International Year of CHEMISTRY 2011

Emerging Issues in Water Resources and Water Quality

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The International Year of Chemistry Global Water Experiment

Water a Chemical Solution

- Students around the world (elementary, secondary and/or tertiary) measure, collect samples or data, e.g., water samples for isotopic composition and pH, send to a collective database

Experiments Include

- "Water no Dirt no Germs" – filtration / disinfection
- "pH of the Planet" - pH measurements
- "Investigating Salty Waters" – dissolved solids measurement
- "Solar Still Challenge" – build and operate solar still

Water is a renewable resource that is under stress

- Introduction – Water Supply and Scarcity
- How water is used
  - Withdrawal vs Consumption (Energy and Agriculture)
  - Sanitation and human health
  - Emerging stressors – Biofuel production, nutrient loads, population/economic concerns
- Basic groundwater issues
  - Groundwater mining - subsidence
  - Seawater intrusion - salinization
  - Artificial groundwater rise, water logging, soil salinization
- List of solutions
  - Conservation, water transfers, water treatment, disinfection
  - Wastewater - water reuse
  - Water Desalination (Thermal and RO)
  - Research topics for increasing supply

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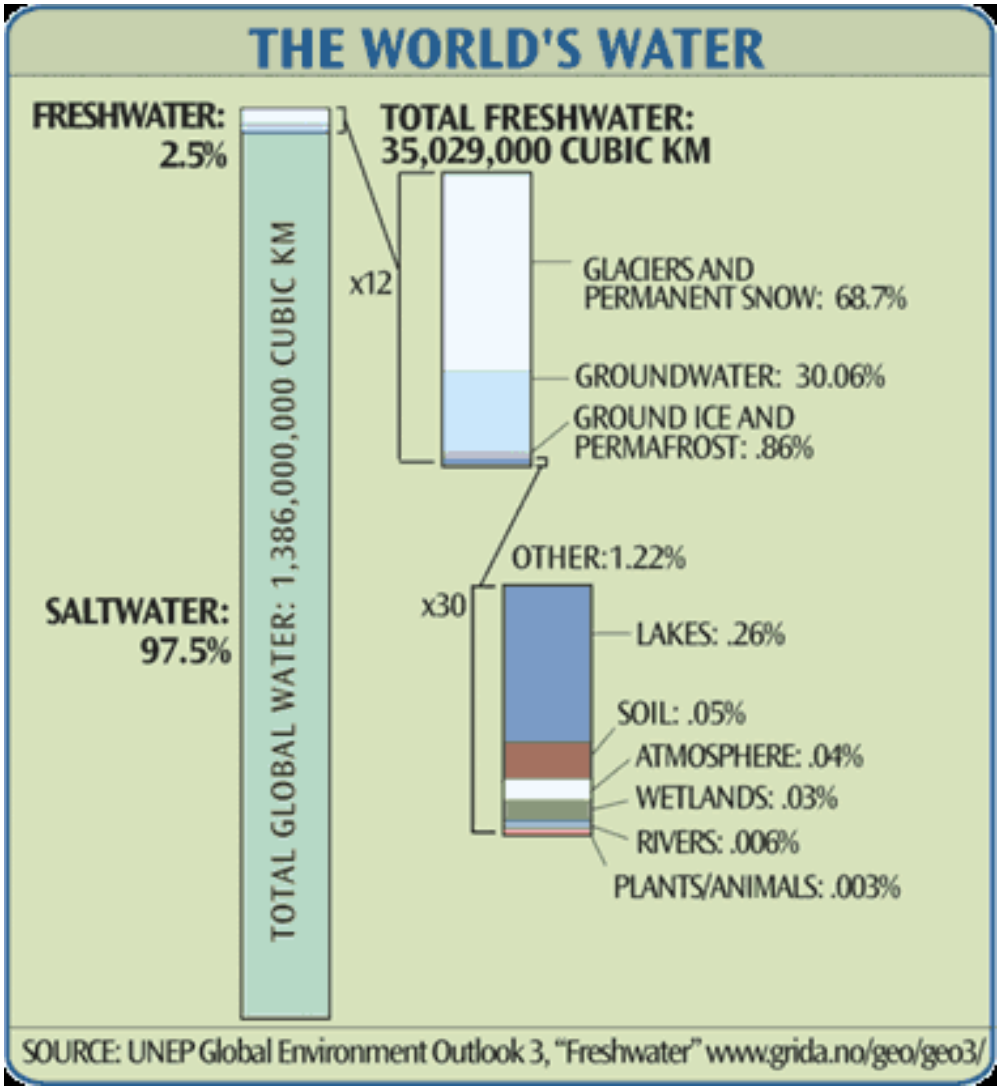
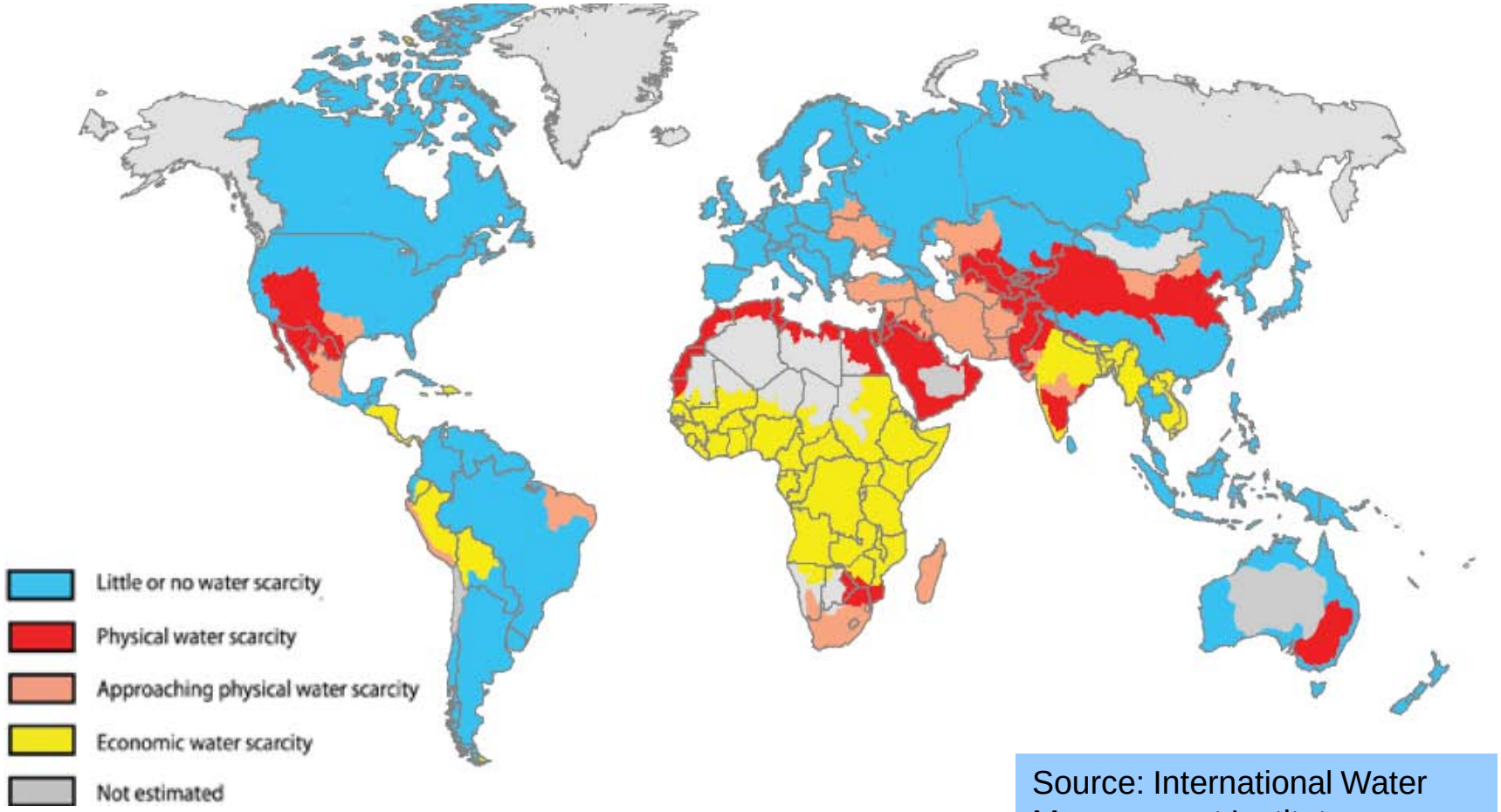
Water is a renewable - essential resource



