WATER AND ENERGY NEXUS AND RENEWABLE-ENERGY-DRIVEN WATER DESALINATION

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By

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I. Water and Energy Sustainability in a Changing Environment

Humanity's Top Ten Problems for Next 50 Years

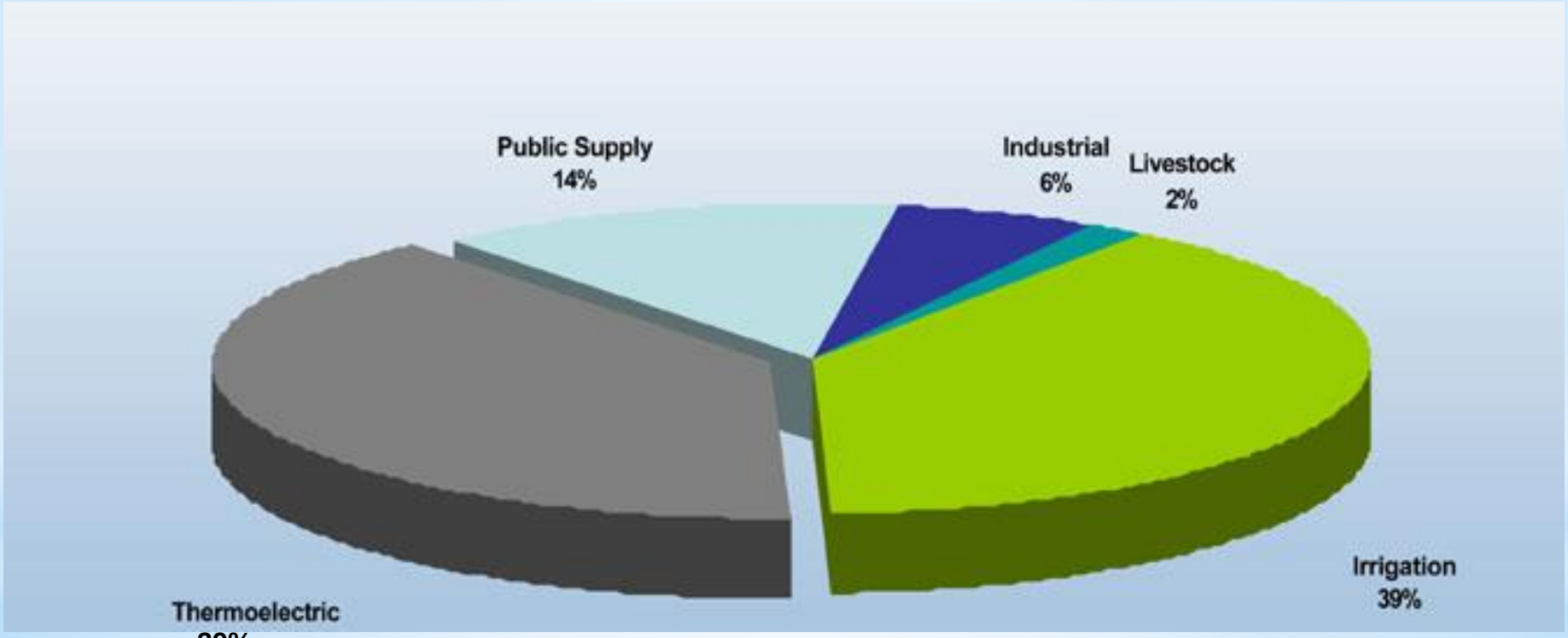
- Energy
- Water
- Food
- Environment
- Poverty
- Terrorism & War
- Disease
- Education
- Democracy
- Population

Source: Richard Smalley, Nobel laureate

Water is a Critical Resource

- Fast growing demand for clean, fresh water
- Increased demand for environmental protection
- All parts of the world are vulnerable to water shortages
- Water availability determines:
  - Electricity supply and demand
  - Electricity grid topology
  - Societal and economic infrastructure sustainability

Estimated Fresh Water Withdrawals by Sectors, 2000

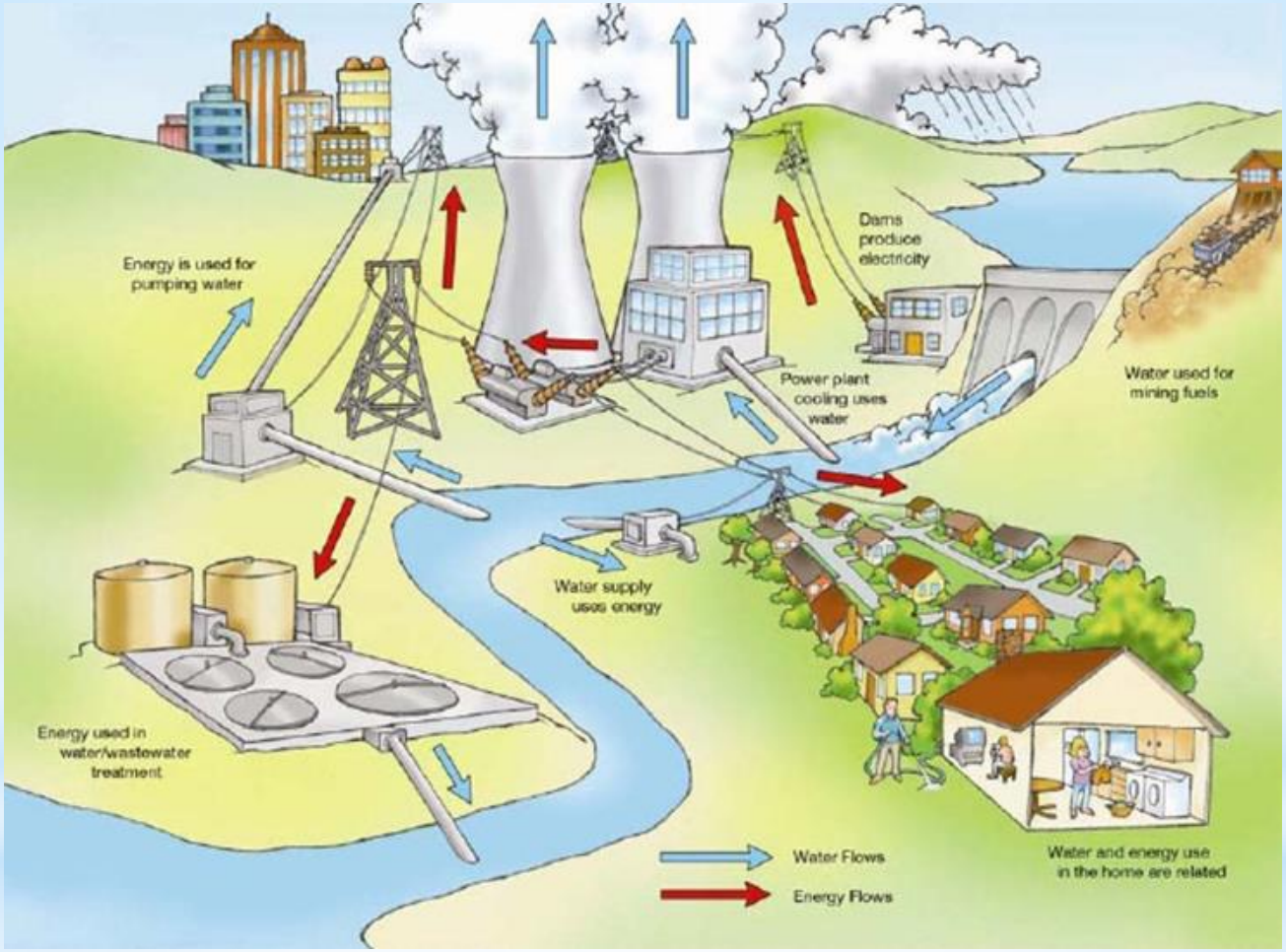


Source: EPRI

Energy is a Critical Resource

- Energy is essential for modern life
- Unsettling energy questions:
  - Are rising prices of oil and gas real constraints?
  - Should we start changing our life style?
  - Is global warming already happening?

