Water

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Drought

"In the most general sense, drought originates from a deficiency of precipitation over an extended period of time (usually a season or more), resulting in a water shortage for some activity, group, or environmental sector."

-- National Drought Mitigation Center, University of Nebraska

<u>Our water use</u> defines drought.

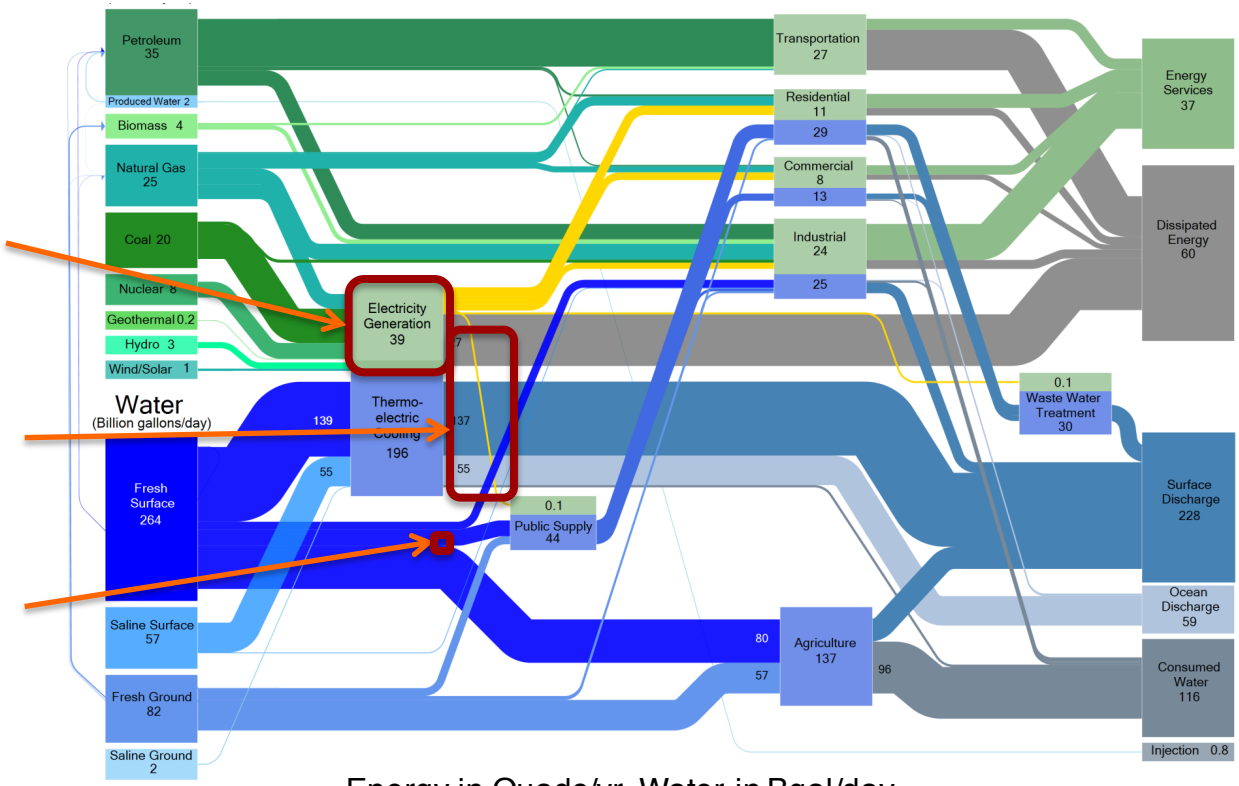
Energy-Water Relationships Today (Nexus)

(Quads/yr)

Thermal Electric Cooling, 25

Water Treatment, 0.5

Desalination, 0.07



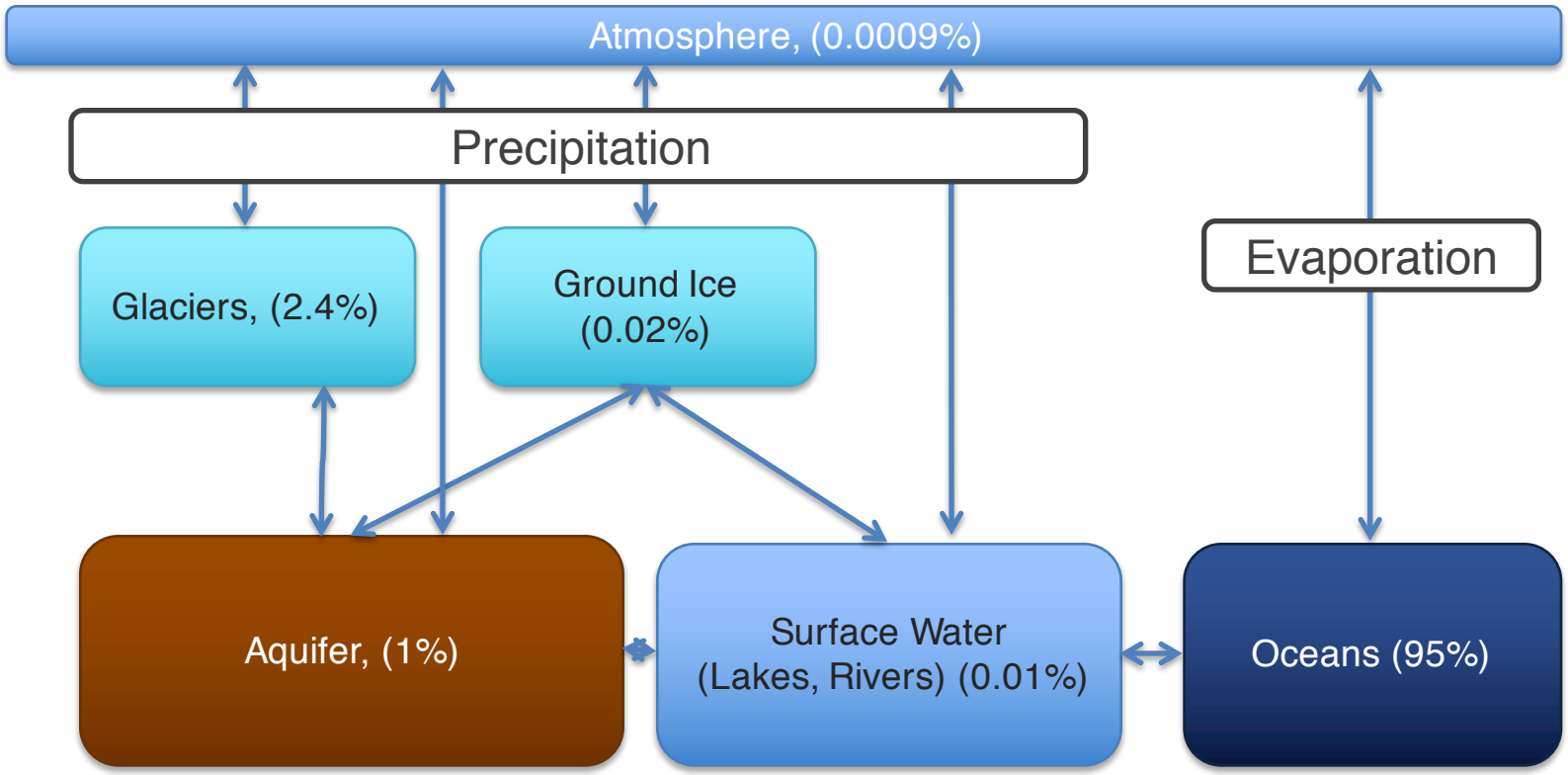
Energy in Quads/yr, Water in Bgal/day

U.S. Department of Energy, "The Water-Energy Nexus: Challenges and Opportunities" (2014).

