Center *of* Advanced Materials *for*
the Purification of Water *with* Systems

Emerging Issues in the Global Water Arena

Mark A. Shannon

Director WaterCAMPWS

Founder United States Strategic Water Initiative

James Bayne Professor of Mechanical Science and Engineering

University of Illinois at Urbana-Champaign

USSWI

MechSE

waterCAMPWS

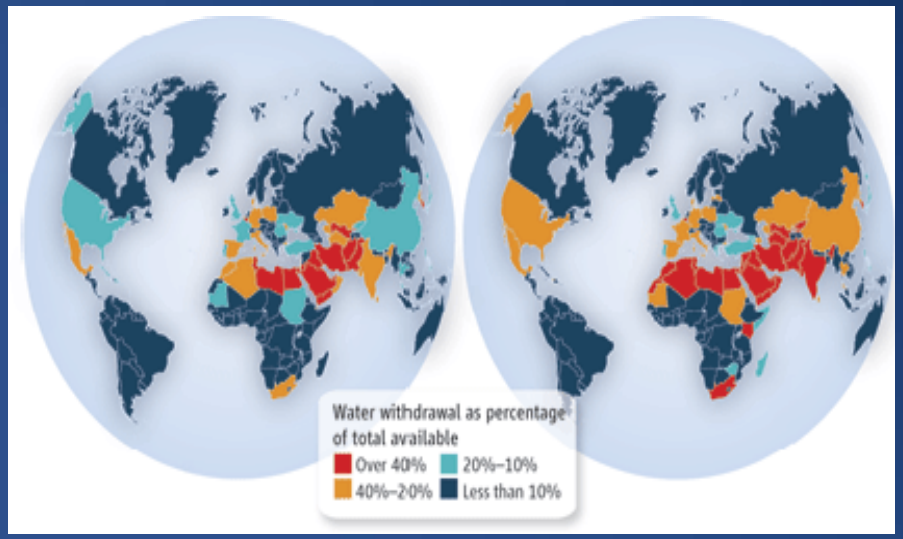
Value of Water

- Low Cost: Cheapest, highest quality product produced
- Impact Huge: Energy, agriculture, livestock, industry, homes, health, and national security.
- Affects EVERY Aspect of Economy: More water, higher quality, lower cost, more wealth
- Traditional Concerns: Safety and health

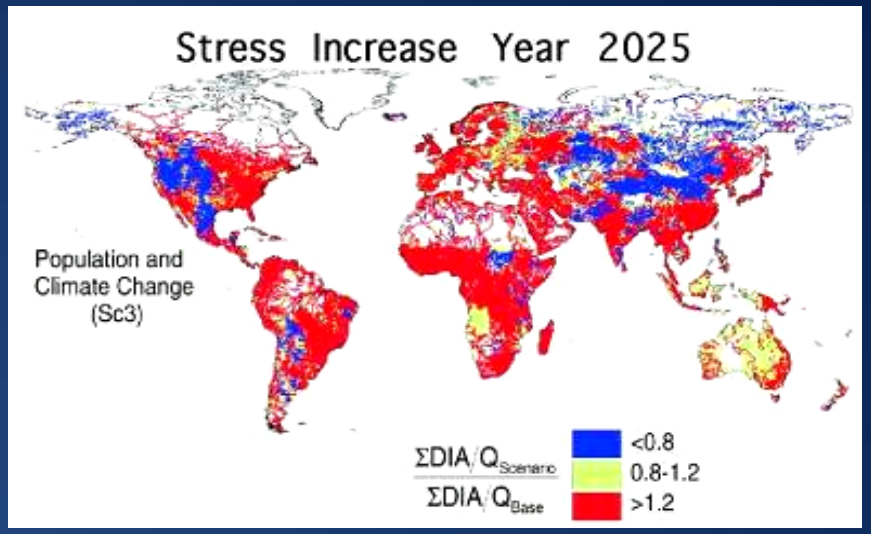
HARD TO OVERESTIMATE IMPORTANCE, BUT TAKEN FOR GRANTED BY MANY IN THE INDUSTRIAL WORLD: THIS WILL CHANGE, EVERYONE EVERYWHERE WILL BE AFFECTED IF WE FAIL TO PROVIDE CLEAN WATER.