Less than 0.007% of all water is directly accessible for human use-(renewable water).

Water scarcity is both a physical and economic phenomenon



Source: International Water Management Institute

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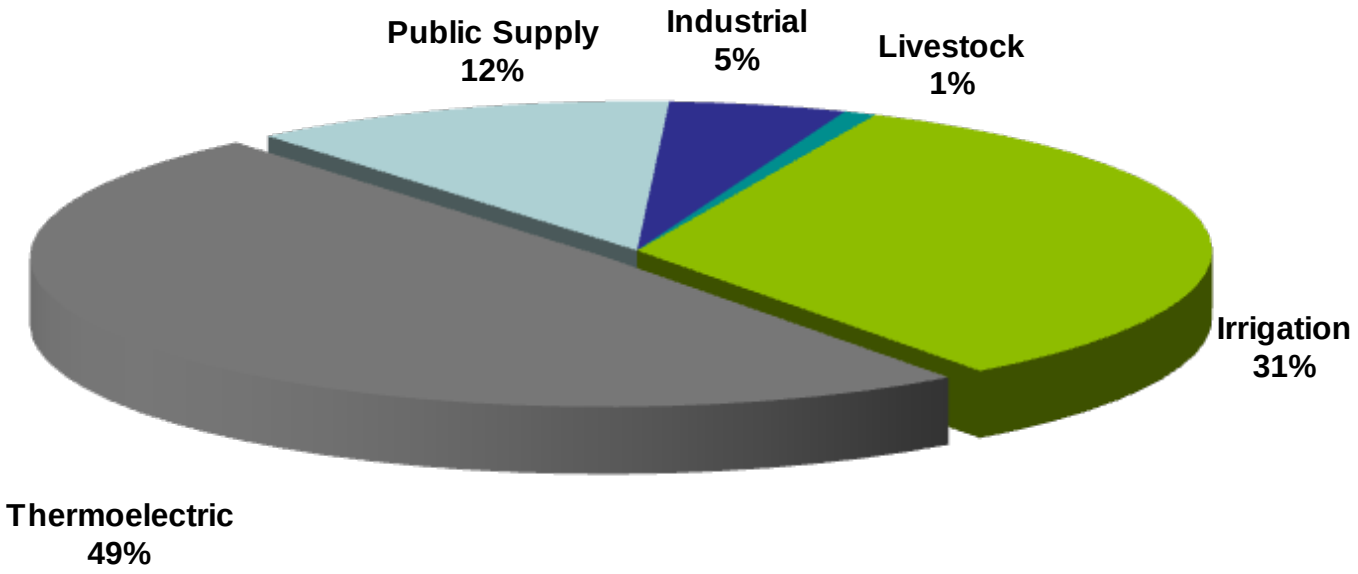
U.S. freshwater withdrawal

