MECH 1905 Buildings for Contemporary Living

Water Supply for Buildings

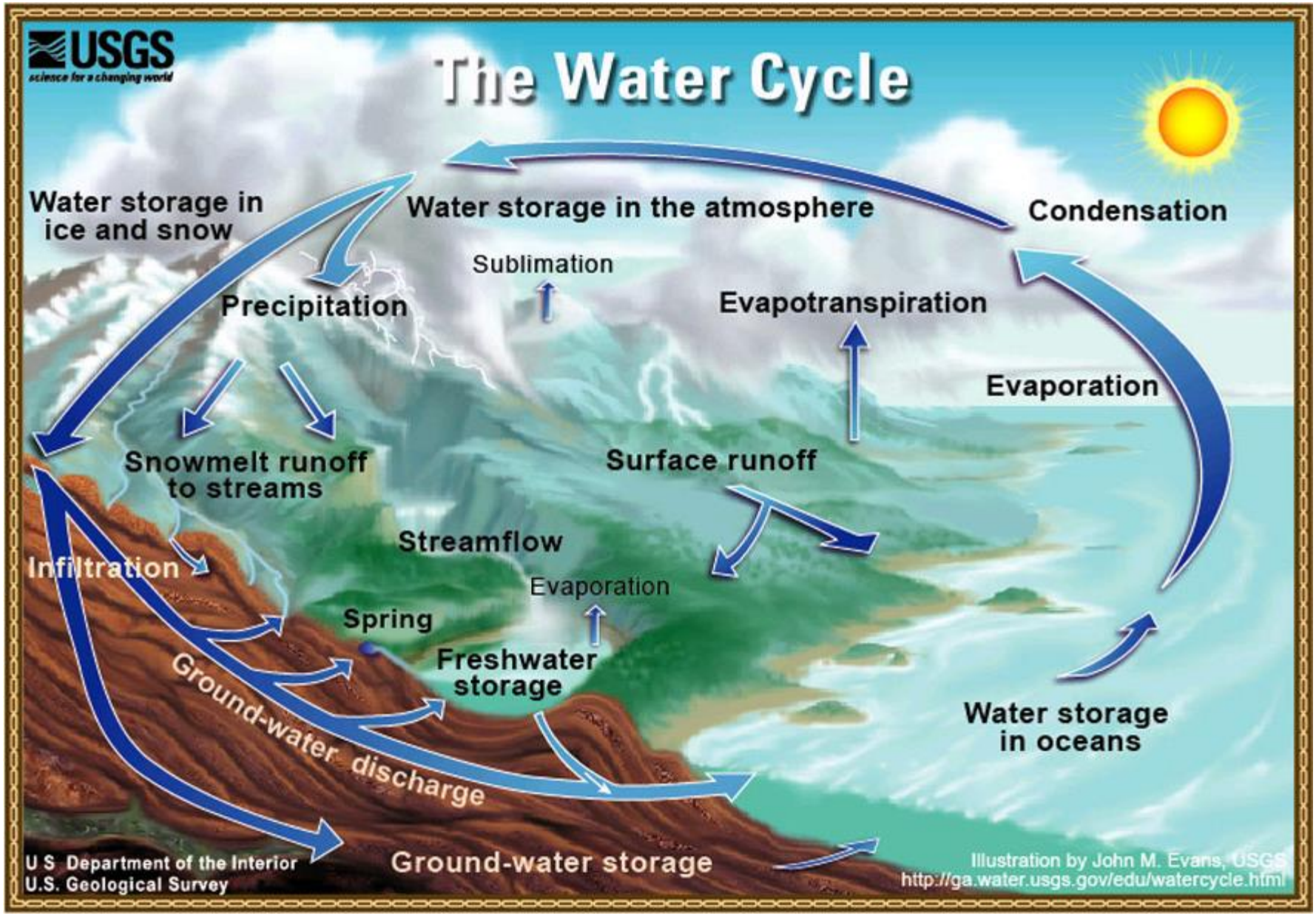
Prof. Yi-Kuen Lee
Department of Mechanical and Aerospace Engineering
Hong Kong University of Science and Technology

Outline

- Water Resources
- Water Quality
- Basic Water Chemistry
- Water Usage
- Hong Kong Fresh Water Supply
- Hong Kong Sea Water Supply

Essential Water

- Water (in its pure form) is a tasteless, odorless substance that is essential to all known forms of life and is known as the universal solvent.
- It appears colorless to the naked eye in small quantities, though it can be seen to be blue with scientific instruments or in large quantities (as in a swimming pool).
- An abundant substance on Earth (1,400 million cubic kilometers estimated), water exists in many forms.
- It appears mostly in the oceans (saltwater) and polar ice caps, but also as clouds, rain water, rivers, freshwater aquifers, lakes, and sea ice.
- Water in these bodies continuously moves through a cycle of evaporation, precipitation, and runoff to the sea.
- Clean water is essential to human health and in many parts of the world it is in short supply.



Hail: solid precipitation of water https://youtu.be/1701cmpi69g

Hail formation (冰雹)

from Prof Duane Friend, Univ of Illinois, USA, https://youtu.be/AN-XFCKYdew

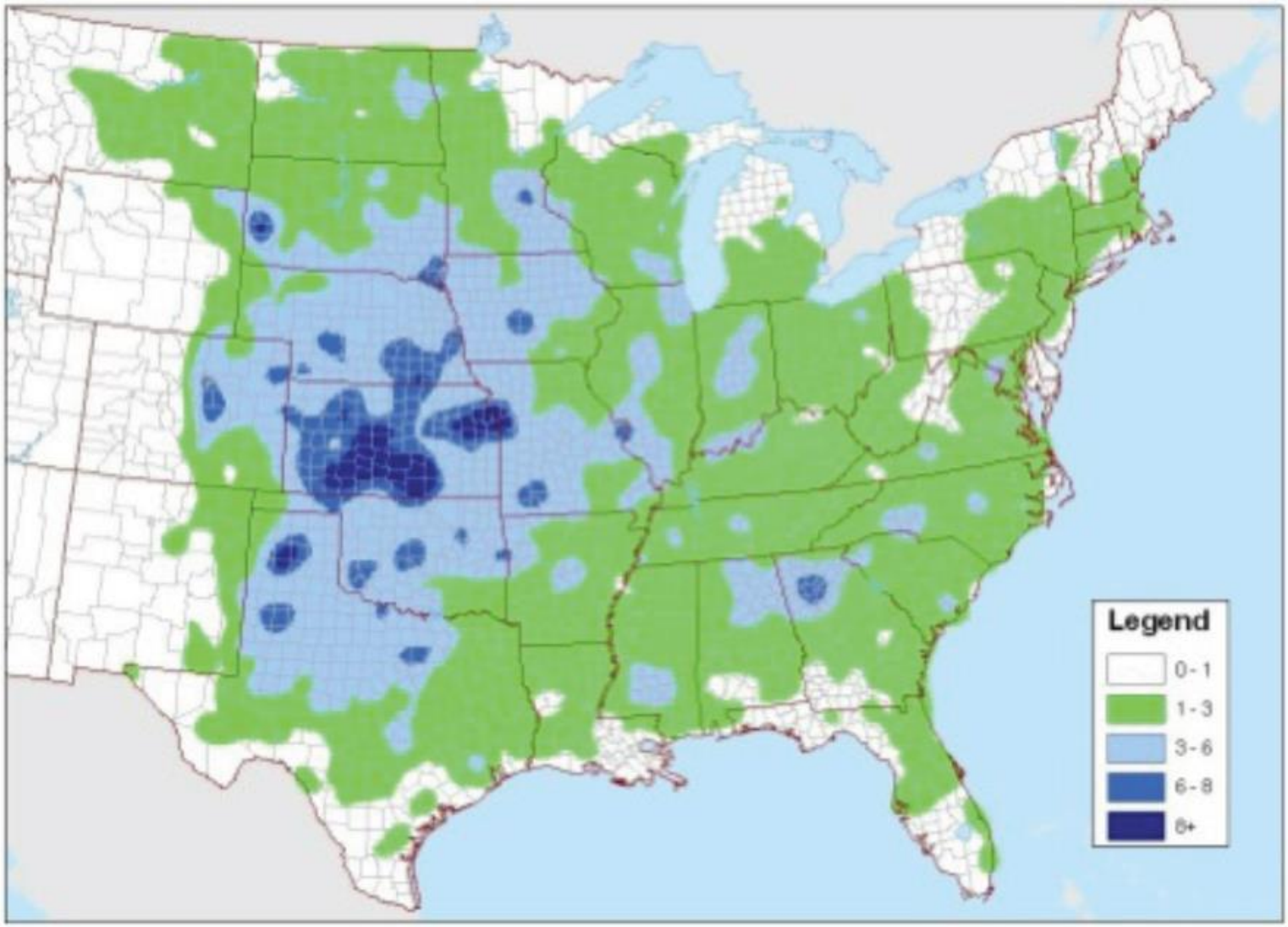
Hailstone Damage: $1B/yr in US

- Severe hail (≥ 1 inch diameter/ 2.54cm) most commonly occurs in thunderstorms, esp in summer
- Largest hailstones occur in supercell thunderstorms (vortex with diameter: 3.2~9.7km) with strong updrafts; tornadoes can also be present
- Risk extends across the US; east of Rocky Mountains
- More than 75% of US cities experience at least one hailstorm a year
- On average, annual hail losses are nearly $1 billion

Note: 45,000 thunderstorms take place each day around the world, 16 million per year; US has 2000~3000 supercell thunderstorm per year; less than half->tornado; Supercell thunderstorm video https://youtu.be/yvIKIgelY6g