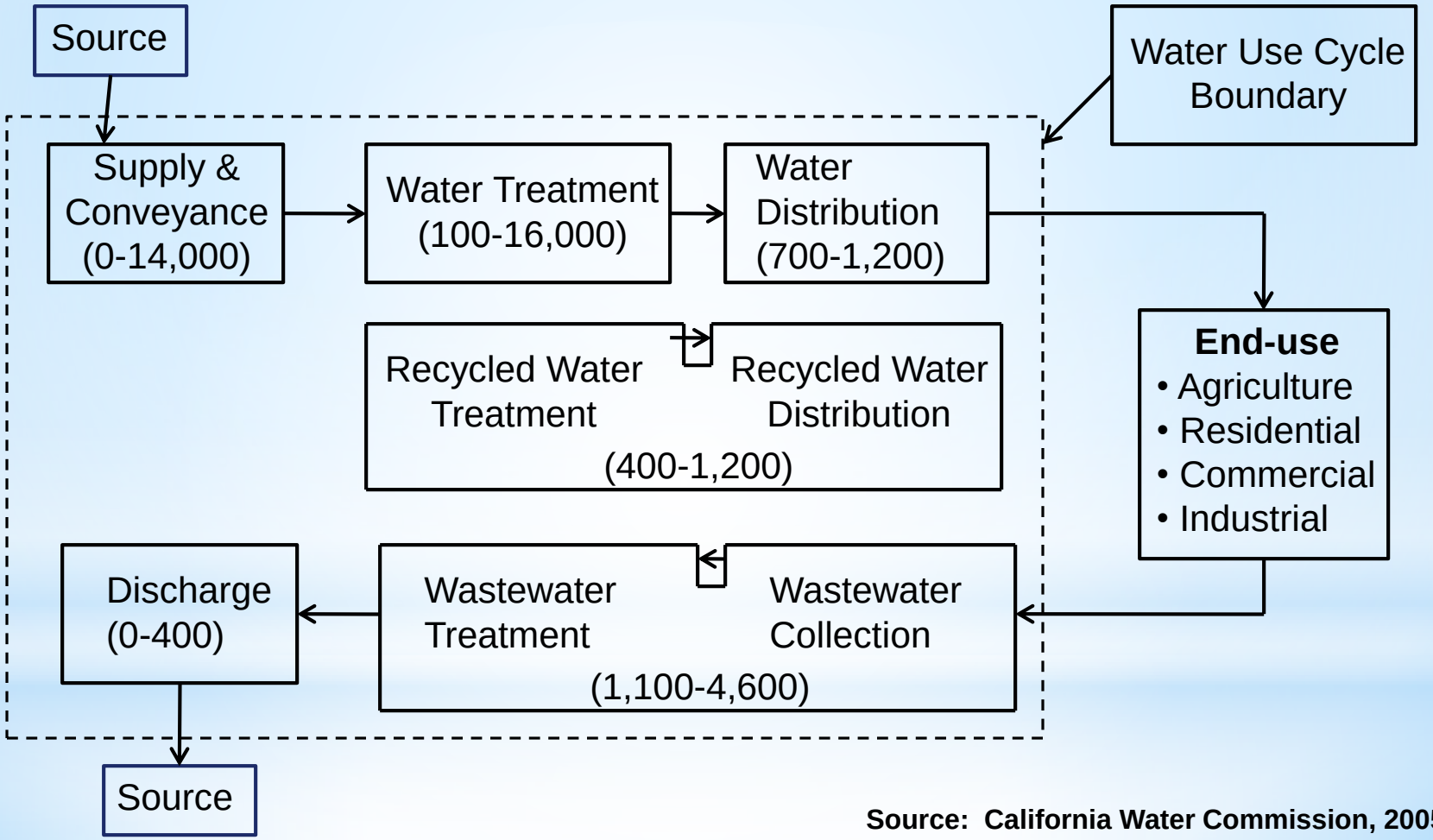
Energy and Water are Inextricably Linked



Water and Energy Nexus

- Water is a limited resource
- Sustainable withdrawal of freshwater is a worldwide issue
- Energy requires water and water requires energy
- Energy – Water issues require a regional perspective

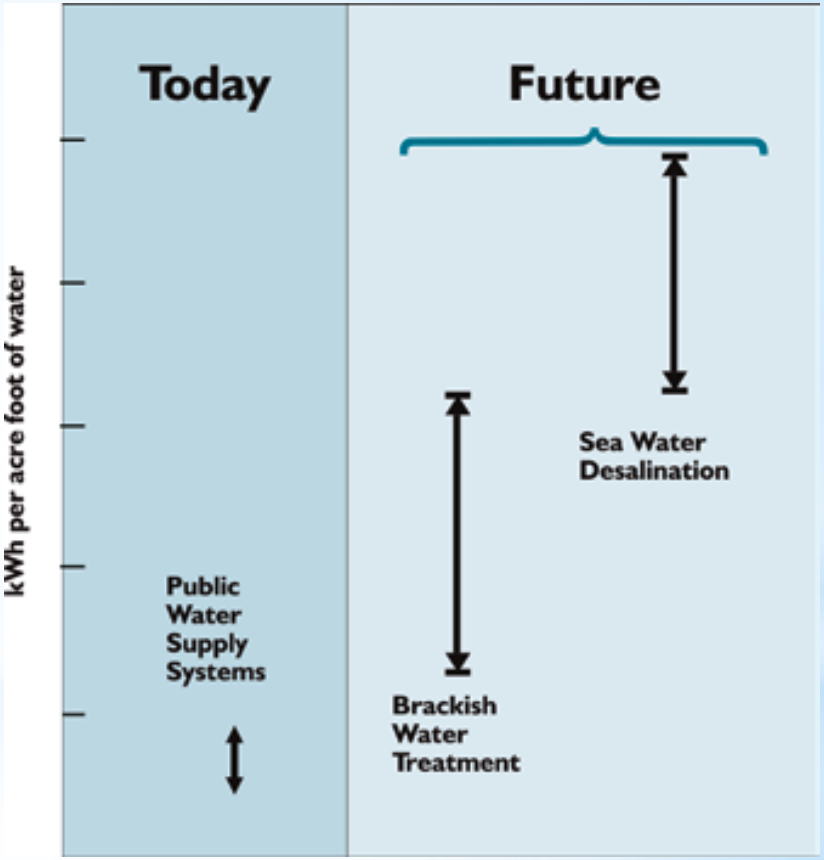
Energy Intensity in Water Use Cycle (kWh/MG)