Estimated Freshwater Withdrawals by Sector, 2005

Total Withdrawals : 1.5 Billion m^3/day



Source : USGS Fact Sheet 2009-3098

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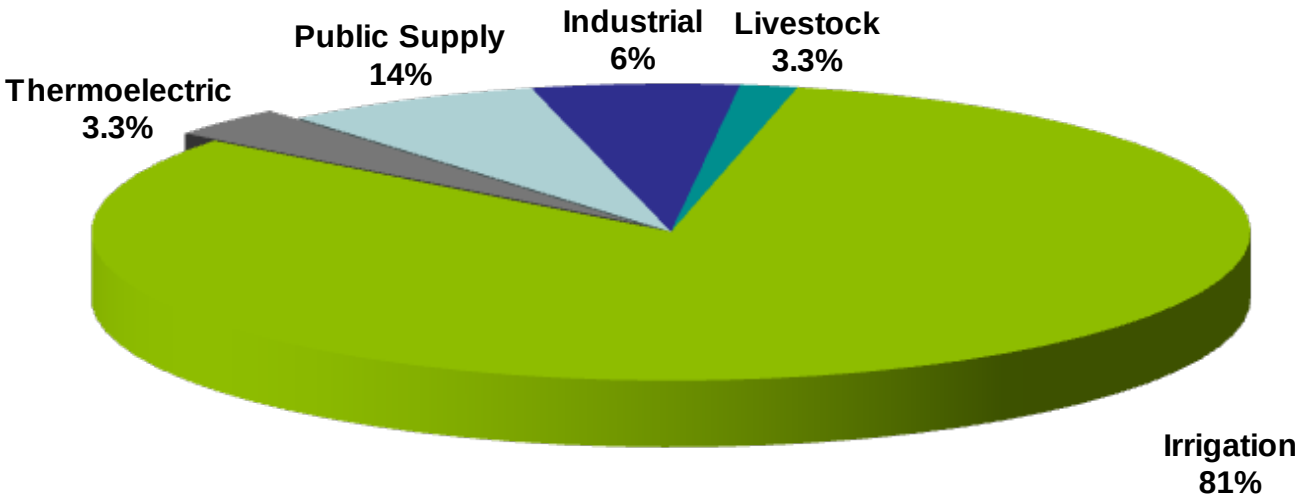
U.S. freshwater consumption

