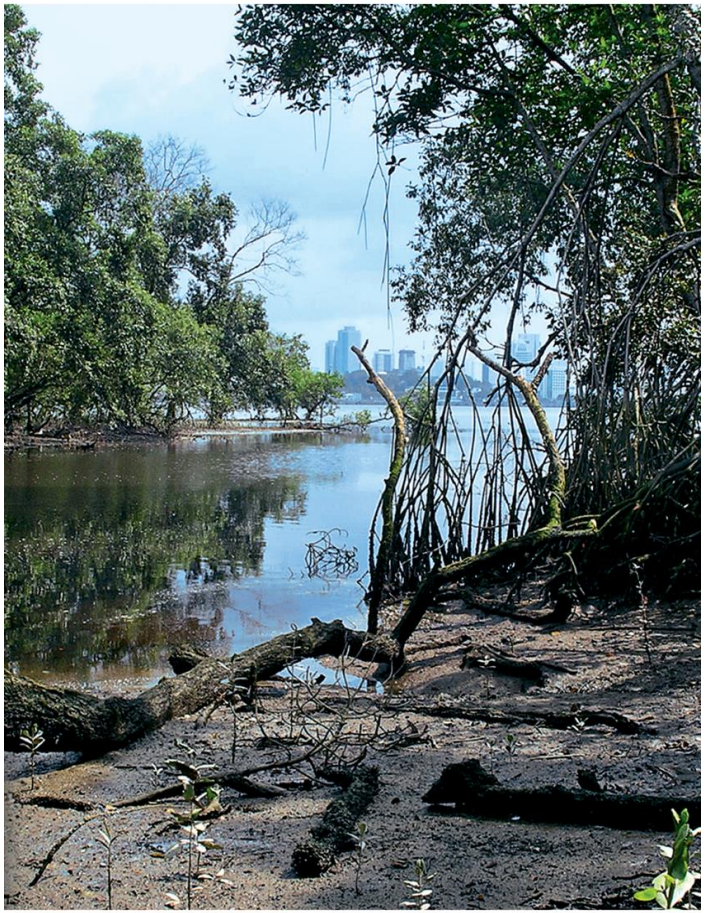
- 16 largest rivers in the world carry half of all surface runoff
- Amazon: carry largest fraction of water
- Lakes: 100 times much water as all rivers and streams combined

Amazon

Lake Superior

Wetlands

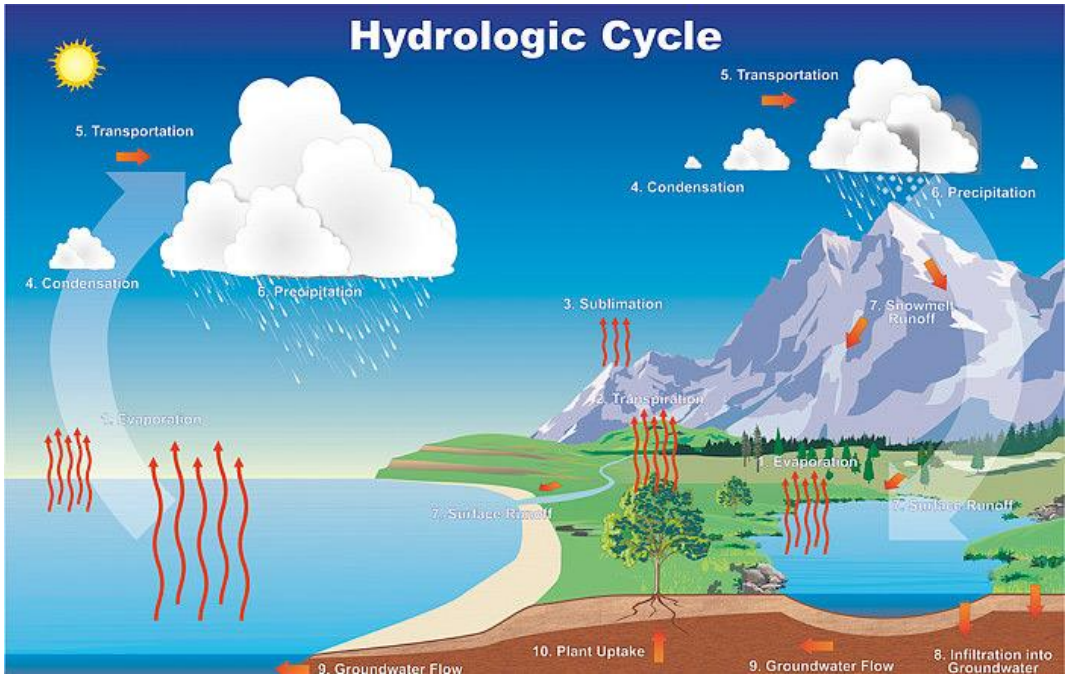
- Lush plant growth stabilizes soil and holds back surface runoff
- Increase infiltration time into aquifers
- Impacts of disturbing wetlands



Courtesy of Mark Davies, University of Sunderland and N. Sivasothi, National University of Singapore

Atmosphere: the Smallest Compartment

- **Contains only 0.001% of the total water supply;**
- **Important mechanism for redistributing water;**
- **Residence time in the atmosphere is 10 days. Some water evaporates and falls within hours.**



Residence time

(Length of time water typically stays in a compartment)

Table 10.2 | Earth's Water Compartments

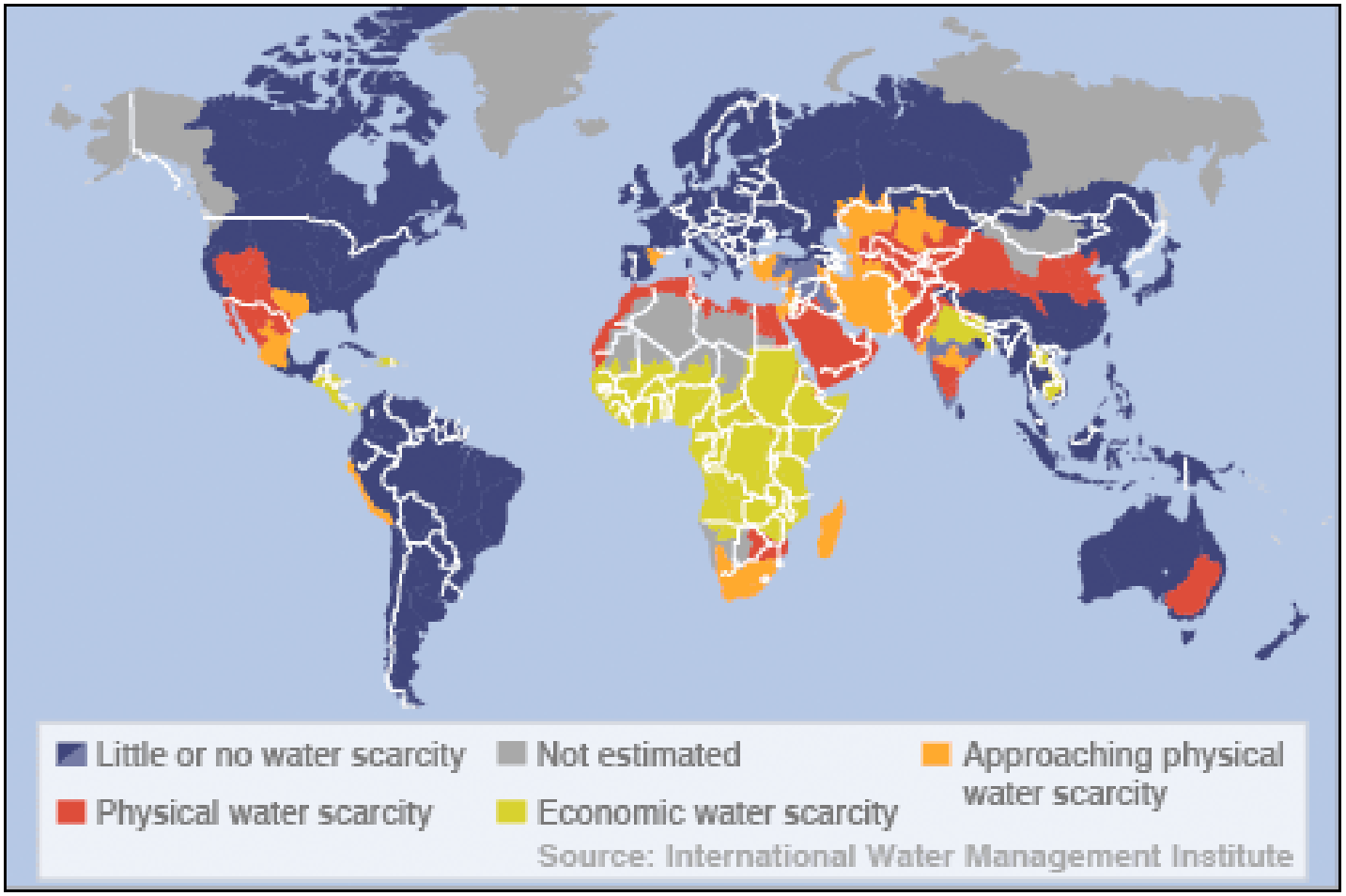
Compartment	Volume (1,000 km³)	Percent of Total Water	Average Residence Time
Total	1,386,000	100	2,800 years
Oceans	1,338,000	96.5	3,000 to 30,000 years*
Ice and snow	24,364	1.76	1 to 100,000 years*
Saline groundwater	12,870	0.93	Days to thousands of years*
Fresh groundwater	10,530	0.76	Days to thousands of years*
Fresh lakes	91	0.007	1 to 500 years*
Saline lakes	85	0.006	1 to 1,000 years*
Soil moisture	16.5	0.001	2 weeks to 1 year*
Atmosphere	12.9	0.001	1 week
Marshes, wetlands	11.5	0.001	Months to years
Rivers, streams	2.12	0.0002	1 week to 1 month
Living organisms	1.12	0.0001	1 week

*Depends on depth and other factors.

Source: Data from UNEP, 2002.

Water Availability and Use

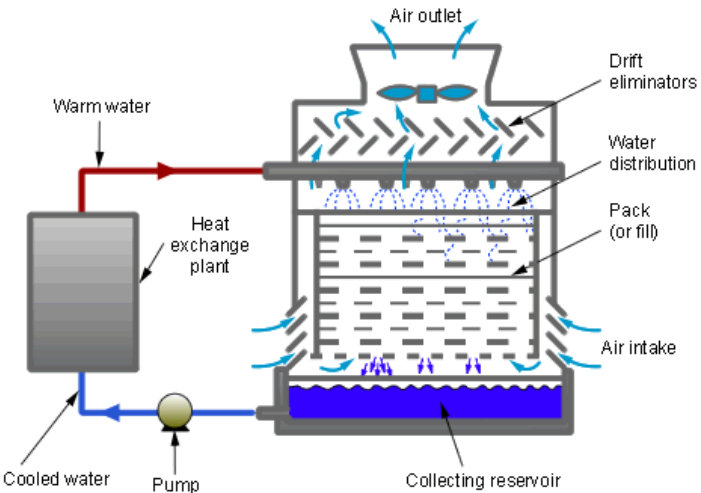
- **Water availability (most important) determines the location and activities of human beings on Earth.**