Source: California Water Commission, 2005

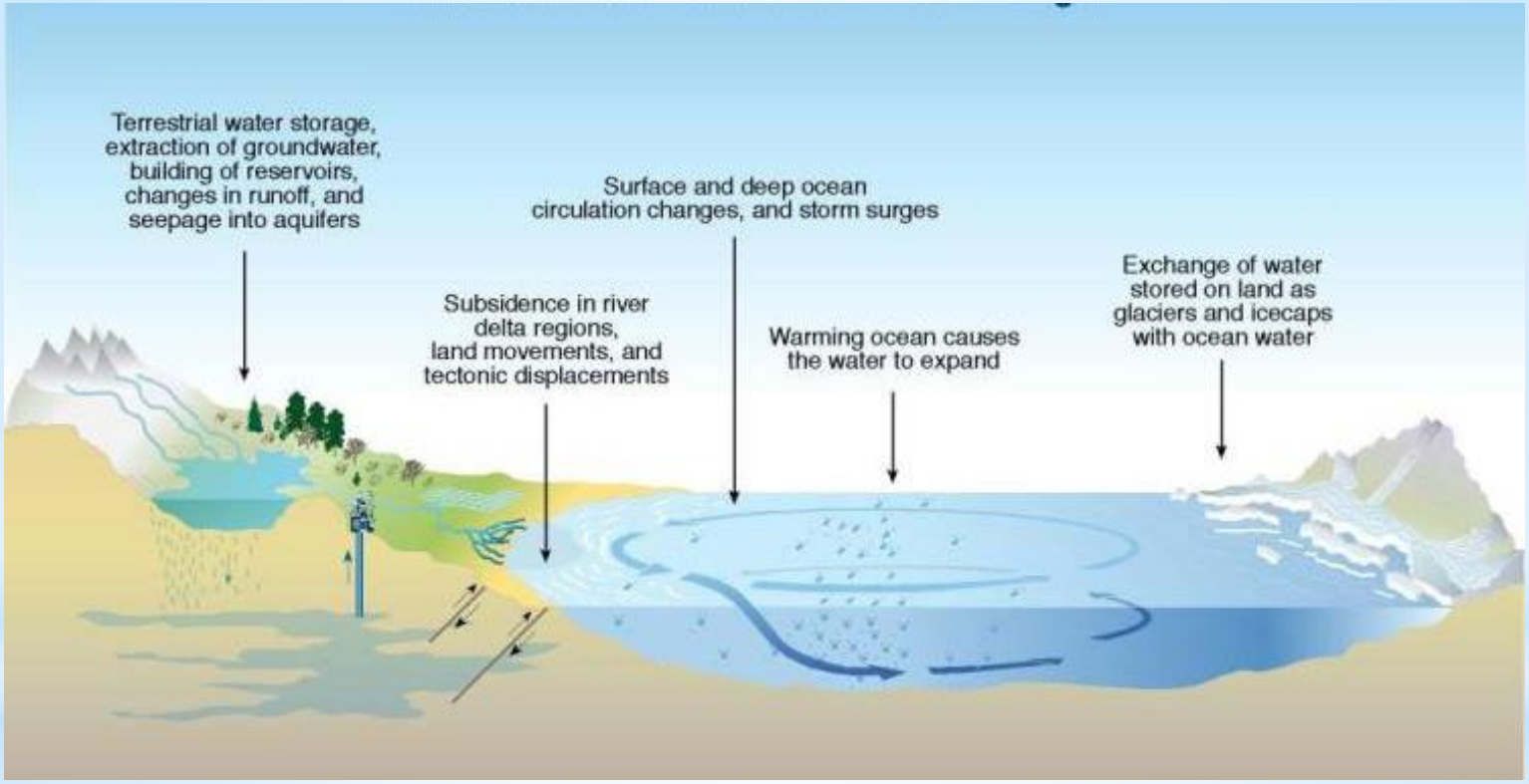
New Water Supplies are Energy Intensive

- Readily accessible water supplies have been harvested
- New tecnologies are required to reduce energy requirements to access non-traditional sources (e.g., impaired water, brackish water, sea water)



Source: EPRI

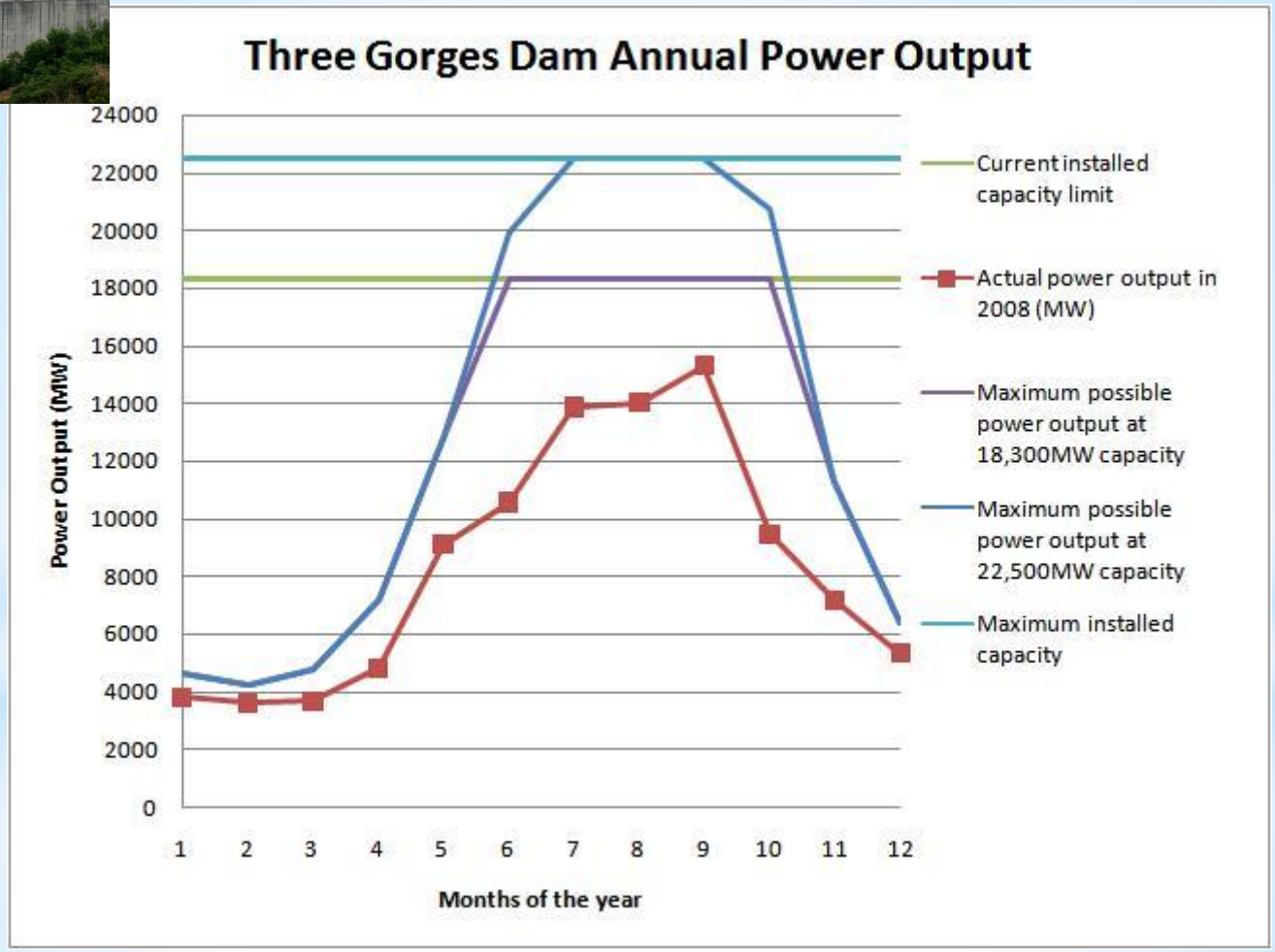
Water and Energy Availability in a Changing Environment