Estimated Freshwater Consumption by Sector, 2000



Source : Hightower 2007

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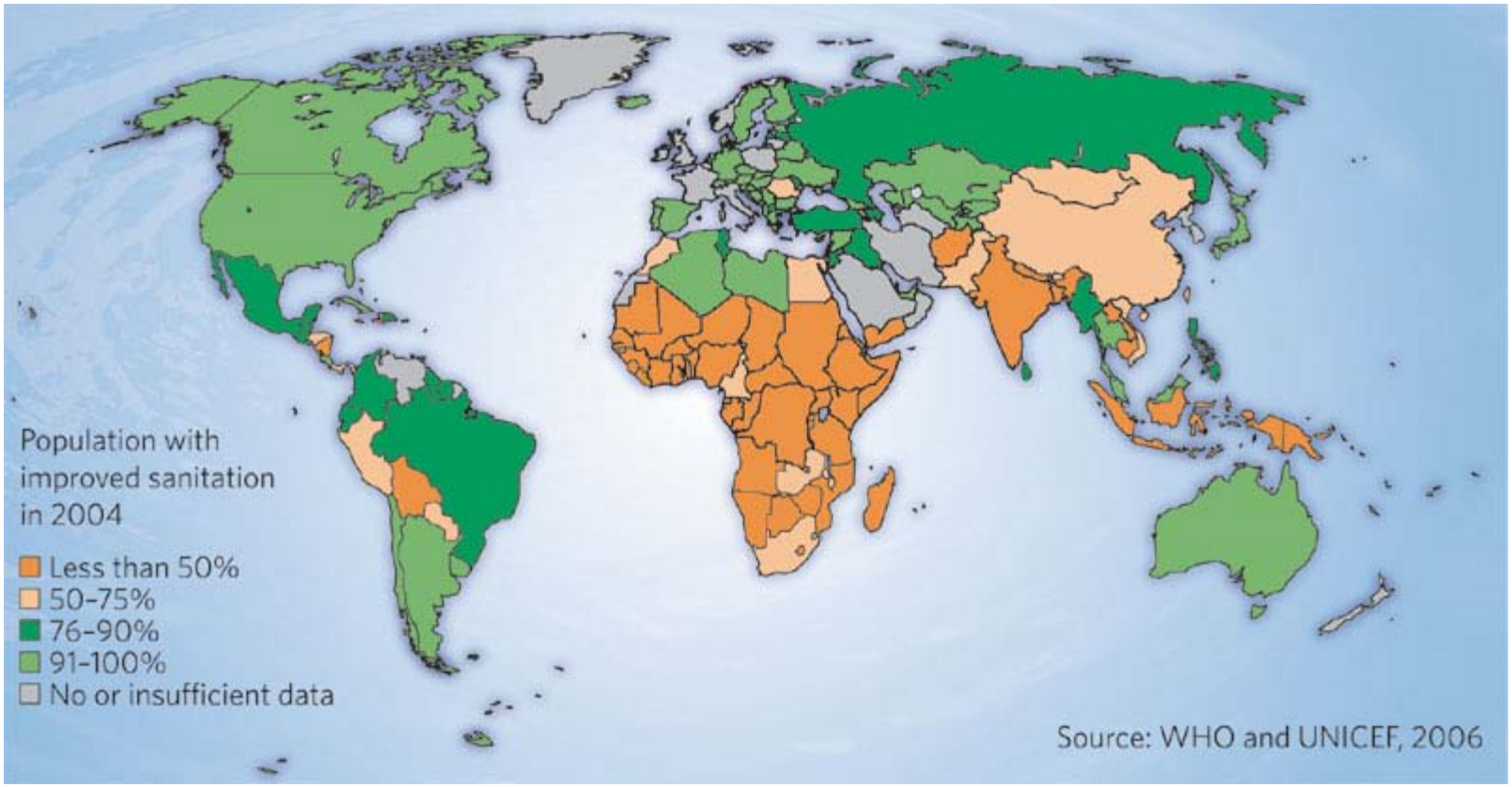
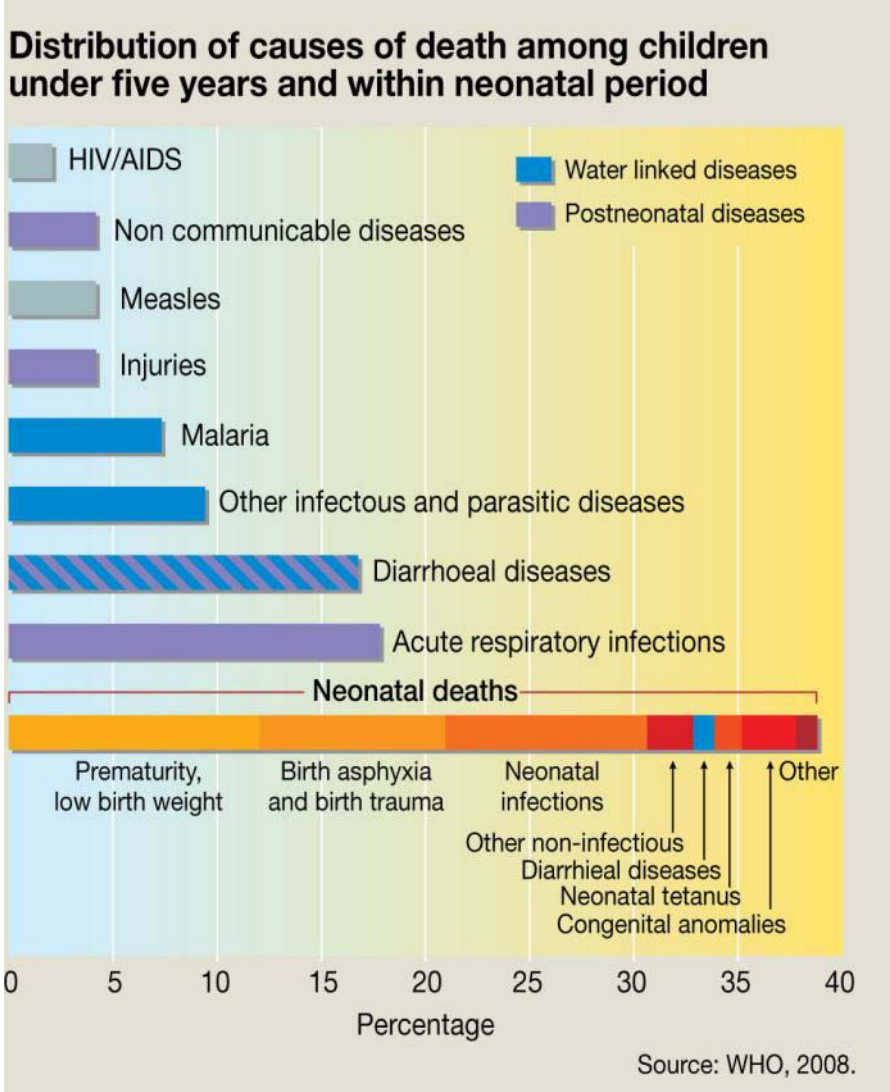
Inadequate sanitation is especially severe in developing world



1.8 million people die every year from diarrhoeal diseases (including cholera); 90% are children under 5, mostly in developing countries. - WHO

Water borne diseases are especially harmful to children



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Emerging stressors on water resources

Biofuel production – increased irrigation

Nutrient load – hypoxic zones

Increased population – exceeds treatment capacity

Climate change – loss of freshwater storage

Source : NASA

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What are some solutions ?

Conservation
- Improved agriculture / irrigation
- Improved recovery / storage

Improved sanitation
- Septic systems
- Wastewater treatment

Water transfers
- Requires energy- water is heavy and expensive to pump

Water reuse
- Wastewater for secondary uses

Water desalination- requires energy
- Thermal for distillation
- Electric for reverse osmosis

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Surface water overdraft leads to drying of Aral Sea

July - September, 1989 October 5, 2008

Source : NASA

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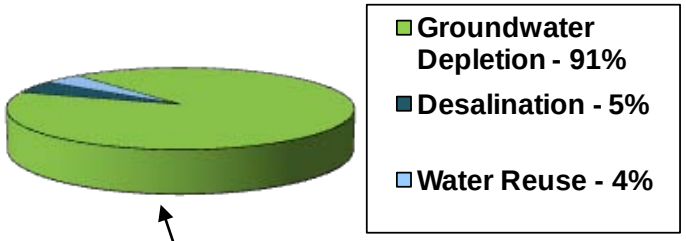
Groundwater overdraft is the major water source in the Middle East and North Africa

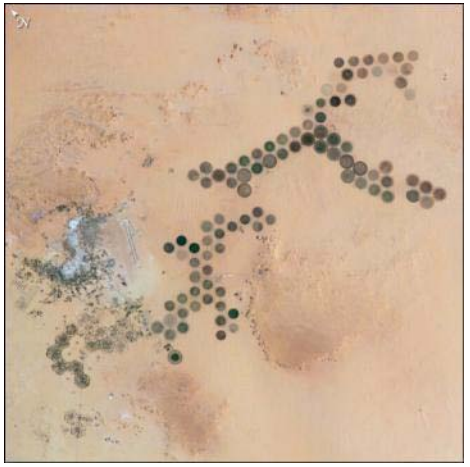


(23 billion m^3)