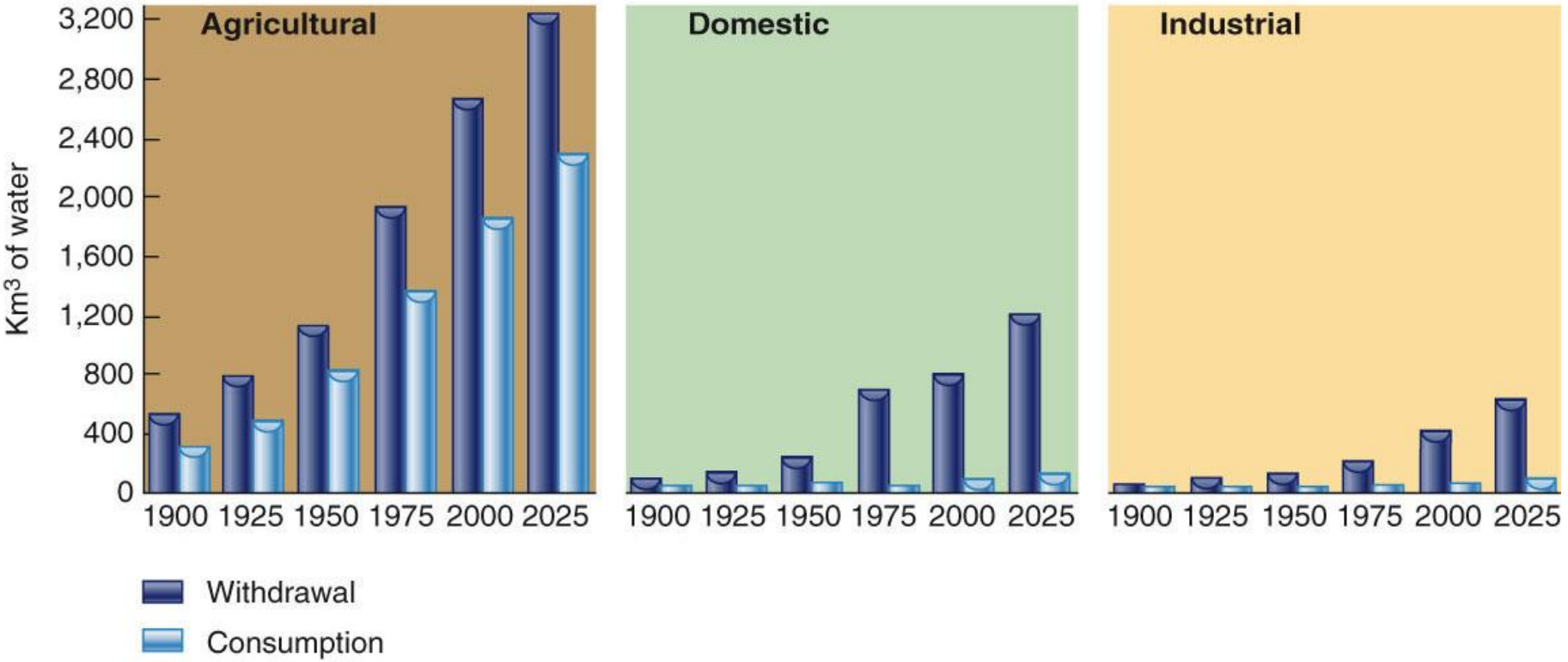
Water Usage

Water usage

- Energy production
- Sanitation
- Heating and air-conditioning
- Food production
- Industrial processes

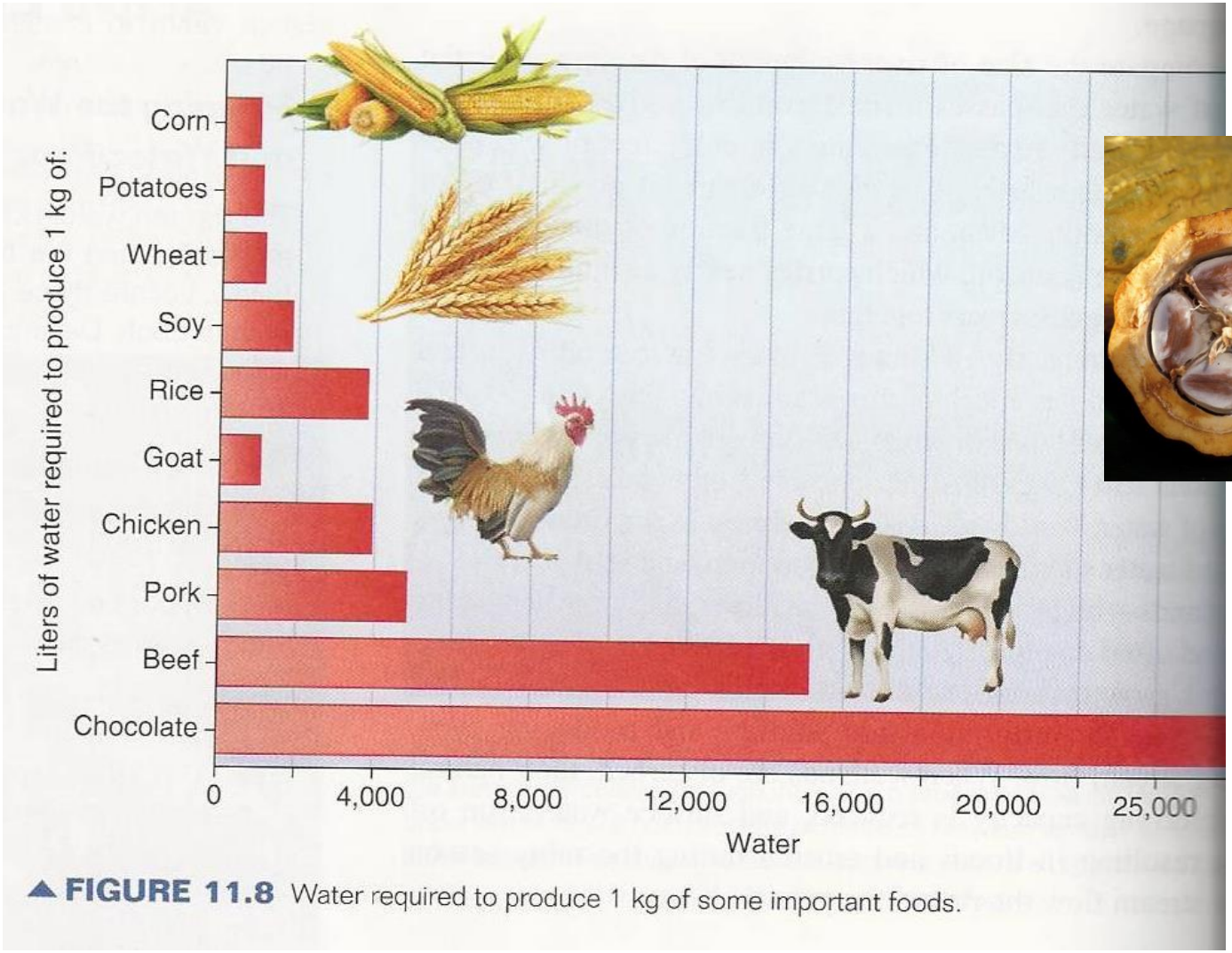


Agriculture: Greatest Water User



Source: UNEP, 2002.

- **Agriculture claims about 70% of total water withdrawal.**



▲ **FIGURE 11.8** Water required to produce 1 kg of some important foods.

Cocoa beans

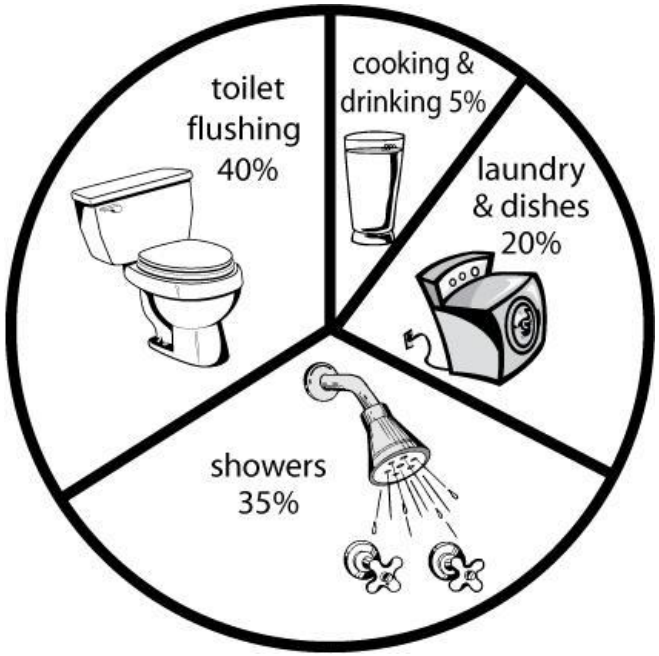
Cattles: feeding with grains (requires water-intensive irrigation system)
Rice: requires 3 times more water than wheat & potatoes
Chocolate: greatest water use (27,000 L → sustain 1350 people)

Industry: 25% of World Water Use

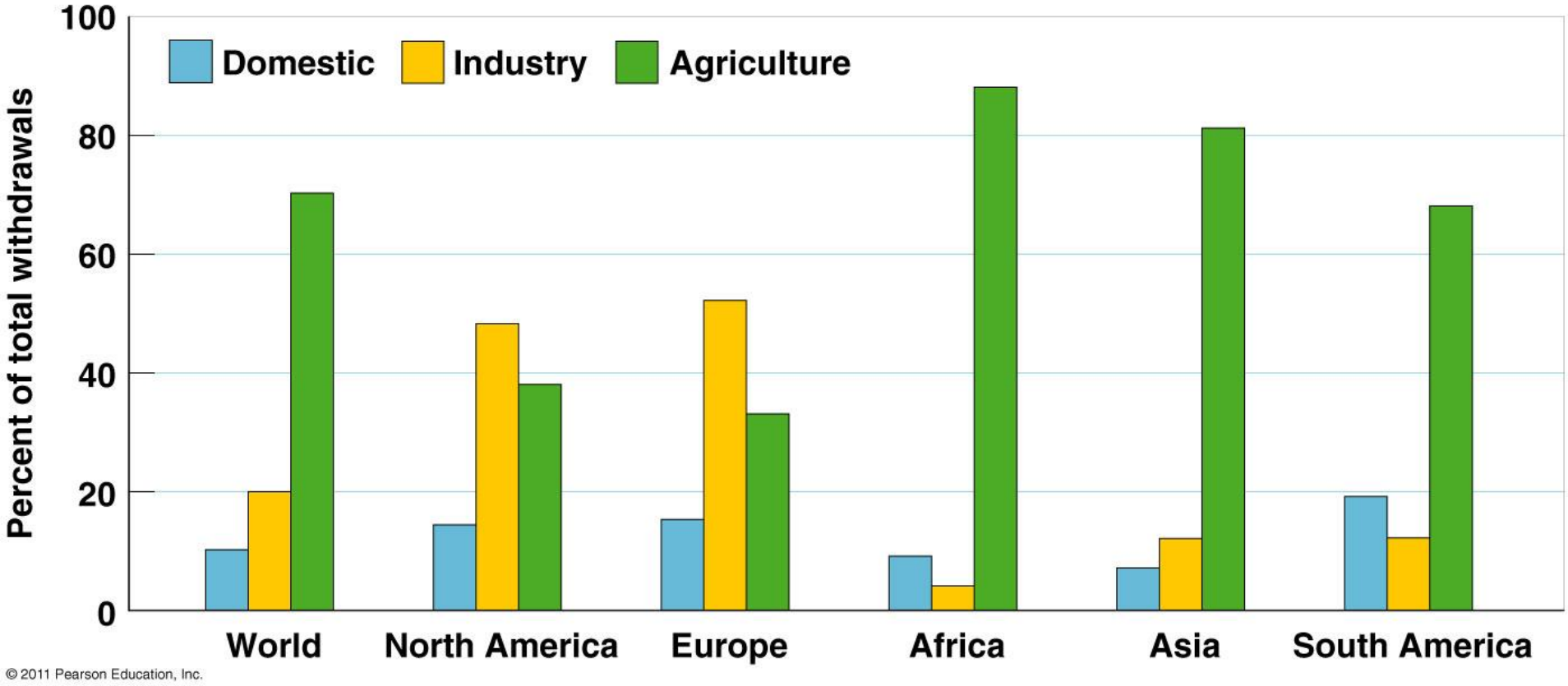
- **Some European countries use 70% of water for industry; some use as little as 5%.**
- **Cooling water for power plants: largest single industrial use of water, typically accounting for 50-75% of industrial withdrawal.**

Domestic: 6% of World Water Use

- **Domestic use: drinking, cooking, and washing.**
- **Amount of water used per household varies.**
- **Developed countries consume 10 times more water daily than those in developing nations.**