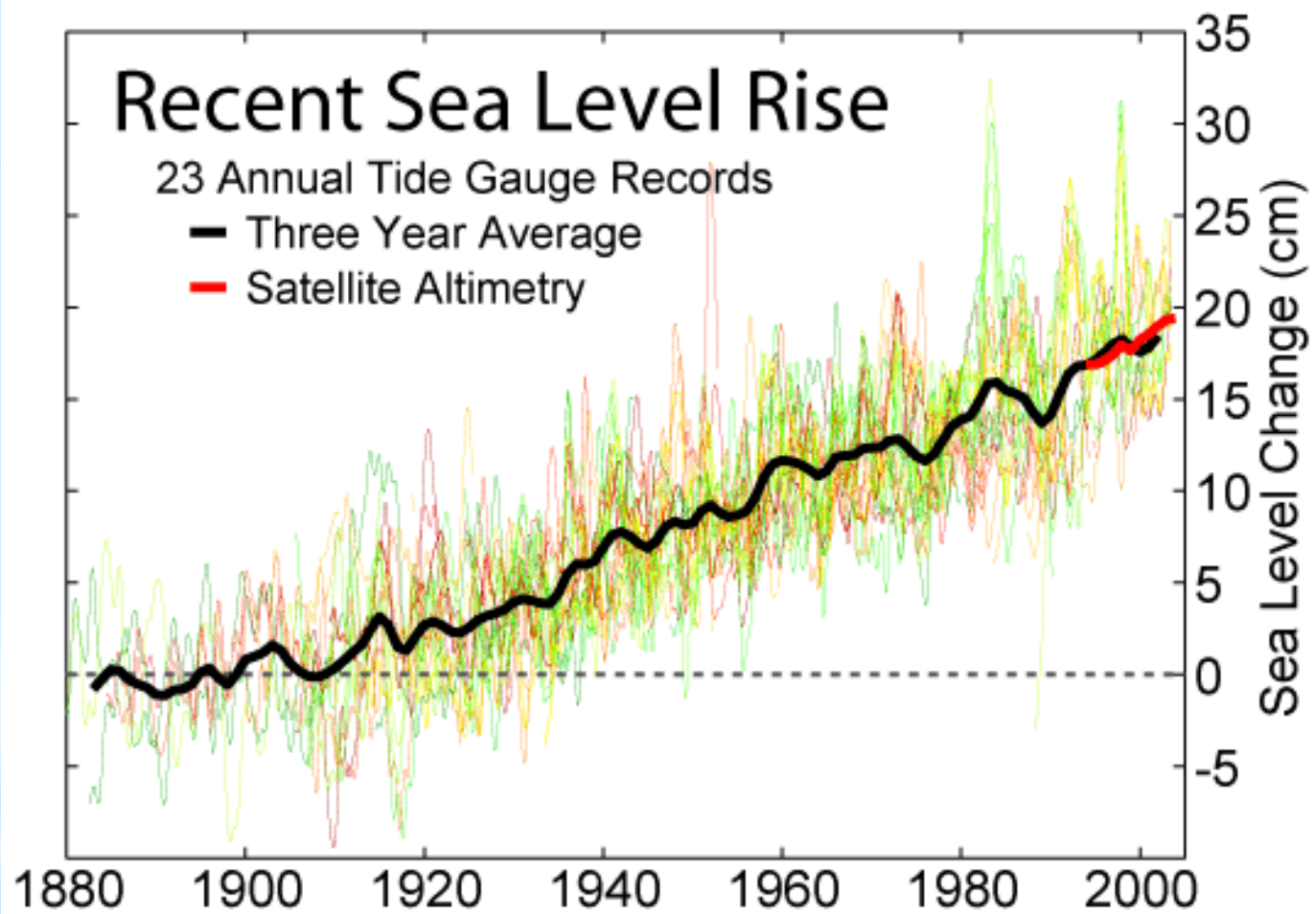


Impact of Climate Change on Water Resources
Joint USA / China Initiative

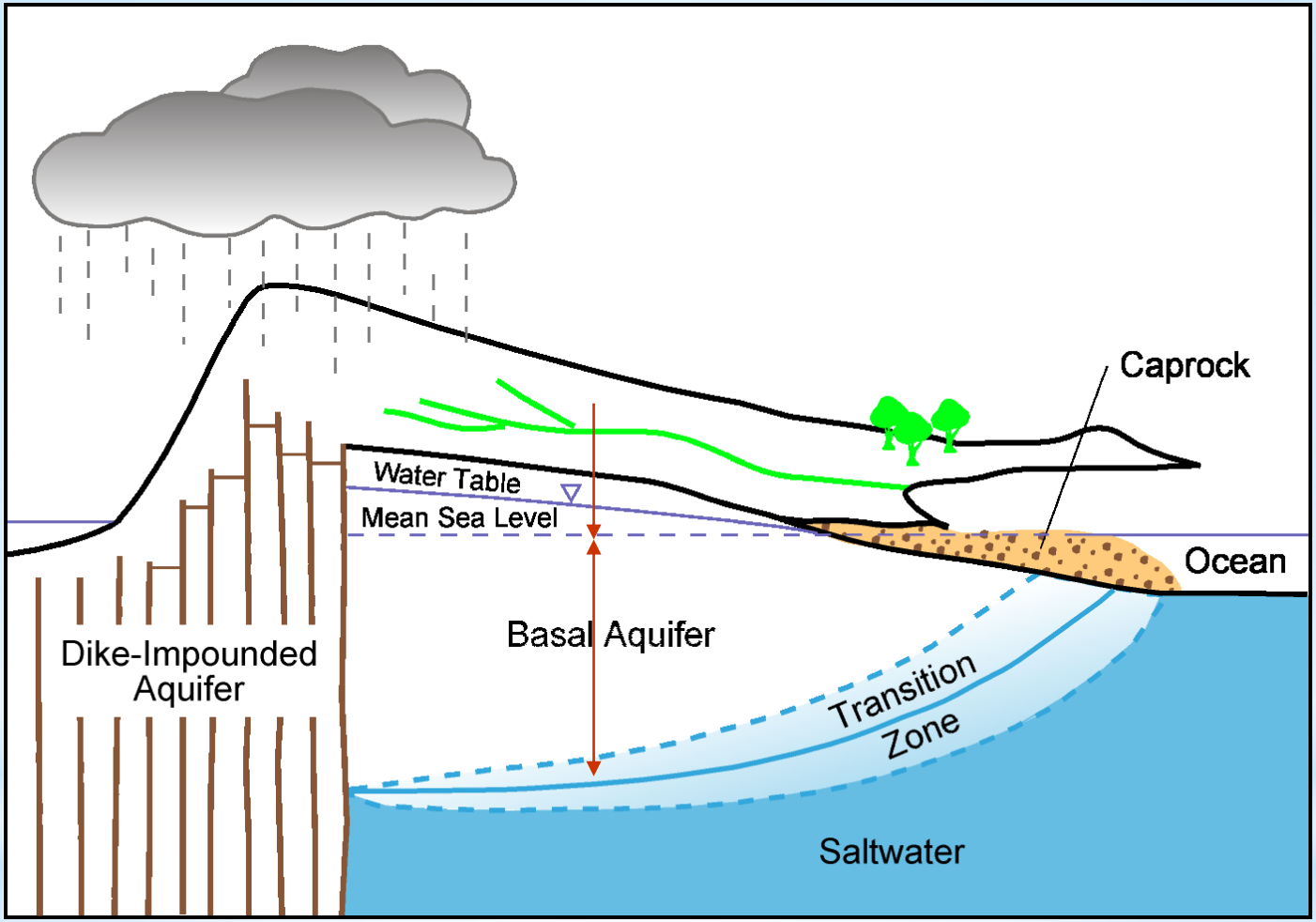
From 1962-2006, the area of Glacier #1 in Tsinghan Province, China, has reduced by 14%

Climate Change and Hydropower Generation




Recent Sea Level Rise
23 Annual Tide Gauge Records
Three Year Average
Satellite Altimetry
35
30
25
20
15
10
5
0
-5
Sea Level Change (cm)
1880
1900
1920
1940
1960
1980
2000

Sea Level Rise and Water Supply for Coastal Cities



Reference:
Liu, C.C.K., and J. Dai (2012). Seawater intrusion and sustainable yield of basal aquifers, Journal of the American Water Resources Association (JAWRA), 48(5):861-870.