Source: World Water Forum (MENA)

Groundwater depletion leads to:

- ***Dropping water table***
- ***Soil salinization***
- ***More energy for pumping***
- ***Seawater intrusion***
- ***Subsidence***



Center pivot irrigation

Al Khufrah Oasis southeastern Libya

Source: NASA

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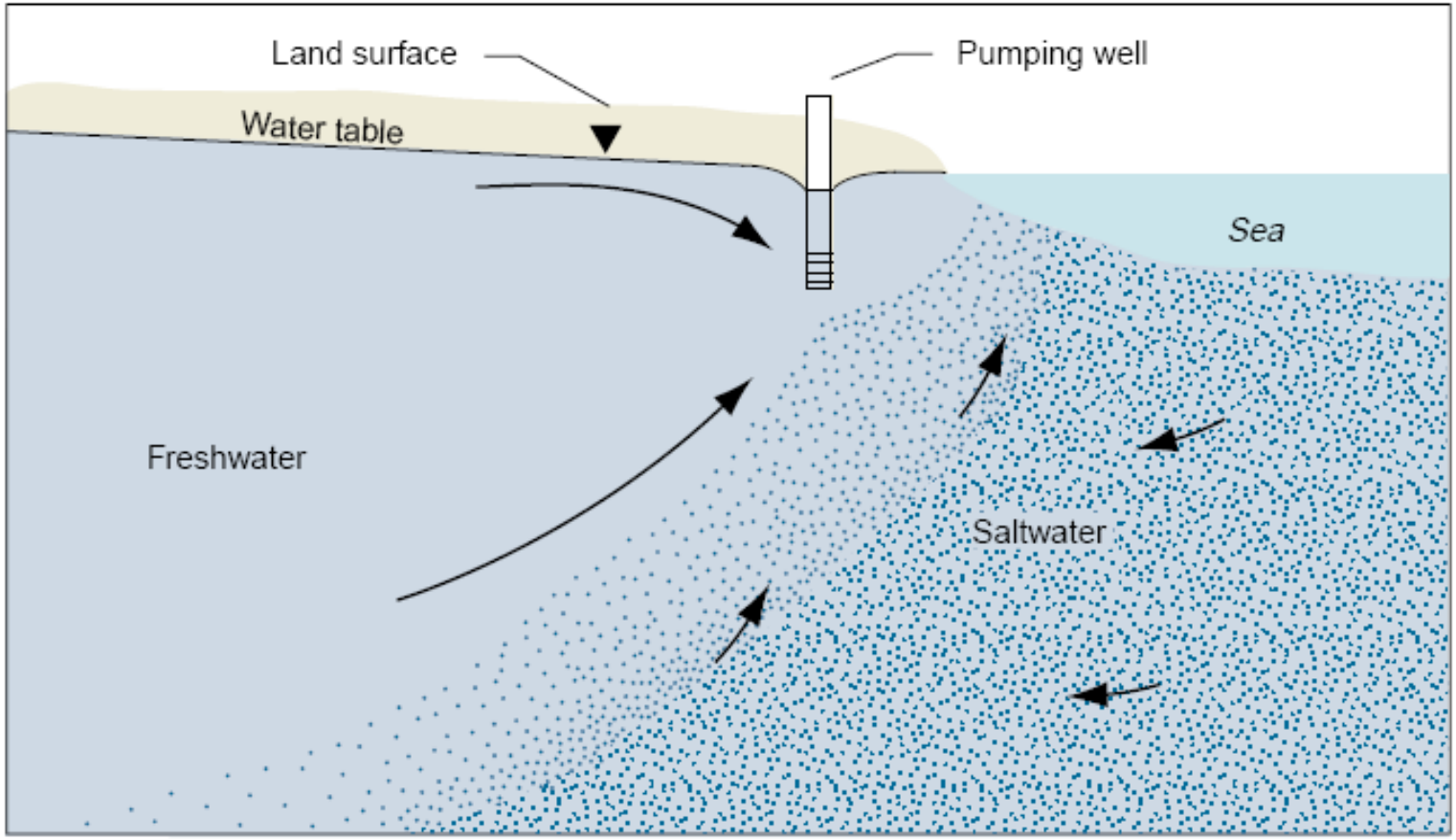
Pumping groundwater may cause seawater intrusion



Source: USGS

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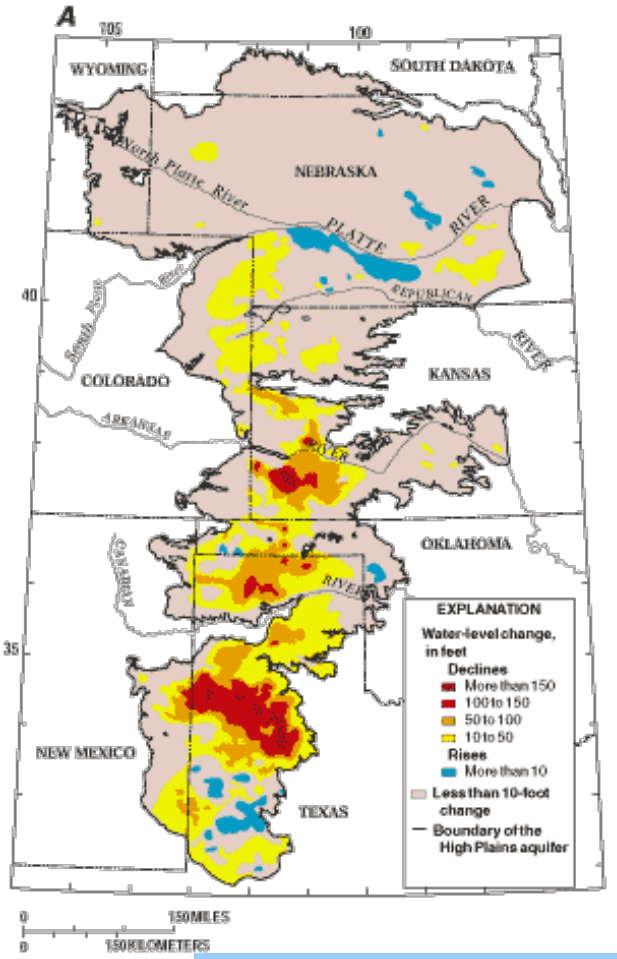
Irrigation causes U.S. Central Plains Aquifer to decline