Future of Water Availability

- Combination of population growth, consumption growth, and clean water declines creating crisis.



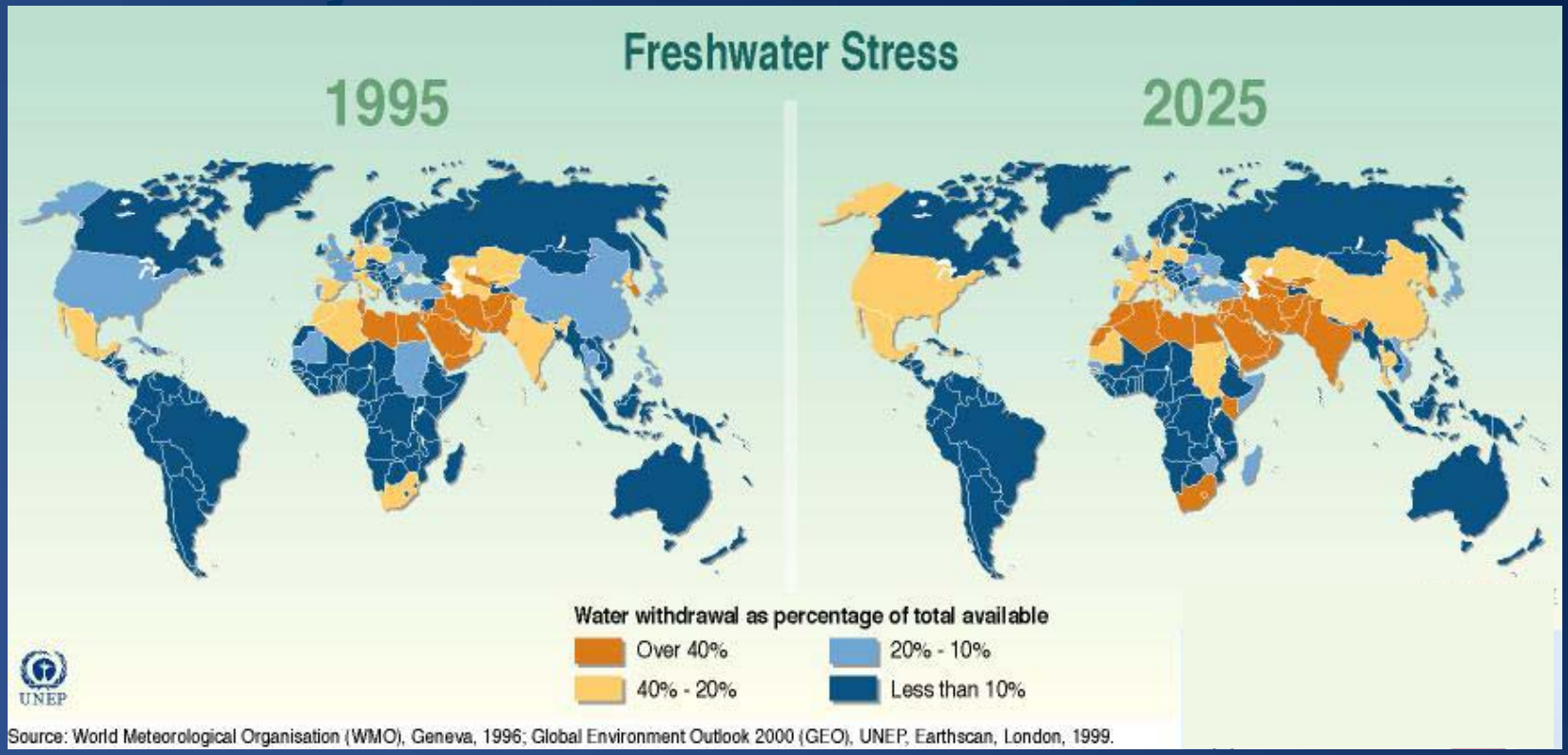
World Map showing water consumption world-wide as percentage of total available water.



World Map showing affect of population and climate change on water stress.

Consumption, withdrawal, and discharge: As population growth pushes consumption higher, water supplies will become more stressed, and withdrawals and discharges will affect life of rivers and lakes, and overall environment ever more so.

