Brackish Ground and Surface Water Source Treatment to Offset Drought Related Supply Shortages to Food, Dairy, Beverages, and Bioprocessing Industries

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24th Annual Practical Short Course on Membrane & Other Separation Technologies

Applications in Food, Dairy, Beverage & Bioprocessing

Organized by: The Separation Sciences Program
Food Protein R&D Center
Texas A&M Engineering Experiment Station
The Texas A&M University System
2476 TAMU
College Station, TX 77843

April 30th, 2014

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Outline

- Diminishing Water Resources
- Water Use by Industry Sector
- TX and CA Drought Example
- Water Demand 2010 to 2060
- Reservoirs 2012 vs 2014
- Technologies for Treatment

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Water Water Water!

- Future water shortages foreseen, if not now
- Additional, reliable, and safe water supply needed for population and industrial growth
- Water supply is an issue of economic growth and national sustainability
- Water can be a possible source of conflict

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Diminishing Water Resources

- Critical worldwide concern
- Previously developing nation's issues
- Now Global Crisis
- Quantity and Quality Issues
- From Surplus to Limited

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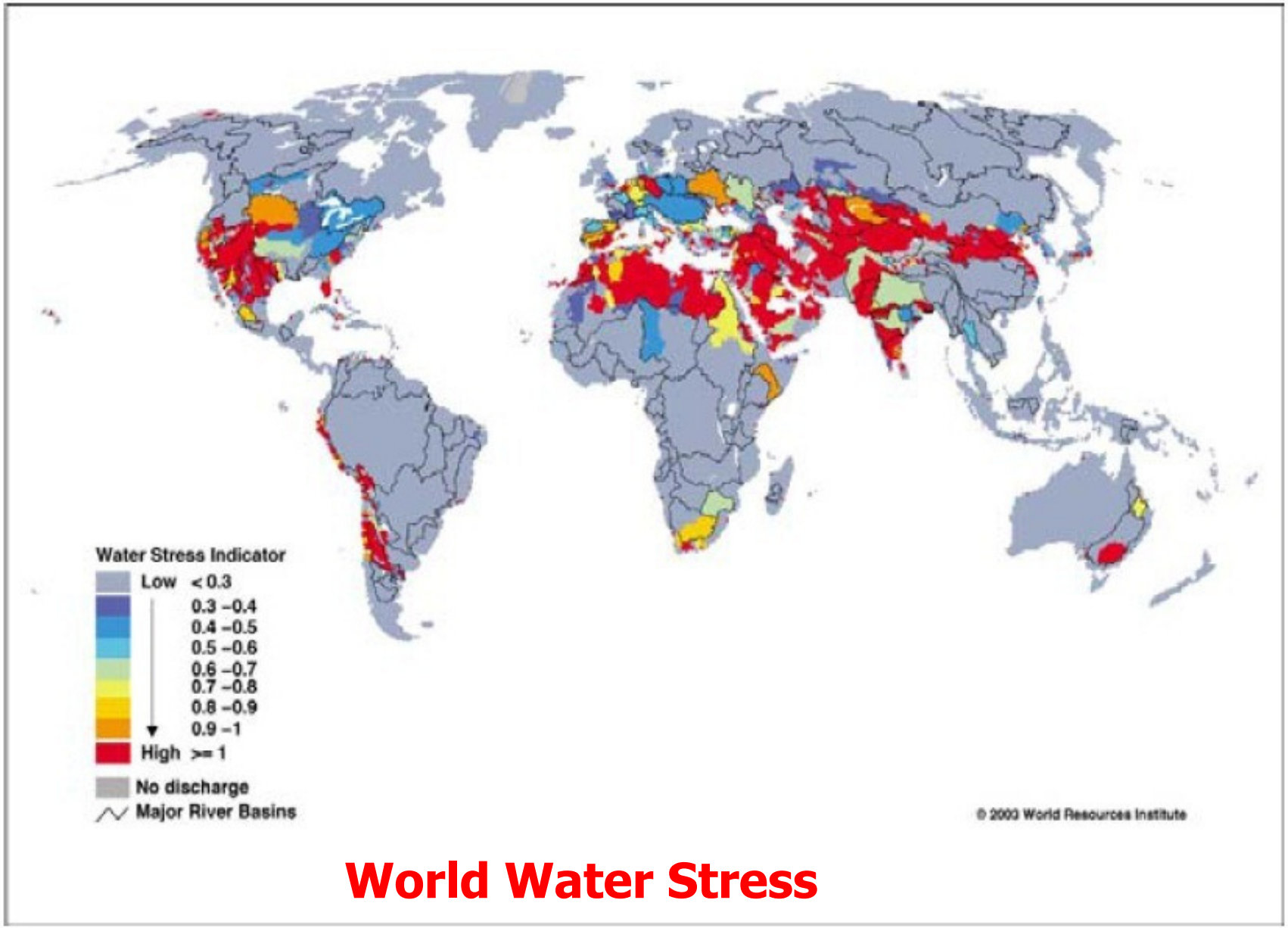

World Water Stress

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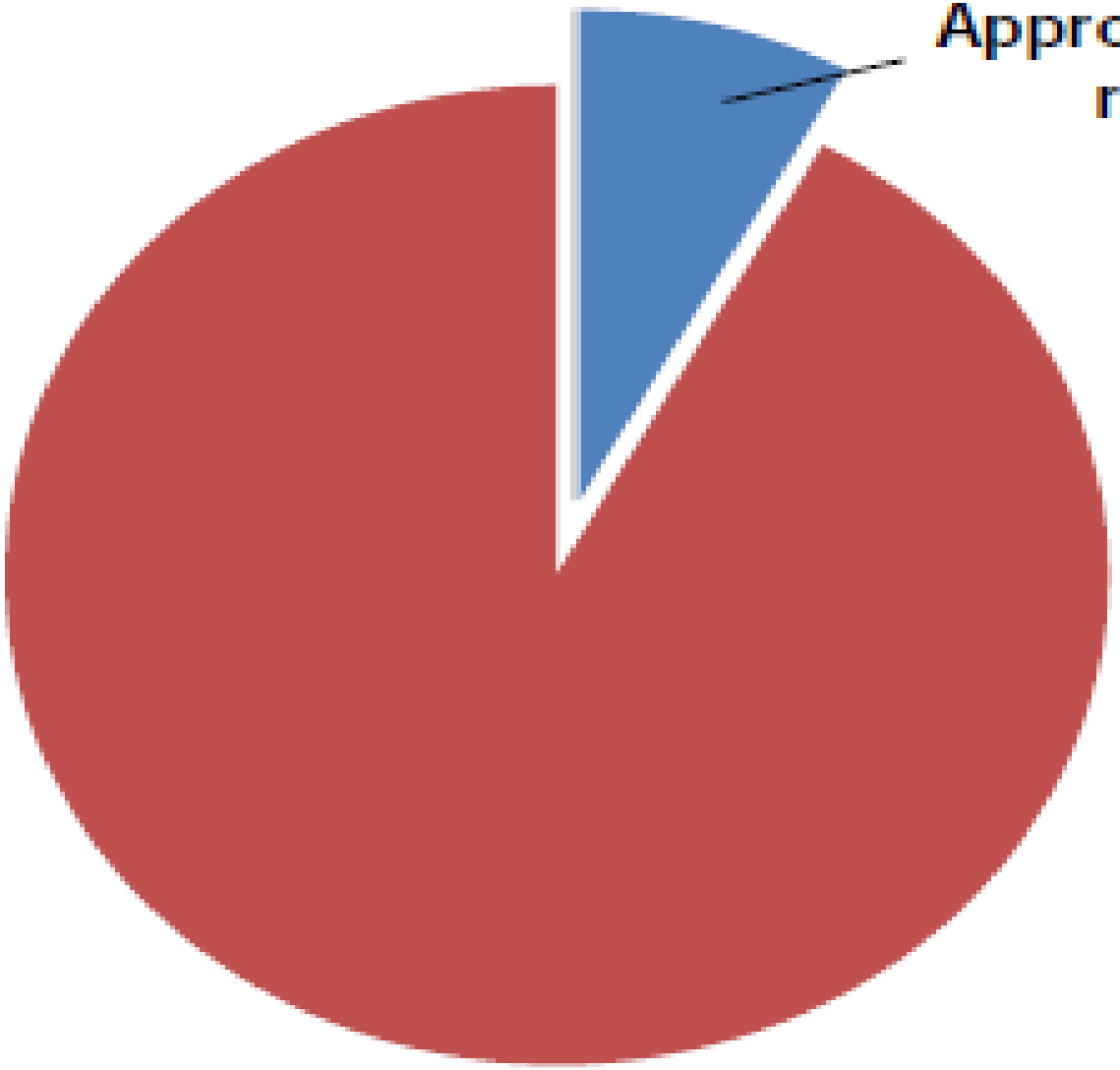

The United States produces approximately 32 billion gallons of municipal effluent per day.

EPA 2012

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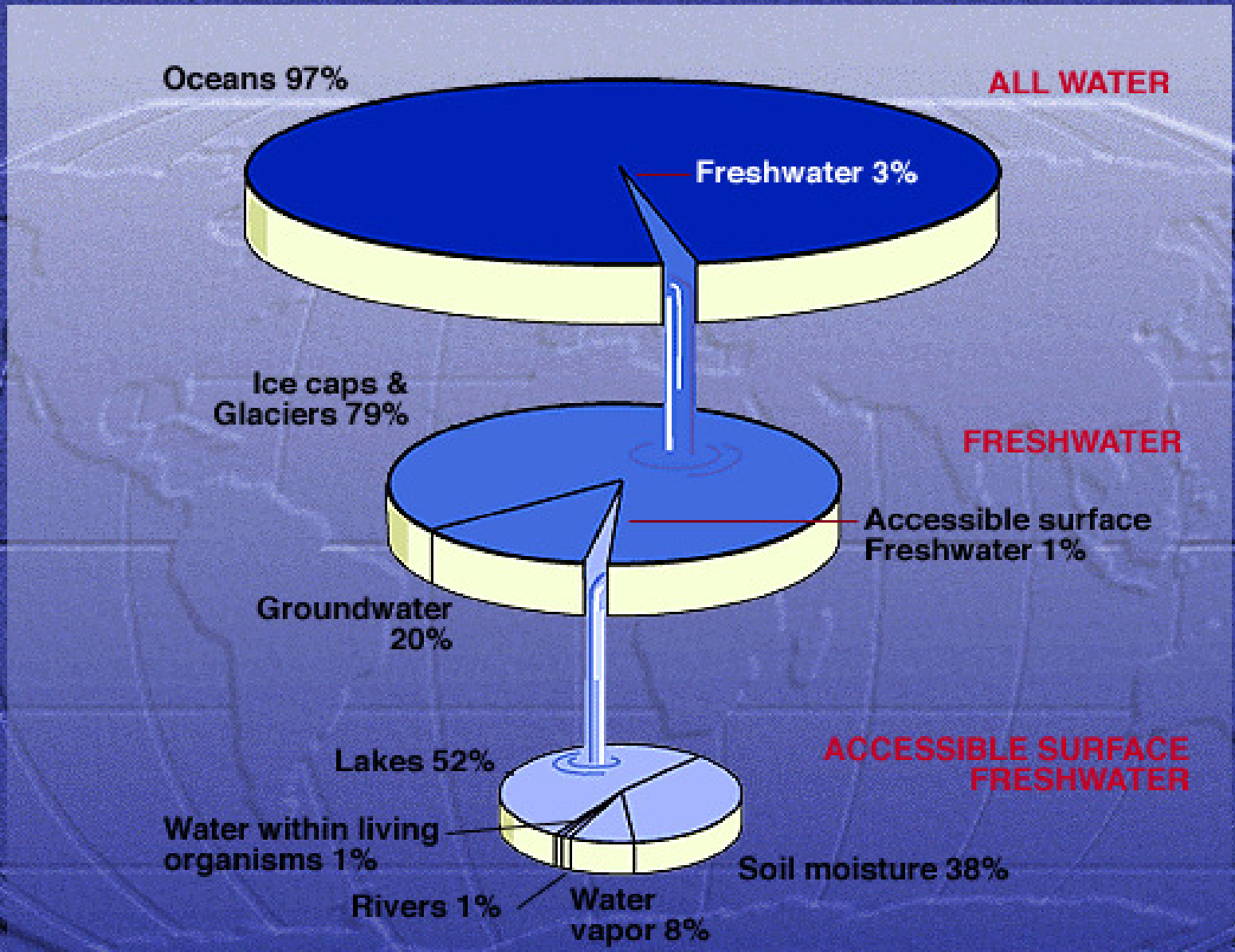
Distribution of the World's Water



Source: Earth Forum: Houston Museum of Natural Science

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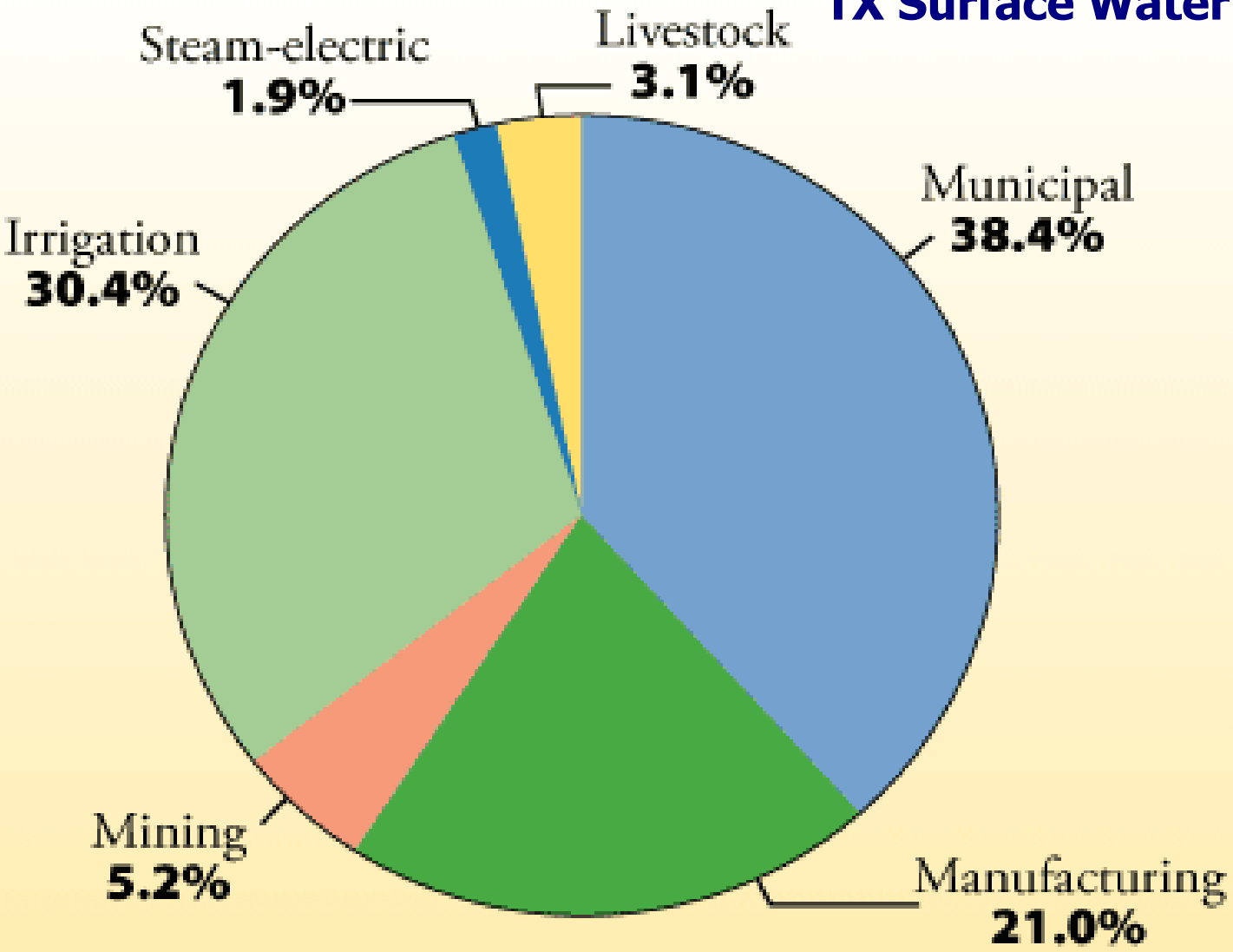
TX Surface Water



Sources: Texas Water Development Board and Texas Comptroller of Public Accounts.