Groundwater levels have declined dramatically because of agricultural pumping.

- Especially severe in the south
- Increases pump lift requirement
- Decreases well yield

Source: http://pubs.usgs.gov/circ/circ1186/html/gw_dev.html#aquifer

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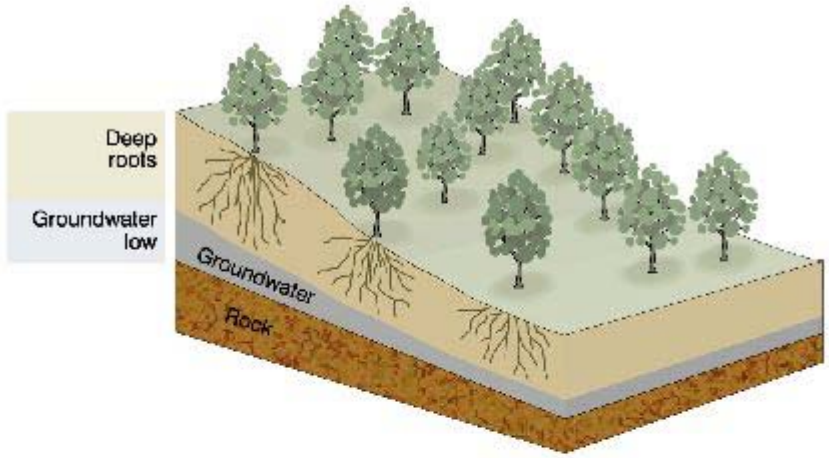
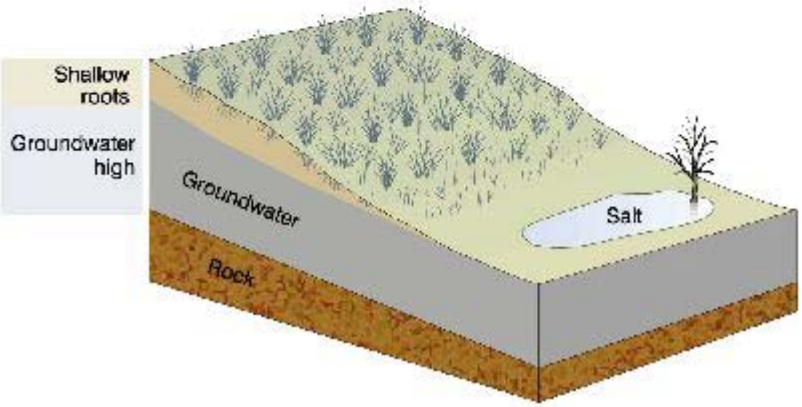
Soil salinity is another result of poor agricultural practices





Dryland salinity- removal of deep rooted plants reduces evapo-transpiration that leads to rising water table

Source: http://www.clw.csiro.au/publications/general2002/effectiveness/salinity.html

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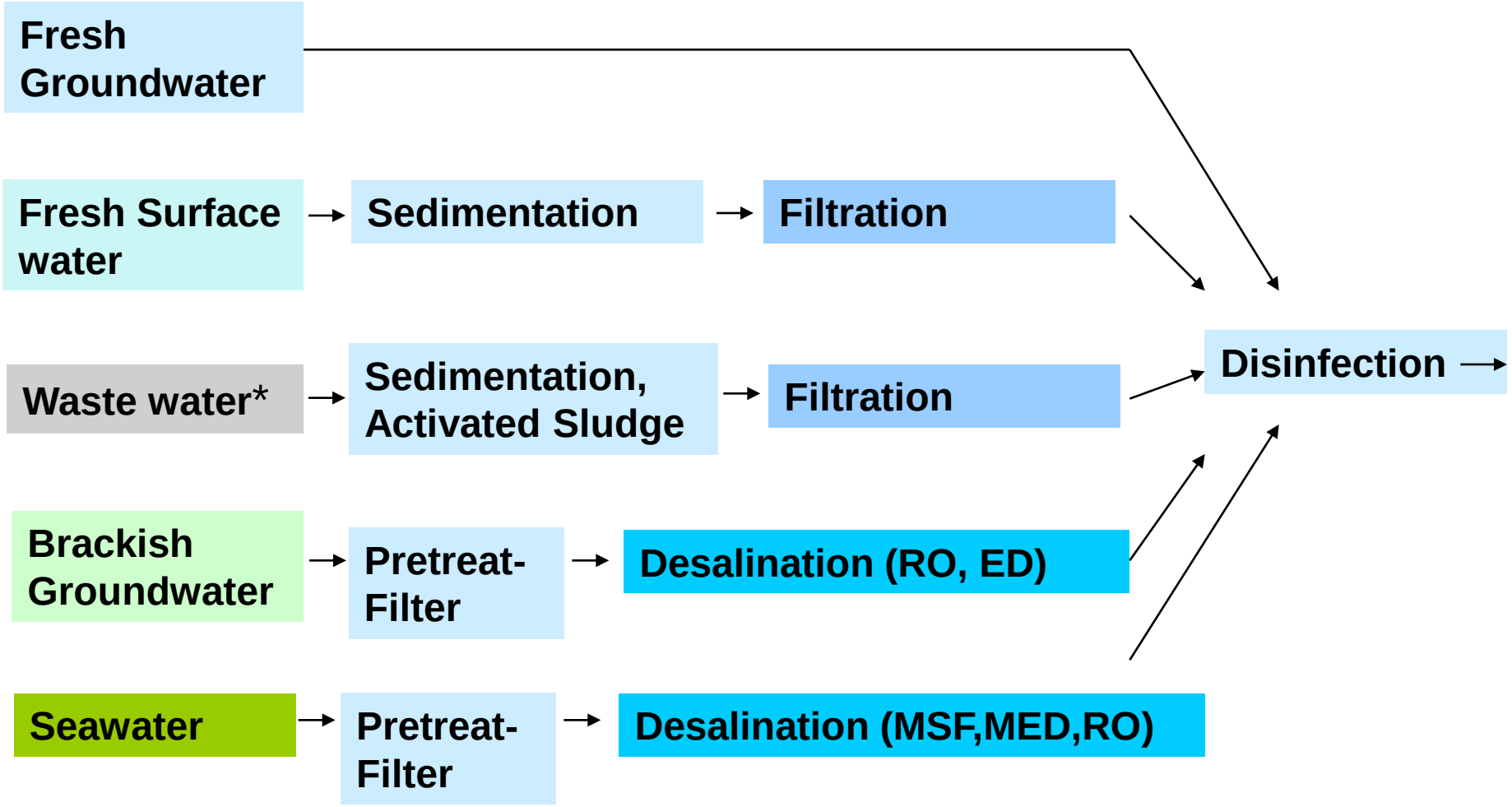
Drinking water can be produced from a variety of sources