Freshwater Stress and Scarcity Projections in World by 2025



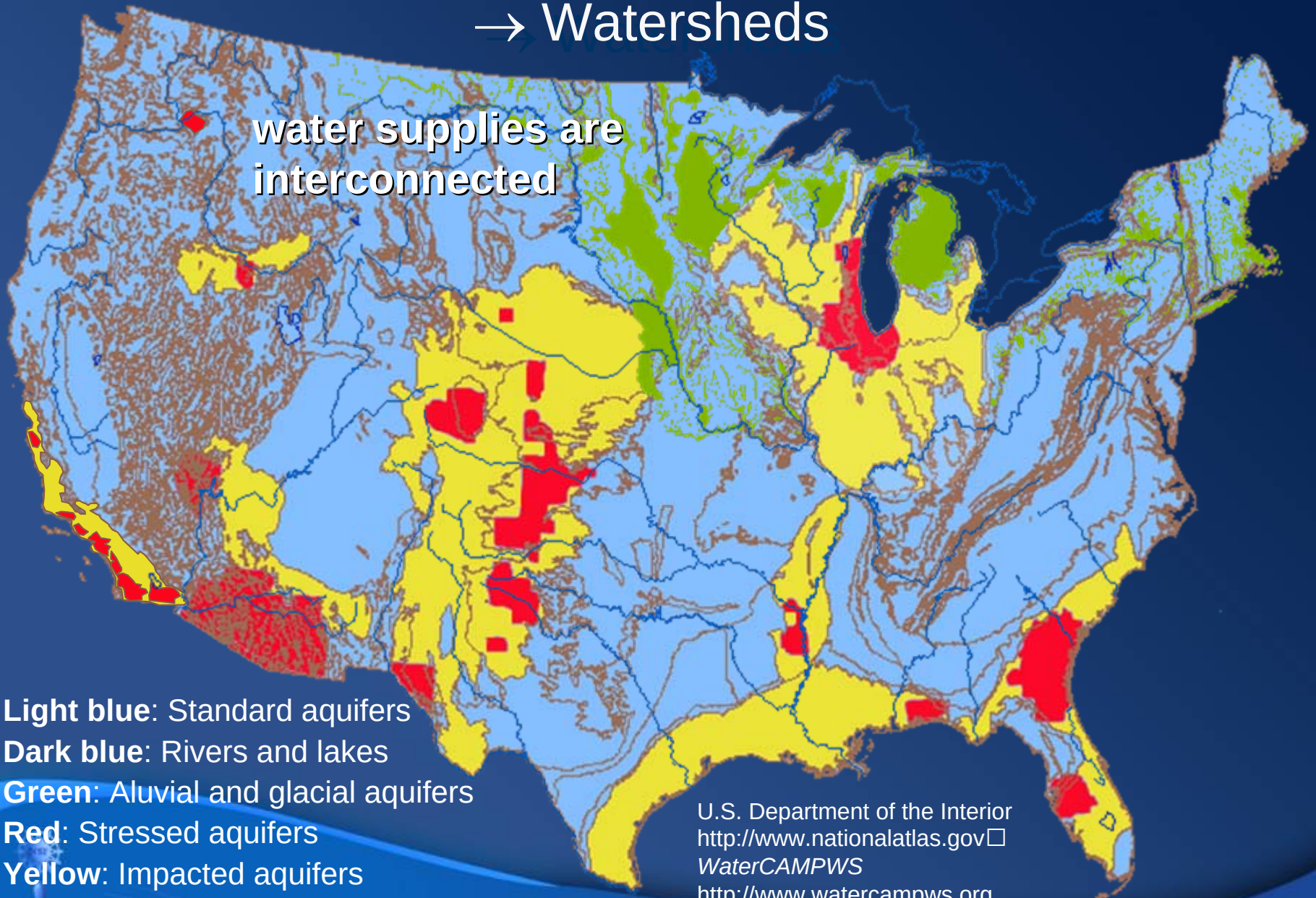
Average Sector Use: Domestic 10% Industry 20% Agriculture 70%

~80% of industrial & domestic use can be reclaimed.