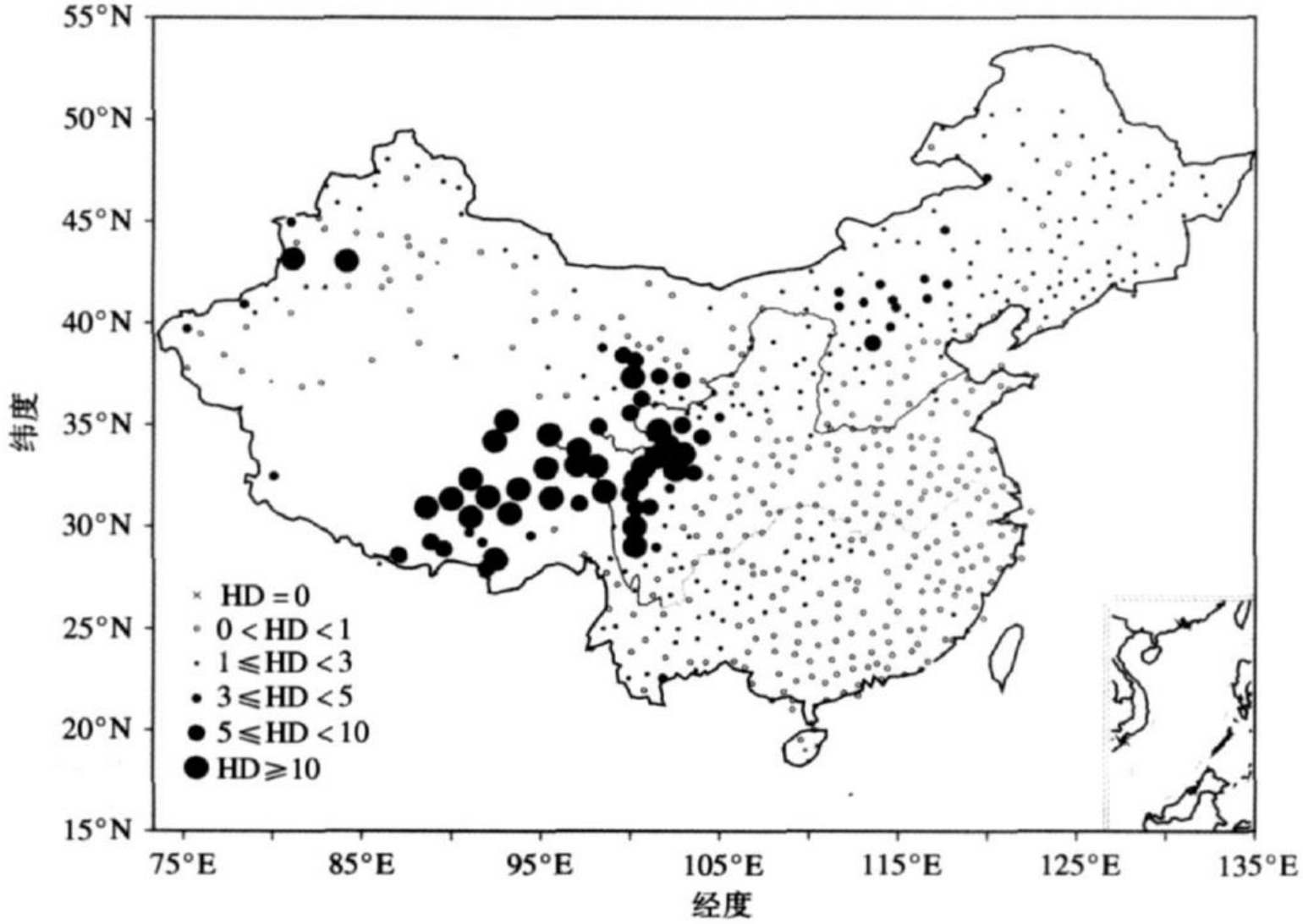
Hail Activity in US

Average number of hail reports per 100 squre miles
2000-2009 reports of hail 1" or larger



Hail Activity in China

1971-2000 reports of haildays (HD) from 614 stations



FH Zhang and H. Gao, J. of Nanjing Institute of Meteorology, 2008

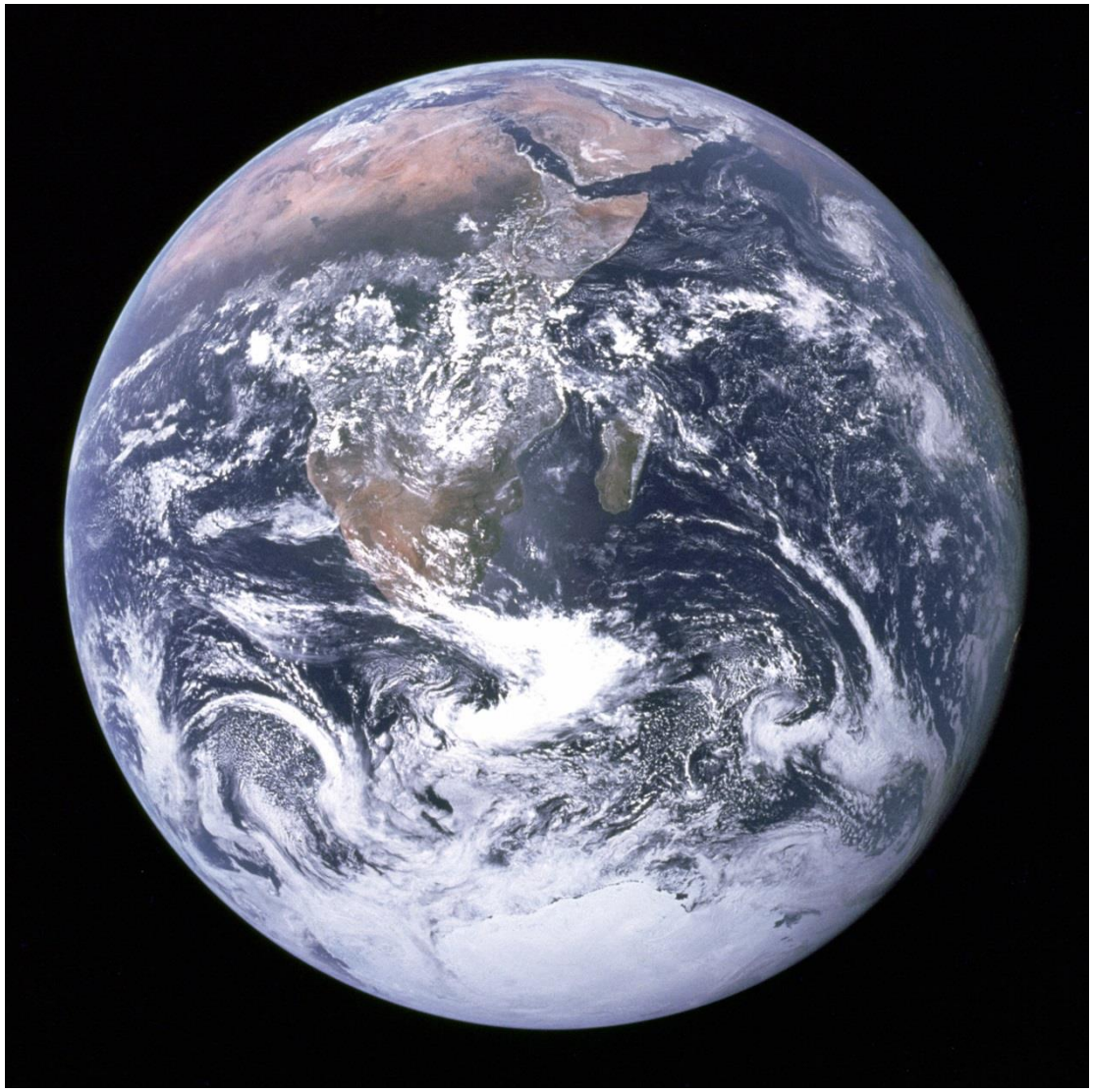
Water's Effect on Life

- From a biological standpoint, water has many distinct properties that are critical for the proliferation of life by allowing organic compounds to react in ways that ultimately allows replication.
- Water is vital both as a solvent in which many of the body's solutes dissolve and as an essential part of many metabolic processes within the body.
- Earth's waters are filled with life including fish, marine mammals such as dolphins and whales, and amphibians.
- Plants such as kelp and algae grow in the water, and are the basis for some underwater ecosystems. Plankton, however, is generally the foundation of the ocean food chain.
- Human civilization has historically flourished around rivers and major waterways.
- Humans use water in typically 3 varieties of ways :
  - drinking as 72% of the mass of the human body is made of water, the body requires between 1 and 7 liters of water per day to avoid dehydration
  - as solvent to dissolve any unwanted matters from the surroundings
  - as a thermal transfer medium for boiling, steaming, and simmering food and temperature control

Water Hygiene

- Hygiene is commonly understood as preventing infection through cleanliness
- Washing with water is the most common example of hygienic behavior
- Frequent hand washing, especially with soap, is among the most common hygienic advice as this has a profound impact on reducing the spread of disease because disease-causing microbes (germs) in the immediate surroundings can be killed or removed
- Food to be eaten or water to be taken into bodies needs thorough cleansing with clean water including the utensils holding the contents in preparation for personal hygiene
- Clean water therefore is essential in personal, public and industrial hygiene

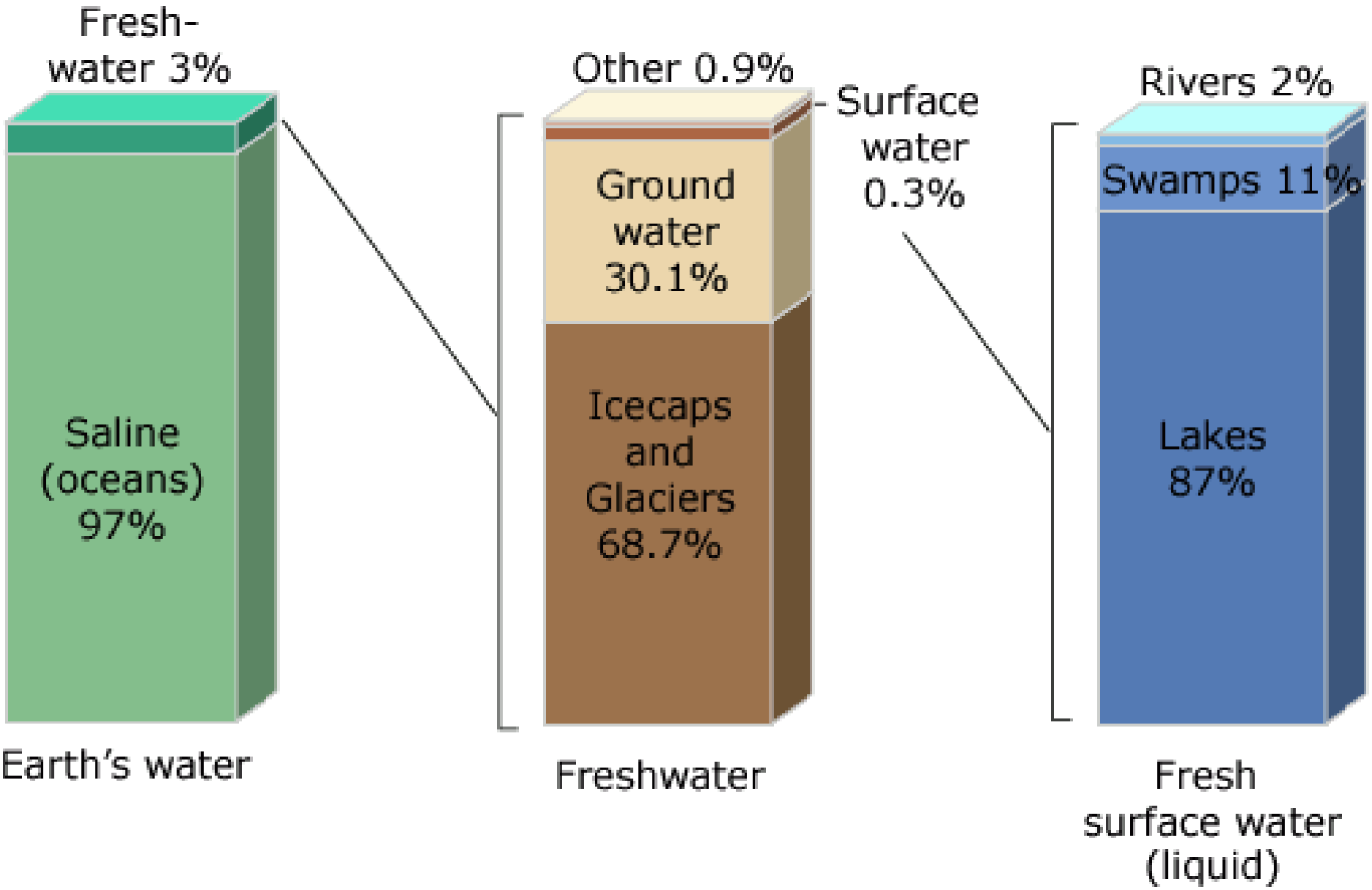
Water on Earth



- Over two thirds of the earth's surface is covered with water, 97.2% of which is contained in the five oceans.
- The Antarctic ice sheet, containing 70% of all fresh water on the planet, is visible at the bottom.
- Atmospheric water vapor can be seen as clouds, contributing to the earth's albedo.