Water

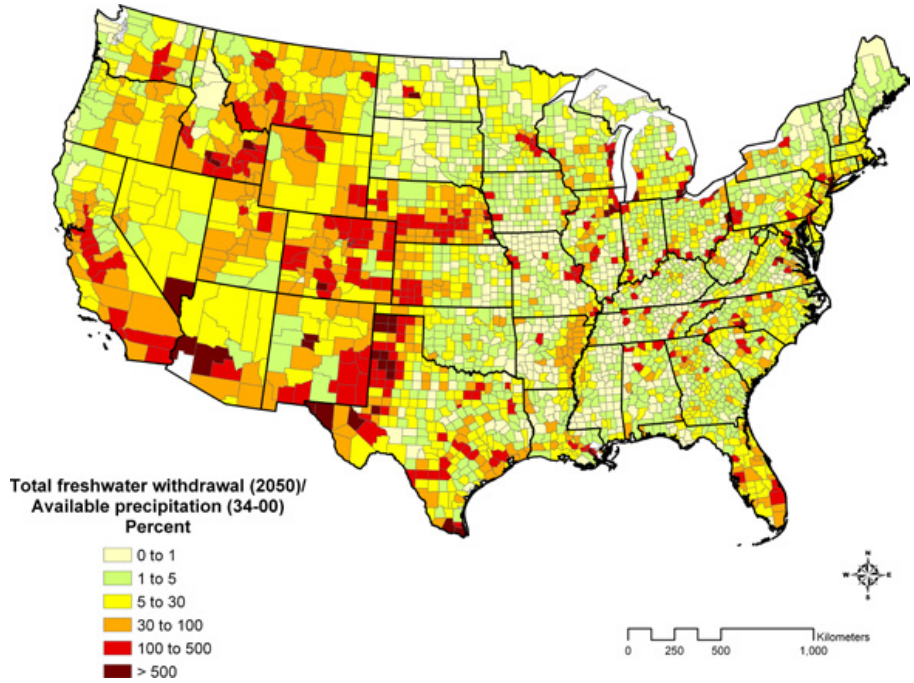
- **Deficits**
- Costs
- Plan

Earth Water Balance



Adapted from: Korzun, V. I., et al., The Water Balances and Water Resources of the Earth, (1978).. I http://water.usgs.gov/edu/earthhowmuch.html

At-risk Regions

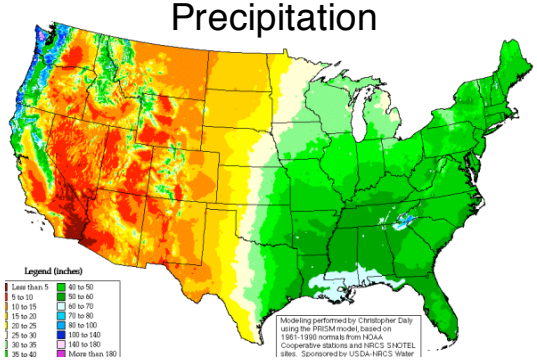


It is a nationwide issue.

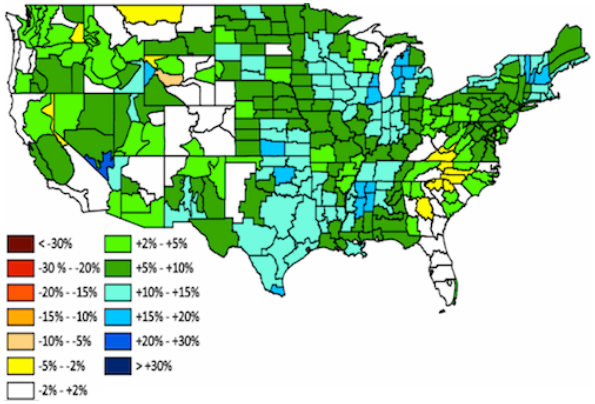
Roy, S. B., et al., Tetratech Report (2010)

Precipitation Supply

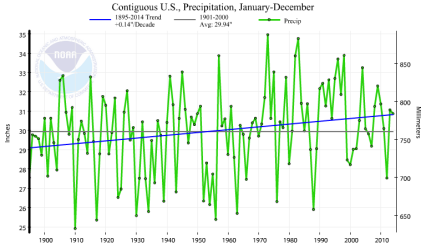
Precipitation



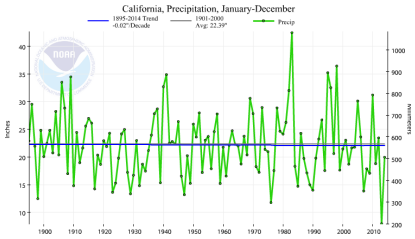
Precipitation Trend (1895-2009)



US



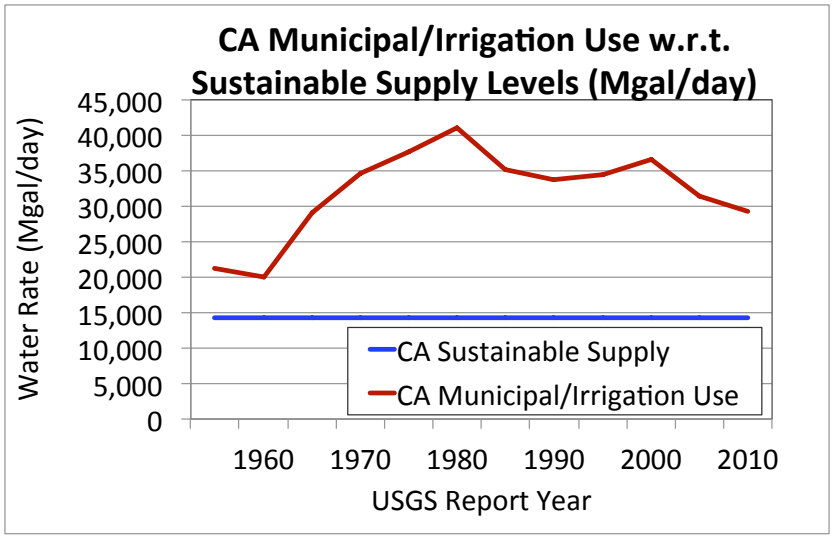
California



Supply is constant.

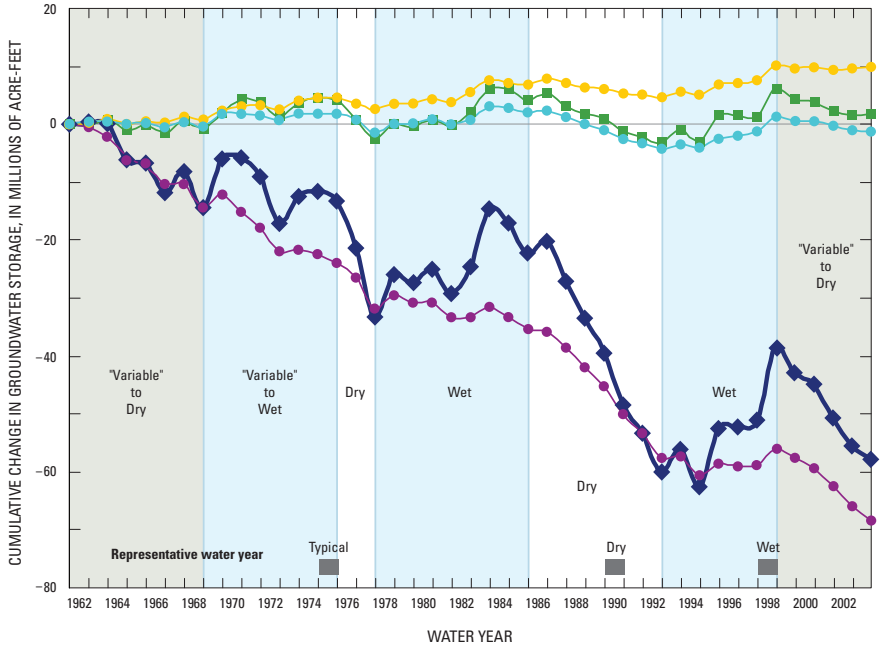
McRoberts, B., et al., J. Appl. Met., 50, 1187 (2011).I George Taylor, Oregon Climate Service. I http://www.cpc.ncep.noaa.gov/charts.shtml

California Water Deficit: > 60 years of Overuse



- In 1955, the CA DWR commented that the state was drawing more water than was sustainable.
- Since then, water use has been consistently above sustainable supplies
- Shortfall has been made up with
  - Colorado River allotment.
  - Groundwater pumping.