II. Water Desalination

Major Desalination Processes

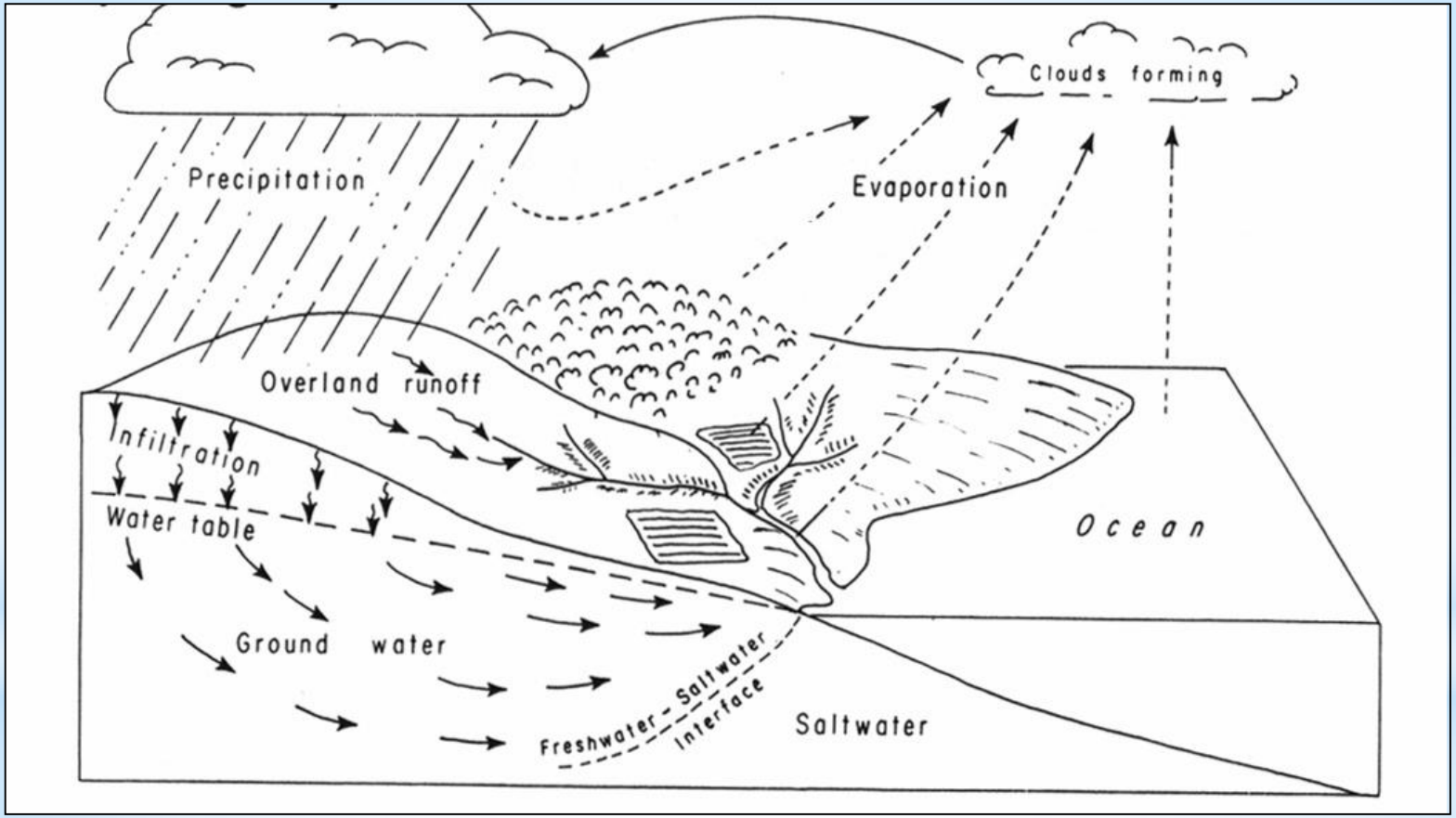
- Thermal
  - Multi-stage Flash Distillation (MFD)
  - Multi-Effect Distillation (MED)
  - Vapor Compression
- Membrane
  - Electro dialysis (ED)
  - Reverse Osmosis (RO)

Minor Desalination Processes

- Freezing
- Membrane Distillation
- Solar Humidification

Reference: Liu, C.C.K. and Park, J.W. (2002). Water Desalination, *McGraw-Hill Encyclopedia of Science & Technology, Ninth Edition, Volume 22*, the McGraw-Hill, New York, pp.404-406.

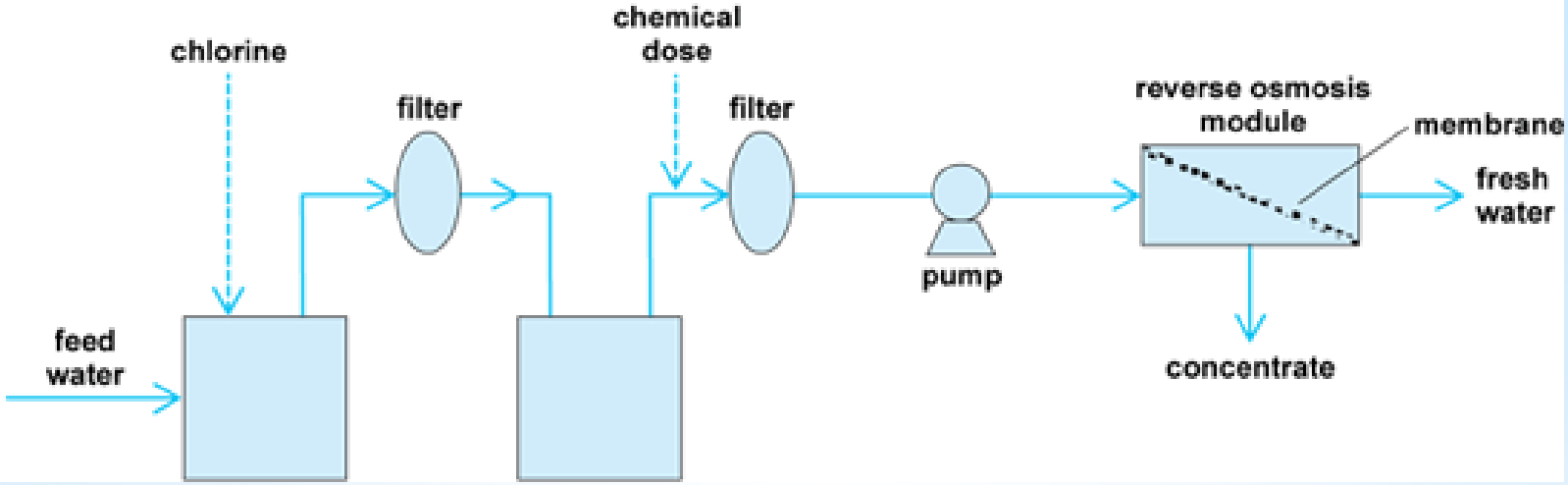
Natural Water Distillation Process: Hydrologic Cycle



The energy required for maintaining the hydrologic cycle is 78 W/m^2 of earth surface; while s*olar energy absorption at the earth's surface is about* 168 W/m^2

Membrane Desalination Processes

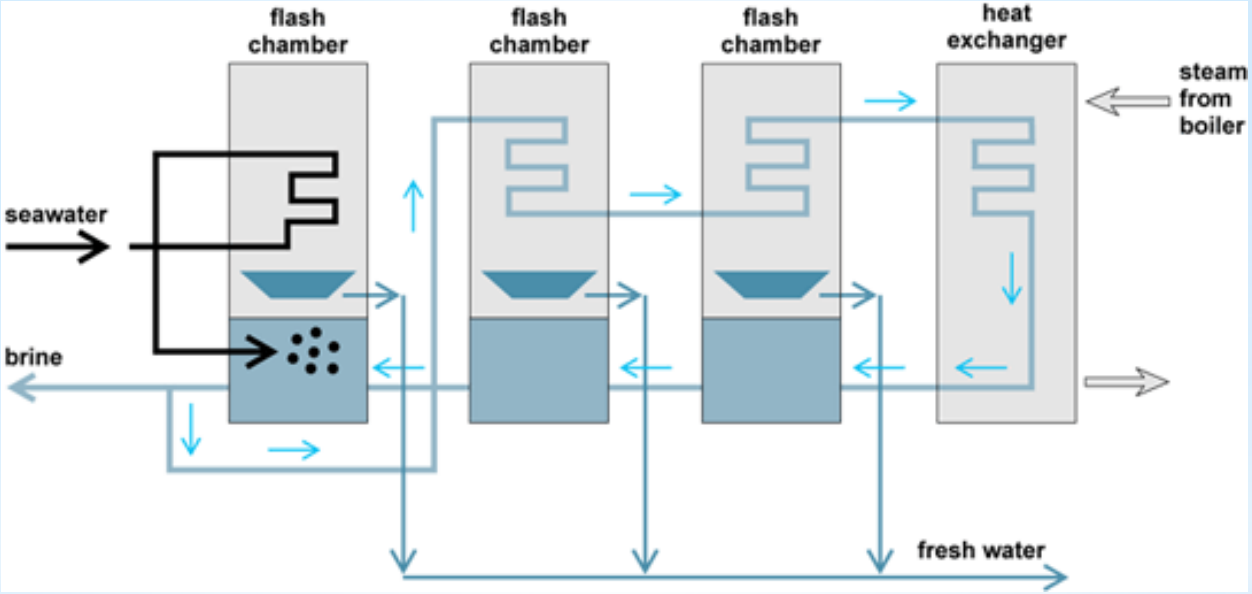
Reverse Osmosis Desalination Process (RO)



Reference: Liu, C.C.K. and Park, J.W. (2002). Water Desalination, *McGraw-Hill Encyclopedia of Science & Technology, Ninth Edition, Volume 22*, the McGraw-Hill, New York, pp.404-406.