Source: www.fracfocus.org & Estimated Use of Water in the United States, USGS 2005

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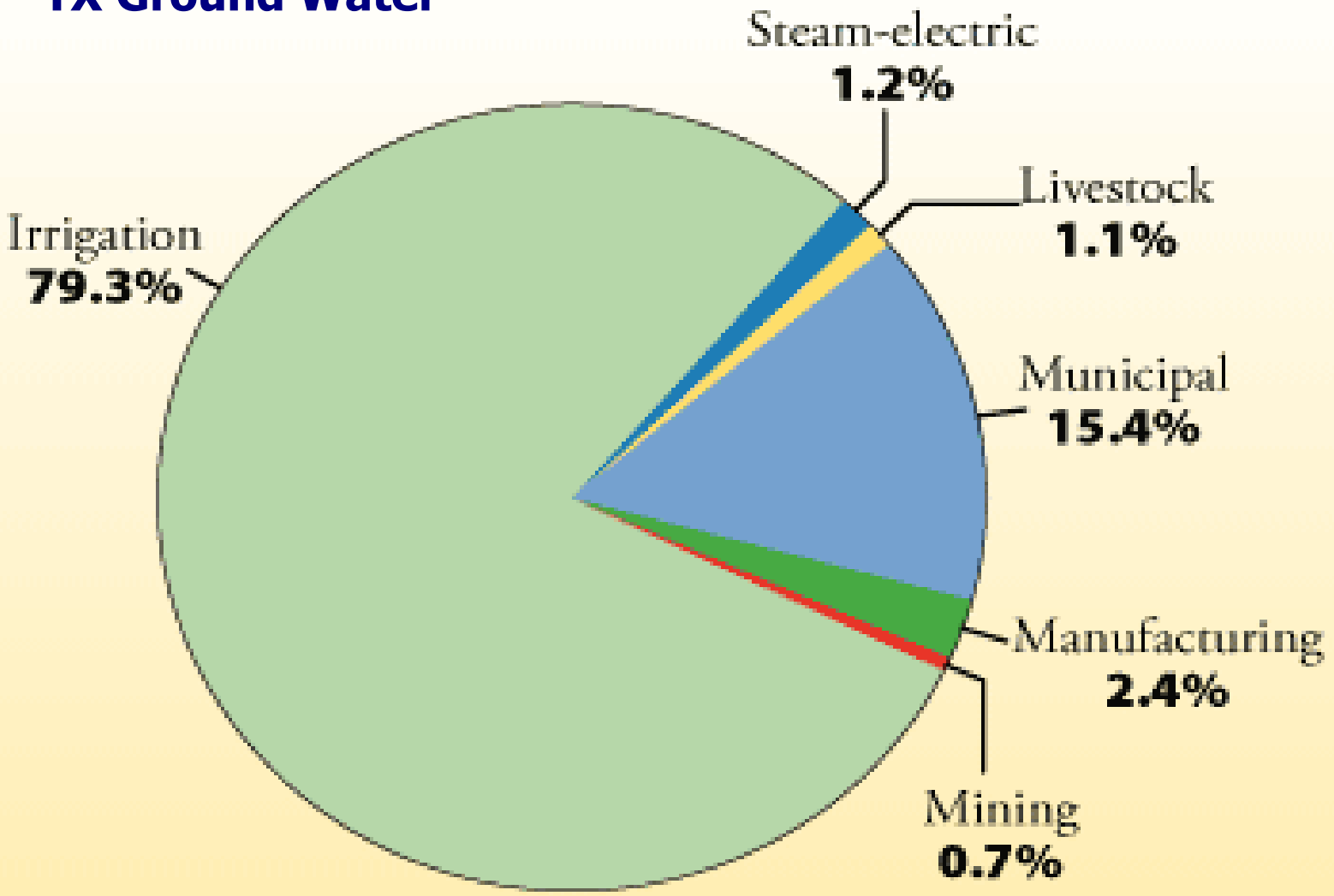
TX Ground Water



Sources: Texas Water Development Board and Texas Comptroller of Public Accounts.

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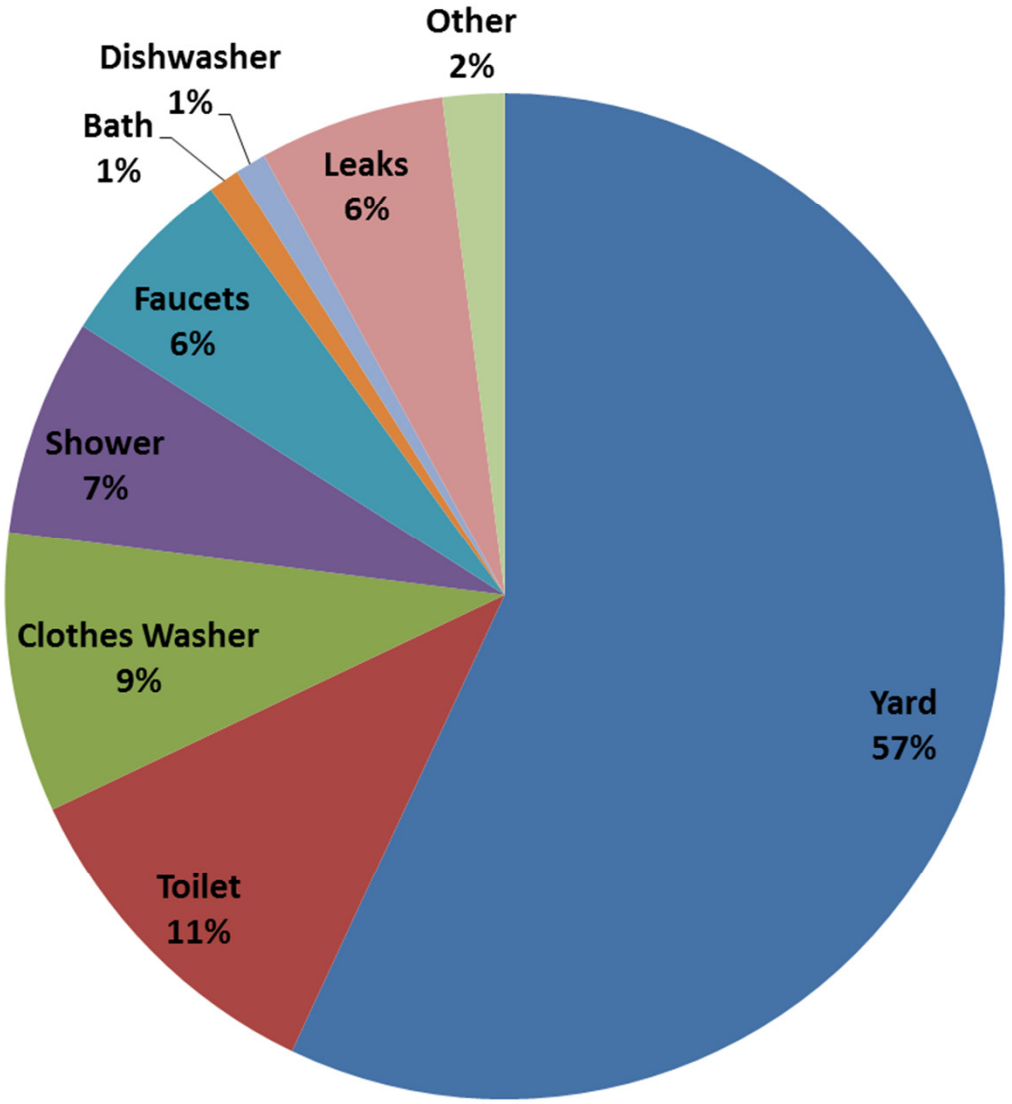
Residential Water Use in the U.S.



Source: AiChE 2011 Eastman Kodak Co.

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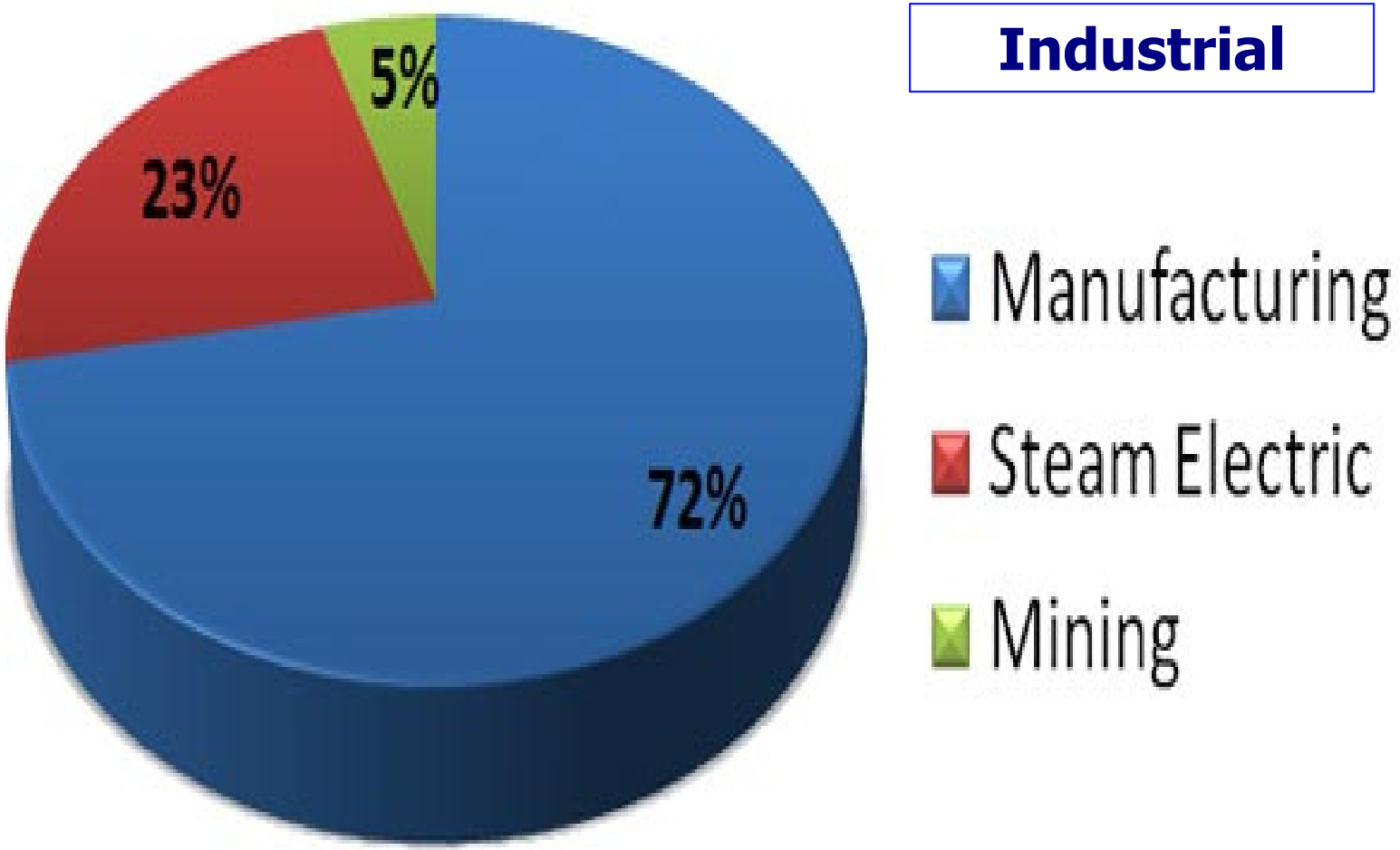
Industrial



Texas Water Development Board
2008 Water Use Survey

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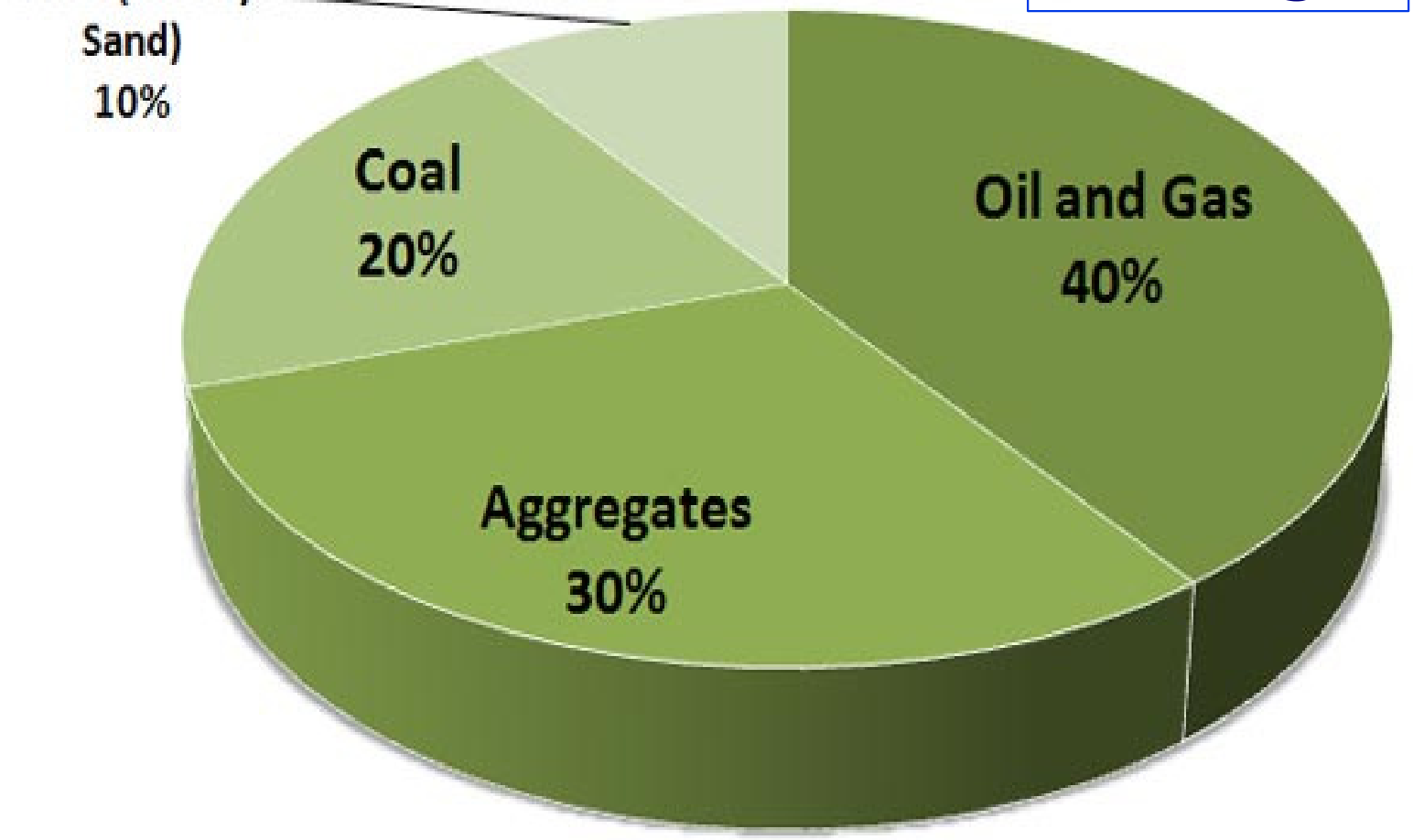
Mining



Current and Projected Water Use in the Texas Mining and Oil and Gas Industry - prepared by the Bureau of Economic Geology at UT-Austin for TWDB, April 2011Survey