San Joaquin Aquifer Water Volume



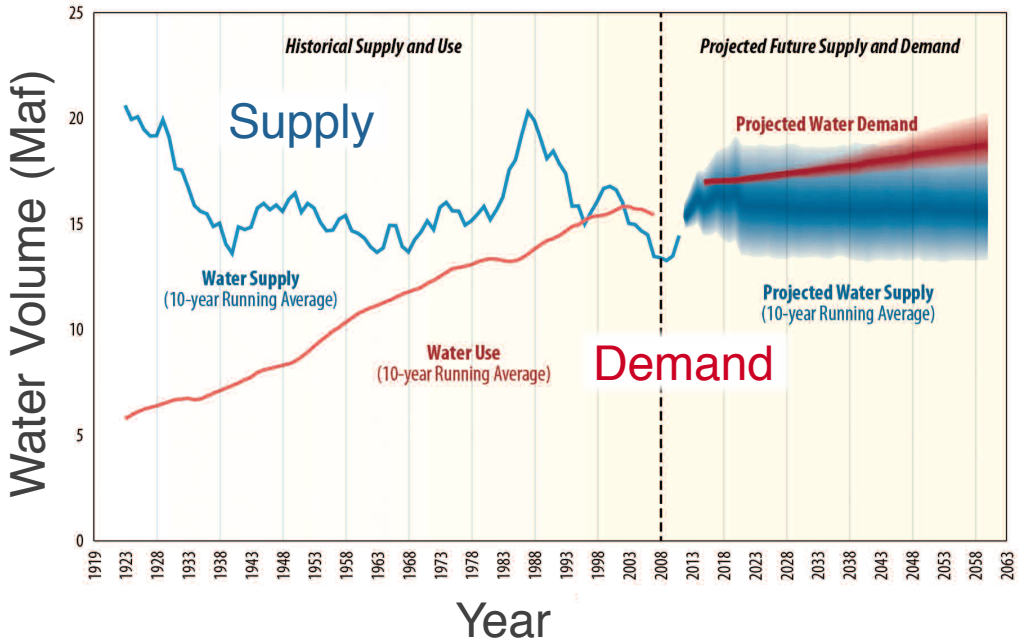
- 100 Maf total useable water volume.

30Maf left?

Faunt, C. F., et al., USGS Professional Paper 1766, (2009)

Precipitation Demand

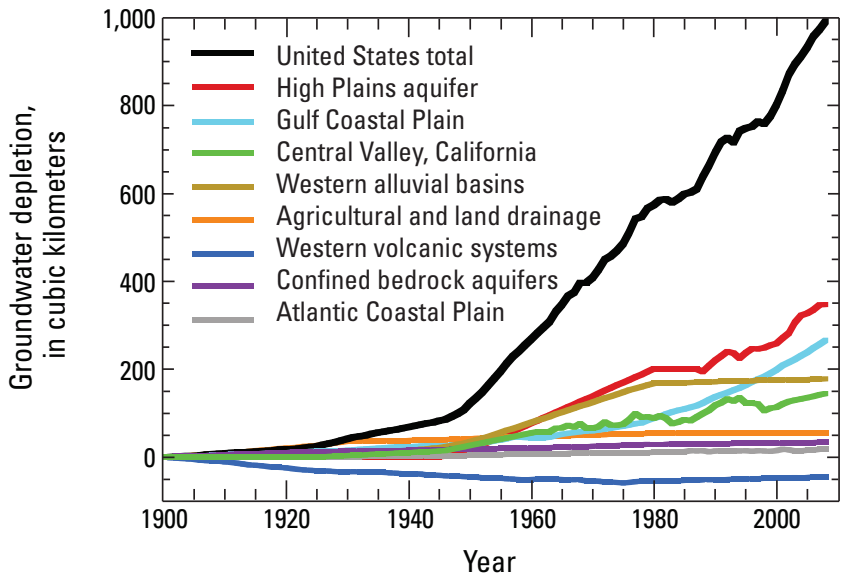
Colorado River 1919-2063 (2008)

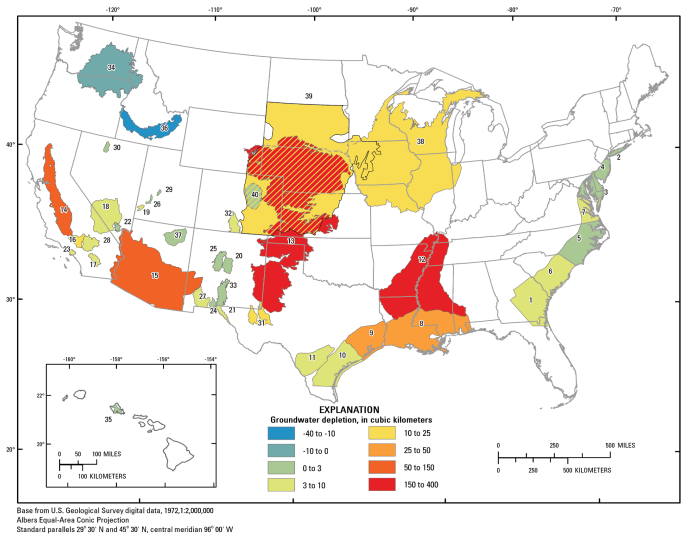


Demand exceeds supply.

Bureau of Reclamation Report, "Colorado River Basin Water Supply and Demand Study Executive Summary (2012).

Water Resource Constraint

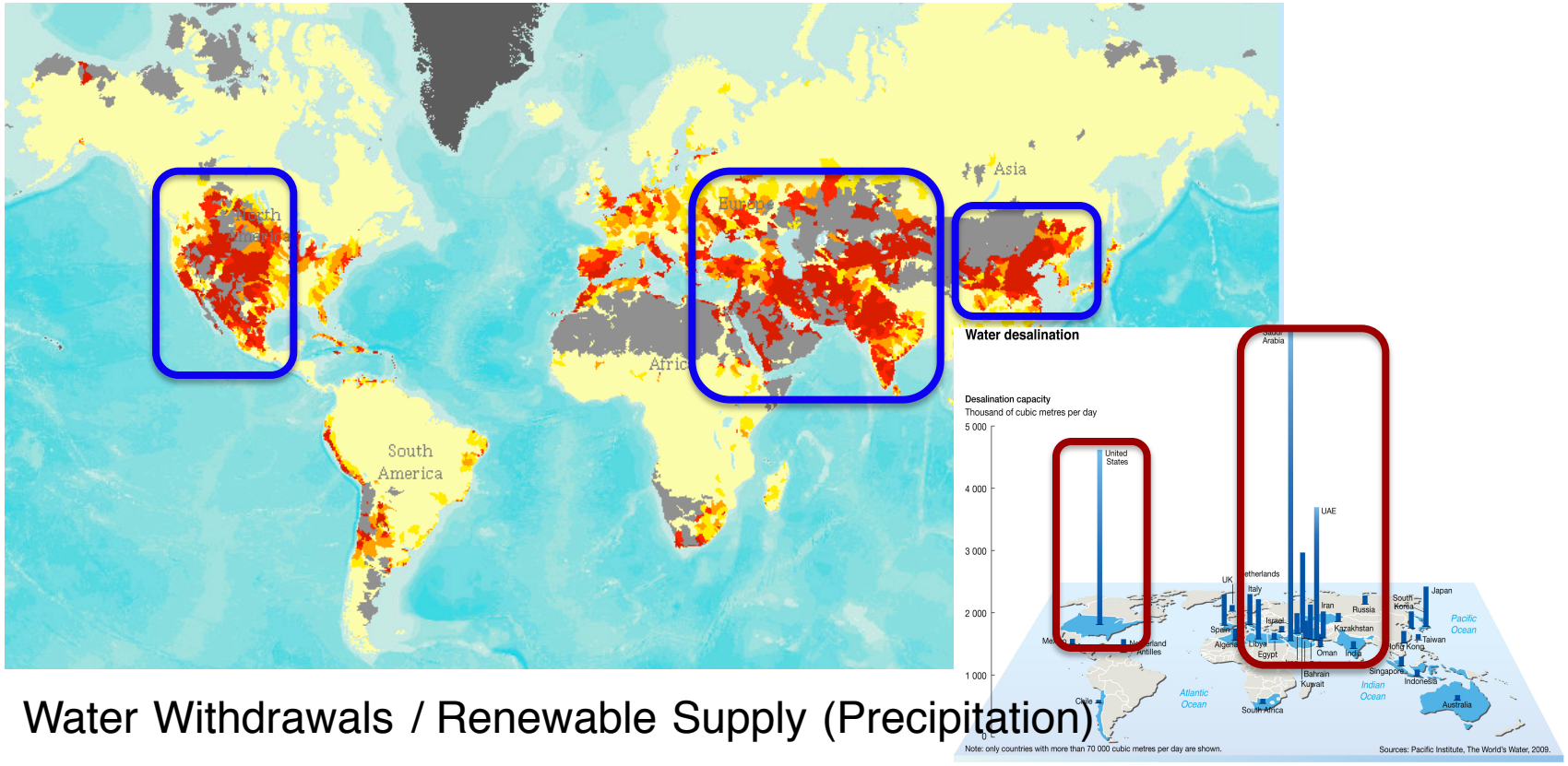




Reservoirs are depleted.