Albedo (反照率): proportion of the incident solar radiation that is reflected by the earth's surface (*ca*. 30~50%)

Distribution of Earth's Water



“Non-Point Source” Pollution

- Stormwater runoff picks up pollutants as it runs off impervious surfaces
  - Oils/Grease
  - Metal Particles
  - Pesticides
  - Pet Wastes/Pathogens
  - Nutrients
  - Excessive Sediment

Stormwater runoff is the real problem

https://youtu.be/eozVMJCYHCM/ Canvas: https://tinyl.io/41GH

Common Misconception

- Stormwater from roads and construction sites is directed to storm drains
- Stormwater that enters a storm drain gets treated
- **Where does it really go?**

The Truth Is…

- Stormwater usually receives no treatment at all
- It goes to the nearest stream!

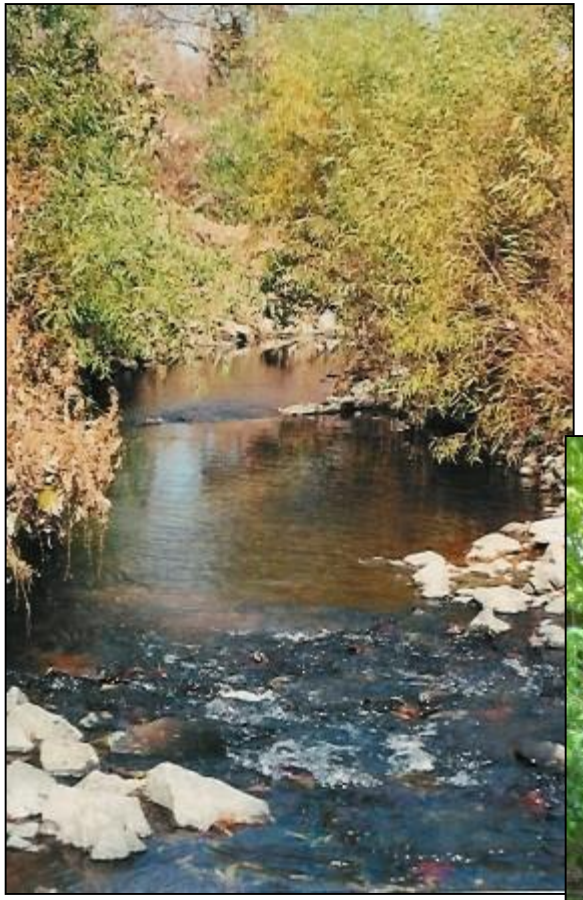
Impacts of Sedimentation

- Bare soil easily washes into storm drains and into streams, clouding the water and suffocating aquatic life.
- Sediments can block culverts and displace flood waters.

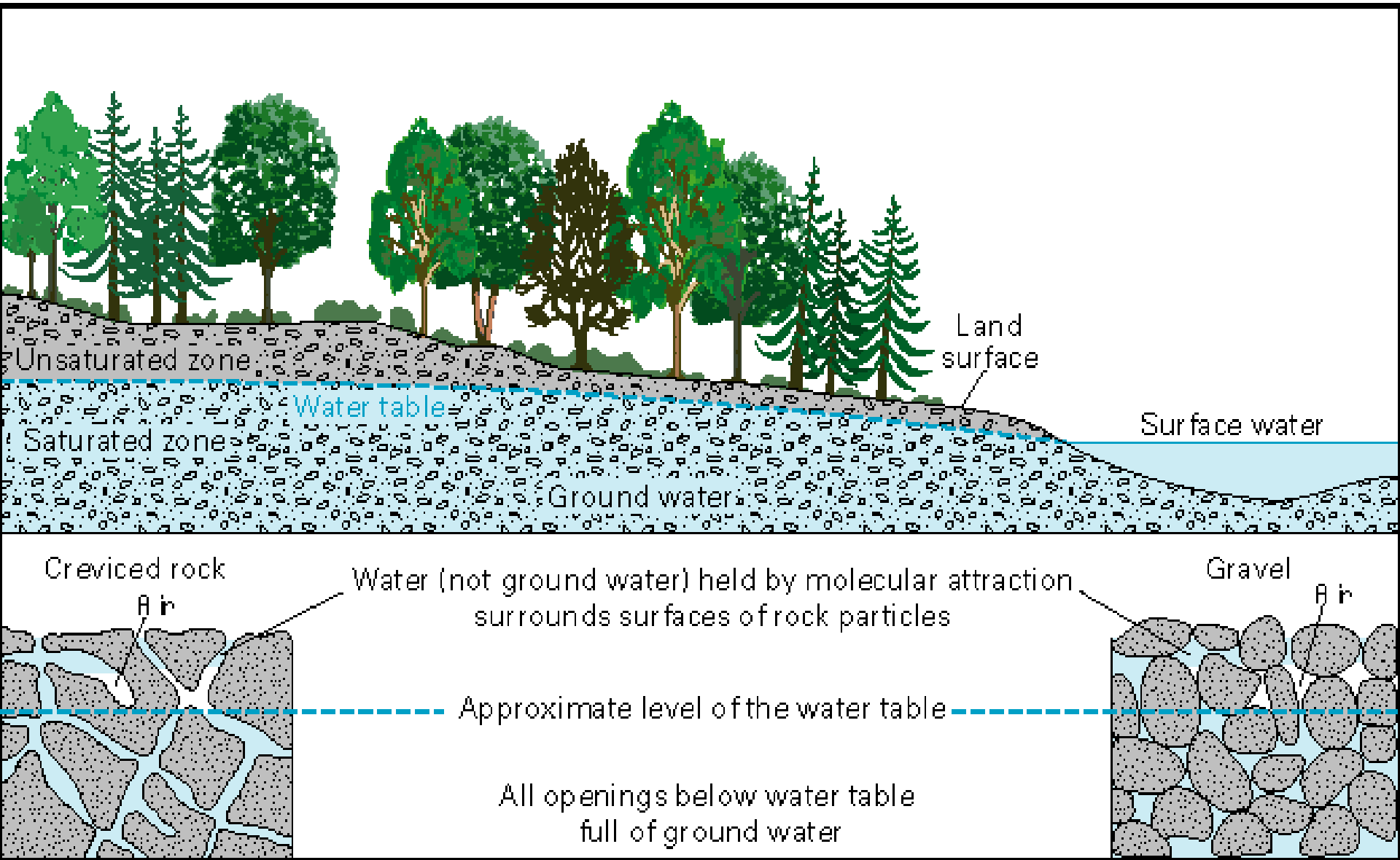
Culvert (涵洞): a tunnel structure constructed under roadways or railways to provide cross drainage