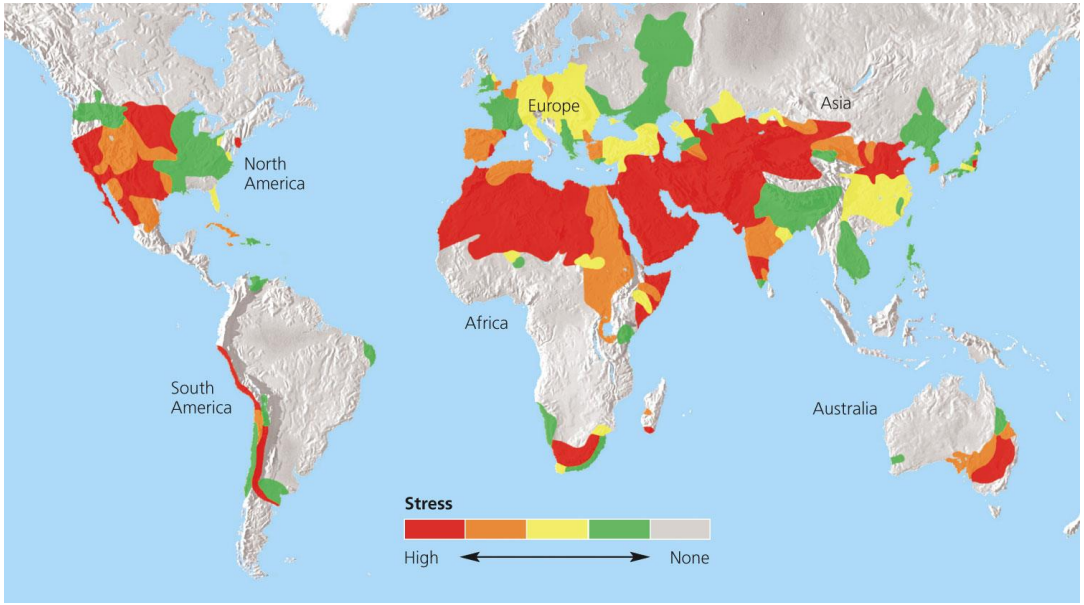
Regional Usage of Water



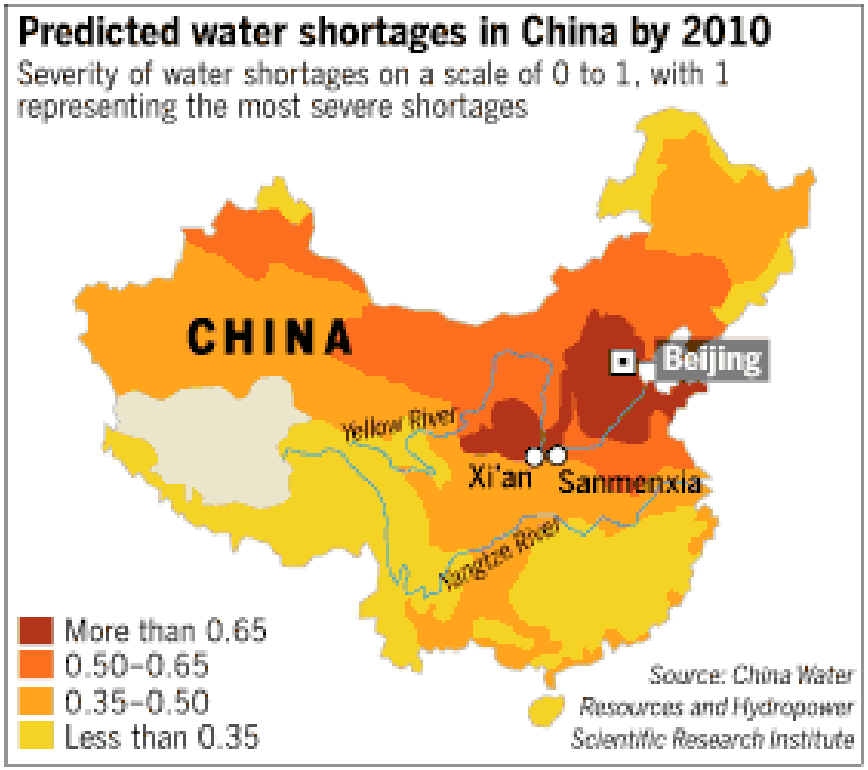
Freshwater Shortages

Water Scarcity

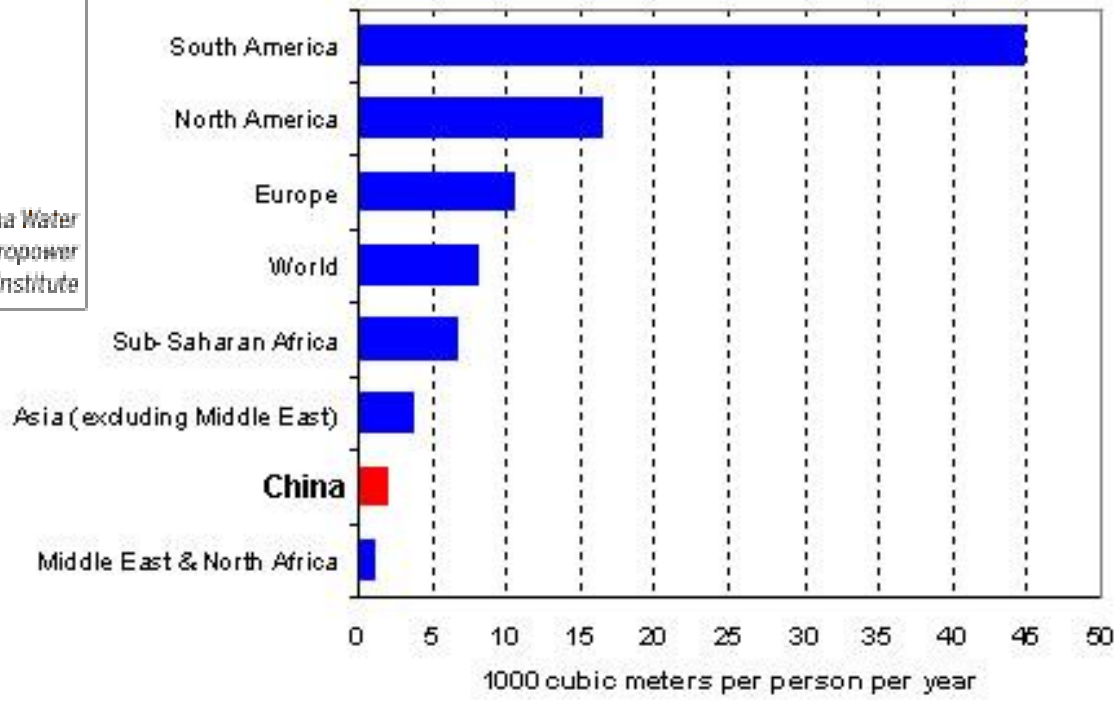
- **>1 billion people lack access to safe drinking water and 2.5 billion don't have adequate sanitation.**
- **2025: 2/3 people in water-stressed countries.**
- **The greatest threats for poor people is to access clean, safe water**



Water Risk in China



Q: Reasons of water scarcity in China? Which area has the highest risk?



Pollution Driving Scarcity

- **43% of water in the seven main rivers are unsafe for human consumption**
- **Industrial wastewater discharge, untreated domestic sewage, non-point source from agriculture**
- **What's more?**
  - **Climate change**
  - **Over-exploitation (population increase)**
  - **Contamination of underground water**

News / Hong Kong / Health & Environment

Pollution in Dongjiang river: Chinese officials 'not aware' of source of chemicals and 'may consider monitoring levels'

Chinese authorities may consider monitoring PFC levels, say water quality advisors

PUBLISHED : Thursday, 10 December, 2015, 6:11pm
UPDATED : Friday, 11 December, 2015, 11:06am

COMMENTS: 4

Ernest Kao

170 SHARES

Chinese officials are "not aware" of any manufacturing activity that may have discharged harmful perfluorinated compounds (PFCs) into the Dongjiang river but may consider monitoring their levels, Hong Kong government water quality advisors say.

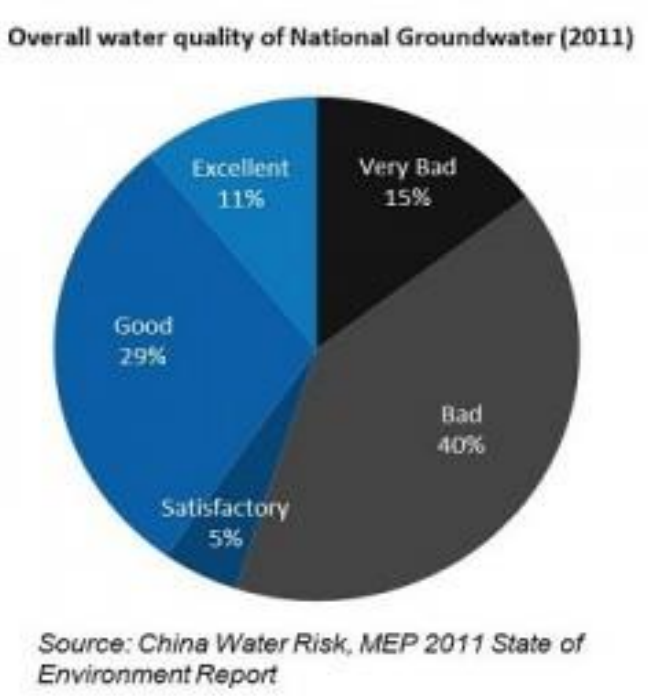
Chan Hon-fai, who chairs the Water Supplies Department's advisory committee on water resources and the quality of supplies, said his group had conveyed concerns to officials in Huizhou during a one-and-a-half day visit to Dongjiang water supply facilities across Guangdong province earlier this week.

"We have conveyed our message to officials in China. Honestly, they have no knowledge of PFC and haven't done anything yet," he said. "They have taken our

Source: South China Morning Post (10 Dec 2015)

Ground Water Pollution

- **Remain serious with over 55% of groundwater falling in the bad and very bad category**
- **Water resources still not fit for human consumption**
  - **58% of 26 key lakes and reservoirs**
  - **55% of national groundwater**
  - **39% of the seven major basins**



Difficult to Access Clean Water

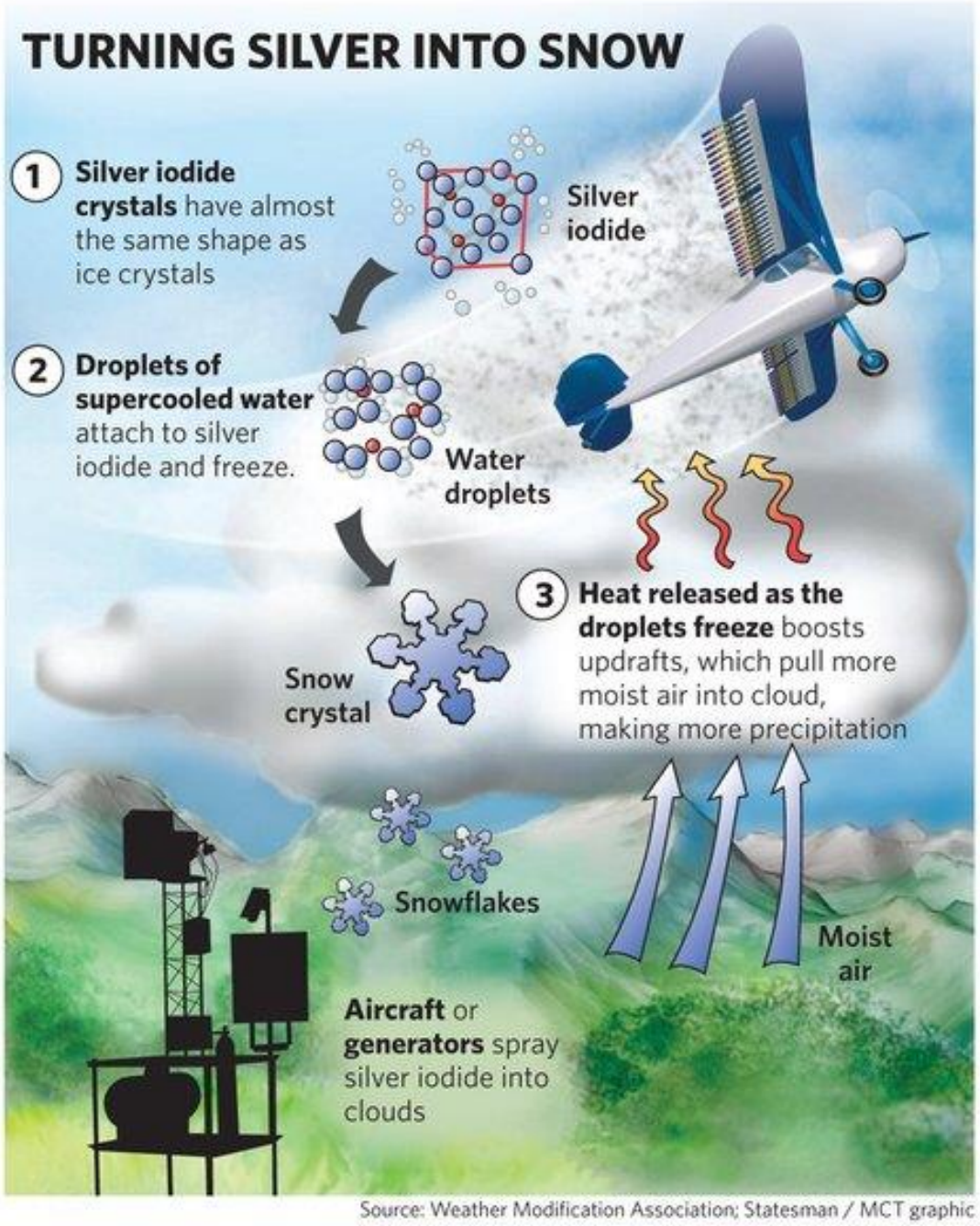
- **Mali: 88% of population lack safe water**
- **Ethiopia: 94%**
- **Rural people have less access to clean water**
- **1.6 million people (90% children under age of 5) die from diarrhea**