USGS SIR2013-5079, "Groundwater Depletion in the United States (1900–2008) (2013). | Data adapted from USGS Circular 1405 (2014).

Water Risk Assessment



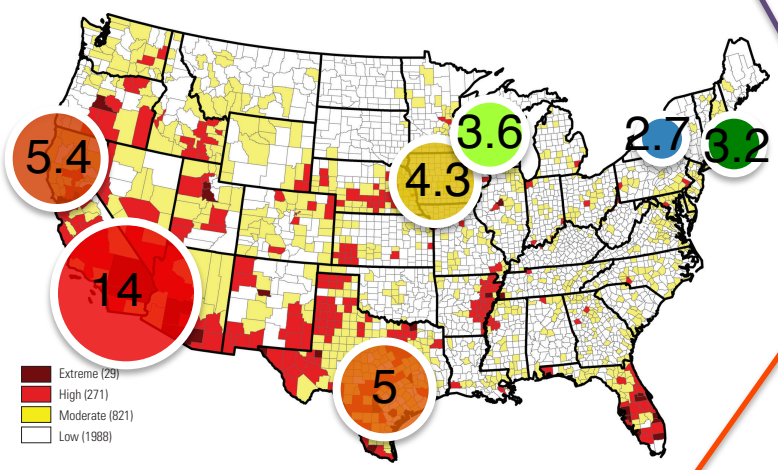
Water Withdrawals / Renewable Supply (Precipitation)

World Resources Institute Aqueduct Water Risk Atlas: http://www.wri.org/applications/maps/aqueduct-atlas | http://www.grida.no/graphicslib/detail/water-desalination_11e4

United States Regional Water Stress

Southwest

Water Supply Intensity (MWh/Mgal)



US Avg: 3.4 MW/MGal

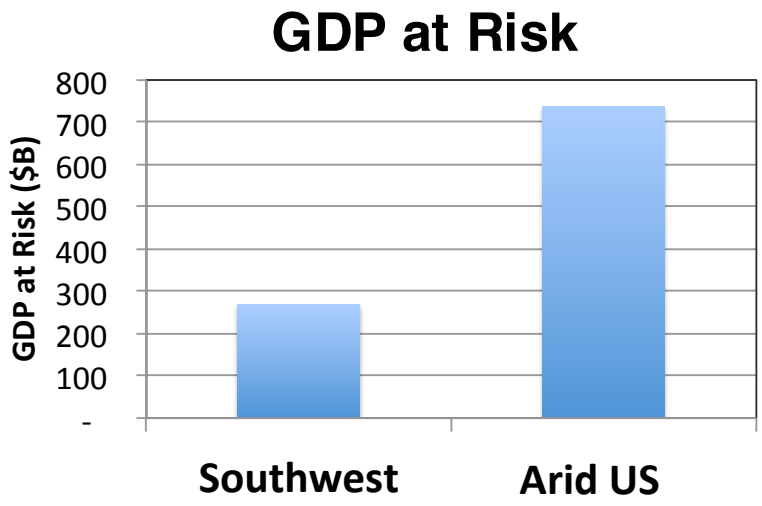
Region	Characteristics
CA,NV,AZ	Least precipitation. Experiencing severe droughts. Advanced long-distance conveyance. Built desalination facilities.
FL,TX	Experiencing supply shortfalls. Built desalination facilities.
UT,ID,NM,CO,OR	Have experienced some degree of shortfall or drought.
MT, WY, WA	Potential to experience shortfalls.
KS,NE	Have some shallow groundwater issues.
MS,AR, OK	Have potential for water supply short falls.

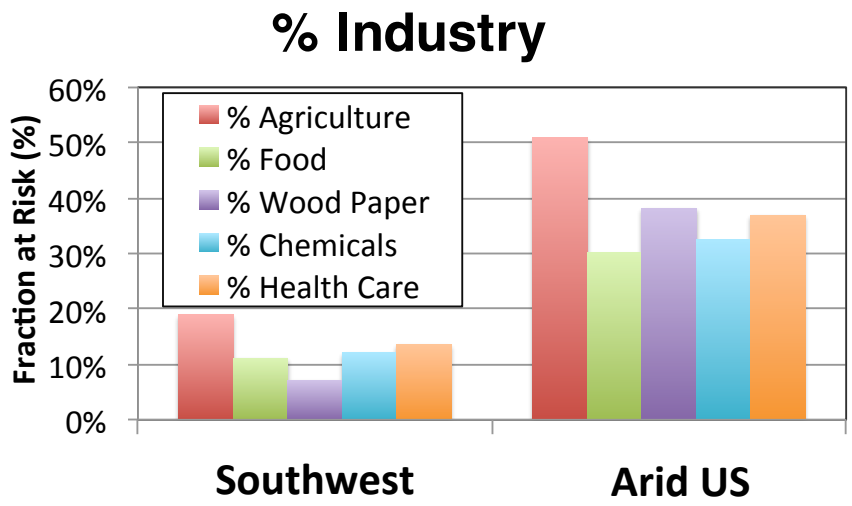
Arid US

The nation is willing to pay for water supplies.

Adpated from Roy, S. B., et al., Tetratech Report (2010). I Twomey, K. M., et al., *Proc. ASME 2011 5th Int'l Conf. on Energy Sust.* 1735–48 (2011).

What is at Risk for the United States





9% of Economy ($1.7T)
50% of Food Supply
40% of Population

Water Use

Arid US	
% Water Supply	17%
% Agriculture	83%
Total Water	49,900,000 Mgal/yr

+

Total Annual Volume:
188 km^3/yr.

Adapted from Google Maps (2015).

Water Depletion Effects

Central Valley

- 50 ft elevation drop.
- Towns out of water.
- Empty lakes and rivers.
- Expensive dust hazard.

E. Porterville, CA

Owens Lake

Colorado River

M. J. Cohen et al., Journal of Arid Environments (2001) 49: 35-48 | http://www.gbuapcd.org/

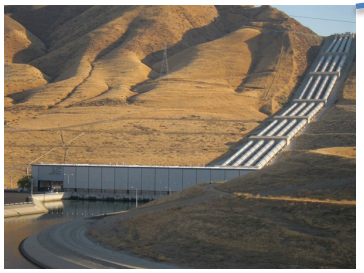
Water

- Deficits
- **Costs**
- Plan

Conveyance Energy Intensity

- State Water Project (SWP)
  - Moves 5% of California's water.
  - Uses 3% of state's electricity.
  - World highest water lift.
  - 14,000 kWh/Mgal.

FIGURE 1-1
Major CVP and SWP Storage and Conveyance Facilities



Department of Water Resources Bulletin 132, Oroville dam, State Water project, Capital Public Radio.