~20% from irrigation and livestock can be reclaimed.

Sources: WRI (2000)

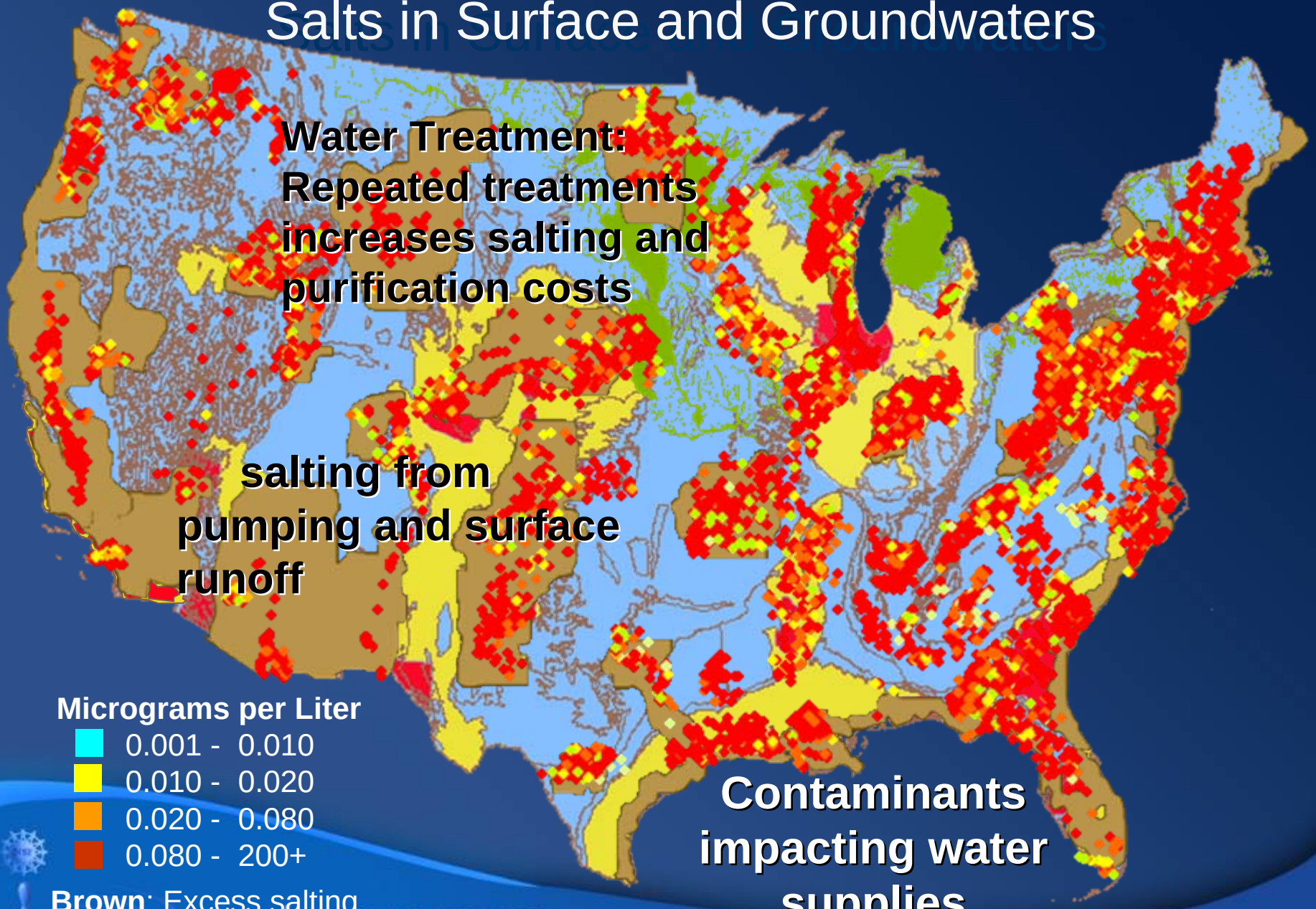
Lakes, Rivers, Aquifers (Standard and Glacial) → Watersheds



Light blue: Standard aquifers
Dark blue: Rivers and lakes
Green: Aluvial and glacial aquifers
Red: Stressed aquifers
Yellow: Impacted aquifers