Living in an Age of Thirst

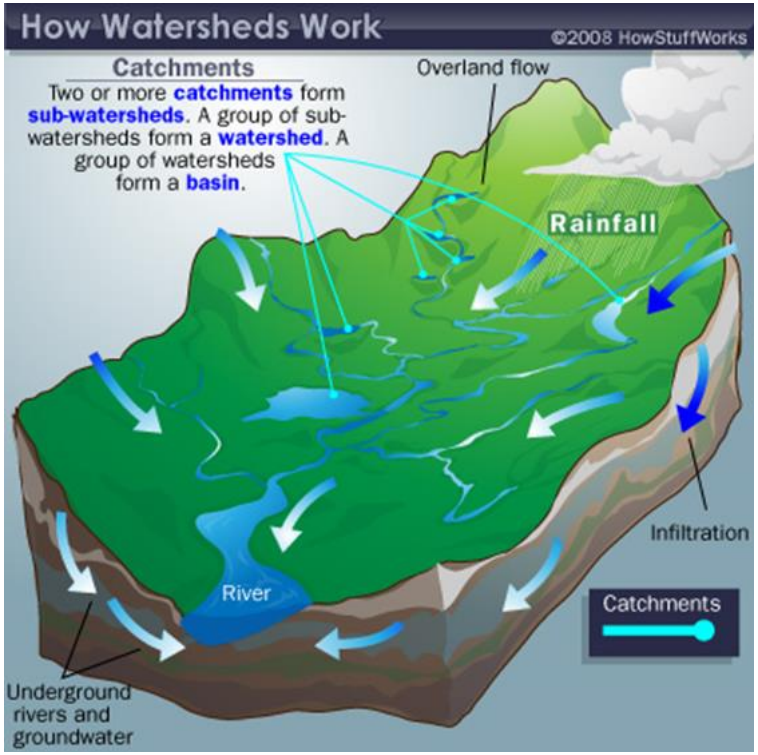
- **Climate change exacerbate water scarcity**
- **UN Millennium Development Goals is to reduce by one-half of people without reliable access to clean water**

How Can We Increase Freshwater Supplies?

Cloud Seeding



Watershed/ Reservoirs

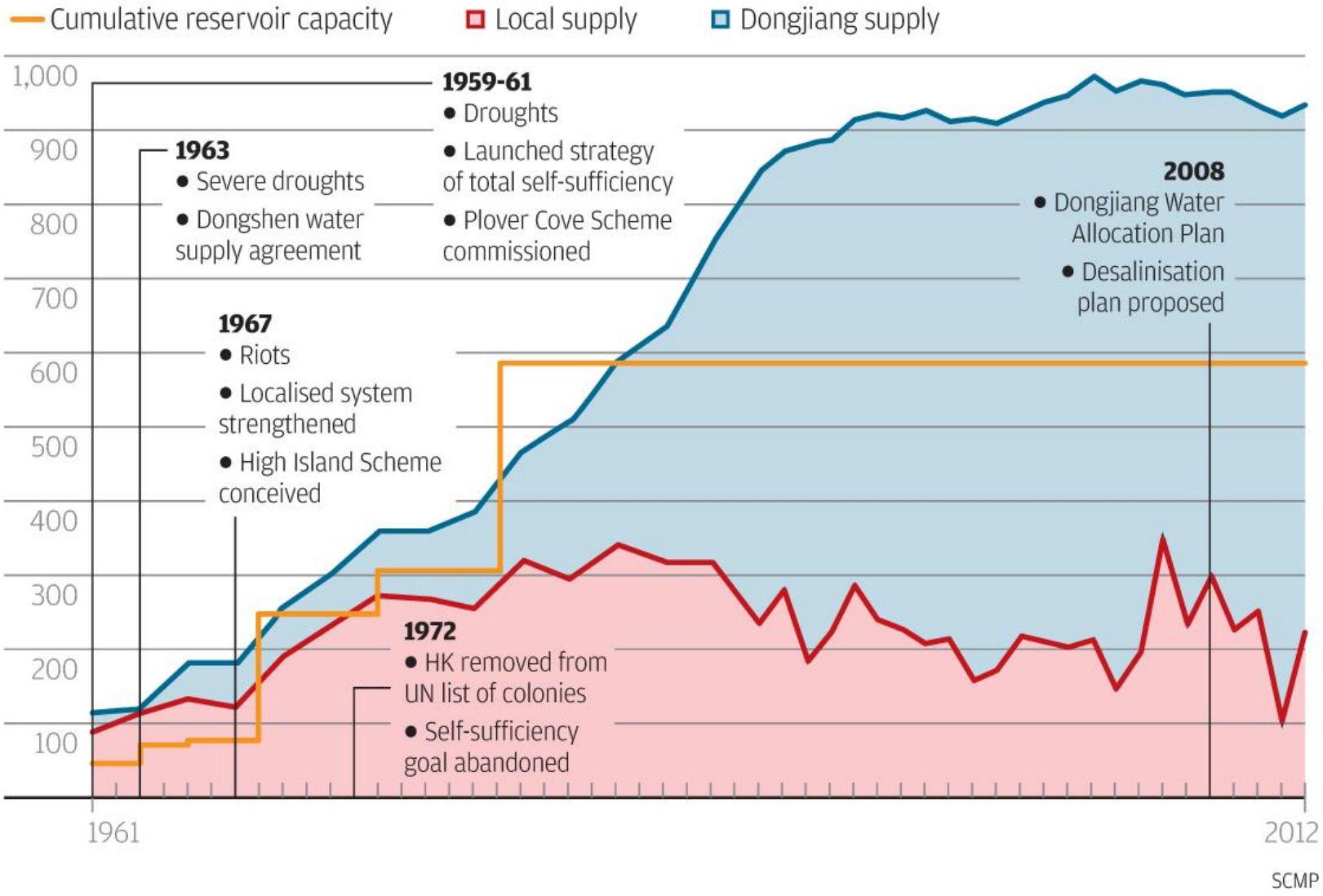


Watersheds

High Island Reservoir in Hong Kong

Hong Kong's total fresh water and cumulative reservoir capacity

Quantity (millions of cubic metres)

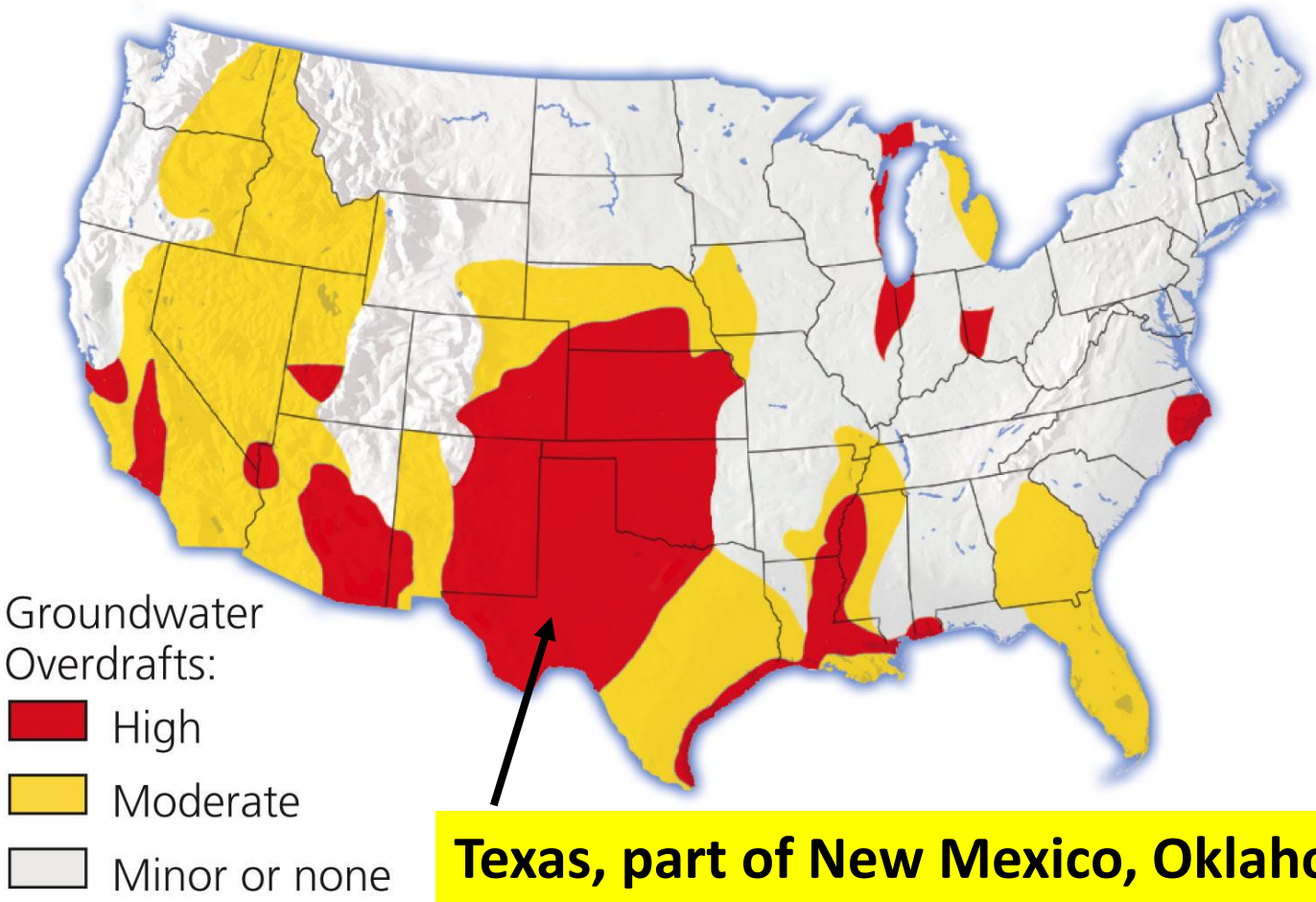


SCMP

Groundwater is Being Withdrawn Faster than it is Replenished

- **Aquifers provide drinking water for nearly half of the world's people**
- **Most aquifers are renewable resources unless their water becomes contaminated or is removed faster than it is replenished by rainfall**
- **Rate of pumping water from aquifers (mostly to irrigate crops) exceeds the rate of natural recharge from rainfall and snowmelt**