Problem: Stream Pollution

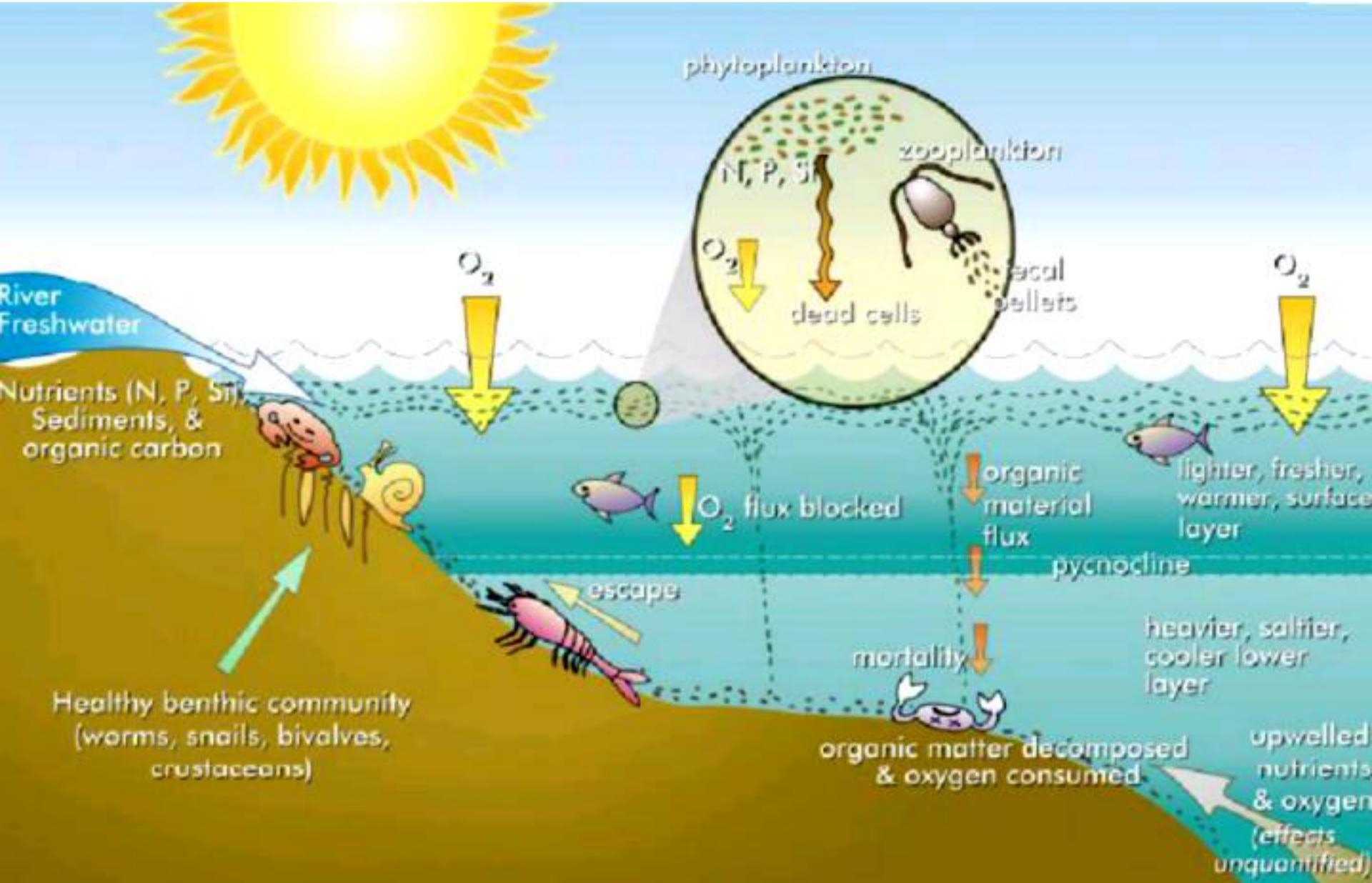
Goal: Clean Healthy Streams



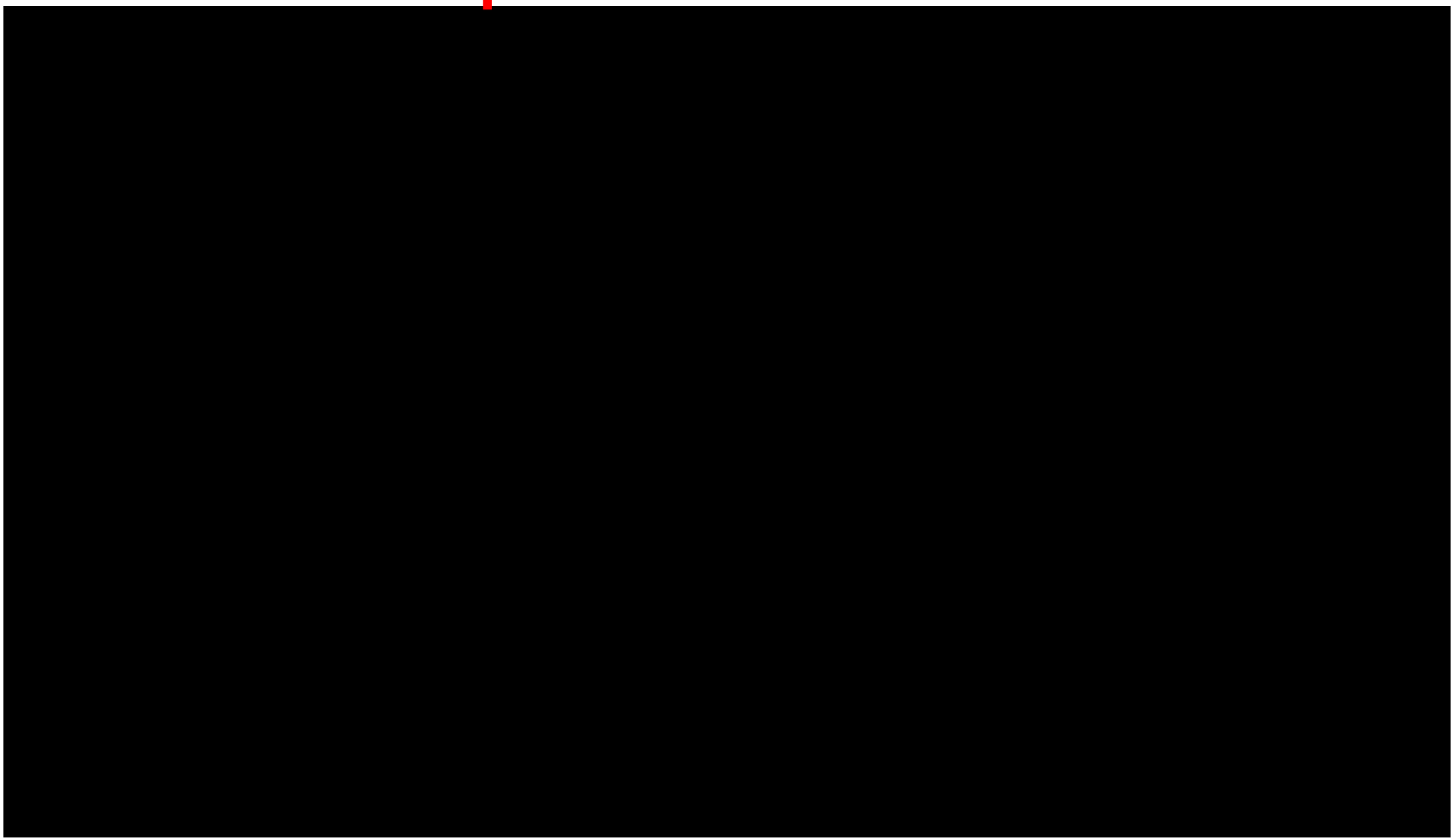
Underground Water



Concept of Eutrophication



Eutrophication Video



Eutrophication: process by which the waste water causes a lake/pond/sea to become overrich in organic & mineral nutrients, so that algae grow rapidly and deplete the oxygen supply

https://youtu.be/mLbDbmmV6Qc, Canvas: https://tinyl.io/41GK

Threats to Water Conservation

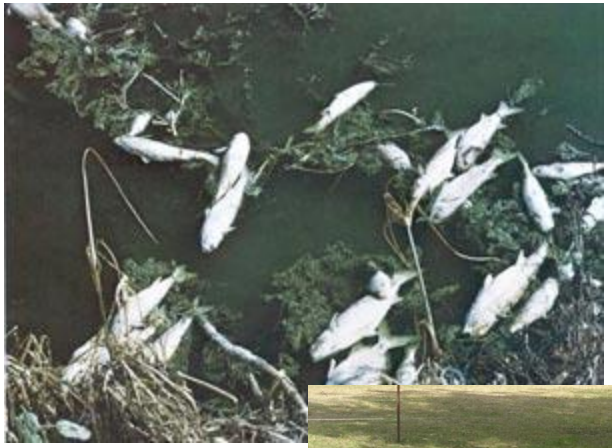
- Rapid development of population
- Rapid development of industries with high water consumption
- Storage facilities / tanks
- Unbalance of soil water results in the ability of water conservation in watershed
- Water supply reduces by water pollution

Reference：水資源開發綱領計畫，水利署
http://hysearch.wra.gov.tw/wra_ext/WaterInfo/wrproj/program/chap3/3.htm

Sources of Water Pollution

Natural

- Decay of dead plant and animal
- Sewage from animals sources
- Marine sediments



Sources of Water Pollution
Anthropogenic

- Household
  - Dirty water is produced when doing some house works like washing dishes.
- Industrial
  - During the process of industry like dyeing and bleaching, water is polluted and then discharge to the sea without any treatment.
- Commercial
  - Commercial operations and wastewater discharges also pollute the sea.
- Farming
  - Fertilizers are used in farming. They may contain some toxic substances like pesticides.
- Construction
  - During construction, many wastes are produced.
  - It may also cause underground tank leakage.

Degrees of Water Quality

Drinkable

Eyes touchable

Skin touchable

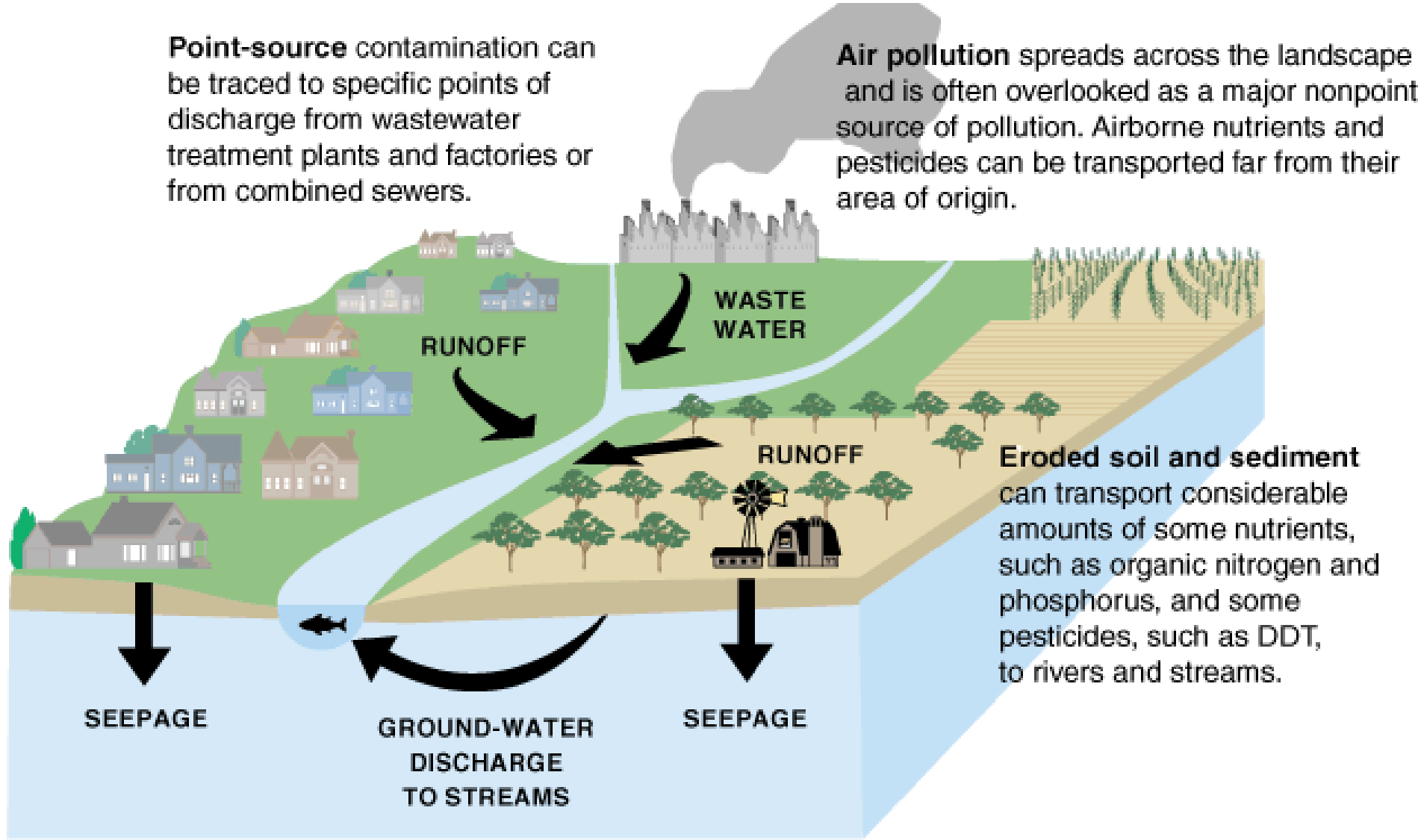
No touch

Safe

NOT Safe

Reference: http://blog.folkgame.org.tw/modules/news/article.php?storyid=82

Water Quality (1)



Water Quality (2)

- A term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for a particular purpose
- Assessment of the occurrence of chemicals that can harm water quality, such as nutrients and pesticides in water resources, requires recognition of complicated interconnections among surface water and ground water, atmospheric contributions, natural landscape features, human activities, and aquatic health.
- The vulnerability of surface water and ground water to degradation depends on a combination of natural landscape features, such as geology, topography, and soils; climate and atmospheric contributions; and human activities related to different land uses and land-management practices.
- Bacteria and microorganisms have gotten into drinking-water supplies, sometimes causing severe illness in a town; chemical pollutants have been detected in streams, endangering plant and animal life; sewage spills have occurred, forcing people to boil their drinking water; pesticides and other chemicals have seeped into the ground and have harmed the water in aquifers; and, runoff containing pollutants from roads and parking lots have affected the water quality of urban streams.