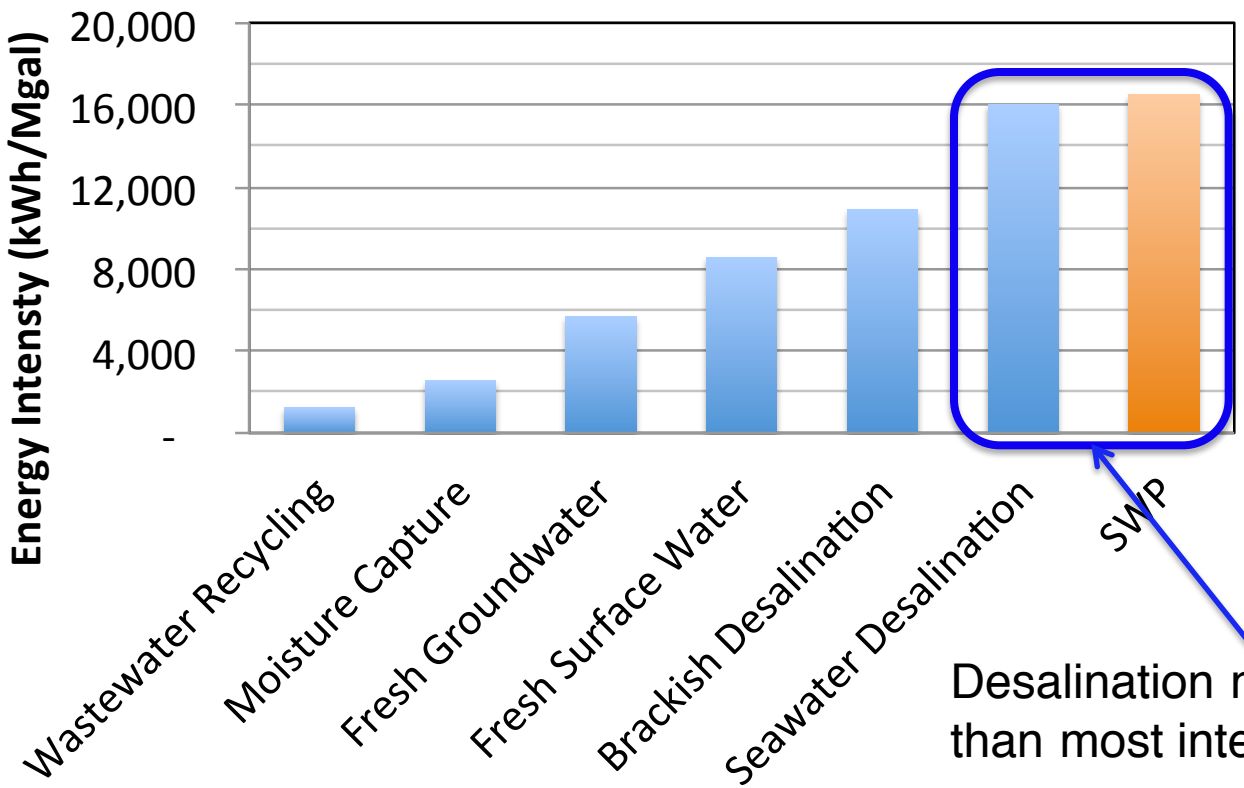
Survey of Conveyance Costs

System	Invst't (2015 $B)	Length (mi)	Cost	
			Energy (kWh/Mgal)	Water ($/Mgal)
NWCS (OK)	$ 14.2B	627	1,600	$1,400
SWP (So. CA)	$ 13.5B	700	14,000	$2,100
CRA (So. CA)	$5.1B	242	6,200	$2,600
CAP (AZ)	$4.0B	343	7,500	$1,800

Annual Energy: 1.2 to 2.4 Quads
Annual Cost: $0.3T to $0.6T

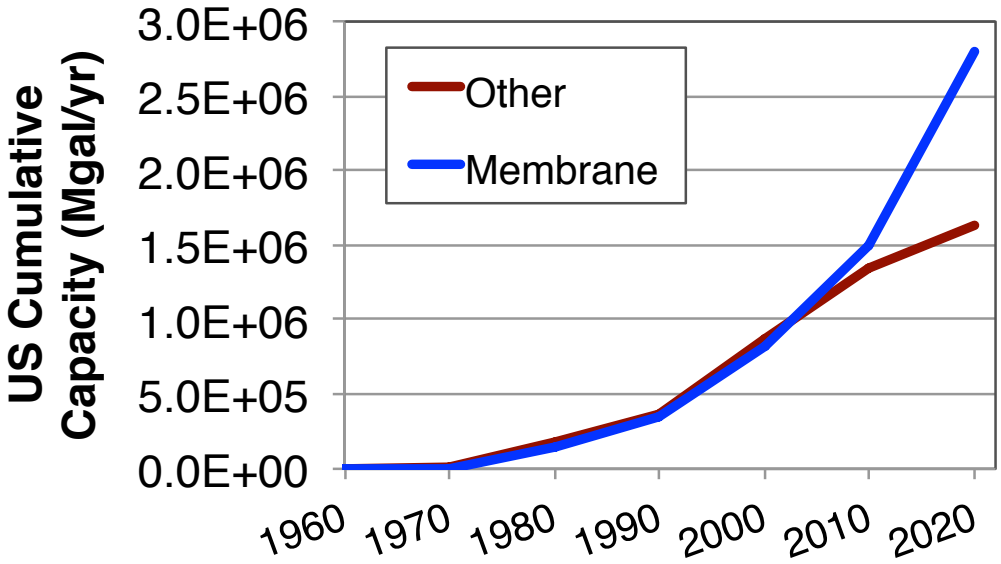
Oklahoma Water Resource Board, OCWP Report (2012). | Smith, K., "Arizona at the Crossroads: Water Scarcity or Water Sustainability?" (2011)., | USBR CRB Water Supply and Demand Report (2012). | http://www.cap-az.com/index.php/cap-history

Delivered Water Source Energy Intensity



Desalination more efficient than most intenstive conveyance.

US Desalination Market



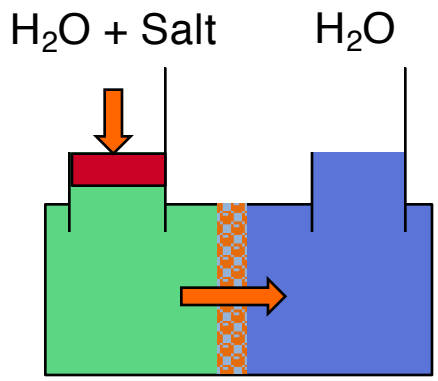
Technologies
Reverse Osmosis (RO)
Nanofiltration (NF)
Multi Effect Distillation (MED)
Multistate Flash (MSF)
Vapor Compression (VC)
Electro-dialysis (ED)

Global Forecast. Oxford, UK: Media Analyics Ltd. I Mezher, T., et al., Desalination 266 (2011) 263–273

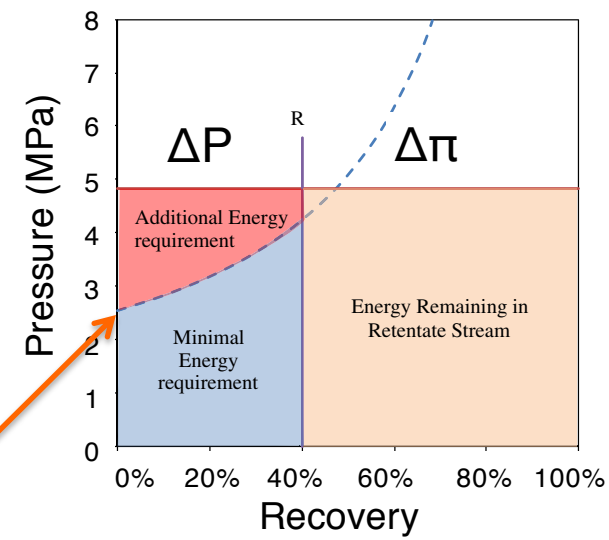
Reverse Osmosis Principle

π: Osmotic pressure
Δπ: Recovery pressure
ΔP: Rate pressure

$$P_{appl} = \pi + \Delta\pi + \Delta P$$



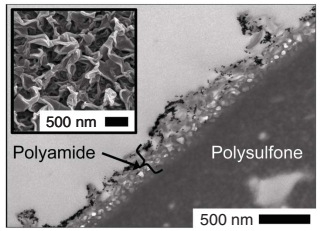
Reverse Osmosis



π ~ (2.3 MPa)