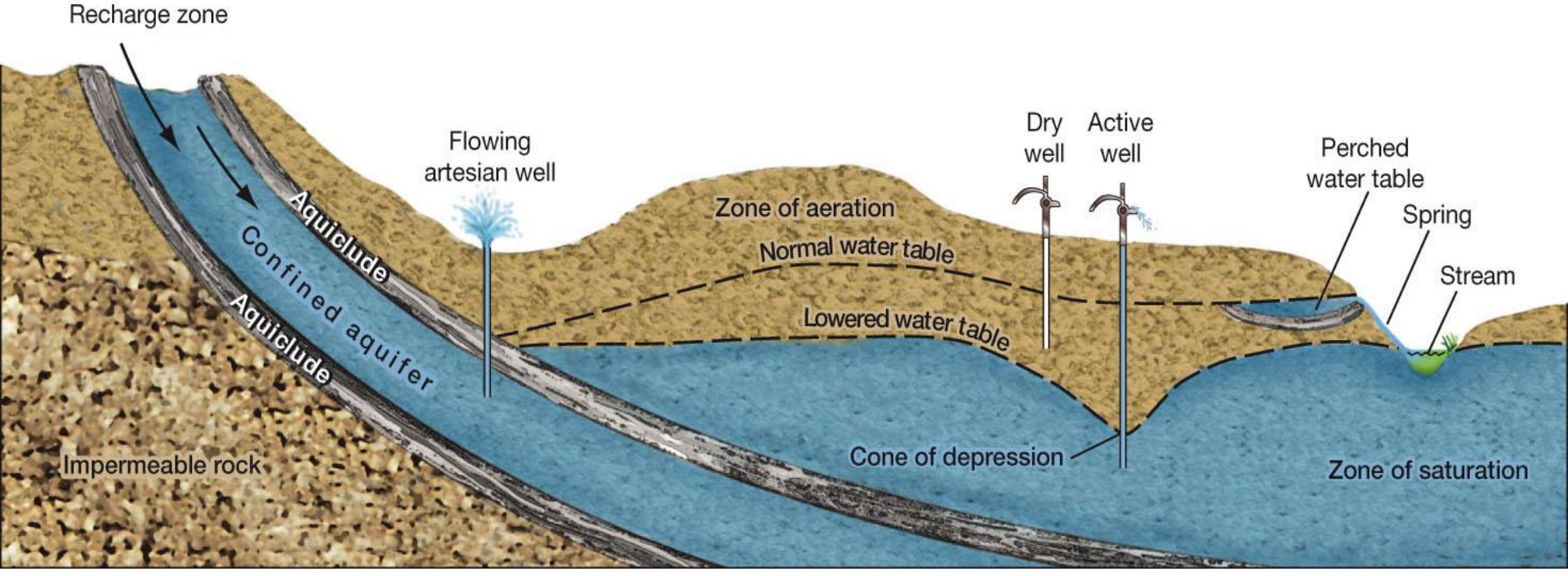
Groundwater Overdrafts in USA



Texas, part of New Mexico, Oklahoma

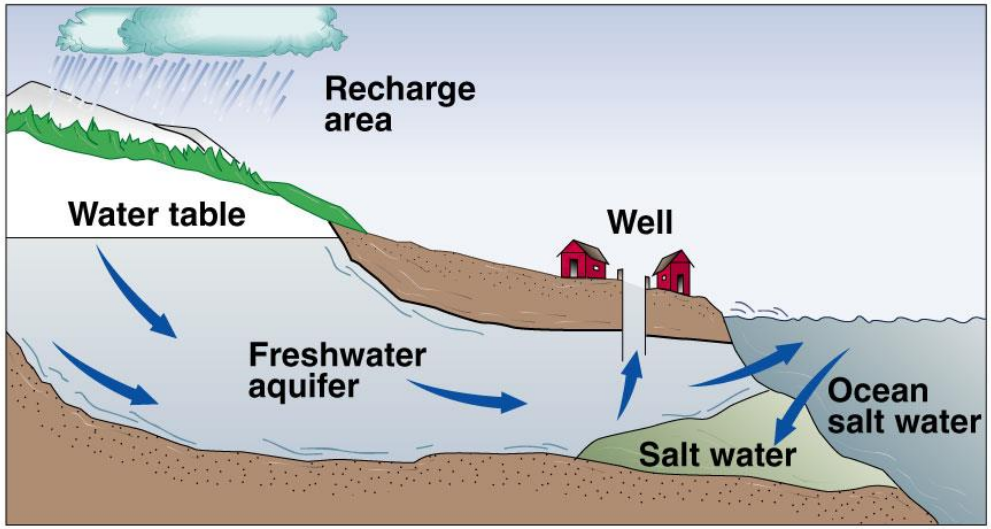
Groundwater Supply Depleted

- **Water withdrawal allows aquifers to collapse, leading to sinking of the ground surface.**



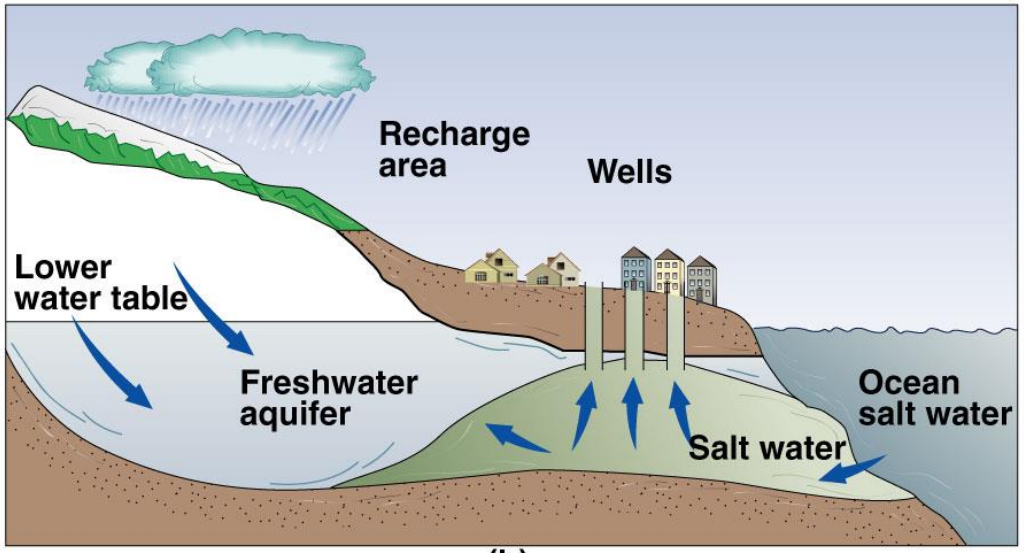
Aquifer Depletion and Saltwater Intrusion

- High water tables keep pressure in the aquifer.
- Lowering the water table reduces pressure.



(a)

- A serious problem in many European countries along the Mediterranean coast.



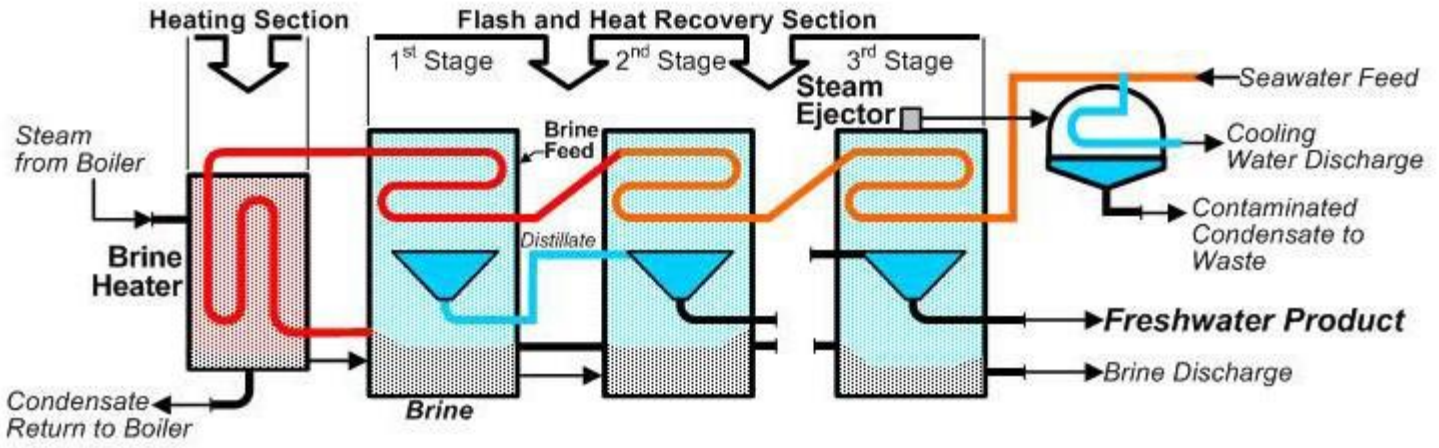
(b)

Concerns of Tapping Deep Aquifers

- **Non-renewable and cannot be replenished on a human time-scale**
- **Limited knowledge on geological and ecological impacts of pumping freshwater from deep aquifers**
- **No international treaties that govern right use of aquifers**
- **High cost of tapping deep aquifers**

Thermal Desalination

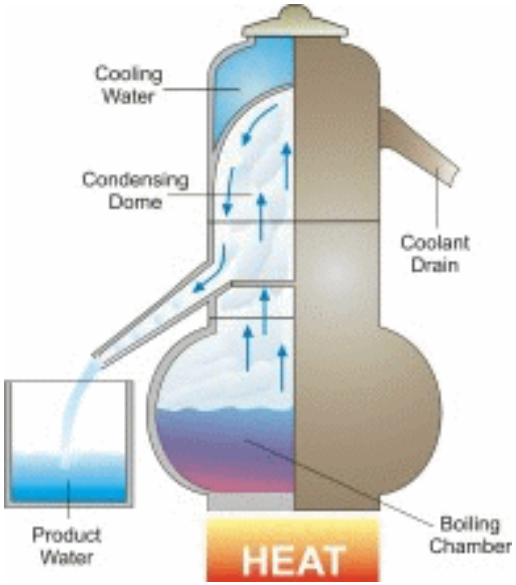
- **Evaporation and condensation at high temperature**
- **Produce large amount of water**
- **Exclusive used in Arabian Gulf region**