Thermal Desalination Processes

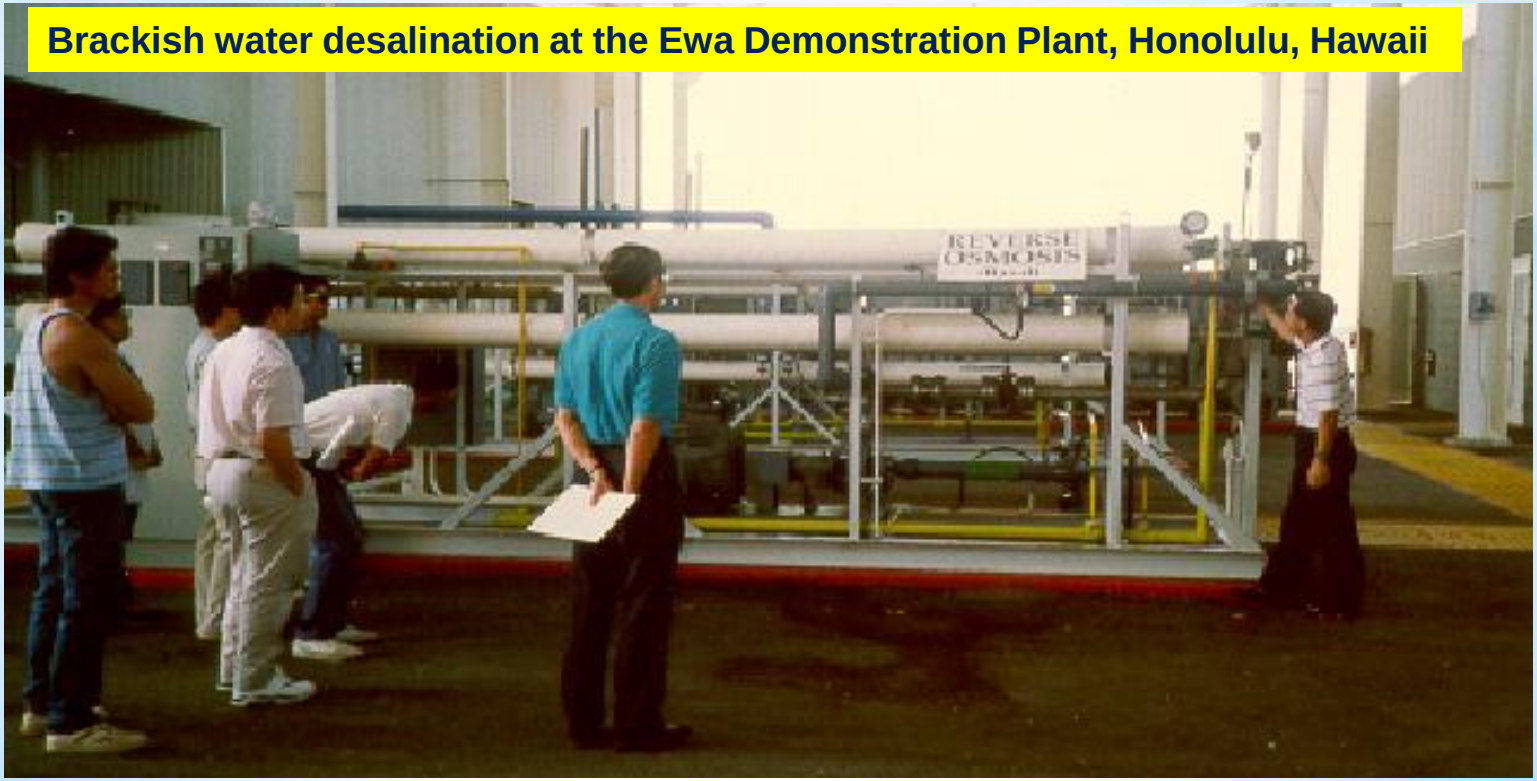
Multi-stage Flash Distillation Process (MFD)



Reference: Liu, C.C.K. and Park, J.W. (2002). Water Desalination, *McGraw-Hill Encyclopedia of Science & Technology, Ninth Edition, Volume 22*, the McGraw-Hill, New York, pp.404-406.

Technological Development Needs for Membrane Desalination Processes

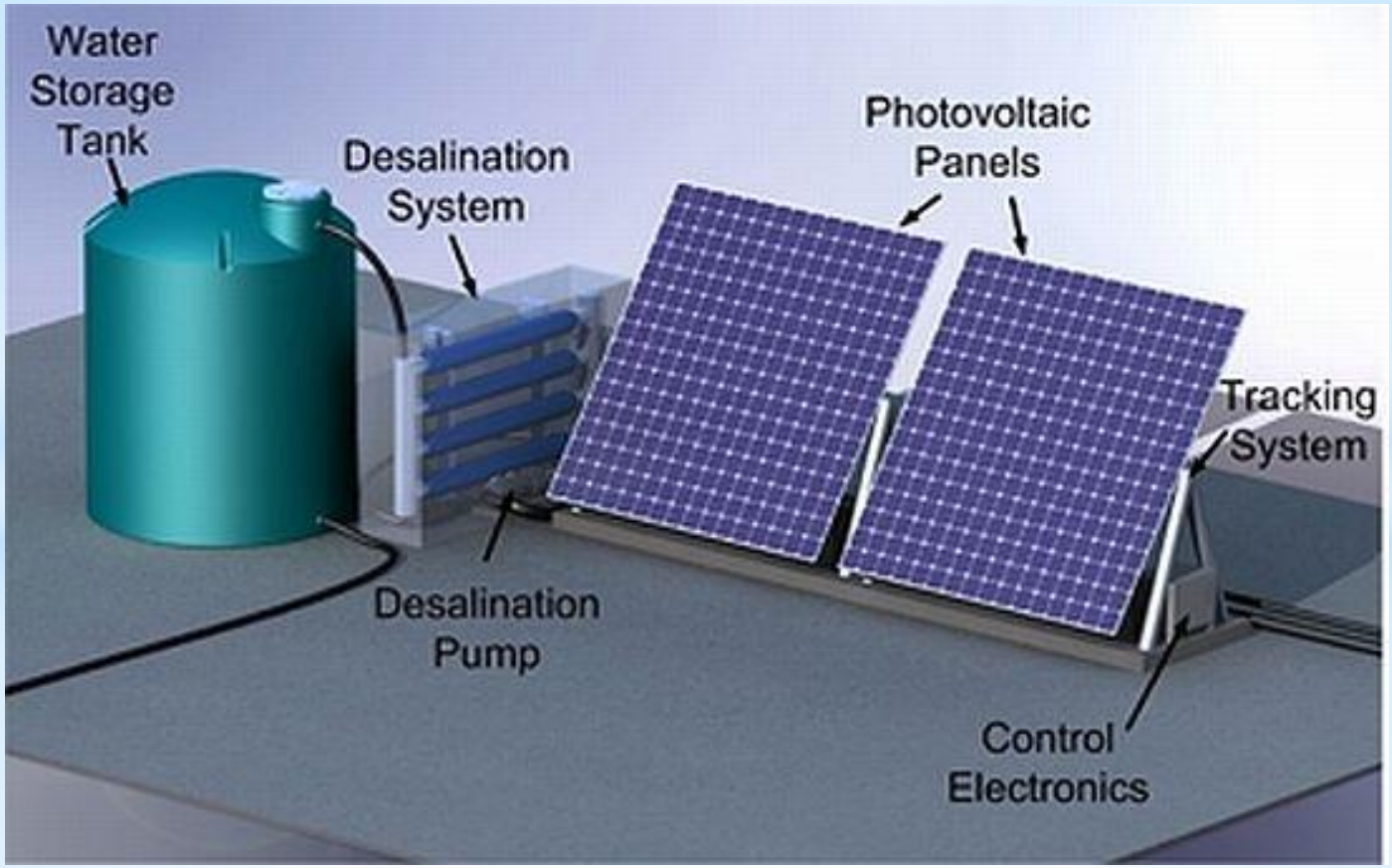
- High energy consumption
- Scaling and membrane fouling