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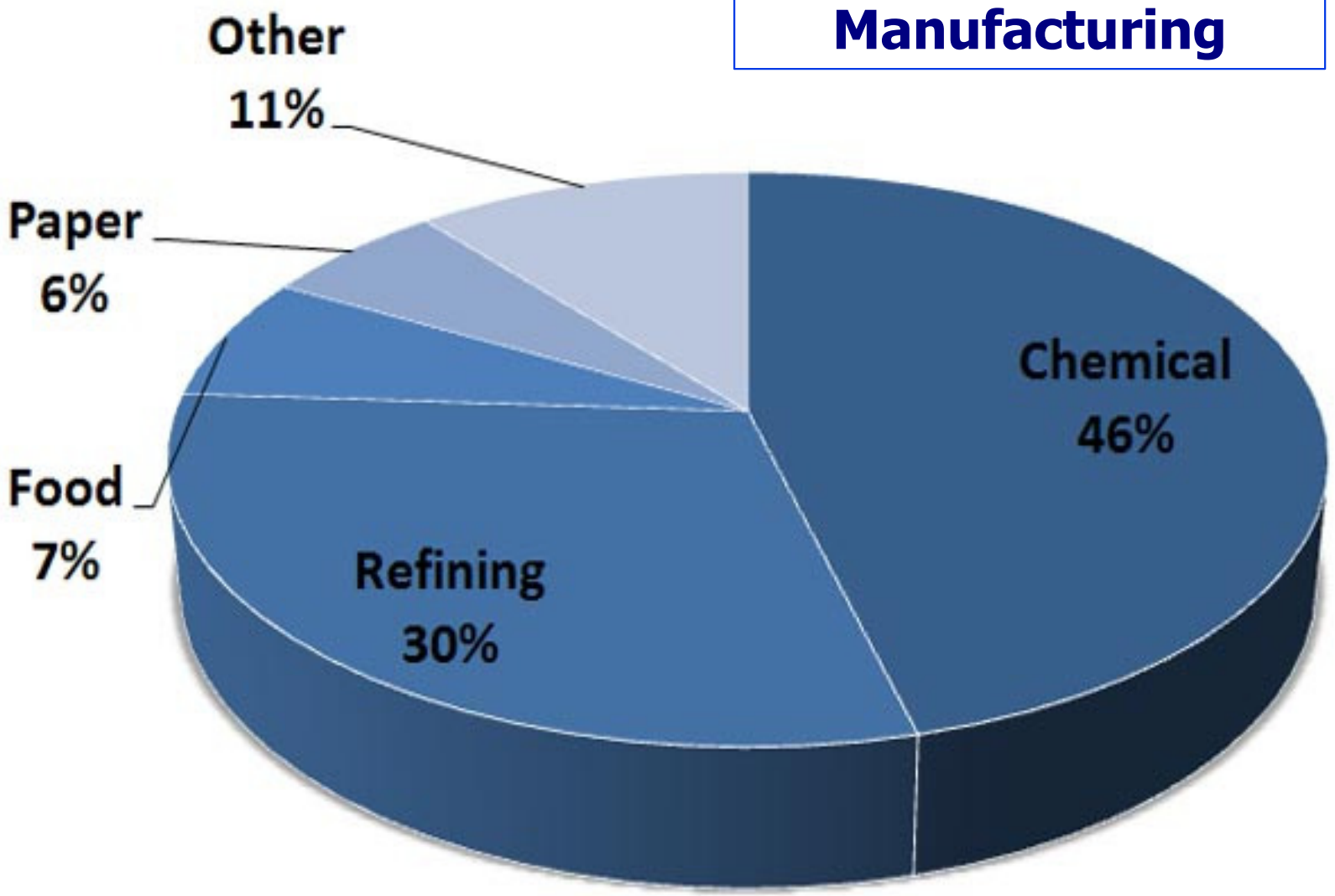
Manufacturing



Texas Water Development Board
2008 Water Use Survey

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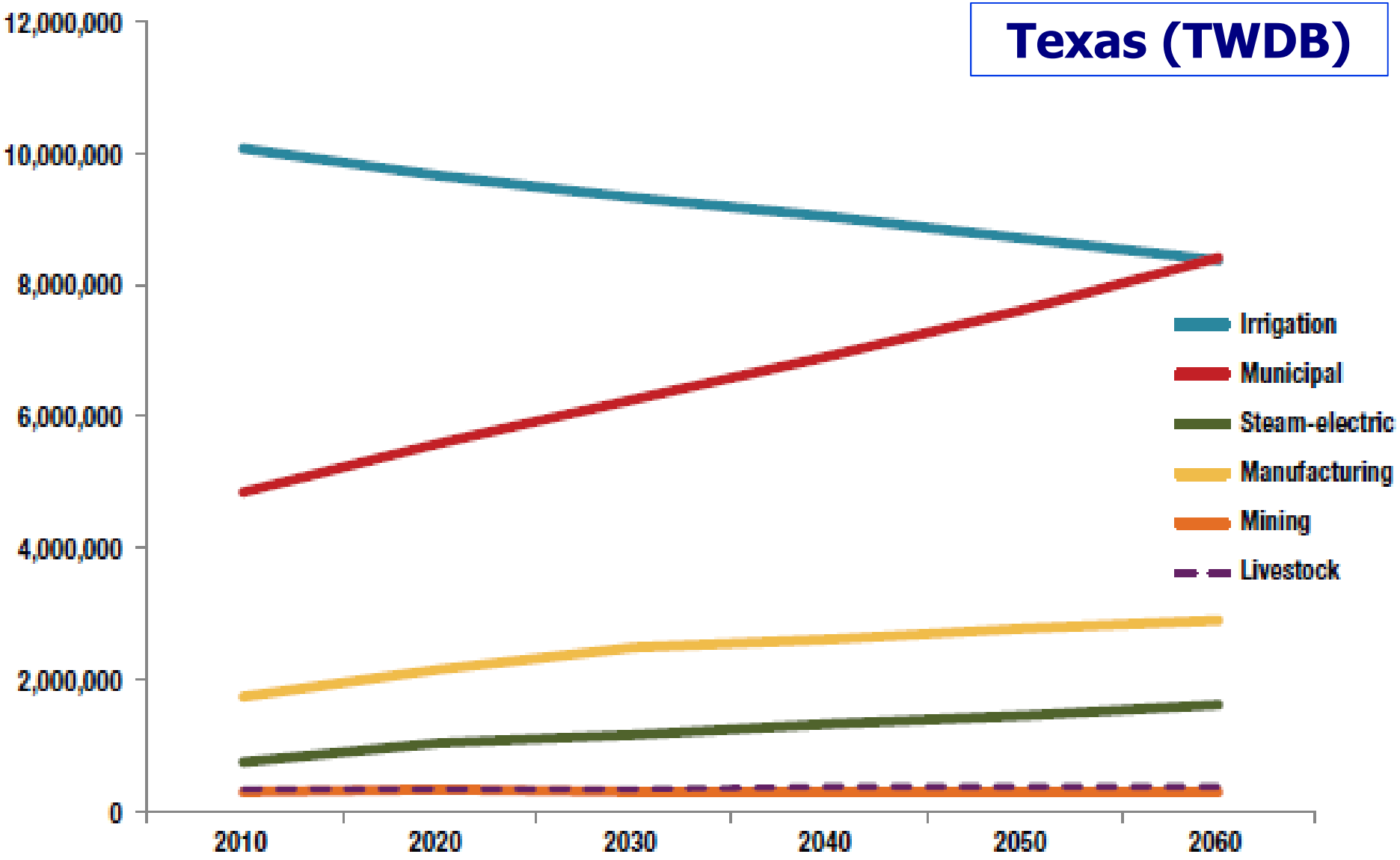
FIGURE 3.6. WATER DEMAND PROJECTIONS BY USE CATEGORY (ACRE-FEET PER YEAR).*

Texas (TWDB)



*Water demand projections for the livestock and mining water use categories are similar enough to be indistinguishable at this scale.

"I am convinced that, under present conditions and with the way water is being managed, we will run out of water long before we run out of fuel." – former CEO of Nestle, Peter Brabeck-Letmathe in *The Economist* (2008)

Source: AiChE 2011 Eastman Kodak Co.

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Impact on Energy

Without sufficient water:

- Challenging to increase energy use to meet the needs of a growing population
- Difficult to transition to a hydrogen economy
- Our ability to use biomass and clean coal derived fuels will be impacted
- We're the Saudi Arabia of Shale Oil and Gas, but we can't utilize it without water
- Increased demands for electricity for using plug-in hybrid vehicles will be impacted as electric power generation is limited by water use

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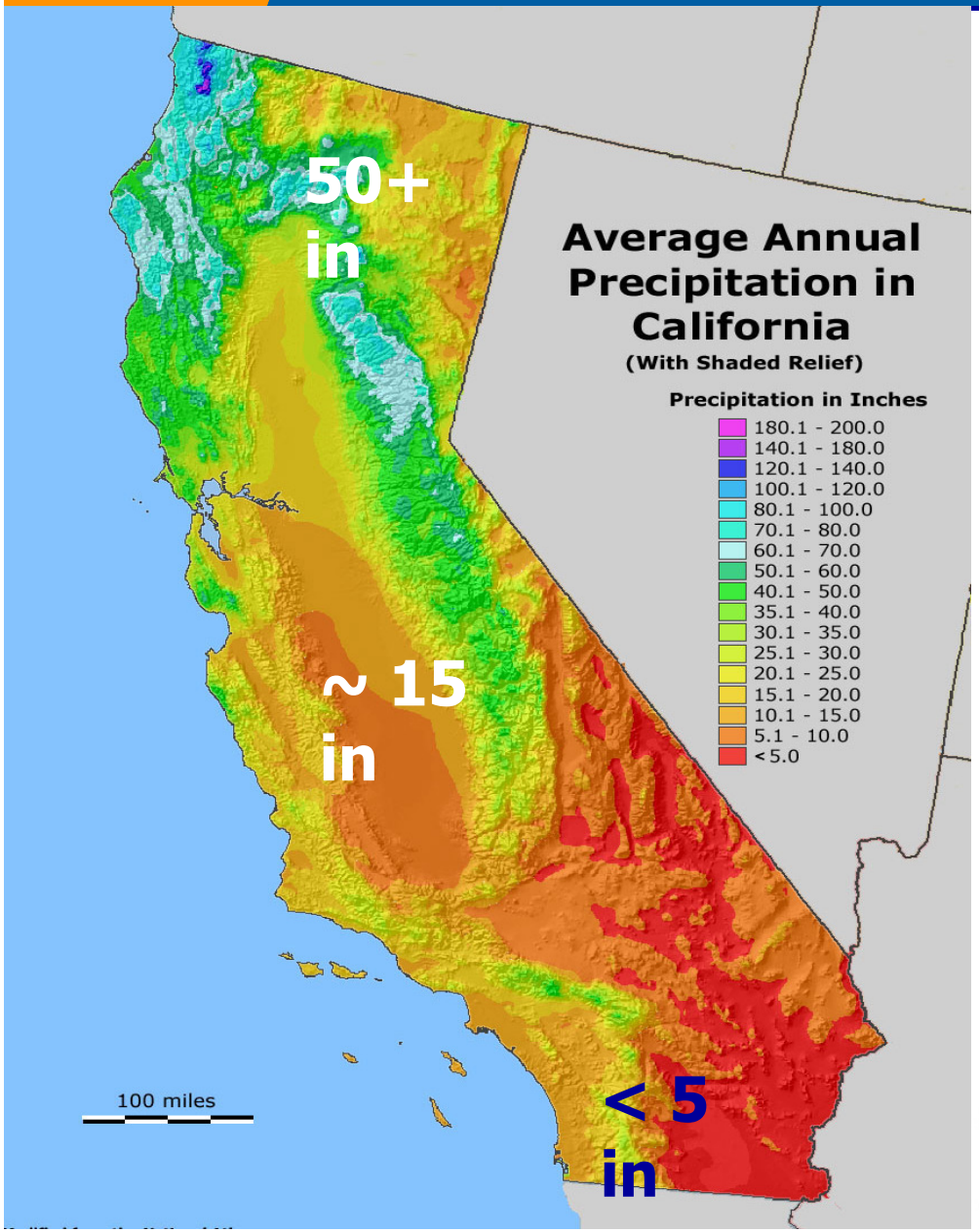
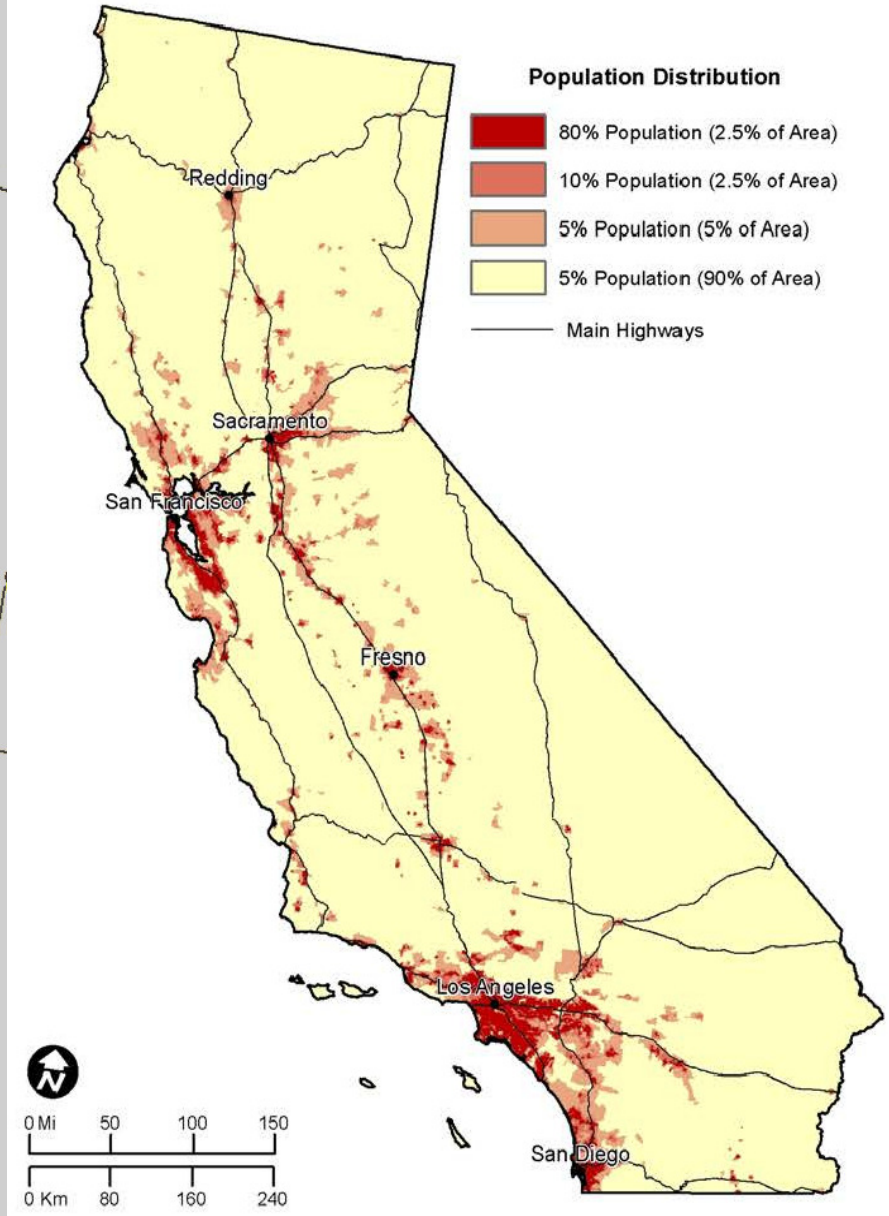
More Drought in the South?