$$dG = Vdp - SdT + \sum_i \mu_i dN_i$$

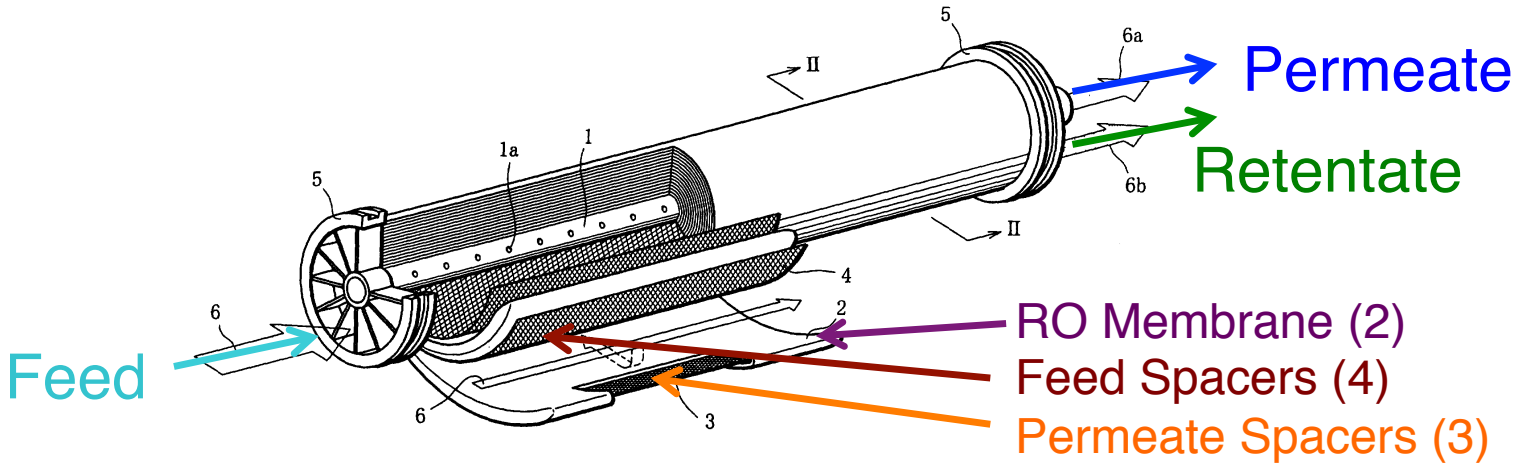
$$\pi = \frac{N_{slt}}{N_{water}} RT$$



Semi-permeable Membrane

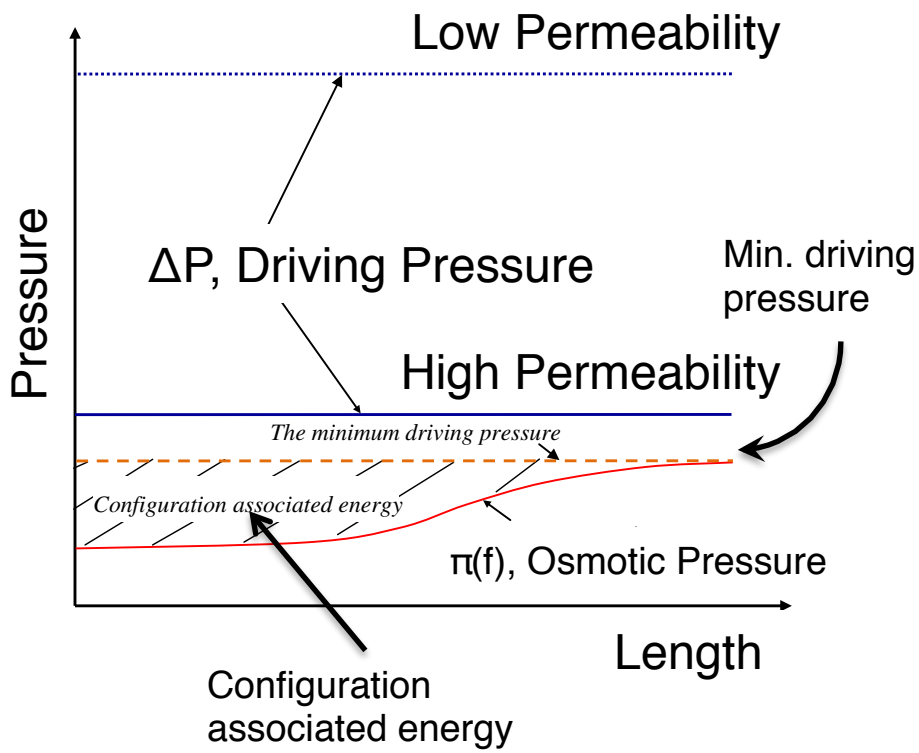
Adapted from: Liu, C., et al., Desalination 276 (2011) 352–358 I Elimelech, M., et al., Science 333, 712 (2011)