Brackish water desalination at the Ewa Demonstration Plant, Honolulu, Hawaii

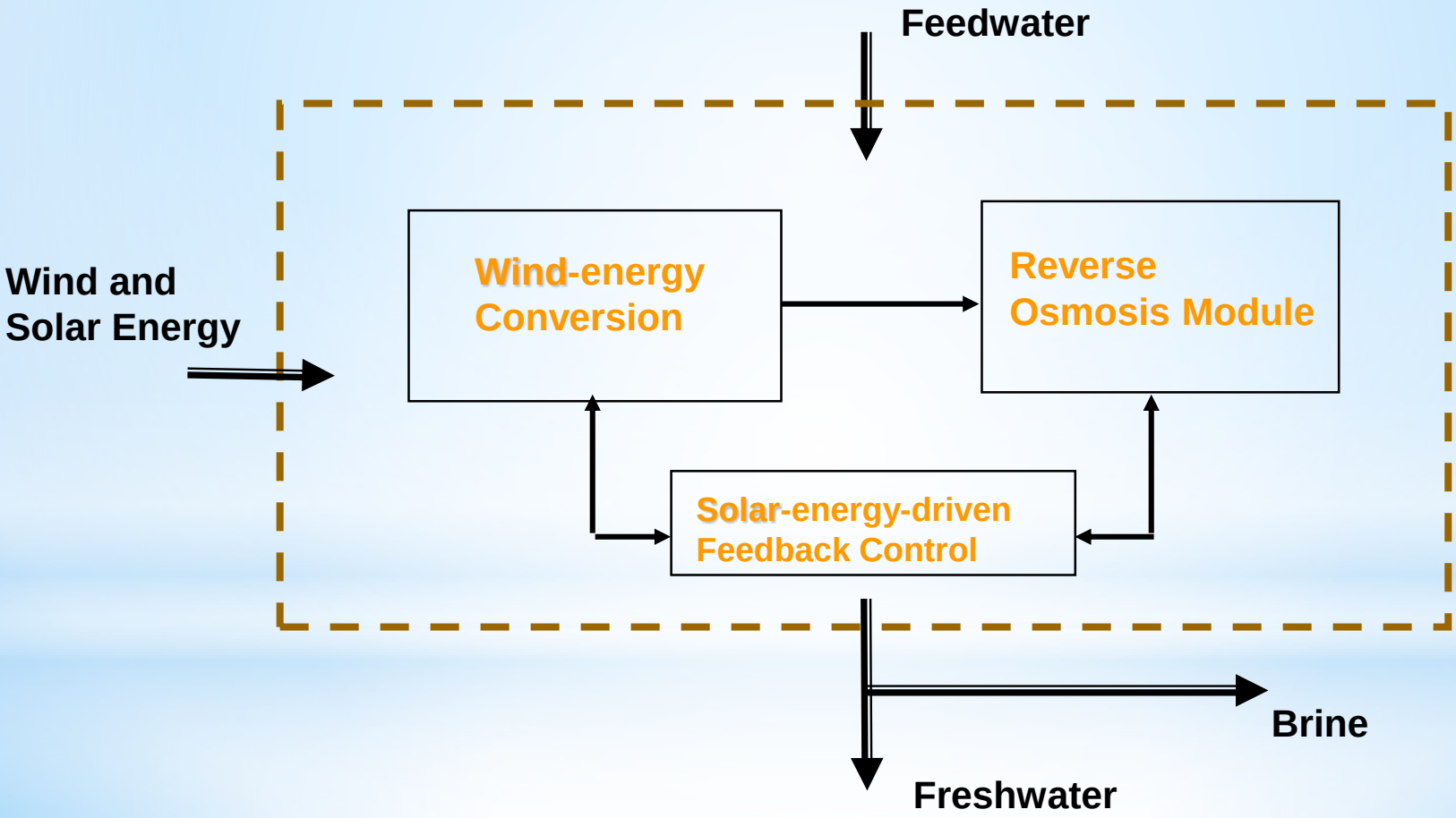
Emerging Technology of Water Desalination

1. Solar-Driven Water Desalination



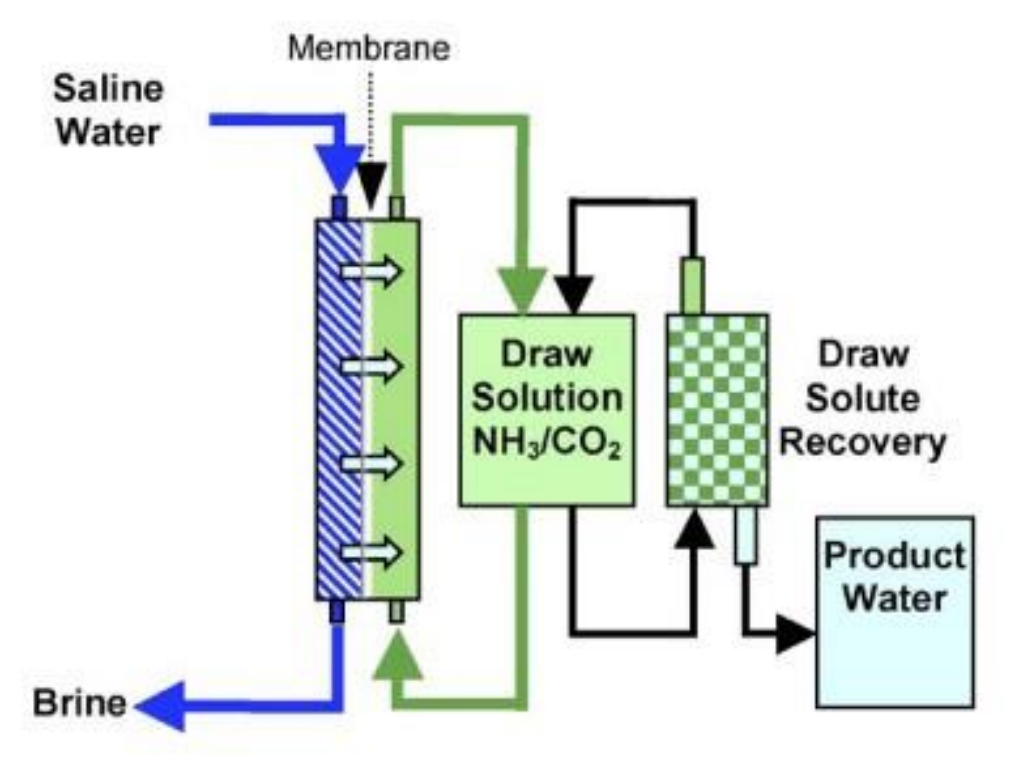
Emerging Technology of Reverse Osmosis Water Desalination