Folsom Reservoir near Sacramento
DROUGHT!!
Lake Travis
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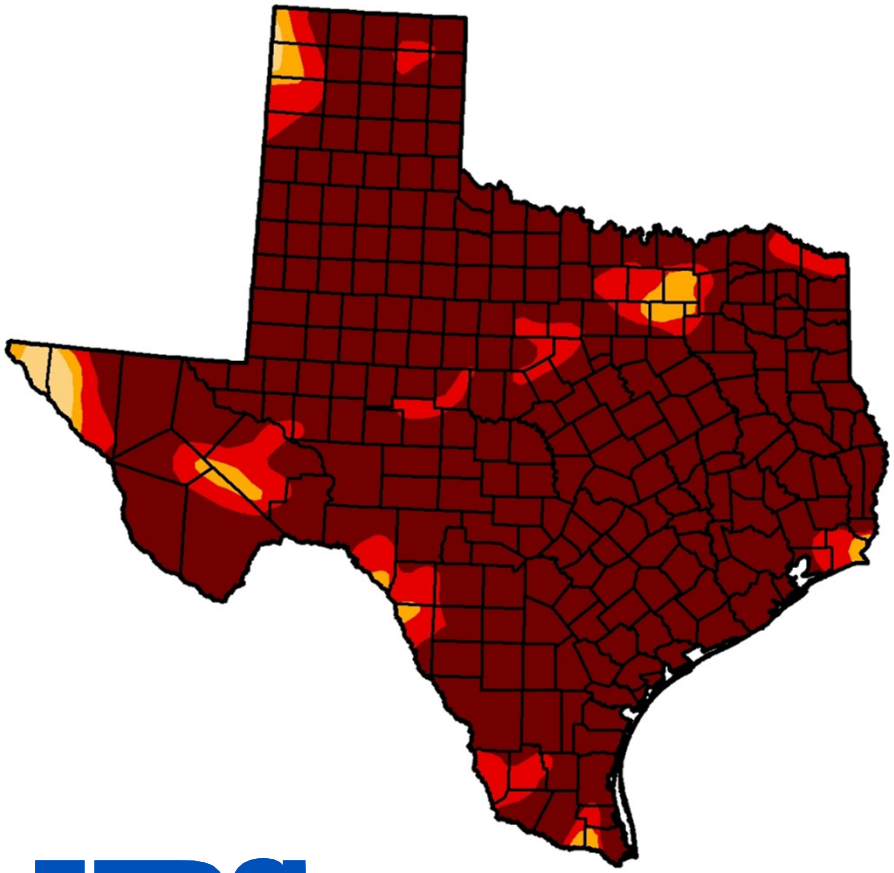
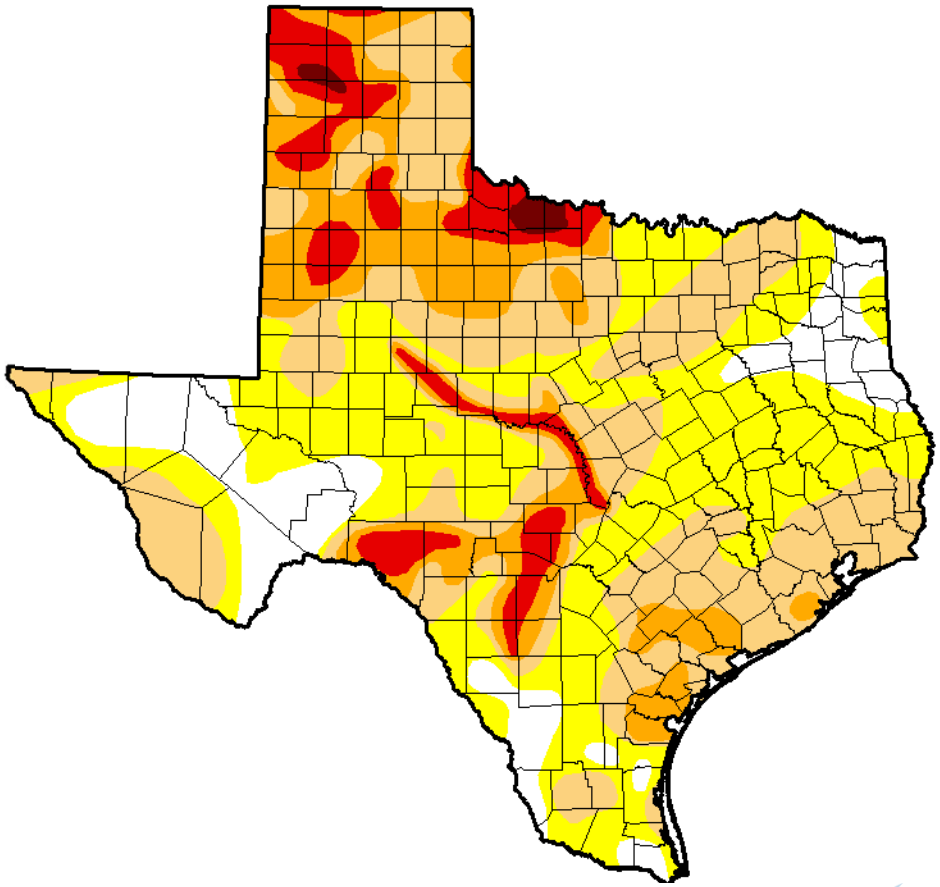
Texas Drought

October 4, 2011



February 25, 2014



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Texas Water Development Board

Wichita Falls – Lake Arrowhead

January 22, 2014
27% Full

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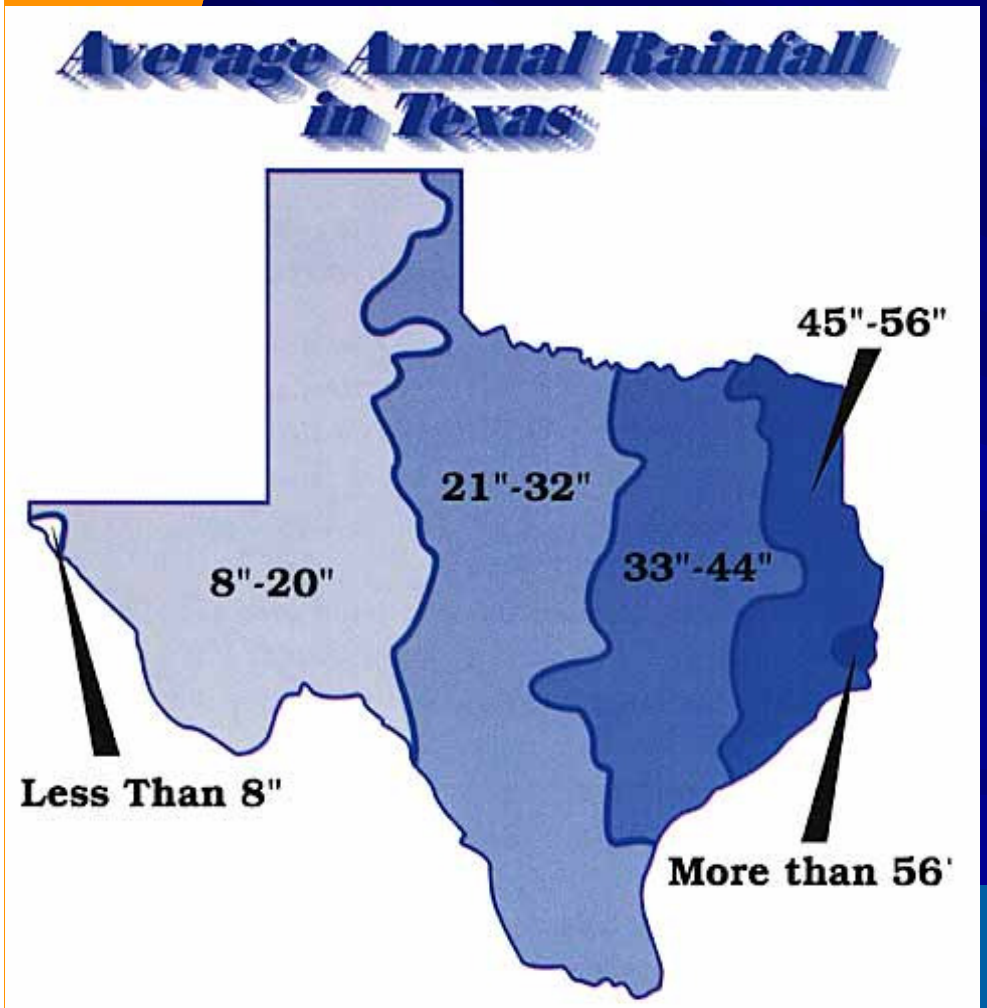
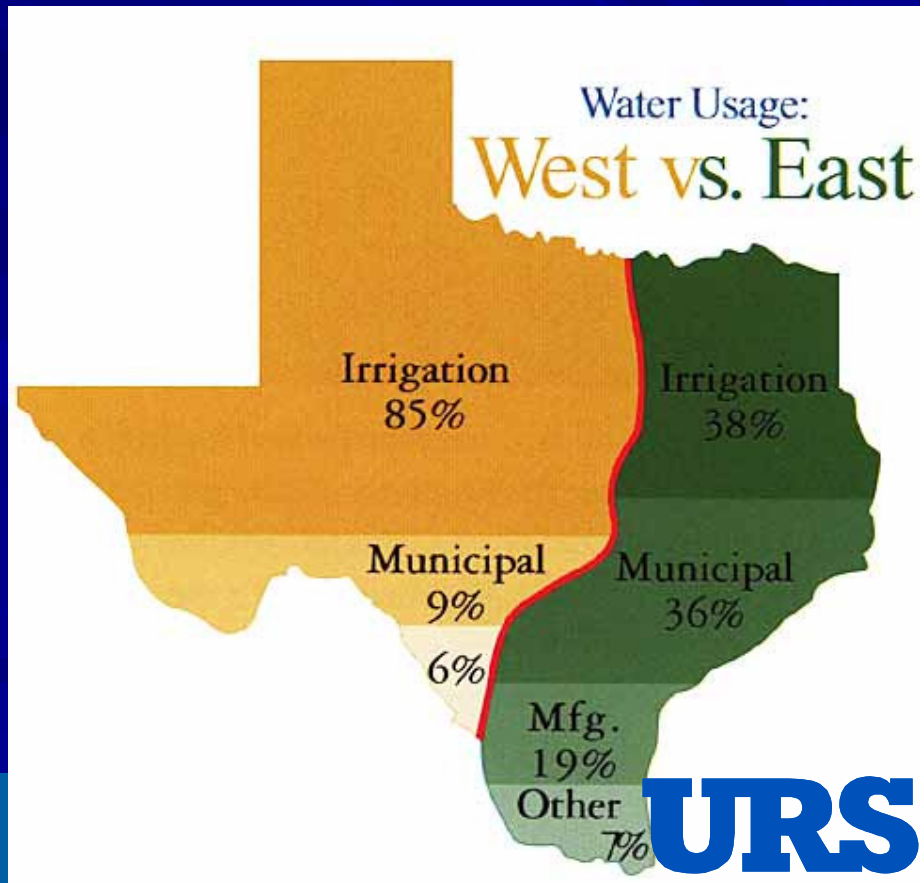
Water Use in Texas





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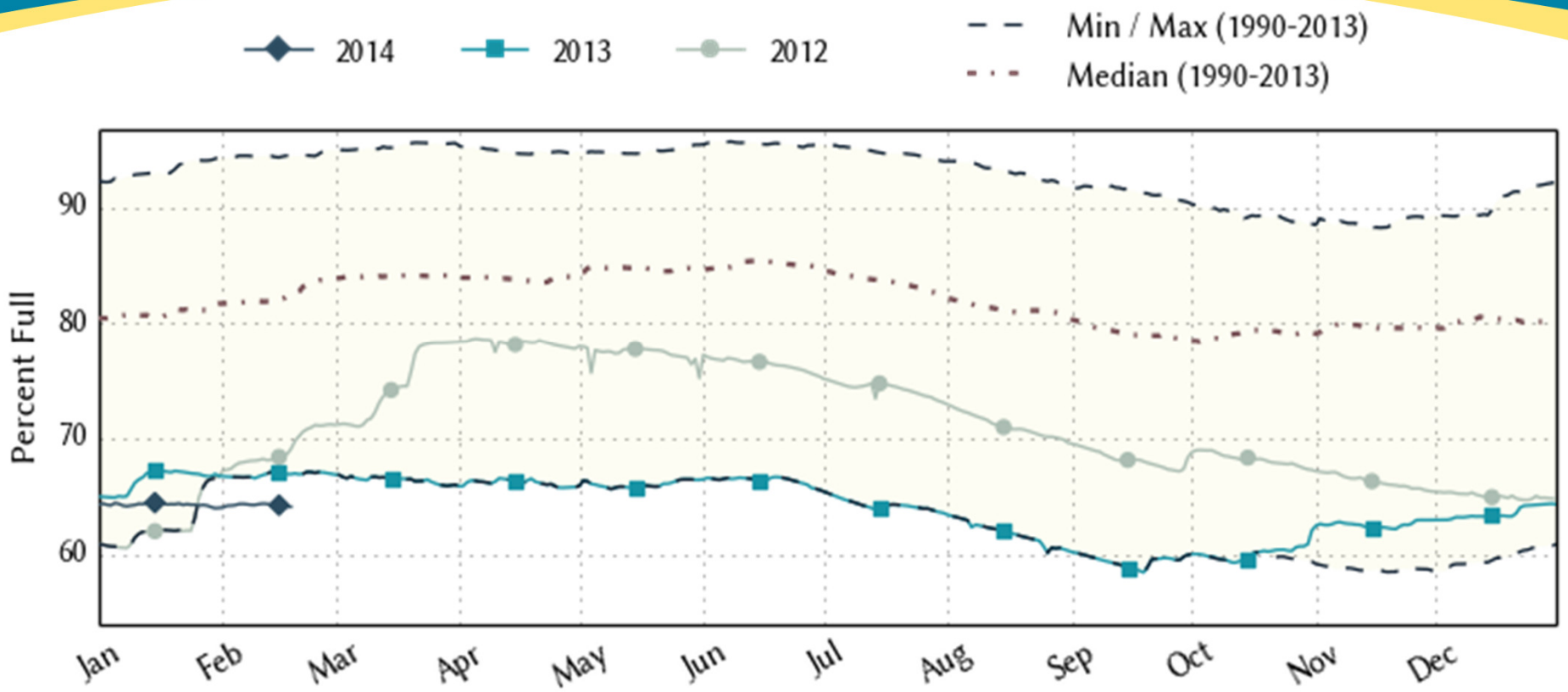
Reservoir Conservation Storage



Texas Water Development Board

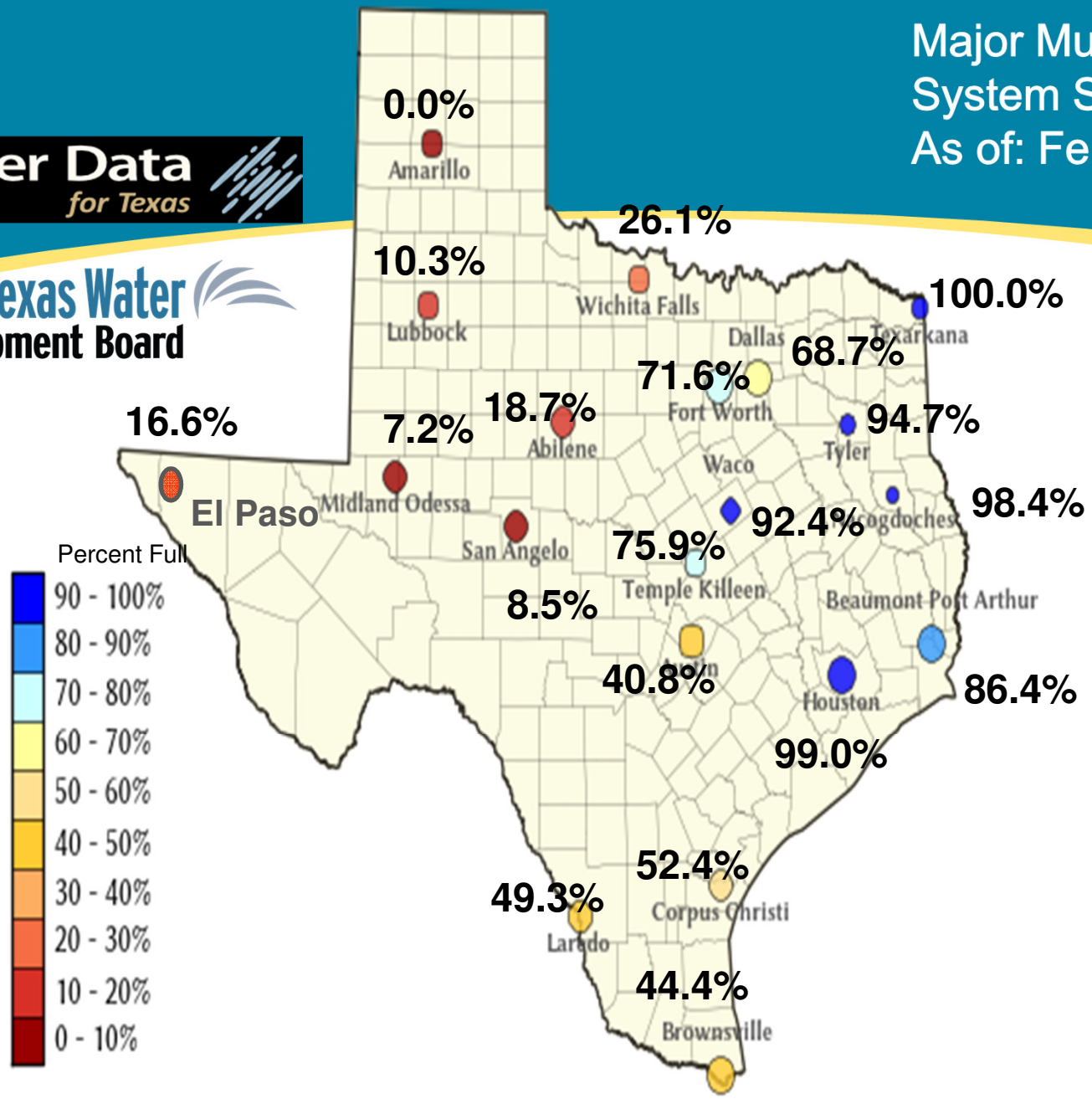
Water Data for Texas

Storage for Feb. 18, 2014: 20.1 Million acre-ft (64.1%)
Conservation Capacity: 31.4 Million acre-ft