Turbidity and Alkalinity of Water

- Turbidity or cloudiness in water, is caused by suspended materials that scatter light passing through the water
- Possible sources of turbidity includes sediments from disturbed or eroded soil and high numbers of microscopic plankton due to excess nutrients and sunlight
- May block out the light needed by submerged aquatic vegetation and burying fish eggs and benthic (bottom dwelling) creatures
- Suspended sediment can carry nutrients and pesticides throughout the water system, damage gills, and interfere with the ability of fish to find food
- Suspended particles near the water surface can absorb extra heat from sunlight, raising surface water temperatures
- Alkalinity is the amount of buffering material in the water.
- If a body of water has an abundance of buffering materials (high alkalinity), it is more stable and resistant to changes in pH.
- As increasing amounts of acid (acid rain) are added to ponds and lakes, their buffering capacity is consumed.

CO_2 and Trace Elements in Water

- Aquatic plants depend on CO_2 in water for growth and respiration.
  - CO_2 increases when organic wastes reduce the oxygen available, making it difficult for fish to use the limited amount of oxygen present.
  - Surface waters normally contain < 10 ppm of free CO_2.
- Iron in water stains fixtures and may have an odor or taste
  - Plants need iron in trace quantities to grow.
  - Values of 0 - 0.5 ppm are acceptable, high values in streams may indicate contamination from landfills.
- Copper in water is from stamp sands or waste rock from copper mines.
  - The national standard for aquatic life is 0.018 ppm and for drinking water is 1.3 ppm.

Odor and Color of Water

- Odor affects the acceptability of drinking water, the aesthetics of recreational water, and the taste of fish.
  - Sewage and industrial chemical waste discharges or natural sources such as decomposing vegetation and microbial activity can cause odor.
- Color of water :

COLOR	POSSIBLE CAUSE
Blue	transparent water with a low accumulation of dissolved materials and particulate matter, indicates low productivity
Yellow/Brown	dissolved organic materials, humic substances from soil, peat, or decaying plant material
Red	can be produced by some algae
Green	water rich in phytoplankton and other algae
Mix of colors	may be caused by soil runoff

Salinity of Water

- Salinity refers to the total amount of dissolved substances including other substances such as sodium
  - Usually expressed in terms of its specific gravity, the ratio of a solution's weight to weight of an equal volume of distilled water at a specified temperature
  - Salinity of sea water is about 3 ~ 4 % of NaCl
  - Some freshwater fish tolerate (or even prefer) a small amount of salt (it stimulates slime coat growth)
  - Parasites (e.g., ich) do not tolerate salt at all, salt in concentrations of (up to) 1 tablespoon per 20 liters can actually help prevent and cure ick and other parasitic infections for fish

Hardness of Water

- Hardness measures of mineral contents mainly Ca and Mg in the form of carbonates, bicarbonates and sulfates in water
  - can cause limescale deposits in kettles, washing machines and pipes
  - hard water requires more soap and synthetic detergents for laundry and washing.
  - using soap on the body in hard water can cause the formation of a scum often referred to as “curd.”
  - total water hardness (including both Ca and Mg) is reported as ppm of $CaCO_3$
  - controlled by addition of chemicals and by large-scale softening with zeolite resins
  - soft water is more likely to corrode metal pipes in which it is carried, and as a result it may have elevated levels of Cd, Cu, Pb and Zn

Status	ppm $CaCO_3$	mg/L as Ca
very soft	0 – 70	0 – 20
soft	70 – 140	20 – 40
medium hard	140 – 210	40 – 60
fairly hard	210 – 320	60 – 80
hard	320 - 530	80 – 120
very hard	> 530	> 120

Conductivity of Pure Water

- Conductivity measurements are used routinely to determine the purity of water.
  - Conductivity is directly proportional to the concentration each ion transporting charges, the charge carried by one of those ions (valence) and the mobility of the ions.
  - Conductivity of aqueous solutions is expressed as

$$\chi = F \cdot \Sigma C_i \cdot Z_i \cdot \mu_i$$

where
χ : conductivity (Siemens/cm)
F : Faraday
C_i : concentration of each species (moles/ml)
Z_i : valence of the species
μ_i : mobility of the species

  - In theoretically pure water, the only two ionic species coming from the dissociation of water are H^+ and OH^- with:

$$[H^+] = [OH^-] = 10^{-3} \text{ eq/L} = 10^{-10} \text{ eq/mL}$$

  - At 25 ^oC $F\mu\ (H^+) = 350\ \Omega^{-1}\cdot cm^2$ and $F\mu\ (OH^-) = 200\ \Omega^{-1}\cdot cm^2$
  - Hence, $\chi = 0.055\ \mu S/cm$ for pure water at 25 ^oC

Conductivity of Water

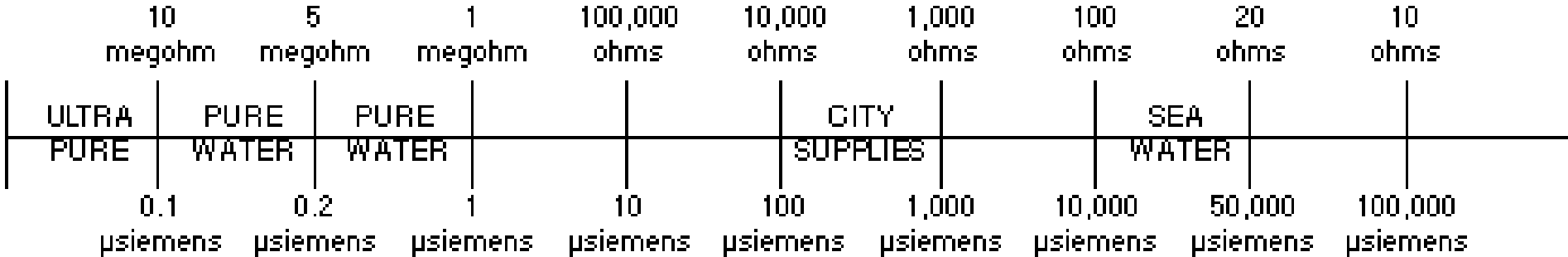
- When a salt (such as NaCl) is added to ultrapure water, it dissolves into the water and dissociates to form positively and negatively charged ions. The resulting conductivity of the aqueous solution is equal to the conductivity of the pure water plus the conductivity from the additional dissolved salts (Na^+ and Cl^- ions):

  $\chi = \chi(\text{pure water}) + \chi(\text{NaCl})$

  $\chi = 0.055 + \chi(\text{NaCl})\ \mu S/cm$

- Conductivity is greatly affected by the temperature, the higher the temperature, the higher the conductivity (the lower the resistivity) due to the increased mobility of the ions.
- Resistivity of water is the reciprocal of conductivity and can be expressed as $M\Omega.cm$

Conductivity and Resistivity of different kinds of water



pH Value of Water

- pH is a measure of the activity of hydrogen ions (H^+) in a solution, or in other word, acidity of the solution
  - $pH = -\log[H_3O^+]$; ($pOH = -\log[OH^-]$)
  - In aqueous systems, the hydrogen ion activity is dictated by the dissociation constant of water ($K_w = 1.011 \times 10^{-14}$ at 25 °C) and interactions with other ions in solution. Due to this dissociation constant, a neutral solution (hydrogen ion activity equals hydroxide ion activity) has a pH of approximately 7. Water with pH values lower than 7 are considered acidic, while pH values higher than 7 are considered basic
  - pH value of water caused by the contents in the water, largely from the dissolved CO_2
  - Rapidly growing algae or submerged aquatic vegetation remove CO_2 from the water during photosynthesis, significantly increasing pH levels
  - Rainwater naturally has a pH of 5.5
  - pH levels > 9.0 begin to be harmful to some fish while pH < 5.5 is harmful to freshwater shrimp, snails, and clams

Oxygen Content in Water

- Dissolved Oxygen (DO) is a measure of oxygen concentration in water
  - level = 5 - 6 ppm is required for growth and activity of most aquatic organisms
  - when the levels < 3 ppm are stressful to most aquatic organisms
  - levels < 2 ppm will not support fish
- Biological Oxygen Demand (BOD)
  - Oxygen is not only required for survival of most living organisms, but is needed to decompose organic (plant) material and human/animal wastes (sewage)
  - BOD is determined by measuring the DO of a freshly collected sample and comparing it to the DO level in a sample that was collected at the same time but incubated in complete darkness, at 20˚C, for 5 days
  - Unpolluted natural waters ≤ 5 mg/L BOD

Nutrients in Water

- Nitrate - Nitrogen is essential for plant growth, but the presence of excessive amounts in water supplies presents a major pollution problem
  - Nitrogen compounds may enter water from agricultural fertilizers, human sewage, industrial wastes, livestock wastes, and farm manure.
  - Nitrate in drinking water must be $\leq$ 10 ppm
- Phosphate measure in the form of phosphate applied as fertilizer to agricultural fields, grass lawns, or golf courses.
  - Phosphates accelerate the growth of algae and aquatic plants
  - Total P > 0.03 ppm will increase plant growth and eutrophication