2. Wind-Driven Water Desalination



Emerging Technology of Reverse Osmosis Water Desalination

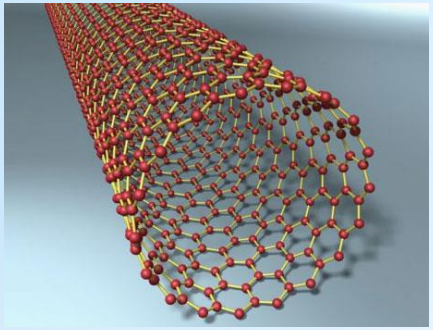
3. Forward Osmosis

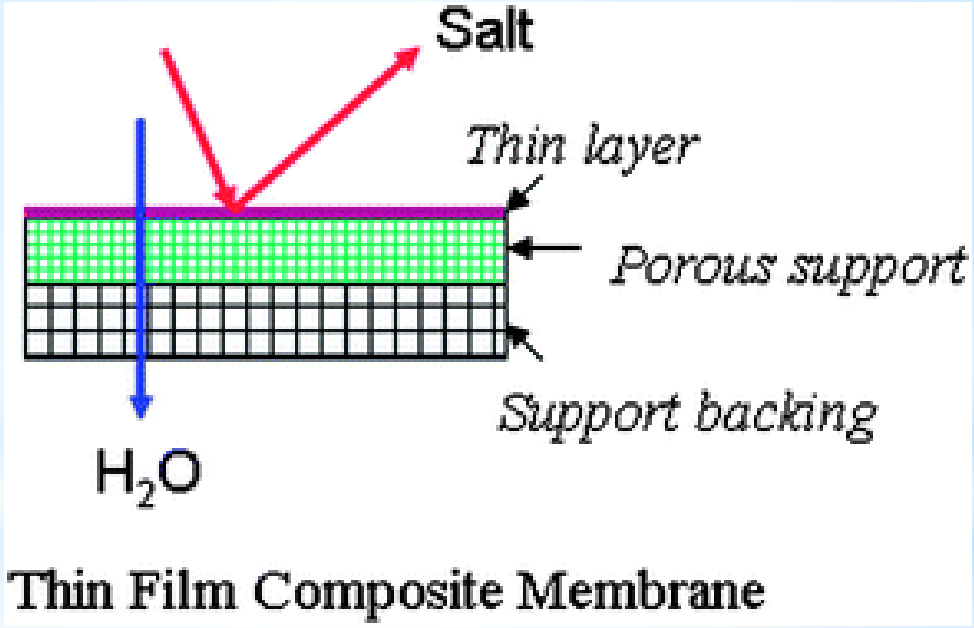


http://en.wikipedia.org/wiki/Forward_osmosis

Emerging Technology of Reverse Osmosis Water Desalination

4. Carbon nanotubes

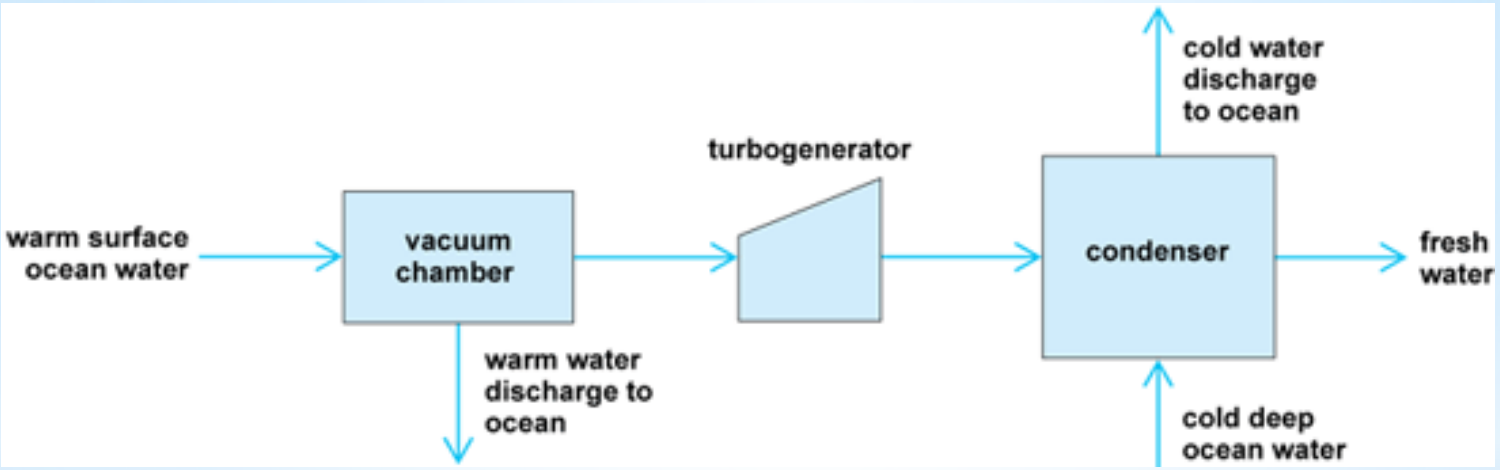




Reference: Li, D. and Wang, H. (2010) Recent developments in reverse osmosis desalination membranes , *J. Mater. Chem.*, 2010,20, 4551-4566

III. Natural-Energy-Driven Water Desalination

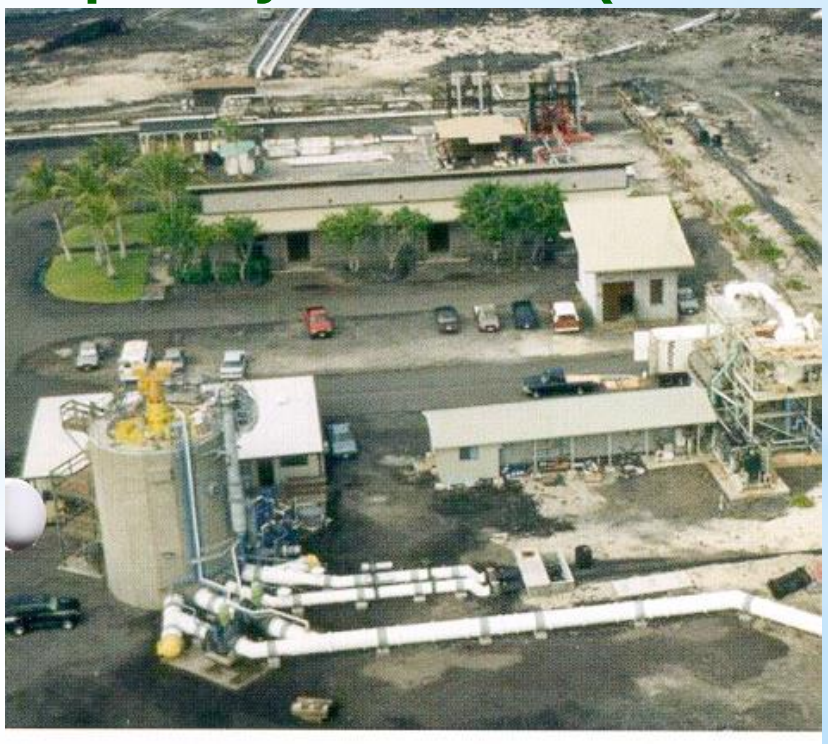
1. Open-cycle OTEC and Water Desalination



Ocean Thermal Energy Conversion (OTEC)

Mini-OTEC (closed-cycle) (1979)

Open-cycle OTEC (1994-98)



Artificial Upwelling and Mixing (AUMIX 奧秘)

Field Experiments in Toyama Bay, Japan, 1990-91

Field Experiments in Hawaii, 1991-92

Artificial Upwelling and Mixing (AUMIX 奥秘)

Laboratory Experiments in the Ocean Engineering Lab., University of Hawaii at Manoa

References:

Liu, C.C.K., and Qiao J. (1995). Artificial Upwelling in Regular and Random Waves, *Ocean Engineering*, 22(4):337-350.

Liu, C.C.K., (2005). Artificial Upwelling of Nutrient-rich Deep Ocean Water for Open Ocean Mariculture, in: *Recent Advances in Marine Science and Technology*, PACON International, Honolulu, Hawaii, pp. 291-300.

III. Natural-Energy-Driven Water Desalination

2. Wind-Powered Water Desalination