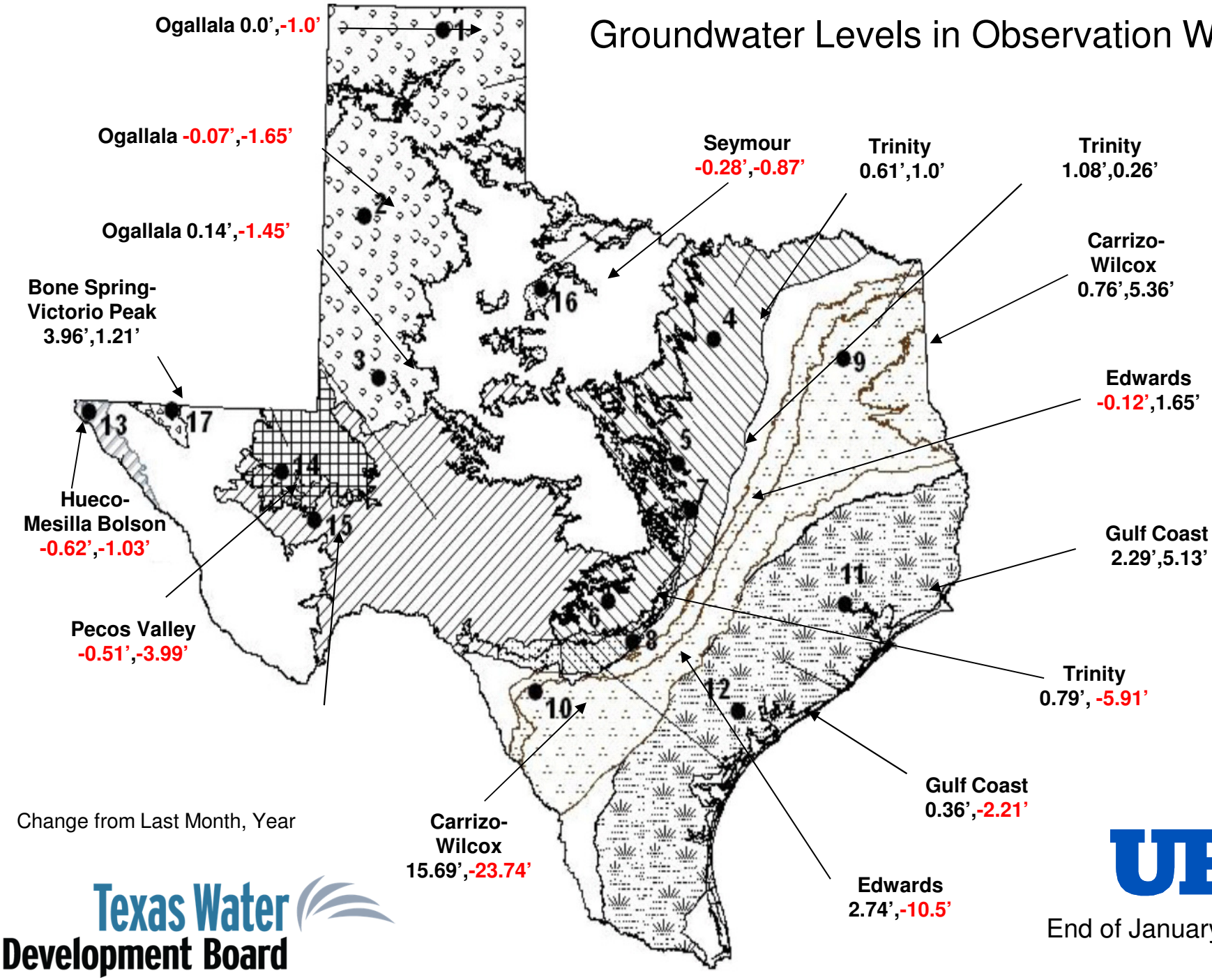
Water Data for Texas

Texas Water Development Board

Major Municipal Reservoir System Storage (% Full)
As of: Feb. 18, 2014



Groundwater Levels in Observation Wells



Change from Last Month, Year

Texas Water Development Board

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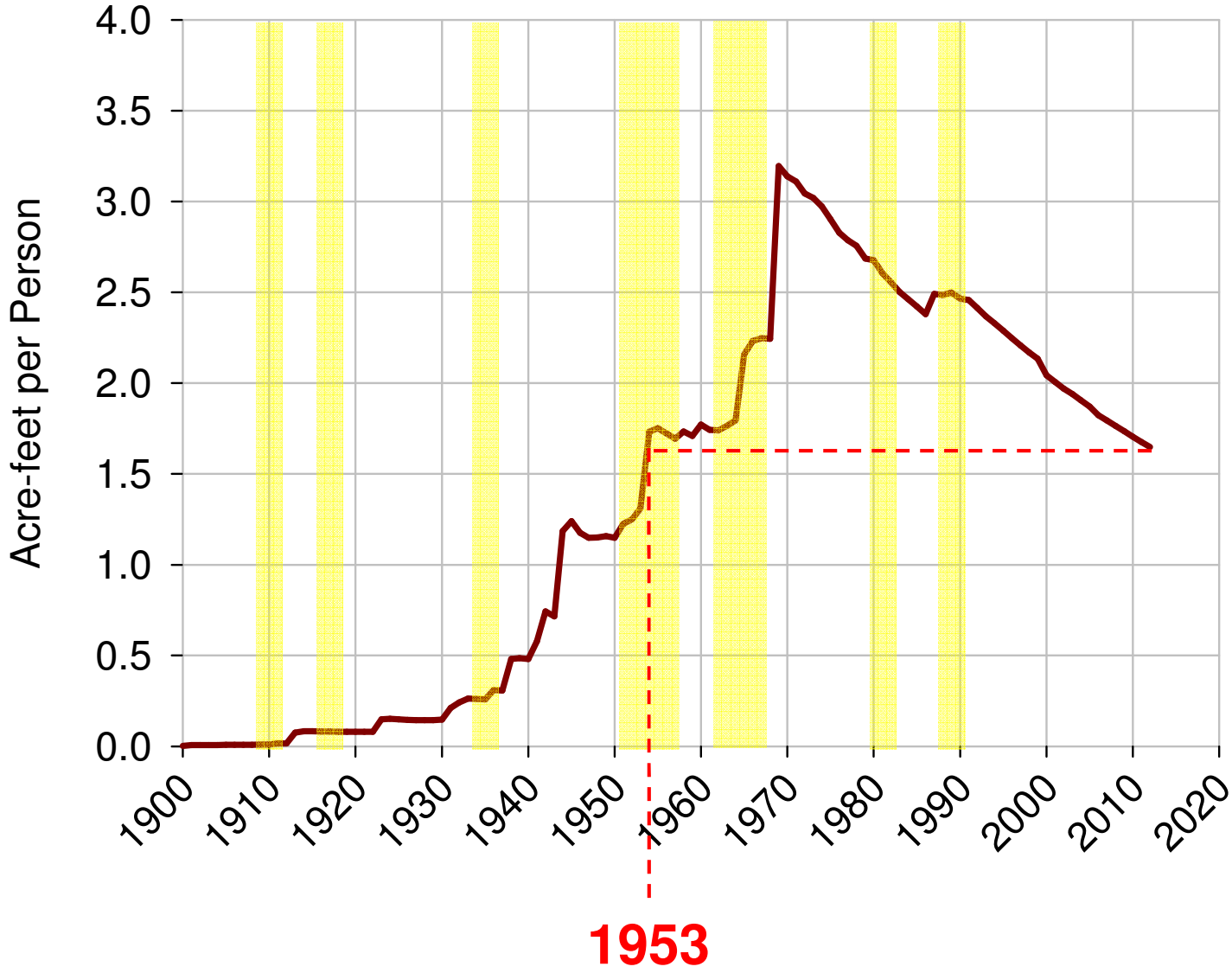
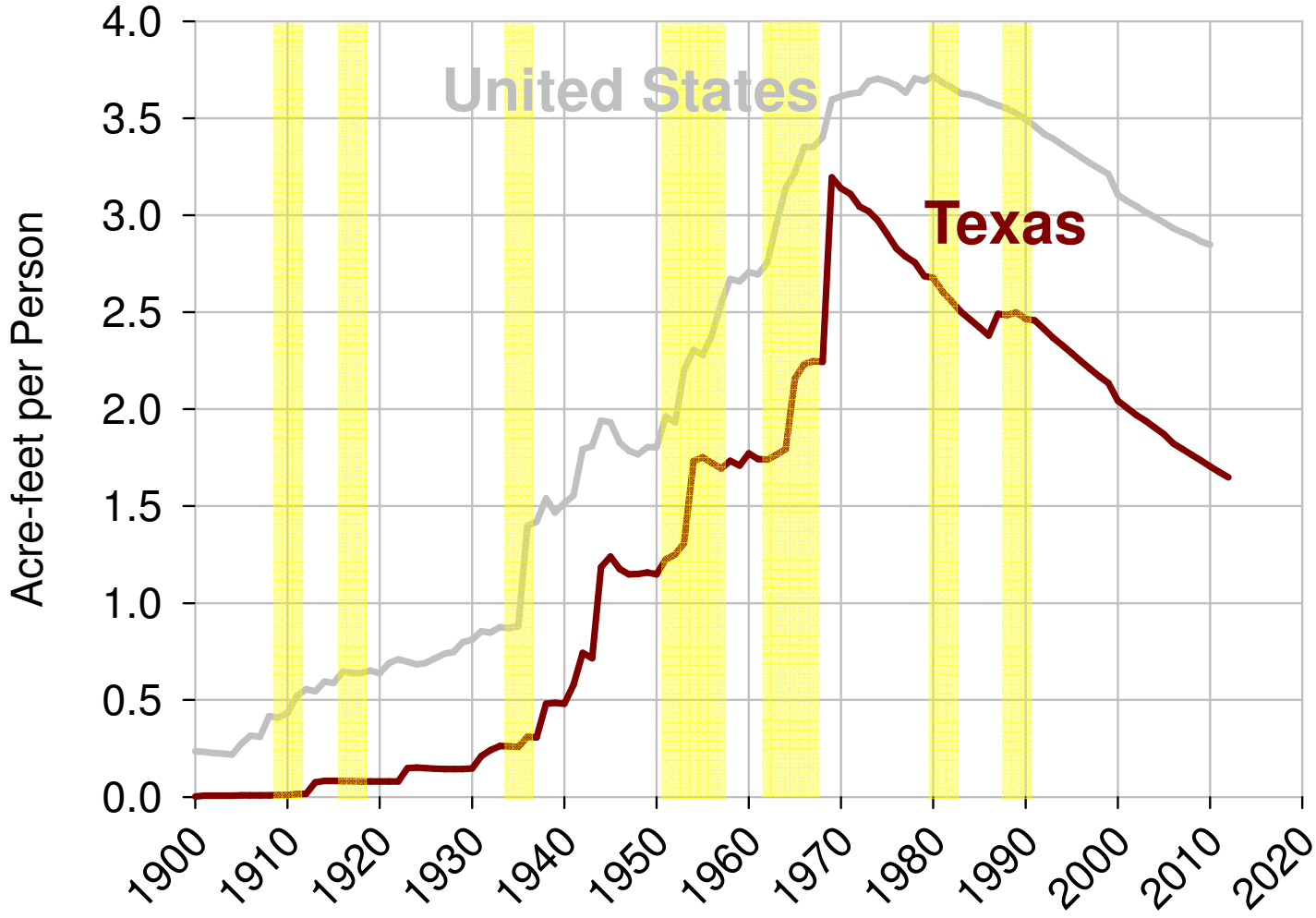
End of January 2014

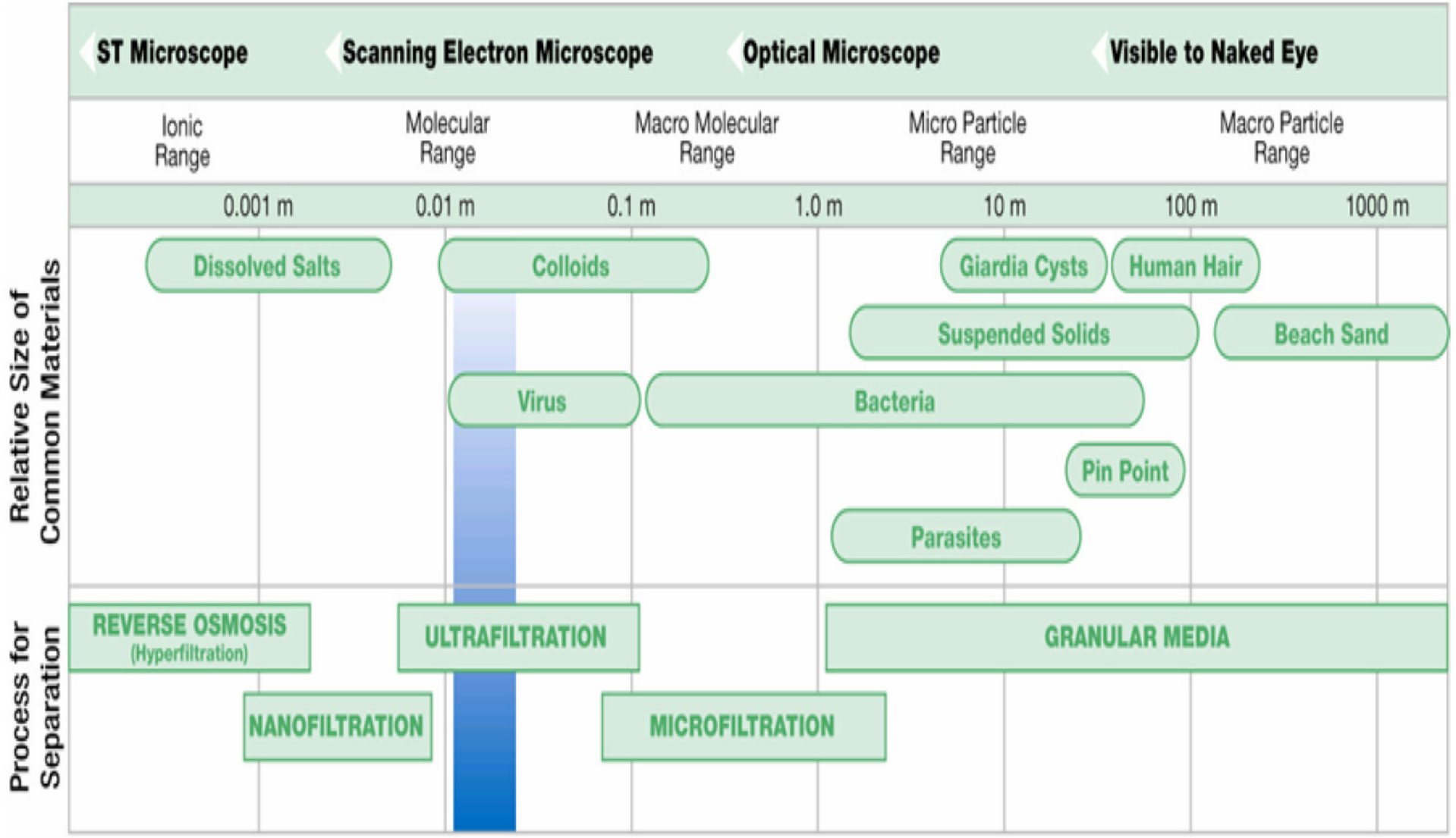
Texas Reservoir Storage Capacity per Capita



Reservoir Storage Capacity per Capita



Membranes Dominate Water Treatment



The filtration spectrum

Source: SAWEA 2005 Workshop, ZENON Environmental, Inc.