Reverse Osmosis Process Summary



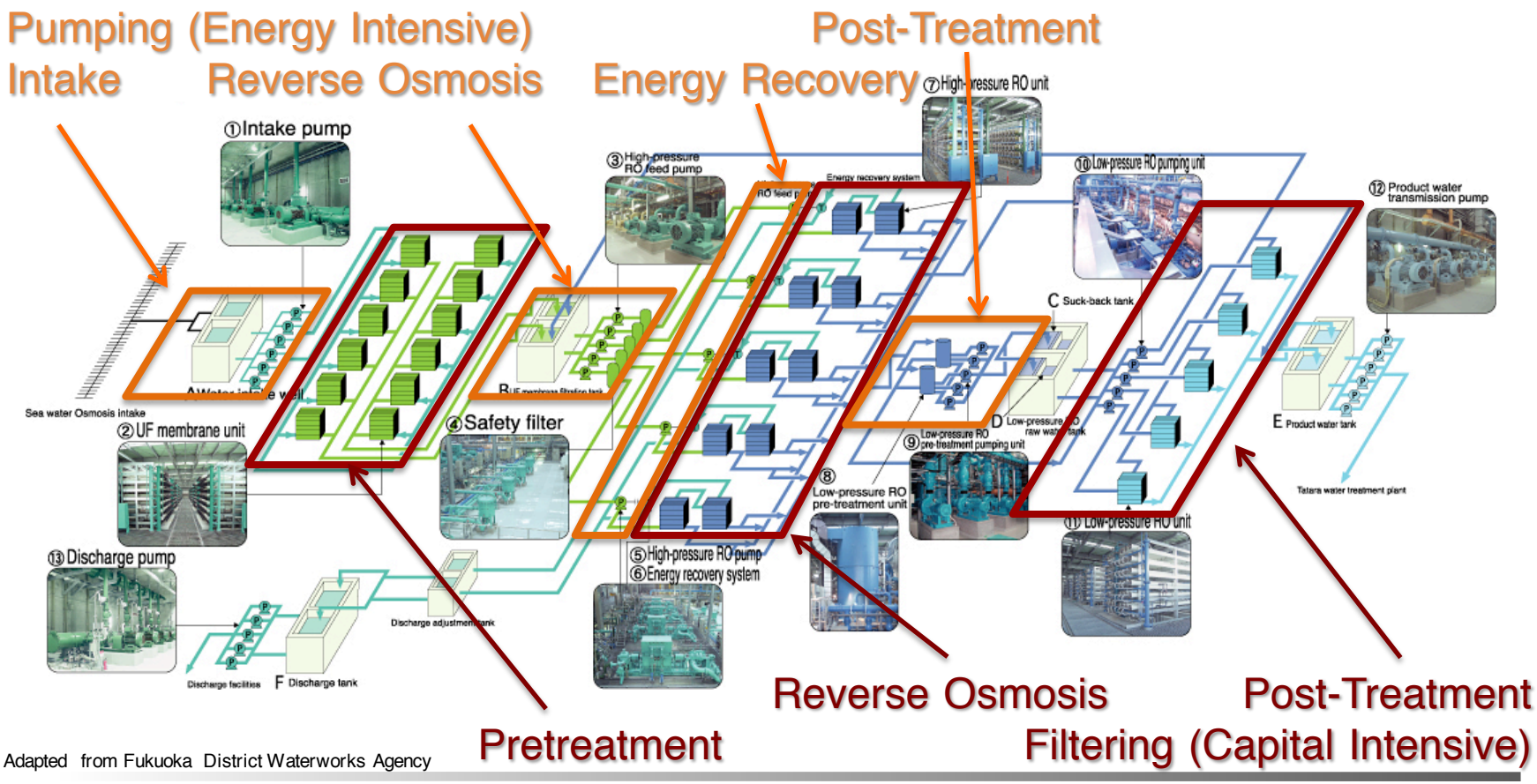
EP1029583 A1

Reverse Osmosis Process Analysis



Liu, C., et al., Desalination 276 (2011) 352–358

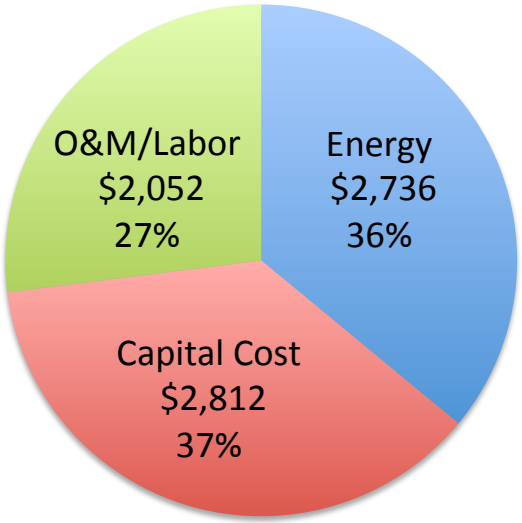
Reverse Osmosis- Plant



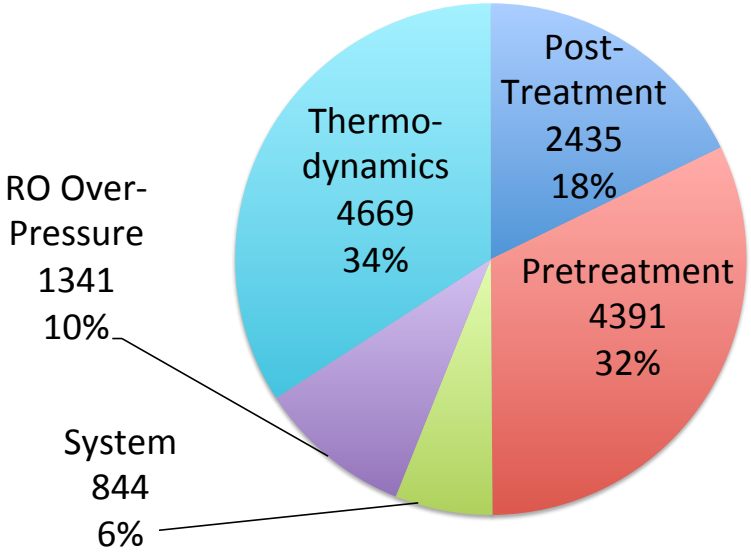
Adapted from Fukuoka District Waterworks Agency

Reverse Osmosis Detailed Energy Budget

Typical RO Plant Costs ($/Mgal)



Typical RO Plant Energy Budget (kWh/Mgal)



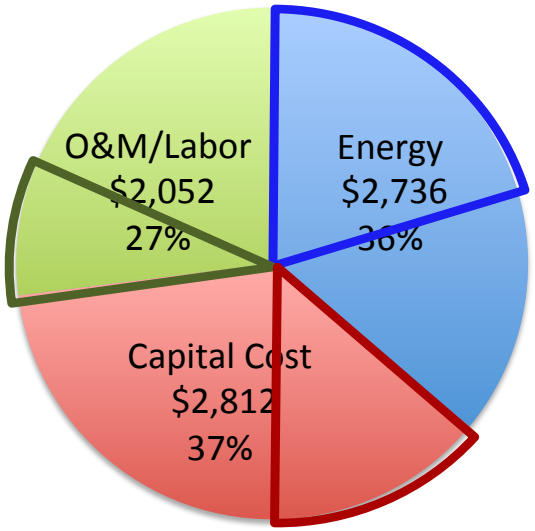
Curre t Desaliantion Cost:	$7500/Mgal
AVG US Wholesale:	$3300/Mgal

Water

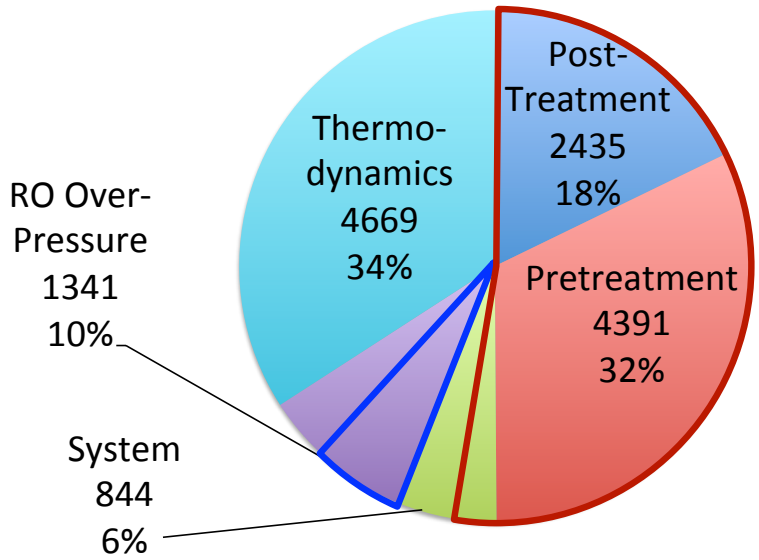
- Deficits
- Costs
- **Plan**

Reverse Osmosis: Potential for Savings

Typical RO Plant Costs ($/Mgal)



Typical RO Plant Energy Budget (kWh/Mgal)

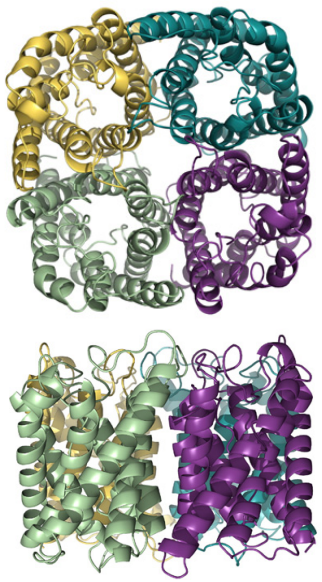


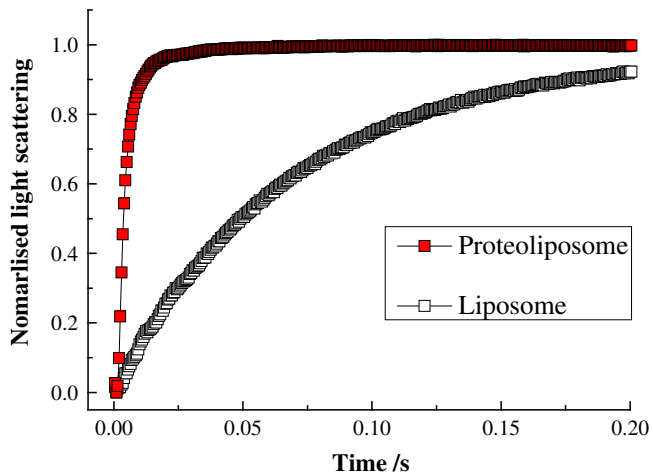
Potential Desaliantion Cost:	$3000/Mgal
AVG US Wholesale:	$3300/Mgal

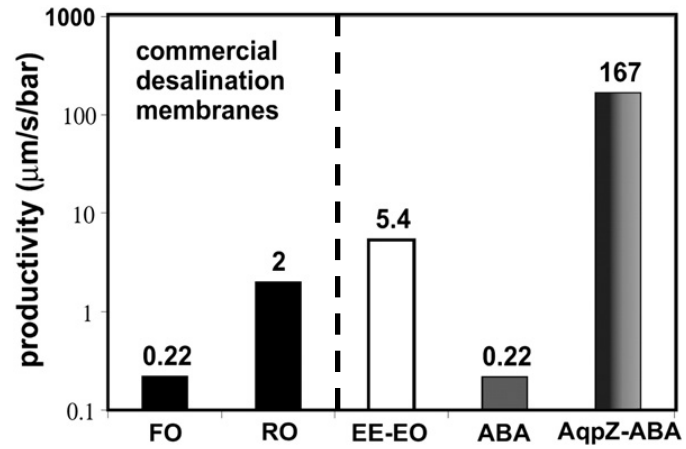
Other Water Sourcing Technologies

- Biomimetic membranes
- Directional Solvents
- Moistrue Harvesting
- Membrane Distillation
- Humidification-Dehumidification
- Water-loss Analysis
- Low-use Methods
- Conservation