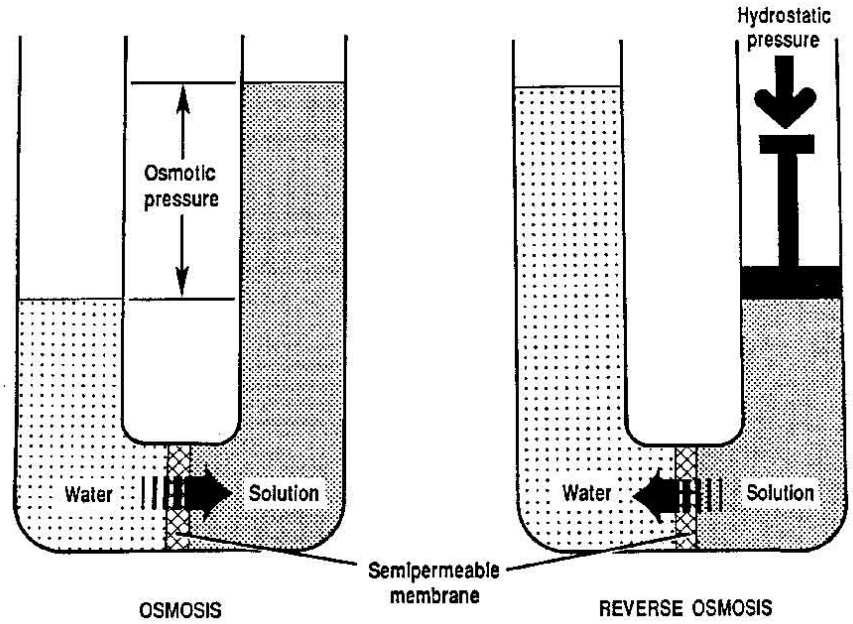


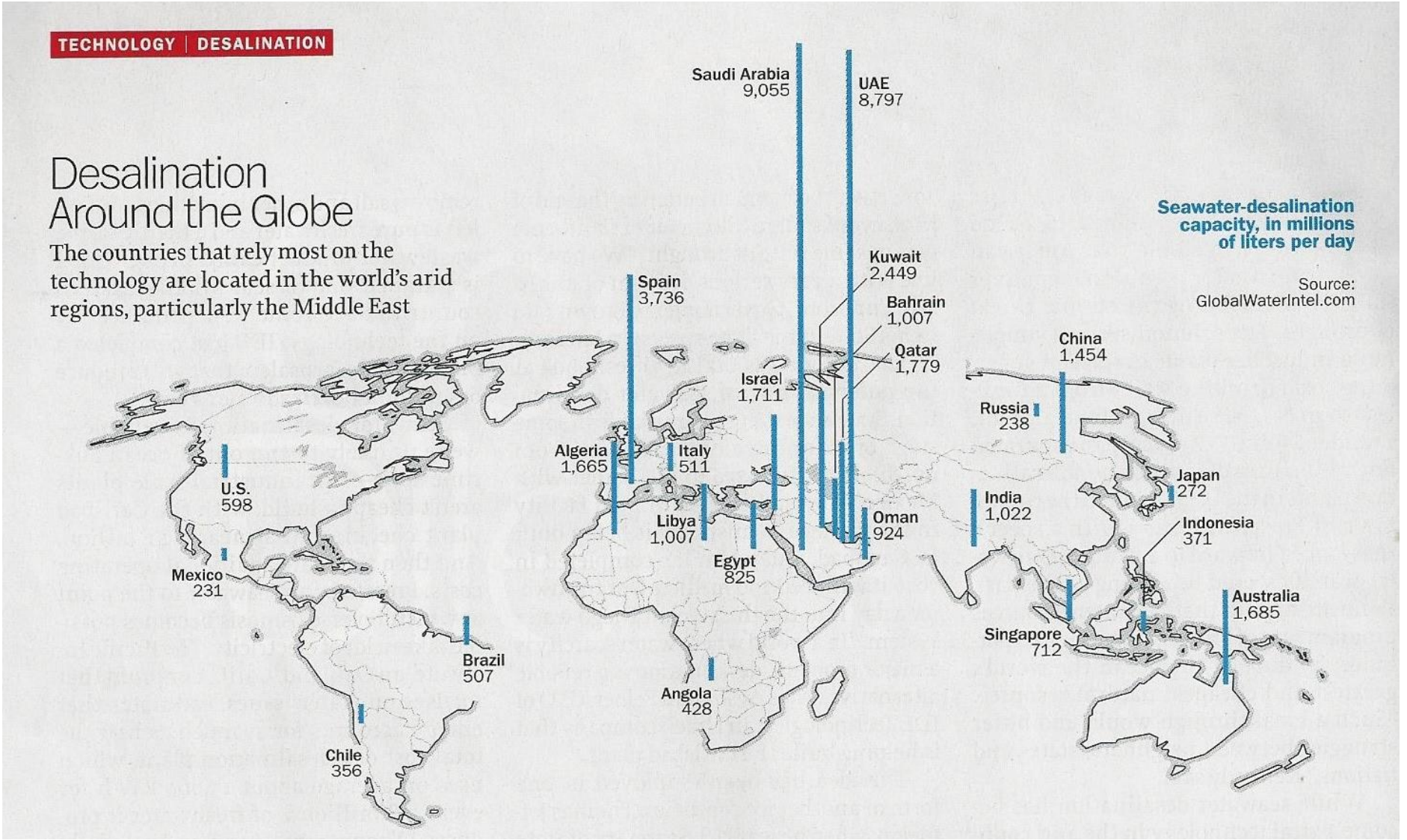
Source: Water Research Foundation

Membrane Desalination

- **Remove dissolved salts from ocean water or from brackish water in aquifers or lakes**
- **Reverse osmosis (or microfiltration) at high pressure**






TECHNOLOGY | DESALINATION
Desalination Around the Globe
The countries that rely most on the technology are located in the world's arid regions, particularly the Middle East
Seawater-desalination capacity, in millions of liters per day
Source: GlobalWaterIntel.com
Saudi Arabia 9,055
UAE 8,797
Kuwait 2,449
Bahrain 1,007
Qatar 1,779
Spain 3,736
Israel 1,711
China 1,454
Russia 238
Algeria 1,665
Italy 511
Libya 1,007
Egypt 825
Oman 924
India 1,022
Japan 272
Indonesia 371
Australia 1,685
Singapore 712
U.S. 598
Mexico 231
Brazil 507
Angola 428
Chile 356

Problems of Desalination

- **Expensive**
- **Large energy to run for the pumps**
- **Chemicals are used to sterilize the water and keep down algae growth**
- **Produce huge amount of brine water**

Diversion Projects: Redistribute Water

- **Dams and canals: store and redistribute water for farms and cities. More than half of the world's 227 largest rivers have been dammed or diverted.**
- **Many great civilizations have been organized around large-scale canal systems.**
- **The 3 Gorges Dam is the largest water diversion project in the world.**

3 Gorges Dam


Sketch Map of The Three Gorges Dam
Lesser Three Gorges
Shennong Stream
Hubei Province
Wushan
Fengjie
Wanxian
Wuhan
The Dam
Fengdu
Yichang
Jing zhou
To shanghai
Chongqing
Wu River
Sichuan Province

Impacts of Dam Projects

- **Worldwide, dam projects forced >23 million people to relocate from their homes and land**
- **Flooding, inundation**
- **Ecological impact is far reaching**
- **Baiji dolphin**
- **Sediment erosion/transport**



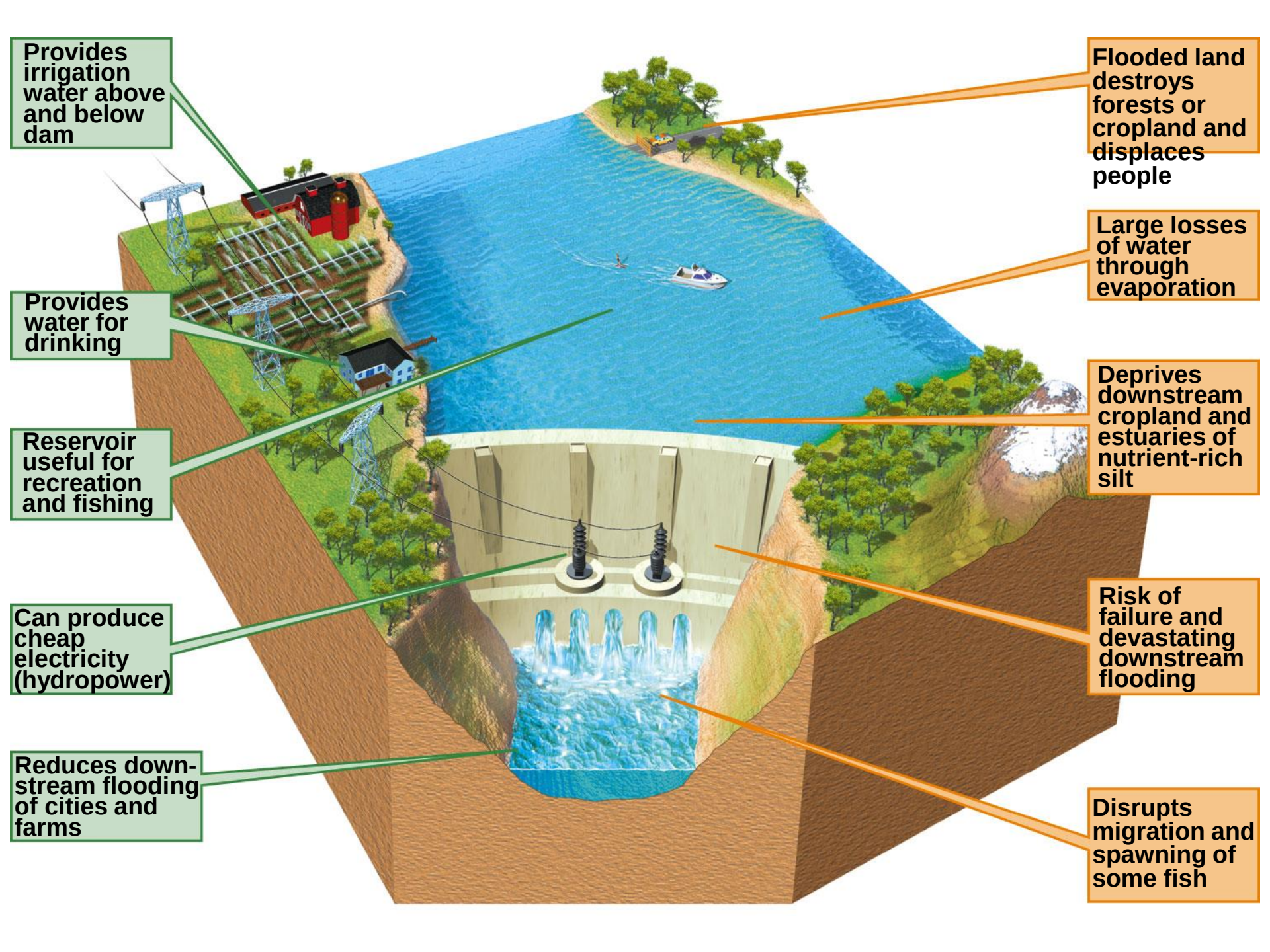
Ecological Effects of Diversion

(a)

Before diversion

(b)

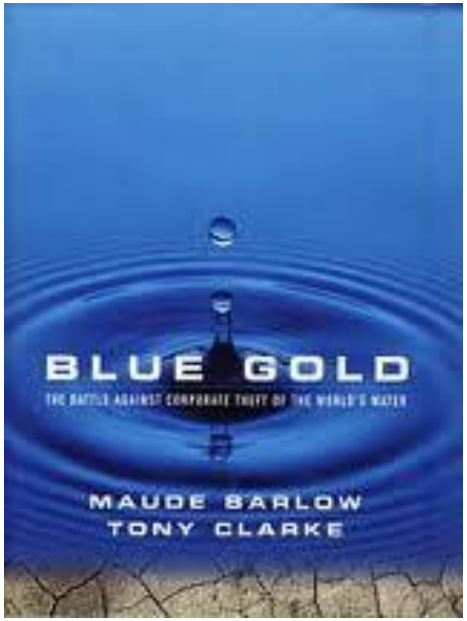
After diversion


Provides irrigation water above and below dam
Provides water for drinking
Reservoir useful for recreation and fishing
Can produce cheap electricity (hydropower)
Reduces down-stream flooding of cities and farms
Flooded land destroys forests or cropland and displaces people
Large losses of water through evaporation
Deprives downstream cropland and estuaries of nutrient-rich silt
Risk of failure and devastating downstream flooding
Disrupts migration and spawning of some fish

Water?

- ***Fortune*** **magazine: "water will be to the 21st century what oil was to the 20th."**

  - water shortages lead to wars between nations



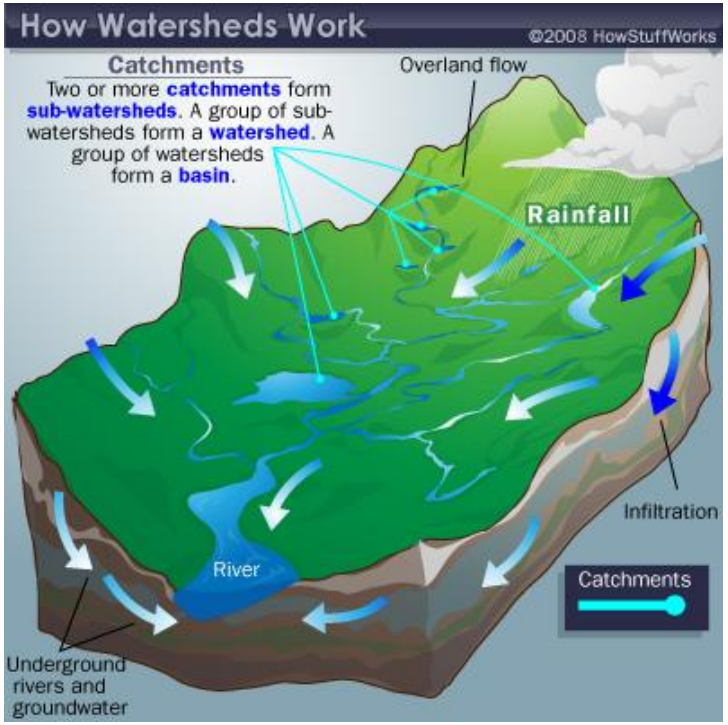
Water Resource Management

- **Great pressure on water resources**
  - **Population growth**
  - **Climate change**
  - **Pollution**
- **Sustainable practice promotion**
  - **Water infrastructure**
  - **Science & technology**
  - **Education**