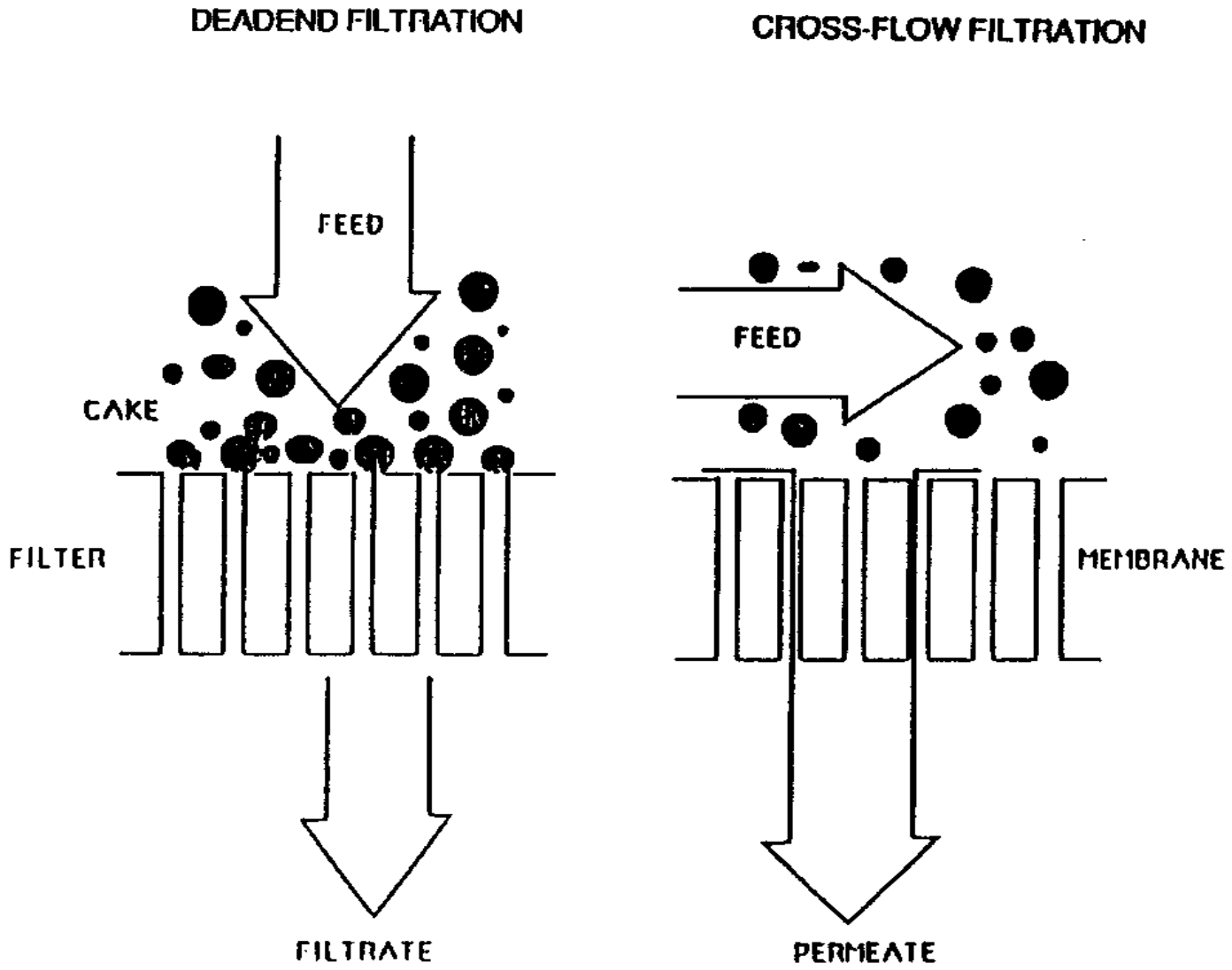


Figure 2. Cross-flow versus dead end filtration.

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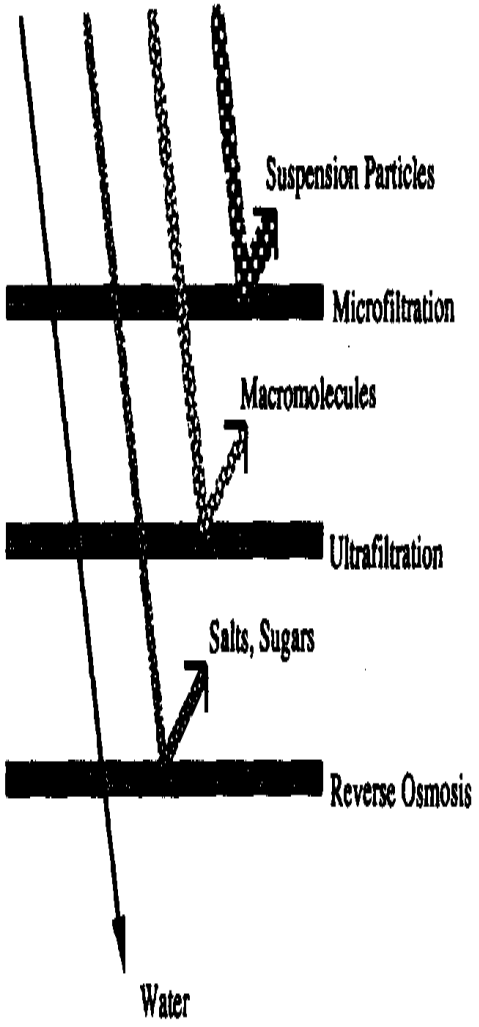
Filtration Classification

- Classification of filtration falls into several categorizes depending on the size of the substance being excluded by the membrane

MF, UF and RF

- **Microfiltration** generally refers to the filtration of suspension particle such as cells and cellular fragments
- **Ultrafiltration** is the filtration of macromolecules
- **Reverse Osmosis** is the filtration of molecules such as salts and sugars



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	Microfiltration	Virus Filtration	High-Performance Filtration	Ultrafiltration TFF	Nanofiltration/ Reverse Osmosis
Components retained by membrane	Intact cells Cell debris	Viruses	Proteins	Proteins	Antibiotics Sugars Salts
membrane membrane membrane membrane membrane membrane membrane membrane membrane membrane membrane membrane membrane membrane					
Components passed through membrane	Colloidal material Viruses Proteins Salts	Proteins Salts	Proteins Salts	Small Peptides Salts	(Salts) Water
Approximate membrane cutoff range	0.05 µm – 1 µm	100 kD – 0.05 µm	10 kD – 300 kD	1 kD – 1000 kD	<1 kD

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- Equivalence between kiloDalton (KD), Microns (micrometers), Nanometers, and Angstroms

KD's	Microns	Nanometers	Angstroms
1,000 KD	0.1 micron	100	1000
500 KD	0.02 micron	20	200
200 KD	0.01 micron	10	100
50 KD	0.004 micron	4	40
10 KD	0.0025 micron	2.5	25
5 KD	0.0015 micron	1.5	15

1 micron is 1×10^{-6} of a meter

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Membrane Classification

- Pressure driven membranes are divided into four main divisions based on pore size
  - Microfiltration (MF)
  - Ultrafiltration (UF)
  - Nanofiltration (NF)
  - Reverse Osmosis (RO)

Decreasing pore size.

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FILTER RATINGS

- Microfiltration
  - Rated by pore size
    - 0.1 - 0.65 Micron
- Ultrafiltration
  - Rated by size of molecule retained
    - 1,000 - 1,000,000 NMWL
- Reverse Osmosis
  - Rated by retention of marker ions
    - NaCl

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MEMBRANE CHEMISTY

- Microfiltration
  - PVDF (Durapore™)
  - Polyethersulfone
- Ultrafiltration
  - Polyethersulfone (Biomax™)
  - Regenerated Cellulose (Ultracell™)
- Reverse Osmosis
  - Thin Film Composite (TFC)
  - Polyamide on Polysulfone
- UF Membranes
  - Conventional with subsurface voids
  - New void-free
  - composite structure
  - (Ultracell™)

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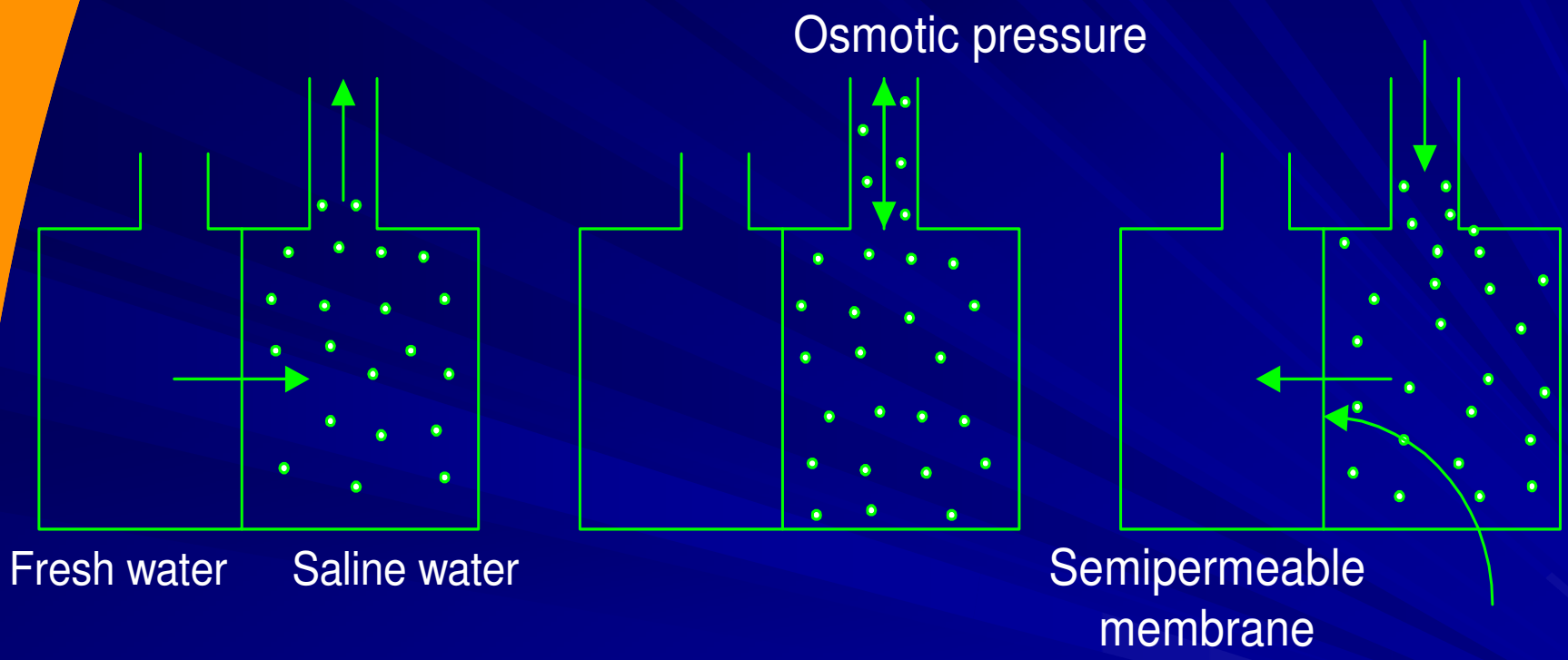
Osmotic pressure
Fresh water
Saline water
Semipermeable membrane
(a) direct osmosis
(b) osmotic-equilibrium
(c) reverse osmosis

Why Desalination?

Water is an essential component of the life support system

Why go for desalination and water reuse?

- Lack of water resources
- Deteriorating quality of fresh water sources
- Reduced cost of water produced by desalination
- Security of supply

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Relevant Technologies in Use

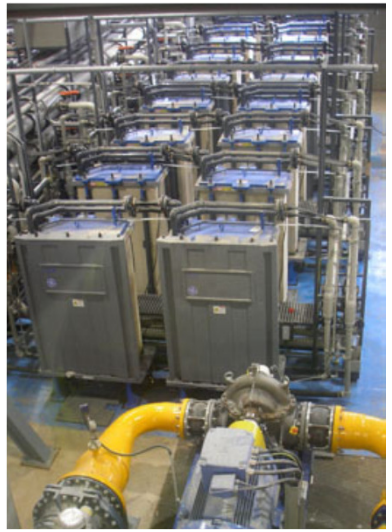
Commercially Available Desalting Processes

Major Processes

- **Thermal**
  - Multi-Stage Flash Distillation
  - Multiple-Effect Distillation
  - Vapor Compression
- **Membrane**
  - Electrodialysis
  - Reverse Osmosis

Minor Processes

- **Freezing**
- **Membrane Distillation**
- **Solar Humidification**



Forces Behind the Development Potential of Desalination

- Independent of climatic variations

- Compared to conventional resources (civil engineering projects) , desalination projects:
  - can be built quickly (2-3 years), close to demand
  - have less problematic right of way
  - are less likely to meet opposition of local groups
  - are modular and easily adapt to demand evolution
  - are more susceptible to private sector investment

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Introduction to Energy & Desalination

Desalination Processes

Thermal – needs thermal and electrical energy

Membranes – needs electrical energy only

Both are energy intensive, accounting for

40-75 % of the operating cost

Why reduce energy consumption → cost and CO_2 emissions

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Summary of Characteristics of Major Flowback Water Treatment Technologies-discharge and or reuse

Characteristics	Ion Exchange	Reverse Osmosis	EDR	Thermal Distillation
Energy Cost	**Low**	**Moderate**	**High**	**High**
Energy Usage vs TDS	Low	Increase	High Increase	Independent
Applicable to	All Water types	Moderate TDS	High TDS	High TDS
Plant/Unit size	Small/Modular	Modular	Modular	Large
Microbiological Fouling	Possible	Possible	Low	N/A
Complexity of Technology	Easy	Moderate/High Maintenance	Regular Maintenance	Complex
Scaling Potential	Low	High	Low	Low
Theoretical TDS Feed Limit	**N/A**	**32,000**	**40,000**	**100,000+**
Pretreatment Requirement	Filtration	Extensive	Filtration	Minimal
Final Water TDS	**200-500 ppm**	**200-500 ppm**	**200-1000 ppm**	**< 10 mg/L**
Recovery Rate (Feed TDS >20,000mg/L)	**N/A**	**Low (30-50%)**	**Medium (60-80%)**	**High (75-85%)**