* TDS < 1000 ppm

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Water reuse (recycling) can meet many needs

- Urban
- Industrial
- Agricultural
- Environmental and recreational
- Groundwater recharge
- Seawater intrusion abatement
- Augmentation of potable supplies

Rapid infiltration basins. (Photograph courtesy of Water Conserv II facility, Orlando, Florida.)

Wastewater reclamation and reuse requires filtration, treatment and disinfection

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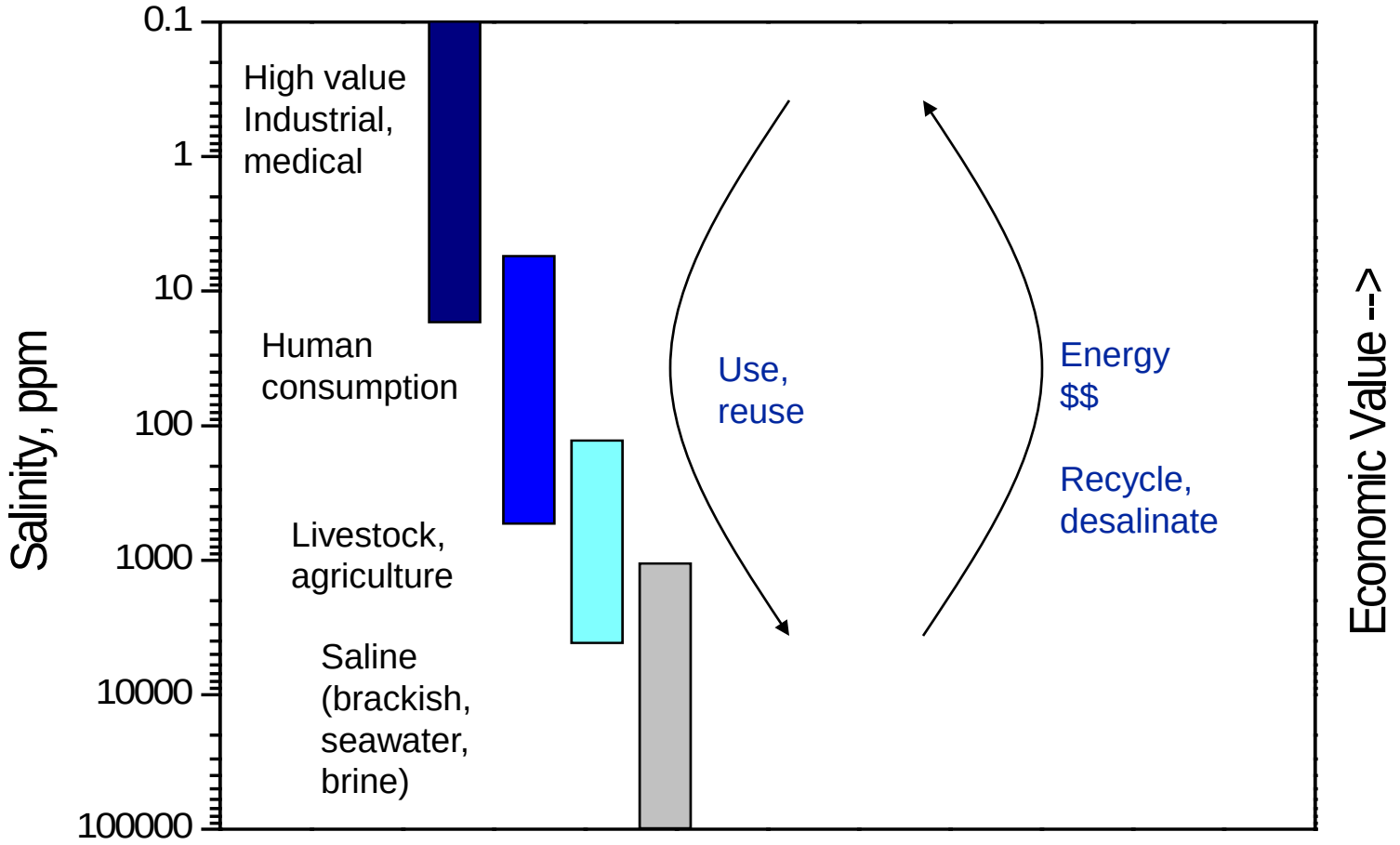
Salinity ultimately determines value of water



Cost of recycling < economic value of the water?