Source: http://pacinst.org

Water Management and Conservation

- **Watershed**, or catchment, is all the land drained by a stream or river
- Minimize plowing and forest cutting on steep slopes
- Retain crop residues on fields
- Wetlands conservation



Reducing Freshwater Waste in Irrigation

- **66% of the freshwater used in the world is unnecessarily wasted**
- **USA: half of the water drawn from surface and groundwater supplies is wasted**
- **Economically and technically feasible to reduce such water losses to 15%**
- **Reasons:**
  - **The cost of freshwater is low**
  - **Lack of government subsidies for improving the efficiency of freshwater use**

Reduce Freshwater Waste in Irrigation

Solutions

Reducing Irrigation Water Waste

- Line canals bringing water to irrigation ditches
- Irrigate at night to reduce evaporation
- Monitor soil moisture to add water only when necessary
- Grow several crops on each plot of land (polyculture)
- Encourage organic farming
- Avoid growing water-thirsty crops in dry areas
- Irrigate with treated waste water
- Import water-intensive crops and meat

Reduce Freshwater Waste in Industry and Homes

- **USA: flushing toilets with freshwater**
- **30 % - 60% of freshwater is lost through pipes, pumps and valves**
- **50% - 75% of grey water from households to irrigate lawns and non-edible plants**
- **Reasons:**
  - **The cost of freshwater is low**
  - **E.g. In USA, public water systems have no meters and charge at low rate**

Reduce freshwater waste in industry and homes

Solutions

Reducing Water Waste

- Redesign manufacturing processes to use less water
- Recycle water in industry
- Landscape yards with plants that require little water
- Use drip irrigation
- Fix water leaks
- Use water meters
- Raise water prices
- Use waterless composting toilets
- Require water conservation in water-short cities
- Use water-saving toilets, showerheads, and front-loading clothes washers
- Collect and reuse household water to irrigate lawns and nonedible plants
- Purify and reuse water for houses, apartments, and office buildings

Use Water More Sustainably

- **Each of us can help bring about such a "blue revolution" by using and wasting less water to reduce our water footprints.**

Solutions

Sustainable Water Use

- Waste less water and subsidize water conservation
- Do not deplete aquifers
- Preserve water quality
- Protect forests, wetlands, mountain glaciers, watersheds, and other natural systems that store and release water
- Get agreements among regions and countries sharing surface water resources
- Raise water prices
- Slow population growth

Use Water More Sustainably

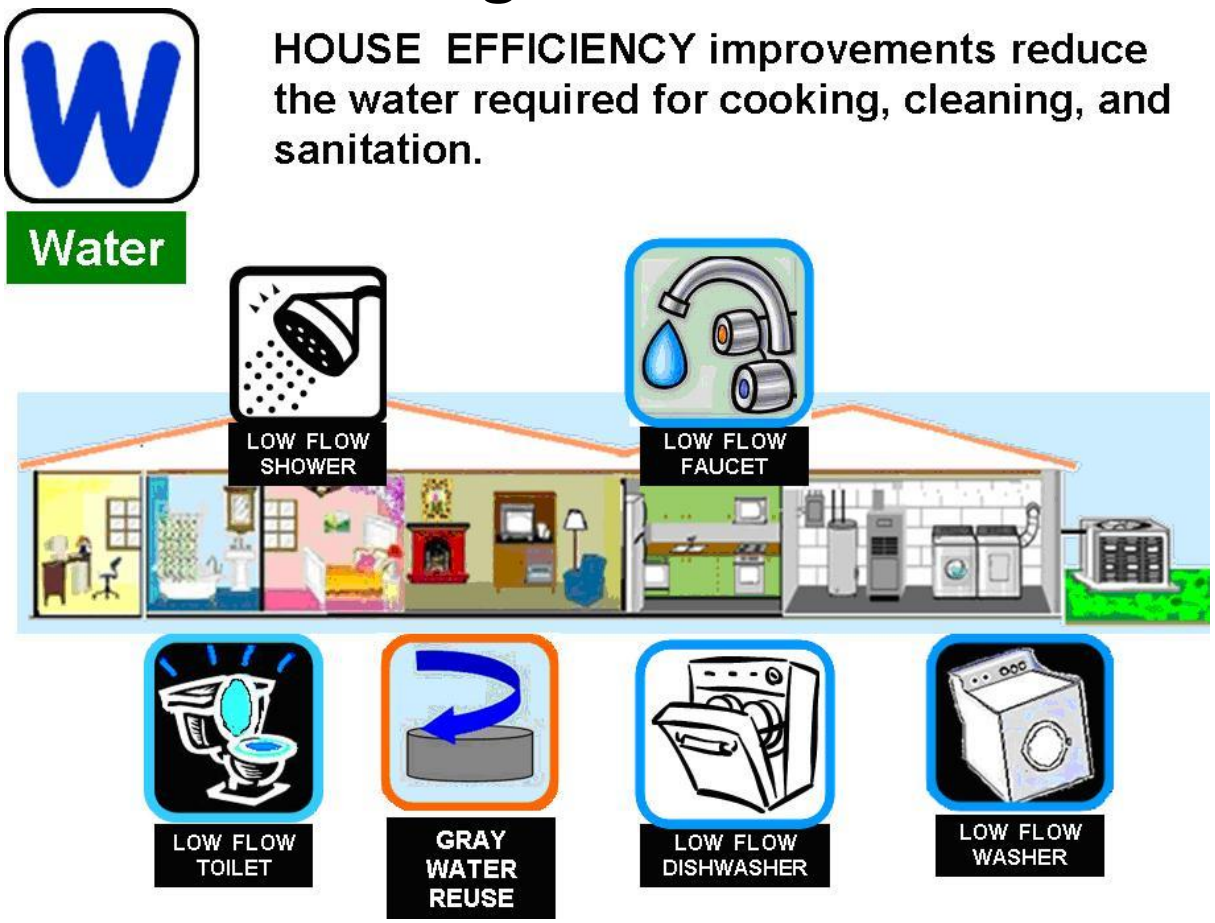
What Can You Do?

Water Use and Waste

- Use water-saving toilets, showerheads, and faucet aerators
- Shower instead of taking baths, and take short showers
- Repair water leaks
- Turn off sink faucets while brushing teeth, shaving, or washing
- Wash only full loads of clothes or use the lowest possible water-level setting for smaller loads
- Use recycled (gray) water for watering lawns and houseplants and for washing cars
- Wash a car from a bucket of soapy water, and use the hose for rinsing only
- If you use a commercial car wash, try to find one that recycles its water
- Replace your lawn with native plants that need little if any watering
- Water lawns and yards only in the early morning or evening
- Use drip irrigation and mulch for gardens and flowerbeds

Efficiency to Reduce Water Use

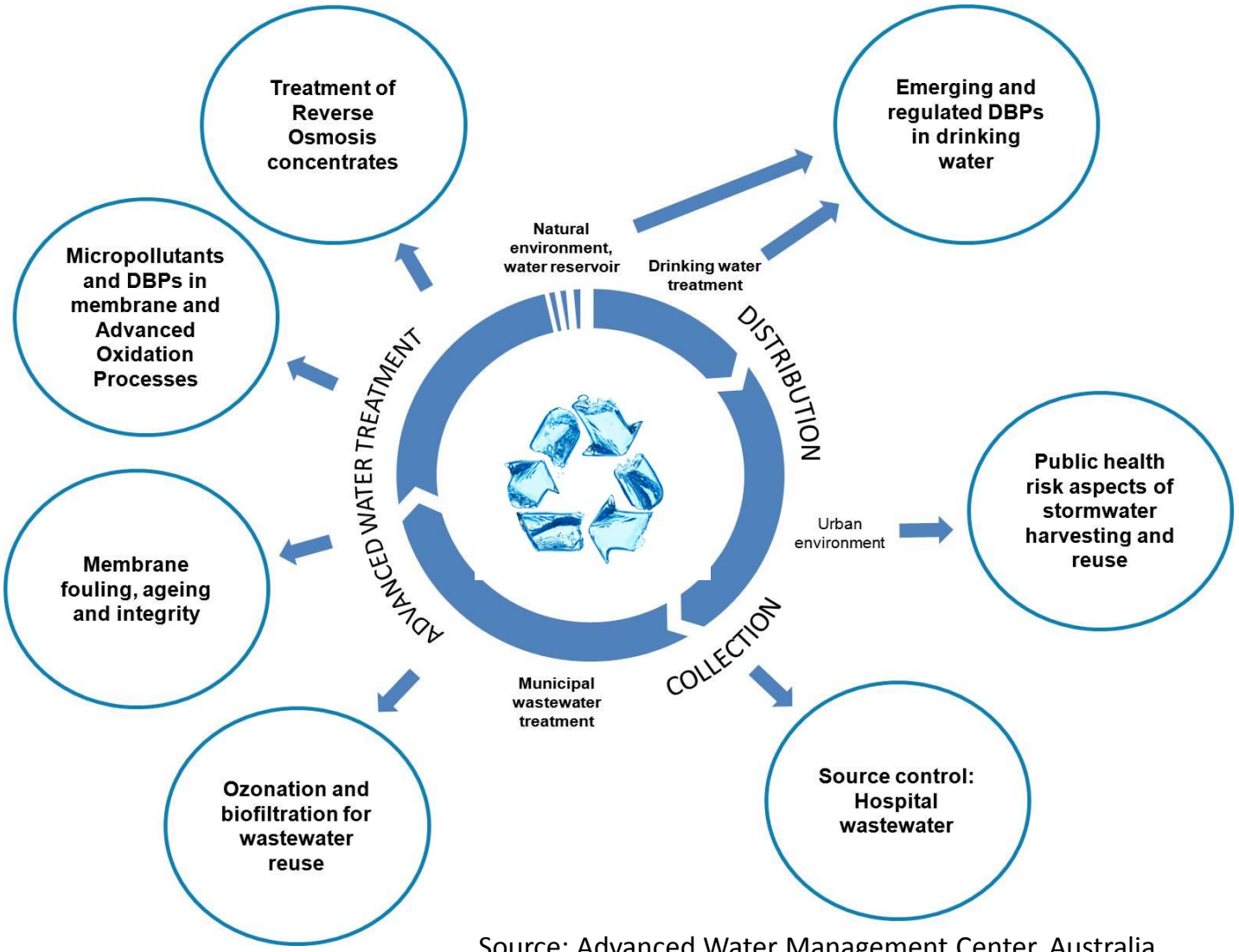
- **Growing recognition that water is a precious and finite resource - conservation.**
- **Water-efficient irrigation and domestic use.**



Sustainable Water

DBPs: disinfection by-products

PPCPs: Pharmaceuticals and Personal Care Products



Source: Advanced Water Management Center, Australia
http://www.awmc.uq.edu.au/water-recycling-research-program

Singapore

- The Singapore Water Reclamation Study initiated in 1998
- NEWater as raw water source to supplement Singapore's water supply
- Undergone stringent purification and treatment processes
  - Dual-membrane
  - Ultraviolet technology

PUB

Water for All : Conserve, Value, Enjoy

NEWater Bottled Reverse Osmosis Water
Source:http://www.pub.gov.sg

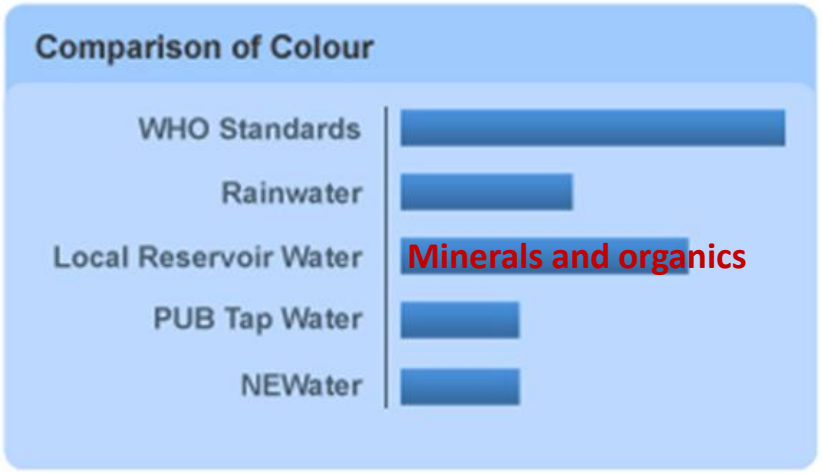
NEWater Technology

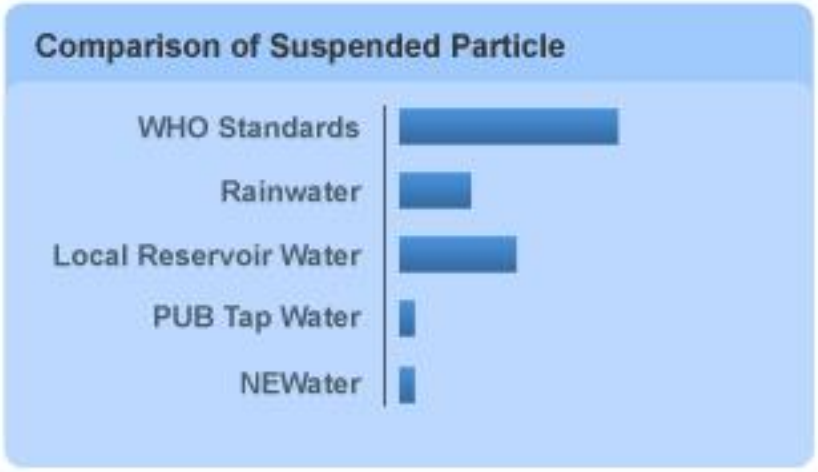
Major processes:

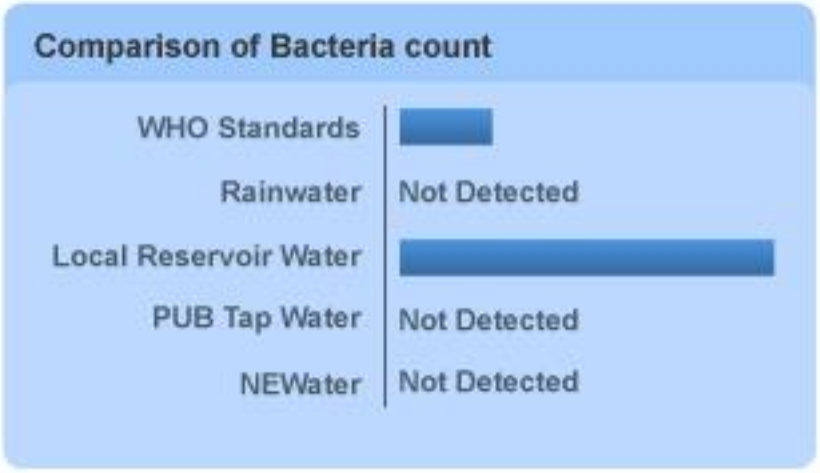
- Microfiltration
- Reverse osmosis
- UV disinfection

Microfiltration ceramic filters

NEWater Quality

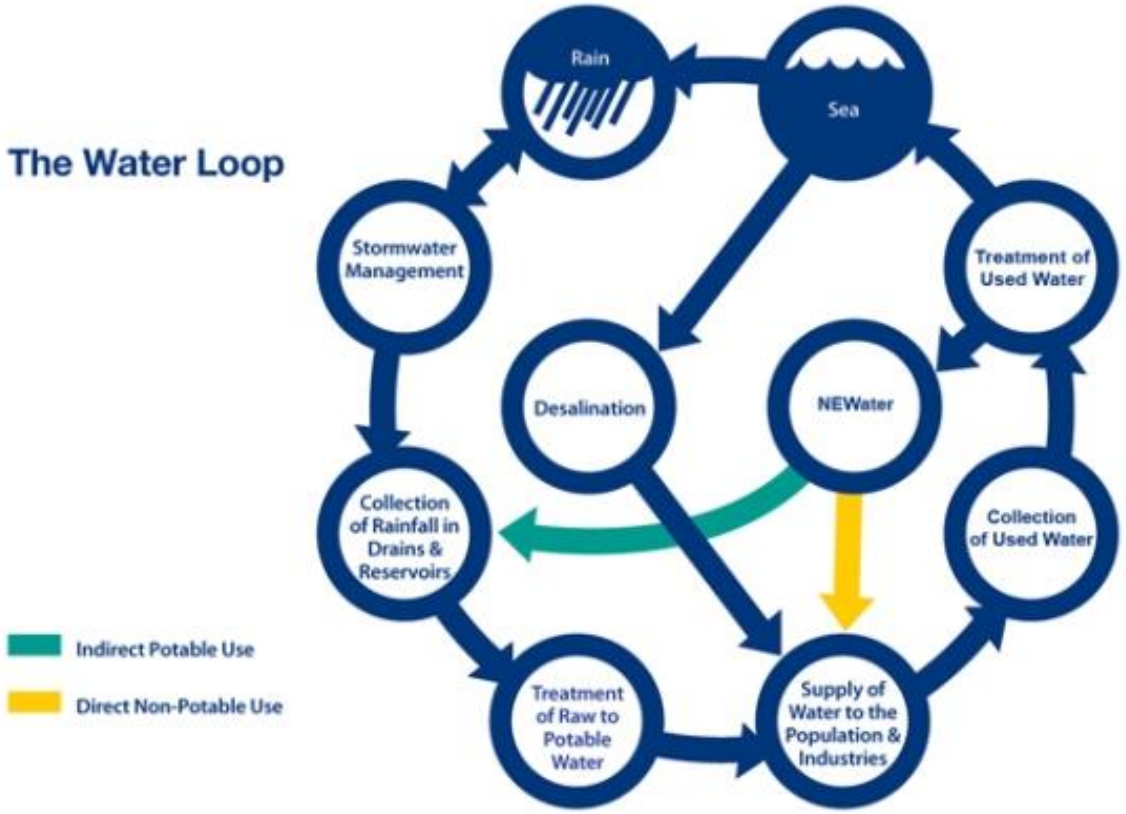






NEWater Usage

- **Industrial & air-conditioning cooling purposes**
- **Non-domestic sector from 55% to 70% by 2060**



Hong Kong

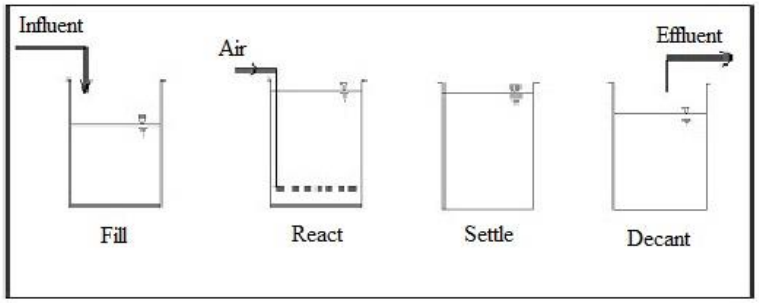
- **Reclaimed water**
  - **Clear in appearance**
  - **Odorless**
  - **Safe to reuse**
- **No plan to replace drinking water**
- **Reduce overall demand for freshwater**

Ngong Ping Sewage Treatment Works

Shatin Sewage Treatment Works

Ngong Ping Sewage Treatment Works

- Commissioned in 2006
- Sequencing batch reactor
- Dual media filter
  - microfiltration
  - reverse osmosis
- Disinfection process



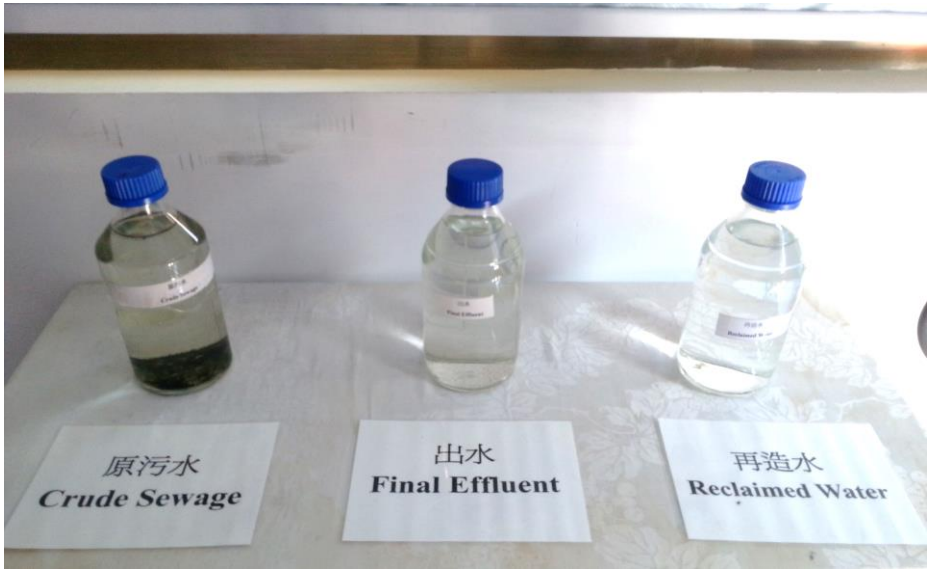
Typical Sequencing Batch Reactor Cycle

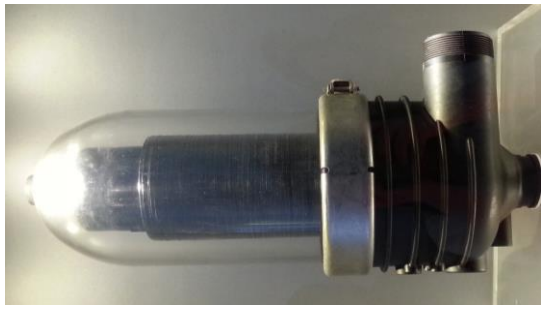
Table 1
Water Quality Criteria for
Reuse of Treated Effluent for Flushing at Ngong Ping

Parameter	Limiting Standards
Colour	≦ 20 Hazen Unit
Ammonia Nitrogen	≦ 1 mg/l
Odour	≦ 100 Threshold odour no.
Dissolved Oxygen	≧ 2 mg/l
Biochemical Oxygen Demand $_5$	≦ 10 mg/l
Total Suspended Solids	≦ 10 mg/l
Turbidity	≦ 10 NTU
E.Coli	≦ 100 cfu/100ml
Total Residual chlorine	≧ 0.5 mg/l
Synthetic detergents	≦ 5 mg/l

Shatin Sewage Treatment Works

- **Commissioned in early 2011**





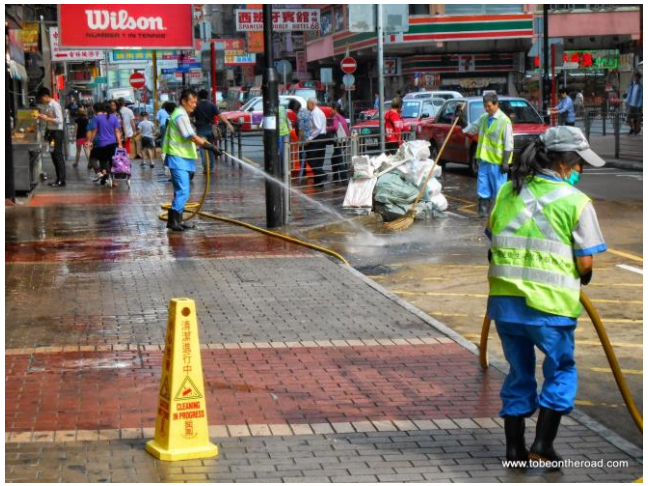
Disc filters

Ultra-filtration membrane

Reverse osmosis membrane

Use of Reclaimed Water

- **Not targeted for drinking**
- Cleaning roads and vehicles
- Irrigating parks and sport fields
- Flushing toilets
- Fire fighting
- Industrial production
- Urban development and landscaping



Desalination in Hong Kong

Old desalination plant in Tuen Mun

Source: Hong Kong Water Supplies Department

Summary

- Water cycle and distribution
  - Freshwater, groundwater, rivers and lakes
- Water availability and use
  - Agriculture, industry, domestic
- Increase water supply
  - Cloud seeding, watersheds/ reservoirs, desalination, dams
- Water resource management and conservation
  - Sustainable water in Singapore
  - Reclaimed water in Hong Kong

References

- Chapter 11, Cunningham & Cunningham 2013
- China water risk (http://chinawaterrisk.org/)
- Hong Kong Water Supplies Department (www.wsd.gov.hk)
- Drainage Services Department, HKSAR (http://www.dsd.gov.hk)
- NEWater website (http://www.pub.org.sg)