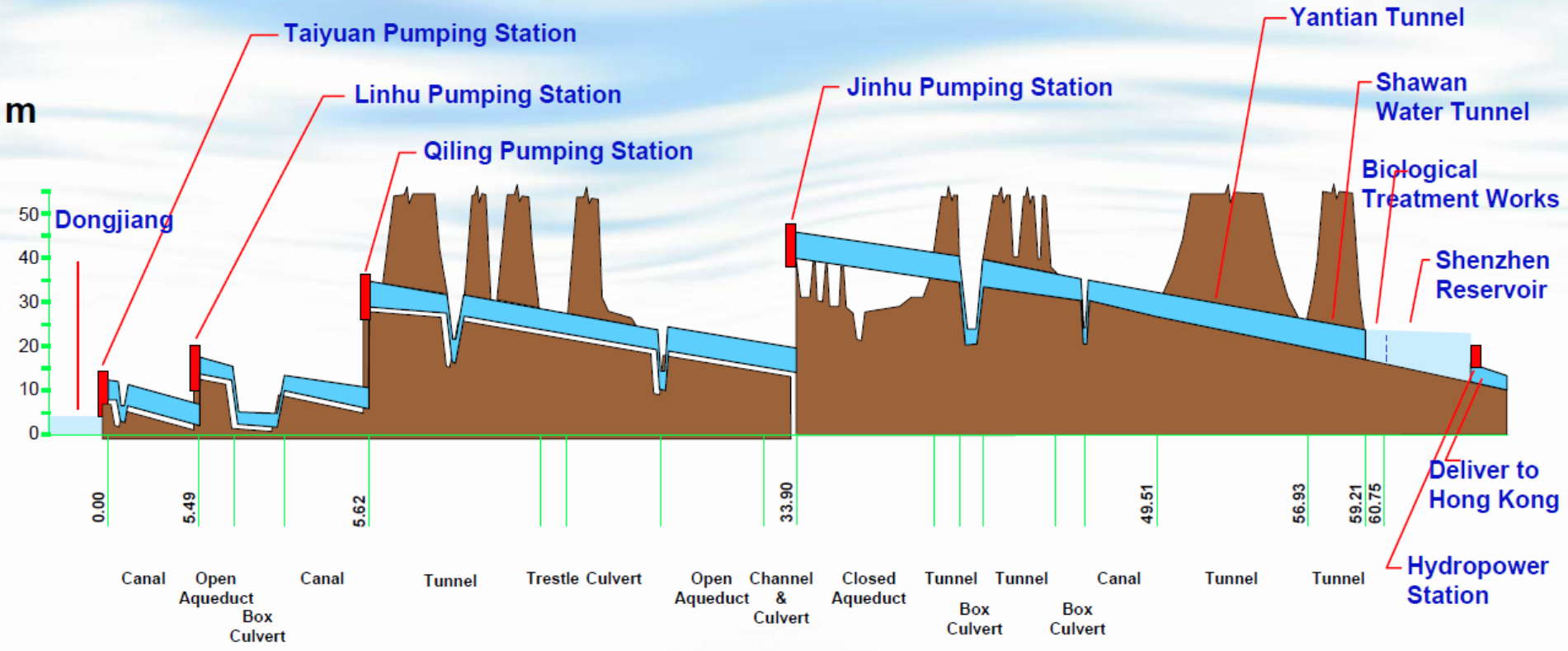
Hong Kong Water Supply

Fresh Water

The Major Source of Water Supply in Hong Kong

- The supply of water from Dongjiang at Guangdong, a province in southern China, is now the major single source of raw water supply for Hong Kong.
- The annual Dongjiang water supply has been now almost 70 - 80 per cent of Hong Kong's total demand starting since the late nineties.
- Initially, water extracted from the river at a point some 83 kilometers north of Hong Kong is pumped over a series of dams and open channels built across the Shima River, one of its tributaries.
- It eventually discharges into the Shenzhen Reservoir before being fed by pipelines to Shenzhen Special Economic Zone and across the border at Muk Wu to Hong Kong.
  - Western Route to Ngau Tam Mei and Au Tau Water Treatment Works and via Au Tau Pumping Station to Tai Lam Chung Reservoir;
  - Central Route via Tau Pass Culvert to Tai Po Tau Pumping Stations, and thence to Tai Po and Sha Tin Water Treatment Works or Plover Cove Reservoir; and
  - Eastern Route via Nam Chung Aqueduct to Plover Cove Reservoir, and thence to High Island Reservoir or Ma On Shan and Pak Kong Water Treatment Works via Harbour Island Pumping Station, Tolo Channel Aqueduct, Sai O Pumping Station and High Island Tunnels.

THE DONGJIANG - SHENZHEN WATER SUPPLY SCHEME
DEDICATED AQUEDUCT
LONGITUDINAL SECTION



Distance (Km)

W10148E

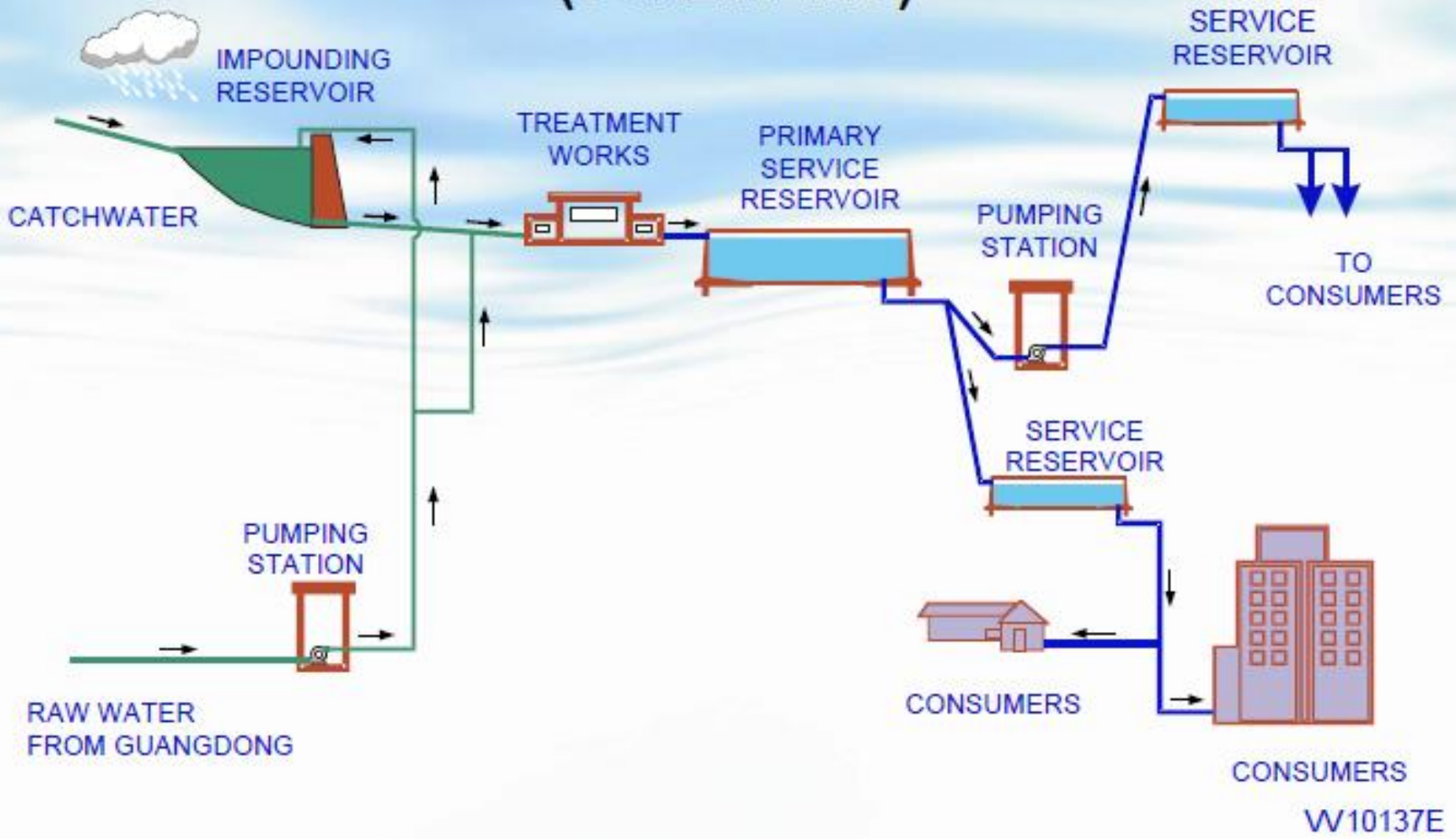
Reservoirs in Hong Kong

1. Kowloon Reservoirs
   - Kowloon Reservoir
   - Kowloon Byewash Reservoir
   - Kowloon Reception Reservoir
2. Tai Tam Reservoirs
   - Tai Tam Reservoir
   - Tai Tam Byewash Reservoir
   - Tai Tam Intermediate Reservoir
   - Tai Tam Tuk Reservoir
3. Tai Lam Chung Reservoir
4. Shing Mun Reservoirs
   - Shing Mun Reservoir
   - Lower Shing Mun Reservoir
5. Aberdeen Reservoirs
   - Aberdeen Upper Reservoir
   - Aberdeen Lower Reservoir
6. Shek Pik Reservoir
7. Plover Cove Reservoir
8. Shek Lei Pui Reservoir
9. Pok Fu Lam Reservoir
10. High Island Reservoir

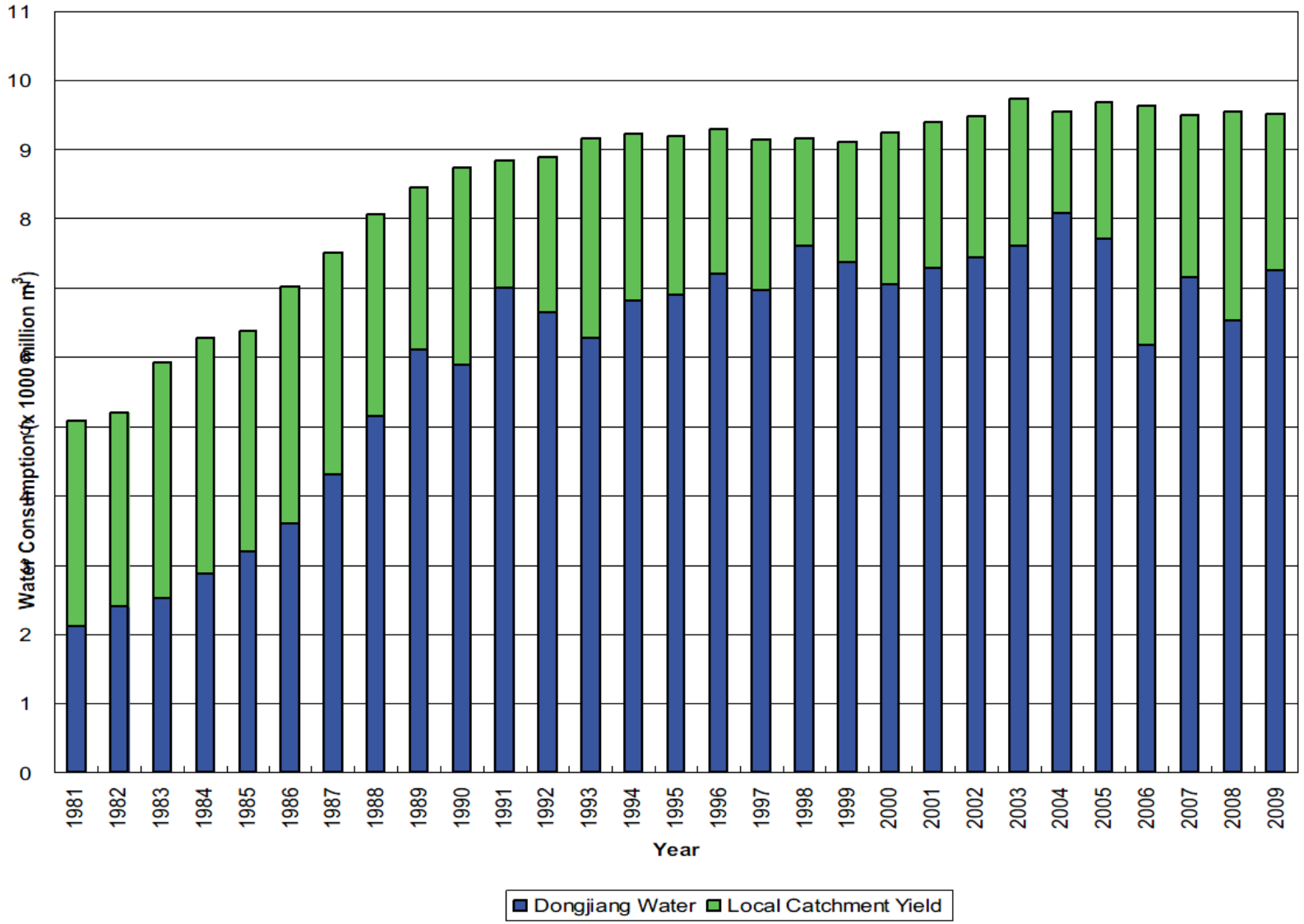
Drinking Water Quality

Parameter	Unit	Monitoring Data (10/2009 - 09/2010)		
		Minimum	Maximum	Average
pH at 25 °C	pH	6.7	9.4	8.5
Colour	Hazen unit	< 3	< 3	< 3
Turbidity	NTU	< 0.1	3.0	0.3
Conductivity at 25 °C	µS/cm	53	200	141
Temperature	°C	11.5	33.4	24.1
Total alkalinity (as $CaCO_3$)	mg/L	5	36	22
Total hardness (as $CaCO_3$)	mg/L	6	68	35
Calcium	mg/L	1.3	19	12
Magnesium	mg/L	0.31	2.3	1.4
Chloride	mg/L	< 5	22	10
Sulphate	mg/L	4	24	14
Ortho-phosphates (as PO_4)	mg/L	< 0.01	0.04	< 0.01
Iron	mg/L	< 0.01	0.18	< 0.01
Aluminium	mg/L	< 0.01	0.32	0.02
Silica (as SiO_2)	mg/L	5.3	15	11