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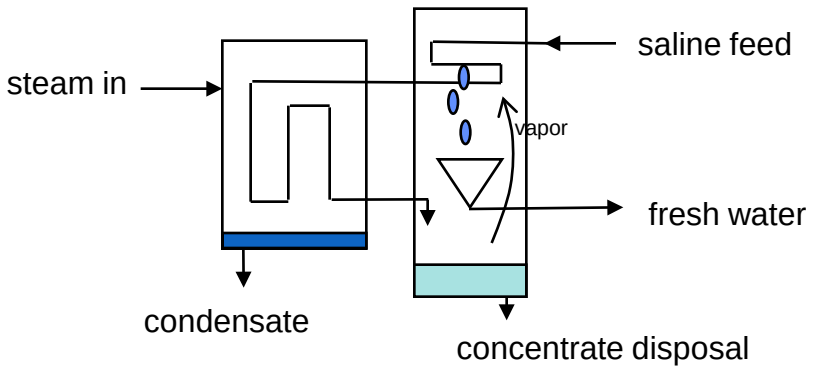
Desalination: thermal processes require phase change

Multi-Stage Flash (MSF) and Multiple Effect Distillation (MED)

Flash evaporation



Multistage Flash Plant

Energy required to boil (or freeze) water:

$C_p = 4\ kJ\ kg^{-1}\ deg^{-1}$

$\Delta H_{vap} = 2500\ kJ\ kg^{-1}$

$\Delta H_{fus} = 323\ kJ\ kg^{-1}$

- **large amount of energy necessary for phase change**
- **heat recovery essential**
- **typical energy use ~250 kJ kg^{-1} (conc. independent)**
- **distillation only makes sense if energy is cheap (Middle East) and salt conc. is high (seawater)**
- **freezing processes have slight advantage**

Note: theoretical minimum energy required to extract fresh water = 3 kJ/kg!

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Thermal desalination overview

- High energy required for phase change (mostly thermal)
- Multiple stages (or effects) to increase efficiency
- Waste heat from power plants provides incentive
- Antiscalants are very important
- High top brine temperatures increase scaling
- Pretreatment not as rigorous as RO
- Corrosion is important
- Water must be “remineralized” to make it less agressive
- Copper from heat exchangers may harm sea ecosystem

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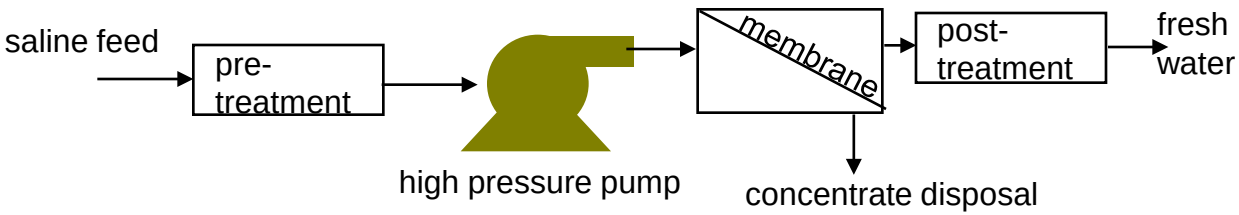
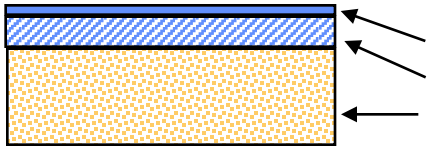
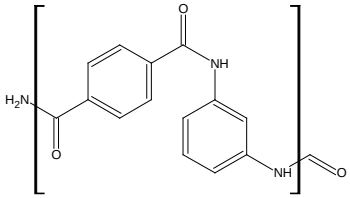
Desalination : membrane process is reverse osmosis



Reverse Osmosis Plant

Thin film composite membrane





polyamide

- **energy use (pump) ~ 10 – 50 kJ kg^{-1}**
- **concentration dependent**
- **energy recovery essential for seawater RO**
- **membranes susceptible to fouling; pre-treatment required**
- **polyamide membranes degraded by Cl_2**

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Membrane desalination overview

- Lower energy required than thermal (**but all electric**)
- Pretreatment is very extensive
- Biofouling is very serious
- RO Membranes do not tolerate disinfectants (Cl_2)
- Not effective for high TDS Seawater (>50,000 TDS). Energy requirement proportional to salinity.
- Energy recovery devices are the norm (turbines, work exchangers)
- Brackish water recovery limited by mineral scaling
- Antiscalants are used to increase recovery of brackish water.

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General trends in desalination

- Desalination requires more energy than other water treatment
- Energy of desalination is proportional to salinity (RO)
- Salinity limits recovery in seawater desalination (35%)
- Divalent minerals limit recovery in brackish water desalination (60-90%)
- Desalination produces large amount of liquid waste
- Seawater discharge of brine is environmentally important
- Inland concentrate disposal is environmentally sensitive

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Research and development can contribute to improving water supply

- Low energy desalination
- Membrane research
- Biomimetic systems
- Corrosion science
- Applied nanoscience
- Novel disinfection technologies
- Computational fluid dynamics
- Sensor development / process control

- Nutrient recovery and reuse
- Water reuse / desalination nexus
- Technology for resource poor environments

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