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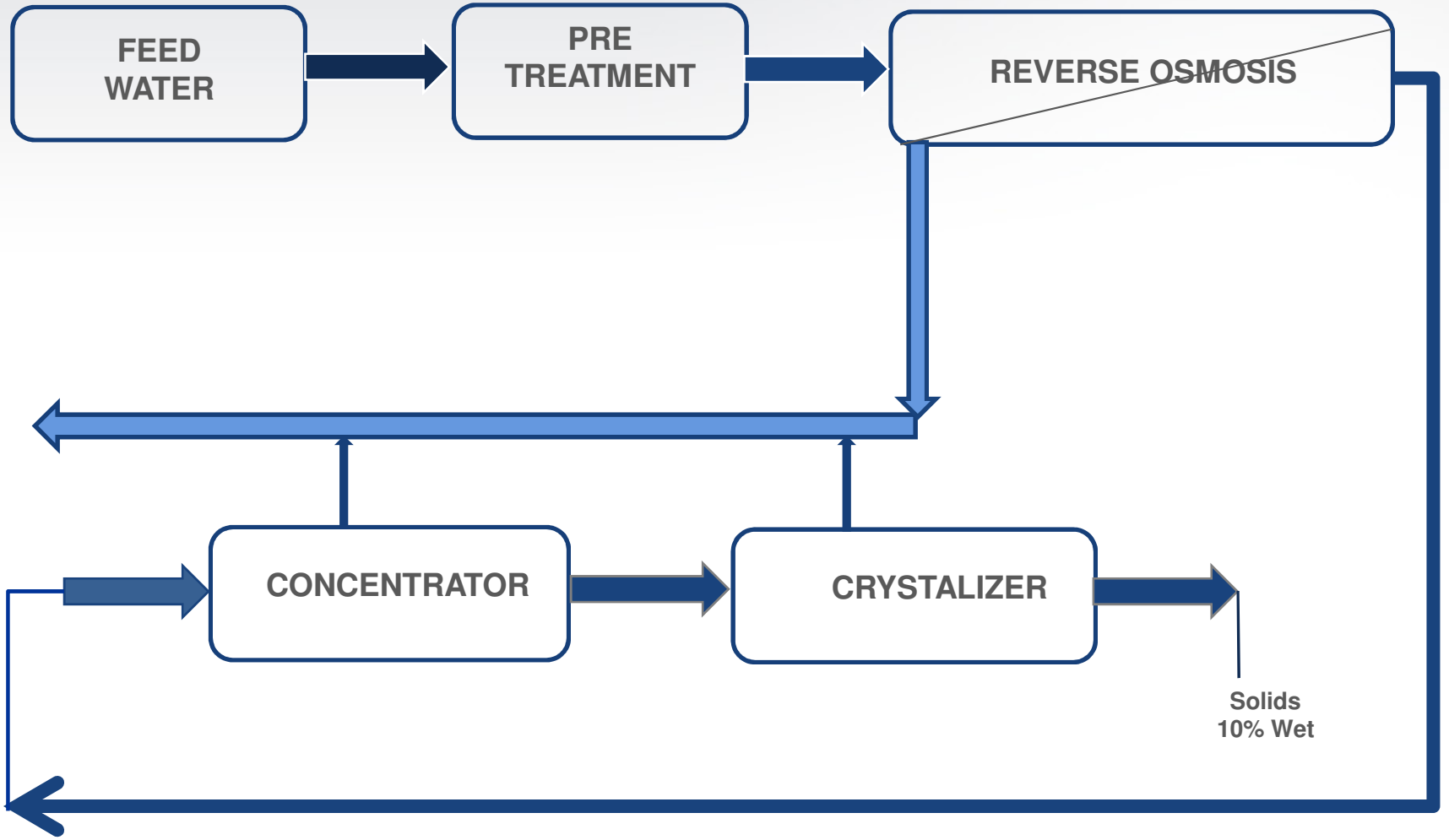
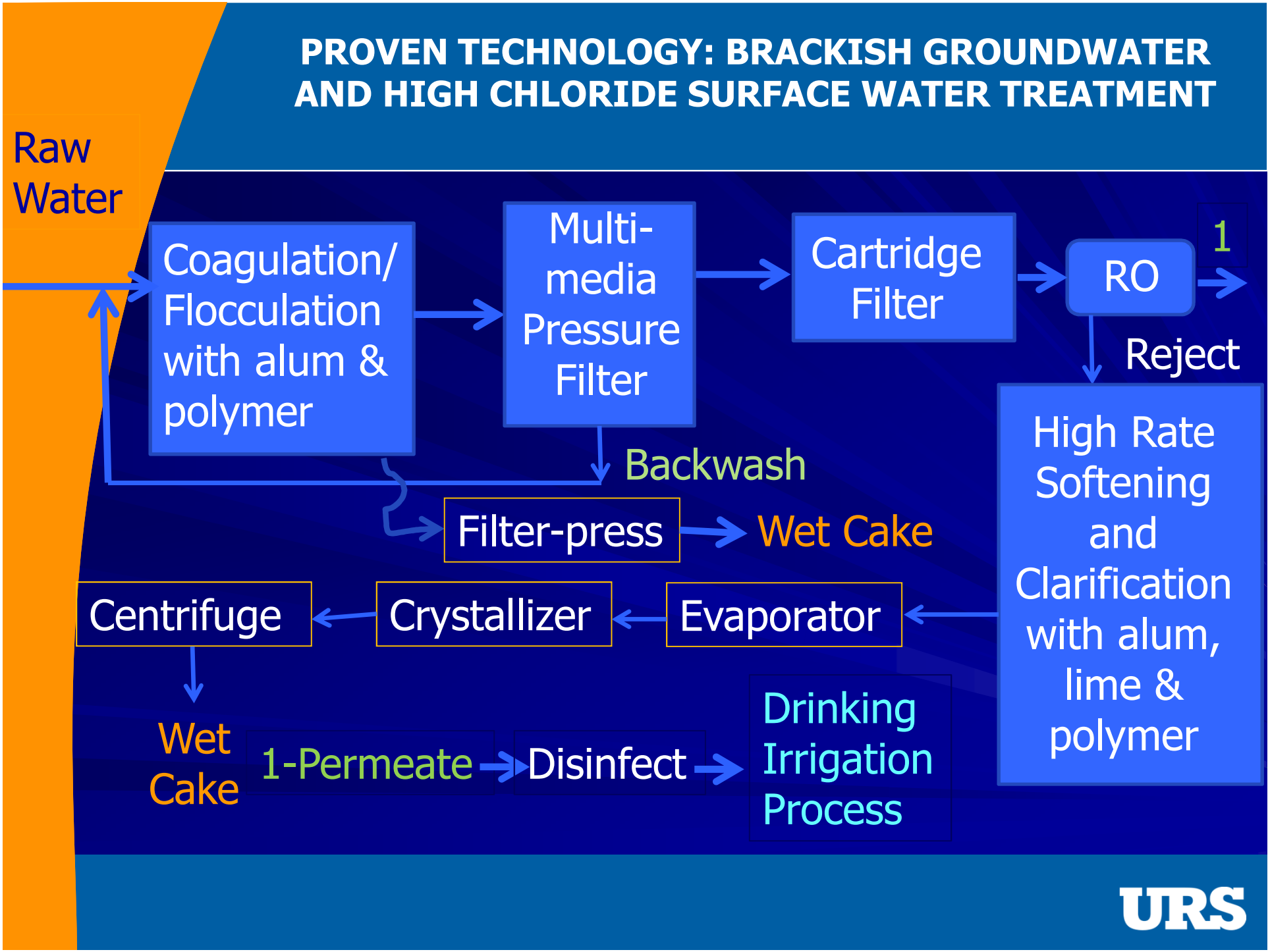
TYPICAL WATER TREATMENT



IDE technologies ltd.

PROVEN TECHNOLOGY: BRACKISH GROUNDWATER AND HIGH CHLORIDE SURFACE WATER TREATMENT



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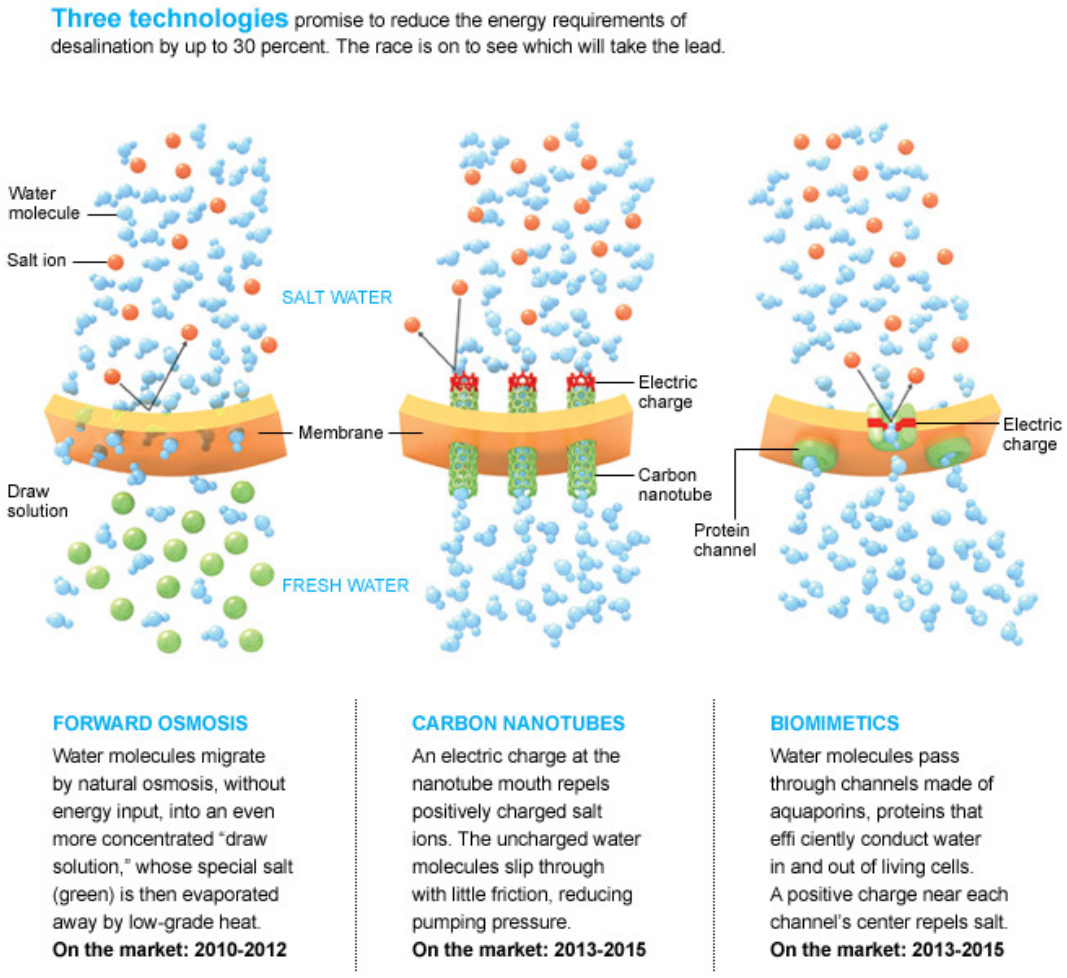
5 Methods:

1. Brute Force Distillation: Heat seawater until it turns to steam, leaving its salt behind, then condense it. This method is however, expensive.
2. Reverse Osmosis: in which water is forced through a membrane that catches the salt. Pumping seawater to pressures of more than a thousand pounds per square inch takes less energy than boiling it—but it is still expensive.

And these other 3 methods are promising a more inexpensive way of desalinating water.

3. Forward Osmosis
4. Carbon Nanotubes
5. Biomimetics



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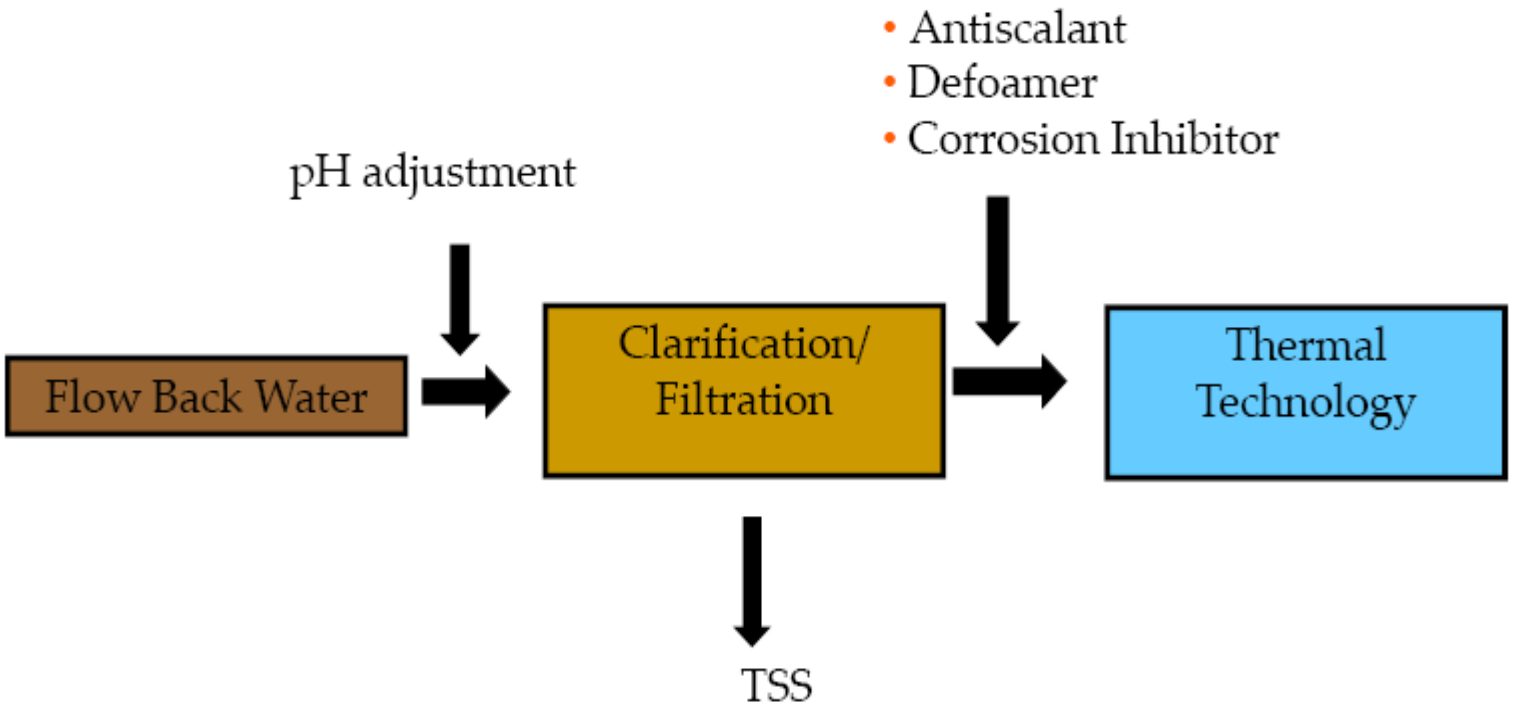
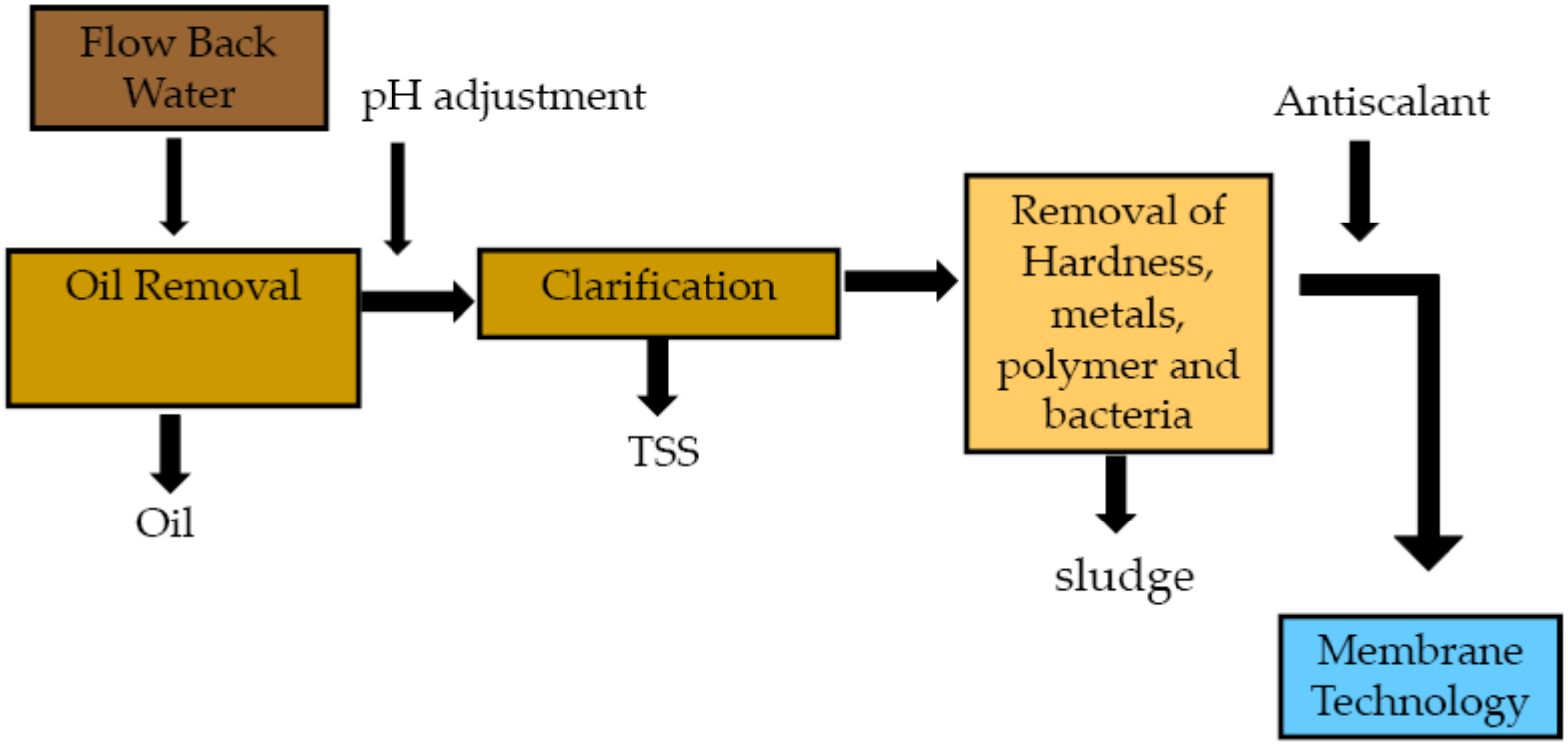
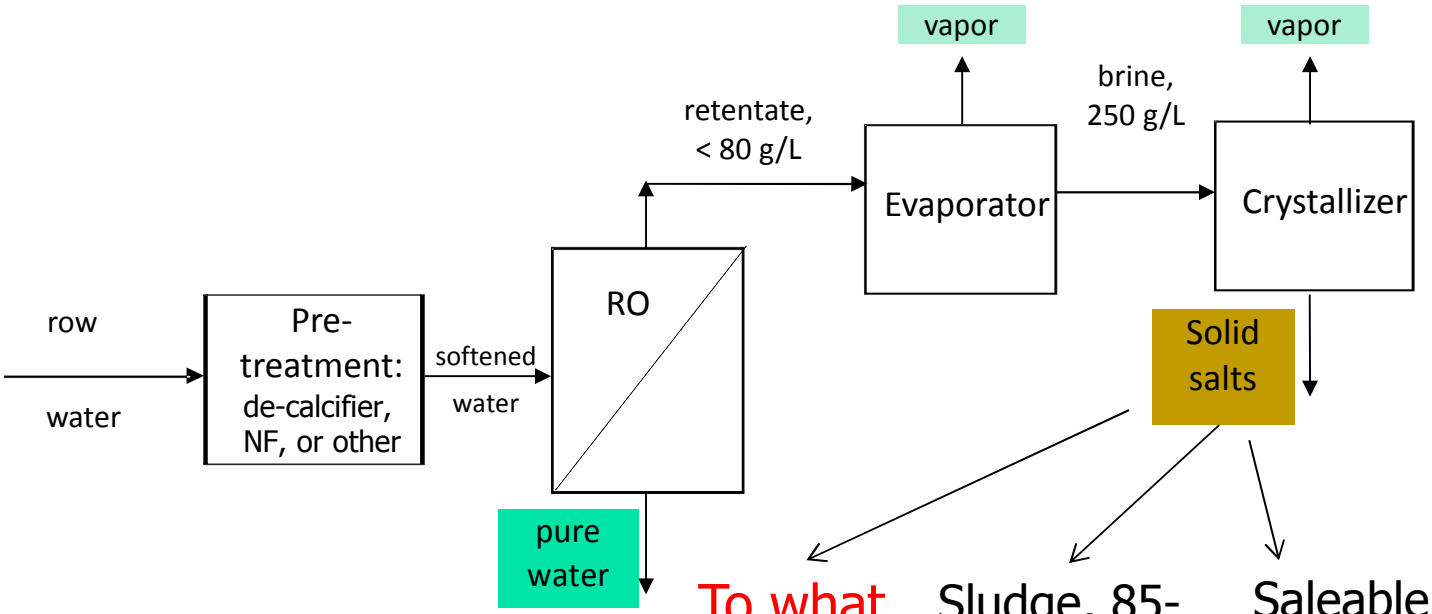
Pre-treatment Followed by Thermal Evaporation and Disposal