A TYPICAL FRESH WATER SUPPLY SYSTEM
(SCHEMATIC)



Hong Kong Water Usage



Hong Kong Status

2005 population : 6.94 million

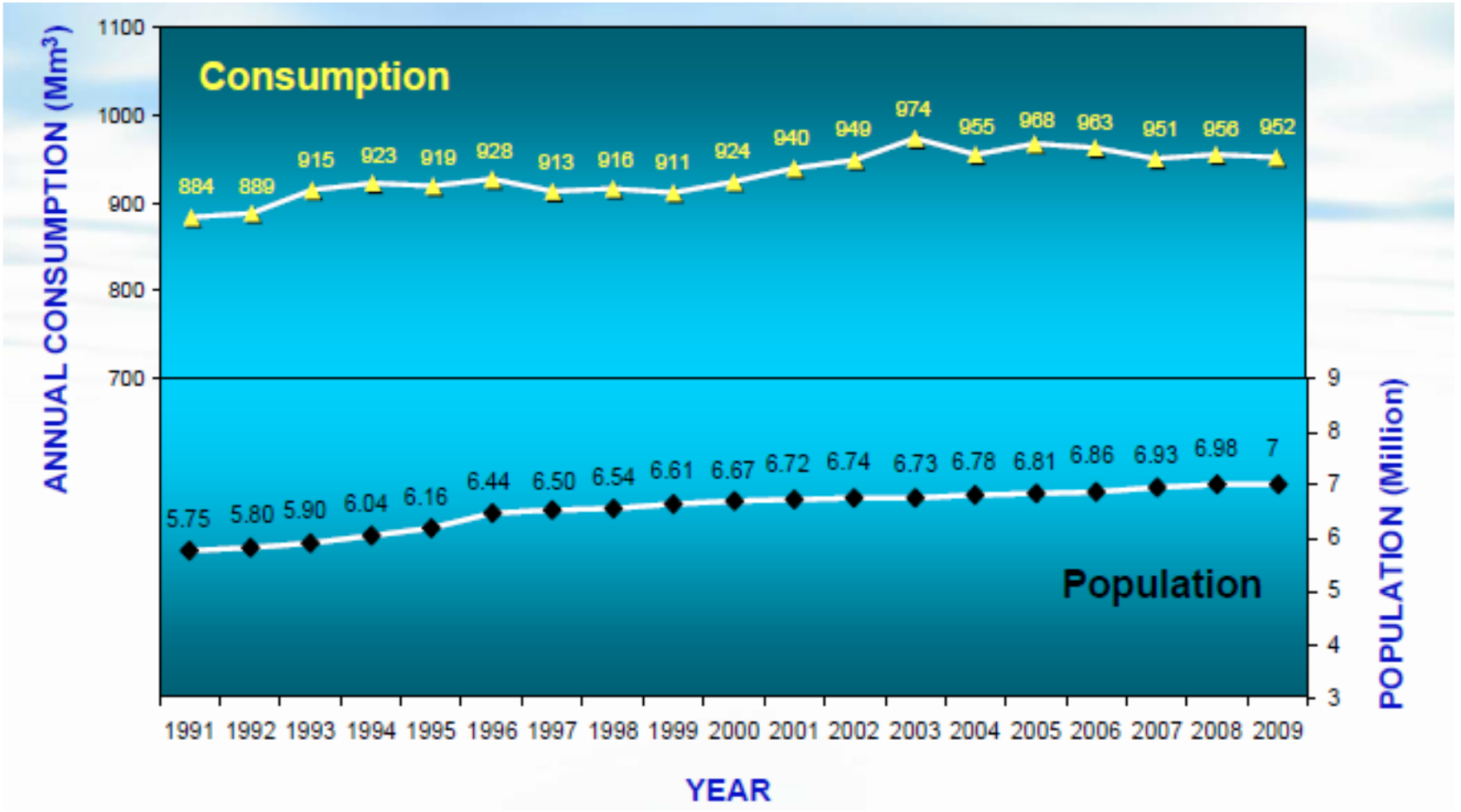
2004 water usage : 955 MM^3

Water from Guangdong: 70 to 80 %

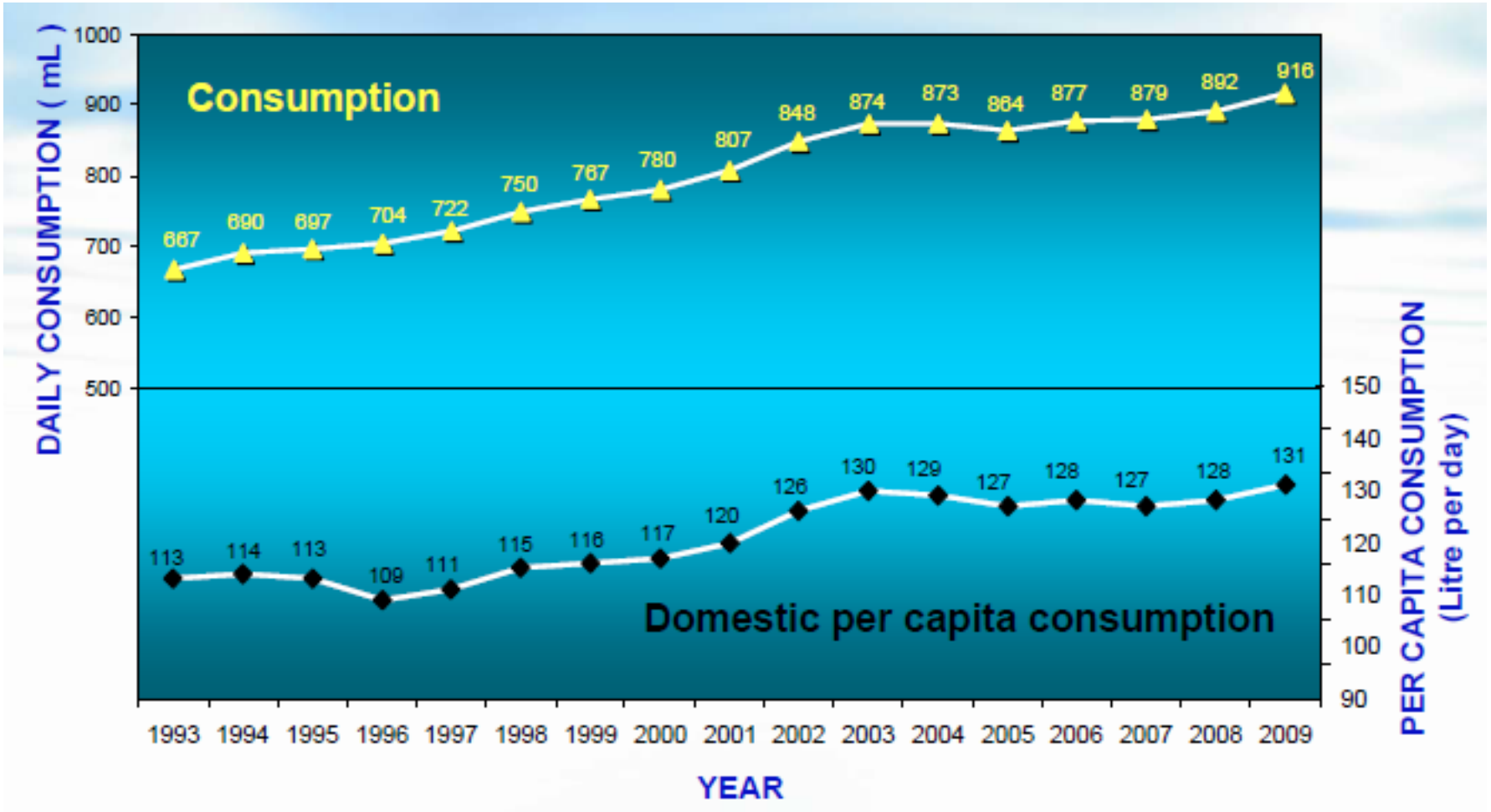
Local water supply : 20 to 30 %

⟹ no water shortage temporarily

Fresh Water Consumption and Population in Hong Kong



Domestic Fresh Water Consumption and per Capita Consumption



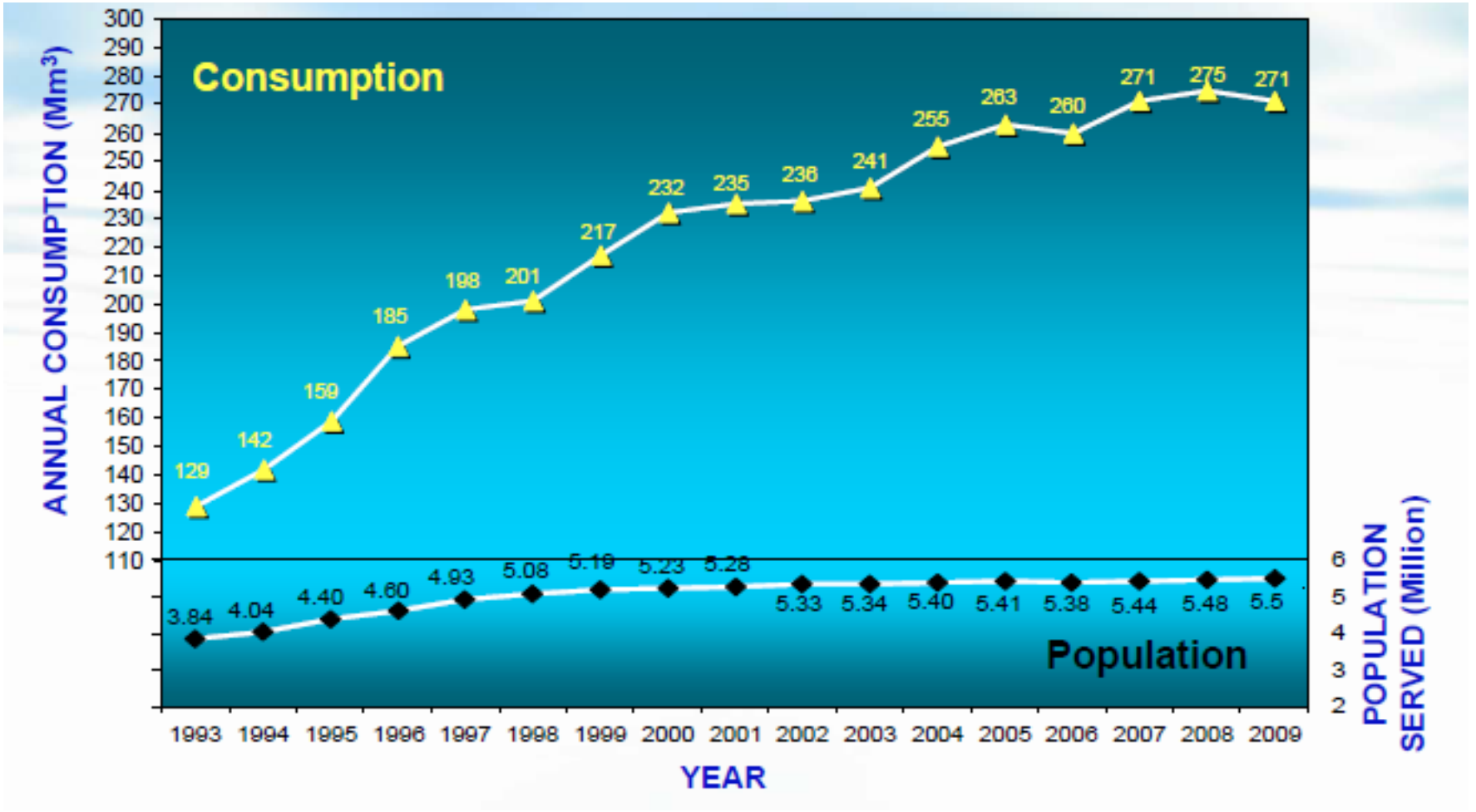
Water Tariff in Hong Kong

- Domestic Supplies
  - the first tier of 12 m^3 is free of charge;
  - the second tier of 31 m^3 is charged at \$4.16/m^3
  - the third tier of 19 m^3 is charged at \$6.45/m^3
  - the fourth tier for any consumption above the level of 62 m^3 is charged at \$9.05/m^3.
- Non-domestic Supplies
  - For trade: \$4.58/m^3
  - For construction: \$7.11/m^3
  - For non ocean-going shipping: \$4.58 /m^3
  - For ocean-going shipping: \$10.93 /m^3

Sea Water for Flushing

香港海水供應區及
計劃擴展的地區
Existing Sea Water
Flushing Supply Zones
and Proposed Extensions

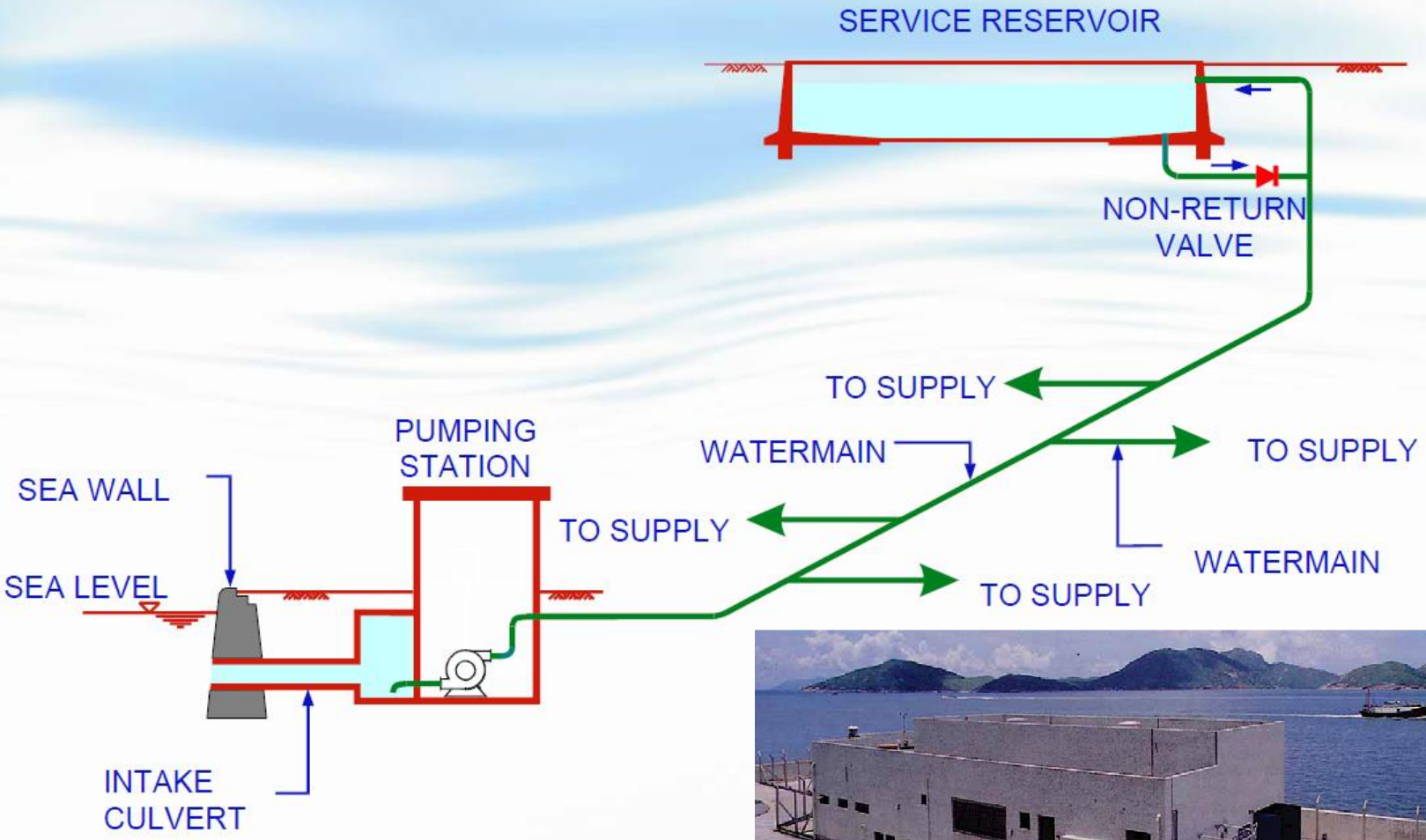
Sea Water Consumption and Population Served



Water Quality of Sea Water

	Target
• Color (Hazen Unit)	< 20
• Turbidity (NTU)	< 10
• Threshold Odor Number	< 100
• Ammonical Nitrogen (mg/l)	< 1
• Suspended Solids (mg/l)	< 10
• Dissolved Oxygen (mg/l)	> 2
• Biochemical Oxygen Demand (mg/l)	< 10
• Synthetic Detergents (mg/l)	< 5
• E. coli (no./ml)	< 1,000

A TYPICAL SEA WATER SUPPLY SYSTEM (SCHEMATIC)