High Permeability Membranes- Aquaporins







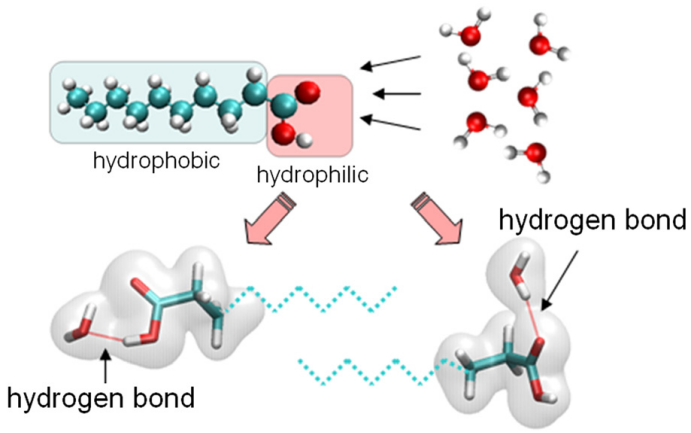
80x Throughput Imprv't.

- Naturally occurring proteins very selective to water.
- Potential for 80x throughput increase w.r.t. commerical membranes.

Tang, C. Y., et al., Desalination 308 (2013) 34–40 | Niellsen, C., Anal Bioanal Chem (2009) 395:697–718

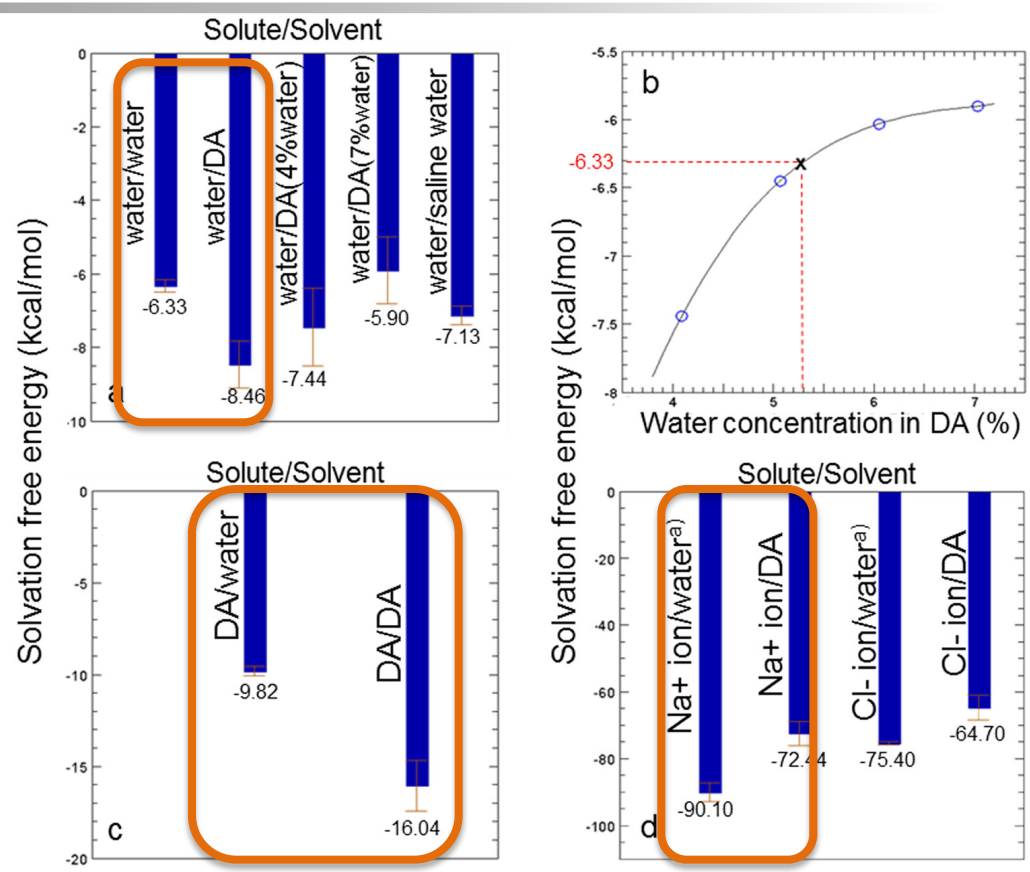
Directional Solvents- Desalination in a Beaker

Decanoic Acid

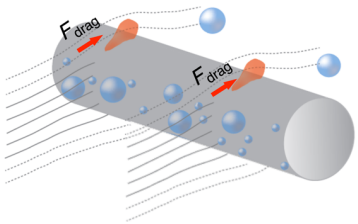


- Membrane-free process for water separation.

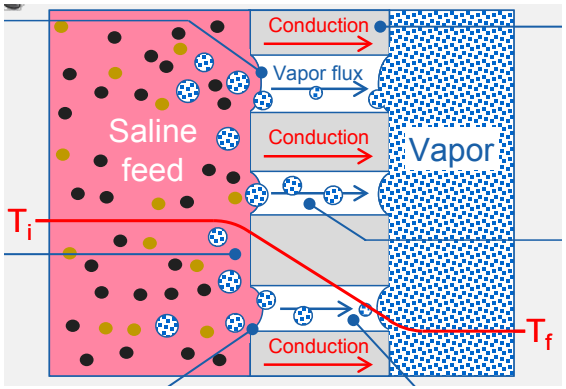
Lou, T., et al., J. Appl. Phys., 110, 054905 (2011)



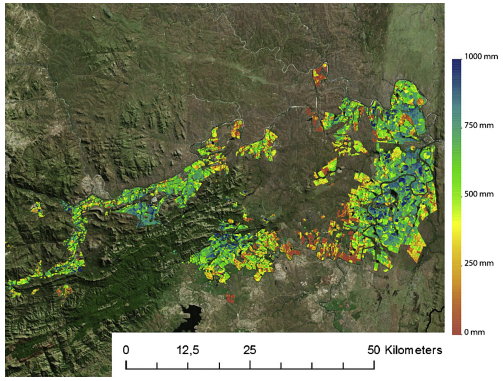
Other Technologies



Moisture Harvesting



Membrane Distillation



Water Loss Analysis

Park, K.-C., et al., Langmuir 2013, 29, 13269–13277 | http://www.dogonews.com/2013/2/28/ingenious-billboard-doubles-up-as-drinking-water-fountain | L. Guey, COST-WSSTP Joint Strategic Conference (2013). | van Eekelen, M. W., et al., Agriculture, Ecosystems and Environment 200 (2015) 126–142

Low-water Techniques

Low water laundry

Optimized Cooking

Optimized Bathing

- Develop techniques to preserve uses of water while using less water.

http://www.seriouseats.com/2010/05/how-to-cook-pasta-salt-water-boiling-tips-the-food-lab.html
http://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/7163/Dry-Bath-Gel--Less-Water-Better-Hygiene-for-South-Africa.aspx
https://www.headboy.org/drybath/?v=7516fd43adaa
http://www.xeroscleaning.com/

Conservation

https://http://www.sacbee.com/news/state/california/water-and-drought/article18303734.html

http://msue.anr.msu.edu/news/irrigation_and_disease_development_in_michigan_vegetables

http://www.mhcustom.com/saving-water-toilet/

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Summary

- Drought: Wanting more water than is available.
  - We can no longer mask it in many regions of the United States.
- A large section of society and economy is at risk.
- Desalination is as efficient as some water conveyance.
  - Cost should drop by at least 60%.
- Multiple methods required to stabilize supply.
  - Could be done while maintaining quality of life.

- This is a solvable problem!