Pre-treatment Followed by Membrane Separation for Disposal



General scheme of a ZLD system



To what else ???

Sludge, 85-95% solids content – disposed of in landfill

Saleable salts – to de-ice roads

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Why ZLD? The main motivations

1) **Fresh water scarcity**: 20 years ago, this problem was recognized in a so large measure that the term 'virtual water' was introduced (Prof. J.A. Allan, Israel). It is the water, which is incorporated in some products, such as avocados, cotton. Thus, Israel reconsiders its agricultural politics in order to reduce water export via these agricultural products.
2) **Social responsibility**: We are recycling bottles, newspapers and plastics.
   Why not water? Only less than 5% of wastewater is presently recovered.
3) **Economics:**
   - potable and fresh water price rises;
   - the regulations on the discharge of waste fluids becomes more stringent; In Colorado, Arizona, California, St.-Petersburg, … the maximum acceptable salt concentration in wastewaters is very low. The discharge of salts is payable. ZLD or nearly ZLD systems will be widely used when the costs of 1 m3 of pure water, including the payment of discharge, will be the lowest, if applying these systems

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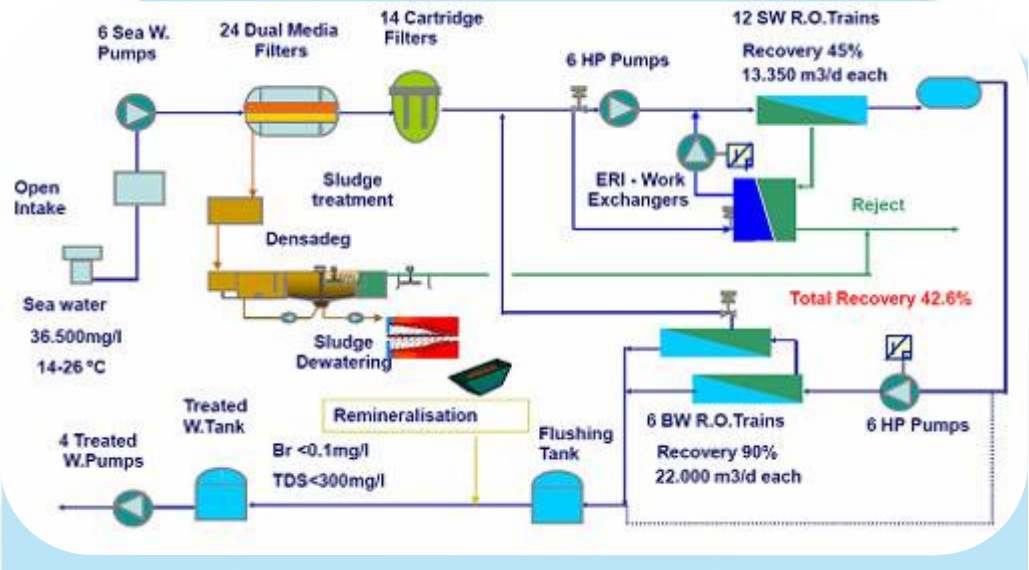
PERTH, Australia
The first large RO seawater desalination plant in the Southern hemisphere and the first to be fed by renewable energies

Global Water Awards 2007

- *DBO Project developed by Western Australian Water Corporation in Alliance with a JV of Degrémont and Multiplex*
- *143,000 m³/d Drinking Water from seawater*
- *Municipal Drinking Water supplying began in November 2006*
- *The environment footprint under control*
  - Brine discharge
  - Reduced energy consumption
  - Wind farm energy
  - Energy recovery



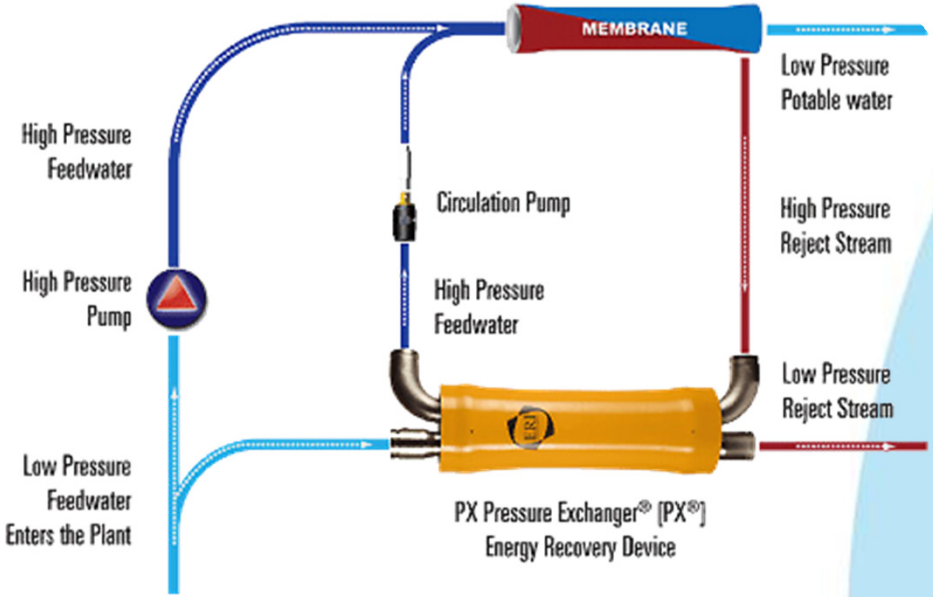
Wind energy to neutralize carbon footprint

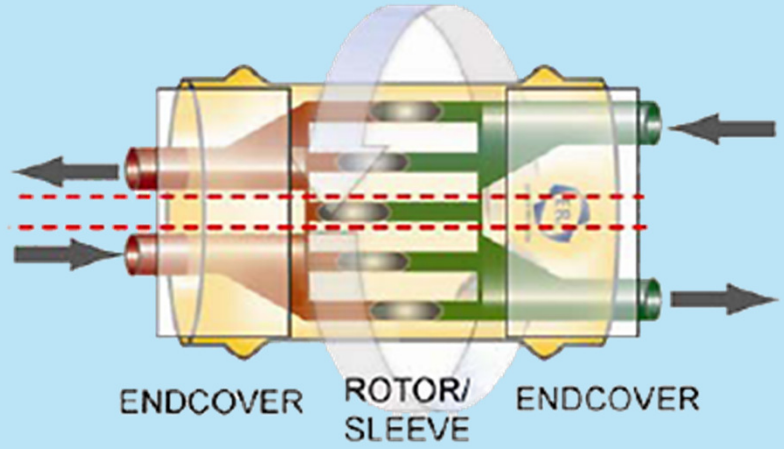
- *Perth SWRO plant: one of the largest facility of its kind in the world to be powered by renewable energy*

- *Connected to the general power grid fed by a Wind Farm constructed by the WA Water Corporation to power the plant:*
  - **Emu Downs Wind Farm**
  - **200 Km North of Perth**
  - **48 Turbines (80 MW)→270 GW.h/year to the grid**
  - **200% of desalination plant energy consumption**

Energy recovery to reduce energy consumption

- *Perth SWRO plant was designed to optimise the energy consumption:*
  - 2.22 kW.h/m³ in the first RO pass (the lowest energy consumption reported)
  - 3.2 – 3.5 kW.h/m³ for overall Plant
- *ERI® PX Pressure Exchanger® (PX®)*





VICTORIA, Australia
A huge desalination plant fed by green energy

WINNER
Global Water Awards
2010
Desalination deal of the year

- *A 30-year BOT contract signed with Aquasure and Victoria state*
- *450,000 m³/d of drinking Water to supply the city of Melbourne and its suburbs (able to be extended to 600,000 m³/d)*
- *Taking up just 38 hectares with 29 buildings, 3 streams, 51 reverse osmosis racks, 55,000 RO membranes and 72 Dual Media Filters, 85km water transfer pipeline…*
- *An ecological space with zero nuisance: 225 hectares coastal park with more than 40,000 plants on the green roof*
- *Wind power to minimise the carbon footprint*
- *To be in operation in 2012*

A major sustainable desalination plant

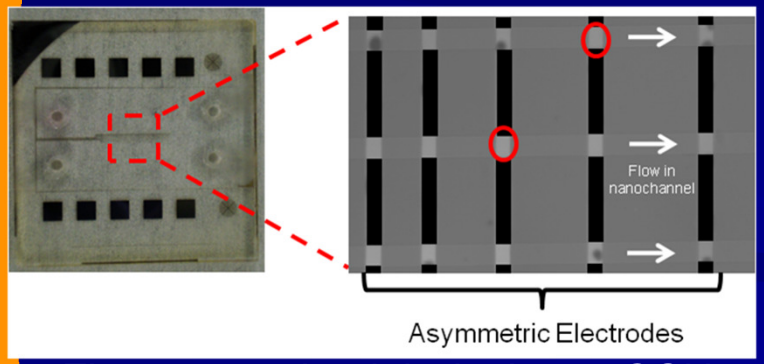
- *A plant with all its equipments designed to optimize its energy consumption and minimize its peak consumption*
- *ERI® PX Pressure Exchanger® (PX®)*
- *Renewable energy resources supplied from AGL's wide and growing portfolio of green power offset by Renewable energy certificates (REC)*
- *Energy provided by the 63MW Oaklands Hill Wind Farm and 420MW Macarthur Wind Farm of power company AGL*

Oaklands Hill Wind farm

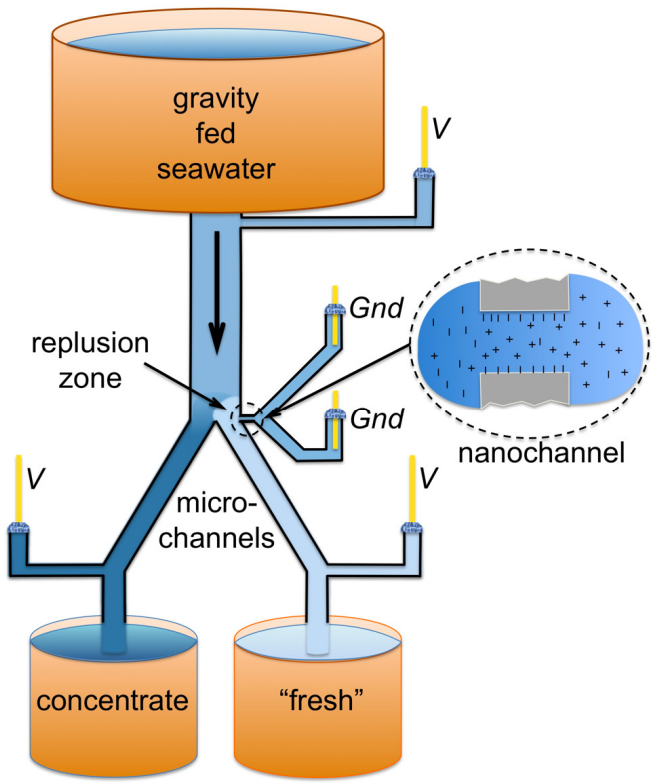
Macarthur Wind farm

Nanotechnology Solutions for New Desalination Systems

- Biological systems are close to the these limits, and operate at the nanoscale
- New water purification technologies using point-of-source supply, point-of-discharge, and point-of-use systems: The new (oldest) paradigm in infrastructure
- New technologies can greatly improve how clean water is supplied and sanitation discharged – Can change everything!



First generation lab device at OSU inspired by biology for desalination at thermodynamic limits



Chip-scale system at MIT to deliver de-salted water from seawater at a fraction of the energy cost

Kim, S. J. *et al. Nature Nanotechnology* 2010

URS