Seafront Salt Water Pumping Station

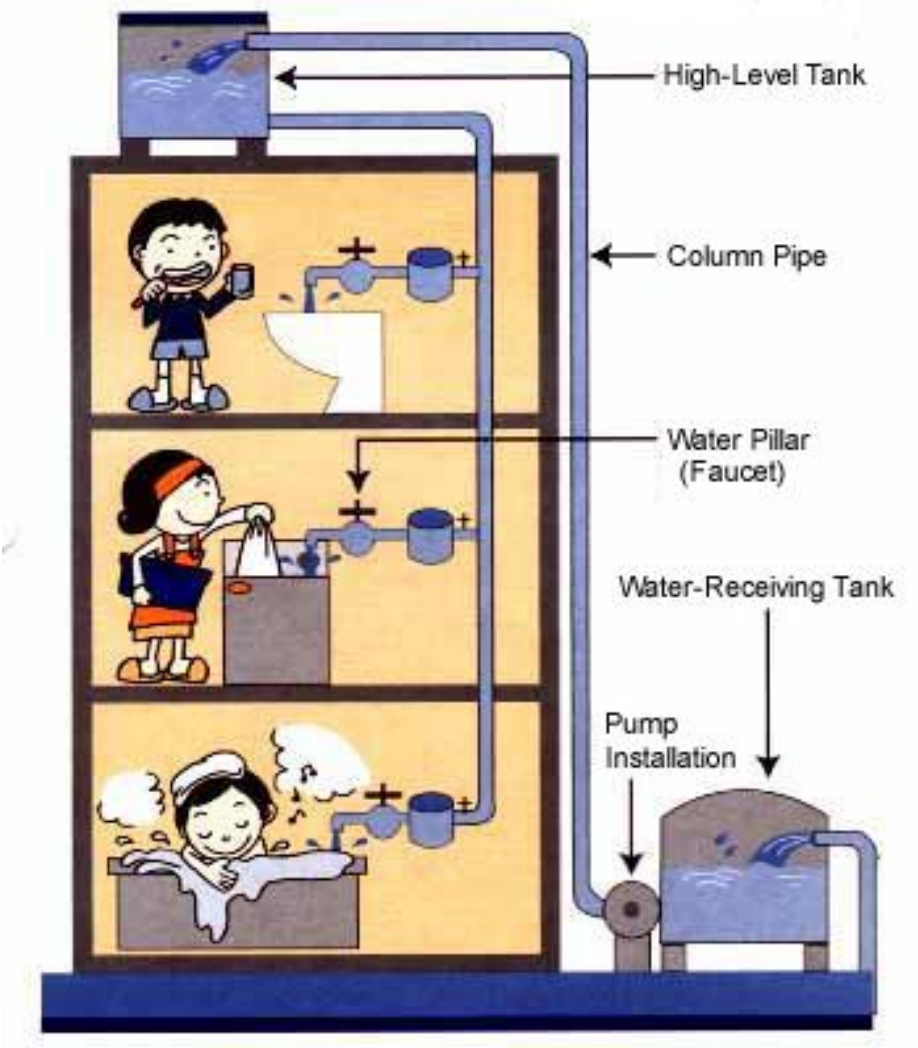
Water Pumping Power for Buildings

- Water is pumped and stored at the top of the building to be used by the occupants by gravity.
- Energy is used to pump water to overcome the gravitational force.
- P.E. = m • g • h

  where m = mass of water
  g = acceleration of gravity
  h = height of the tank for water to be delivered
- Notice that in SI unit system, m will be in kg; g = 9.8 m/s; and h in m; and P.E. will be in kg-m^2/s^2 which is Joule
- Recall,

$$J = \frac{kg \bullet m^2}{s^2} = N \bullet m = W \bullet s$$

  where J is Joule, N is Newton ($kg\text{-}m/s^2$) and W is Watt (J/s)
- Other energy involved might be in the form of friction through the pipes and bends of the plumbing system
- Pumping power = P.E./time



Example

Water is pumped from the tank situated at the basement 5 m below the ground level to the tank located at top of the building 120 m above the ground. The dimension of the top tank is 10 m (w) x 20 m (l) x 5 m (h). Calculate the minimum power of the pump needed to completely fill the tank in 24 hours.

Solution

volume of water in the top tank = 10 m x 20 m x 5 m = 1000 m^3

density of water taken as 998.2071 kg/m^3

potential energy = mgh = 998.2071 x 1000 kg x 9.8 m/s^2 x (120 + 5 + 5) m

= 1.2717 x 10^9 kg-(m/s^2)-m

= 1.2717 x 10^9 Newton-m

= 1.2717 x 10^9 Joule

minimum power needed to fill the tank = 1.2717 x 10^9 Joule/(24 x 60 x 60) s

= 1.4719 x 10^4 Watts

= 14.719 kW