U.S. Department of the Interior
http://www.nationalatlas.gov
WaterCAMPWS
http://www.watercampws.org

EPA Critical Drinking Water Contaminants and Salts in Surface and Groundwaters

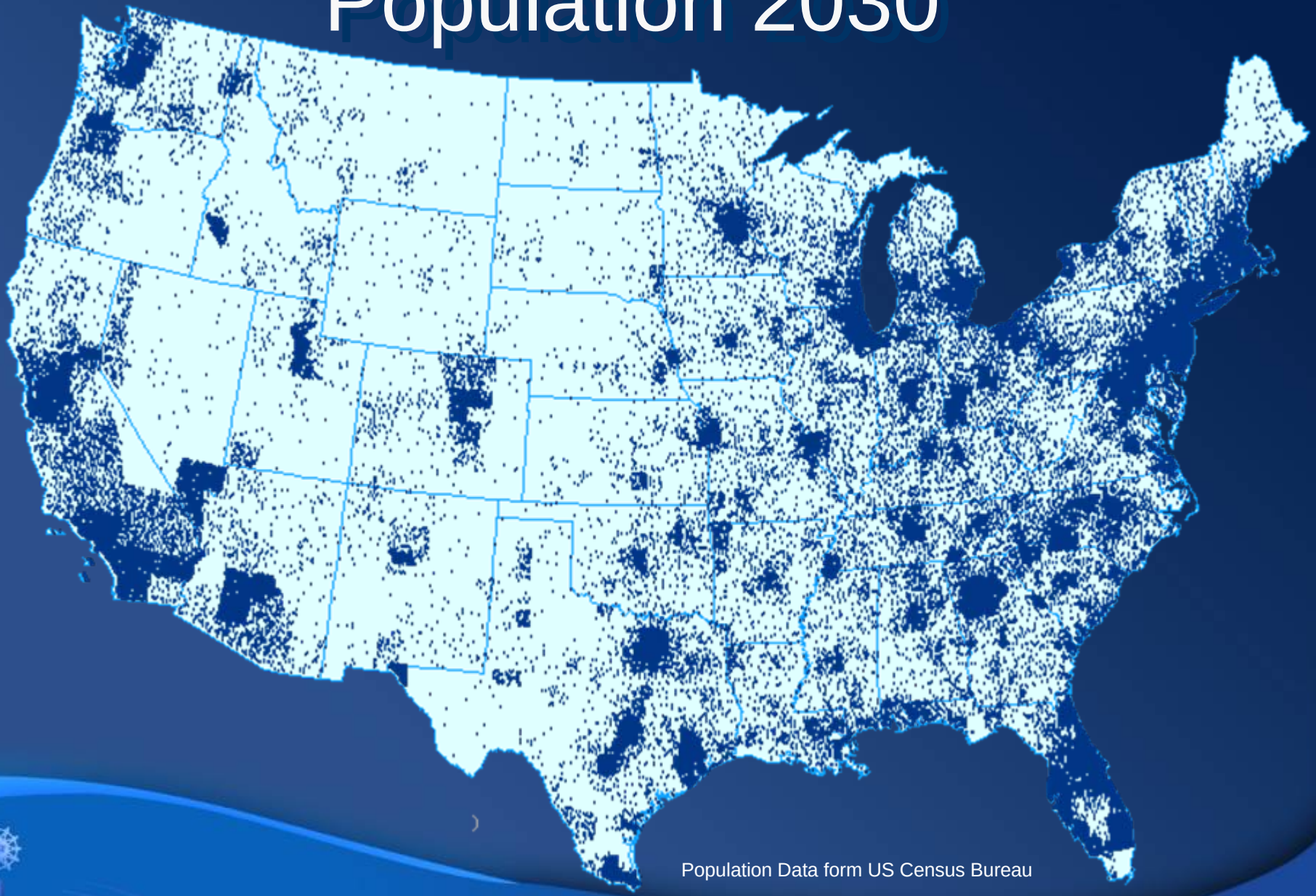


Mark A. Shannon http://WaterCAMPWS.org

Population 2000

Population Data form US Census Bureau

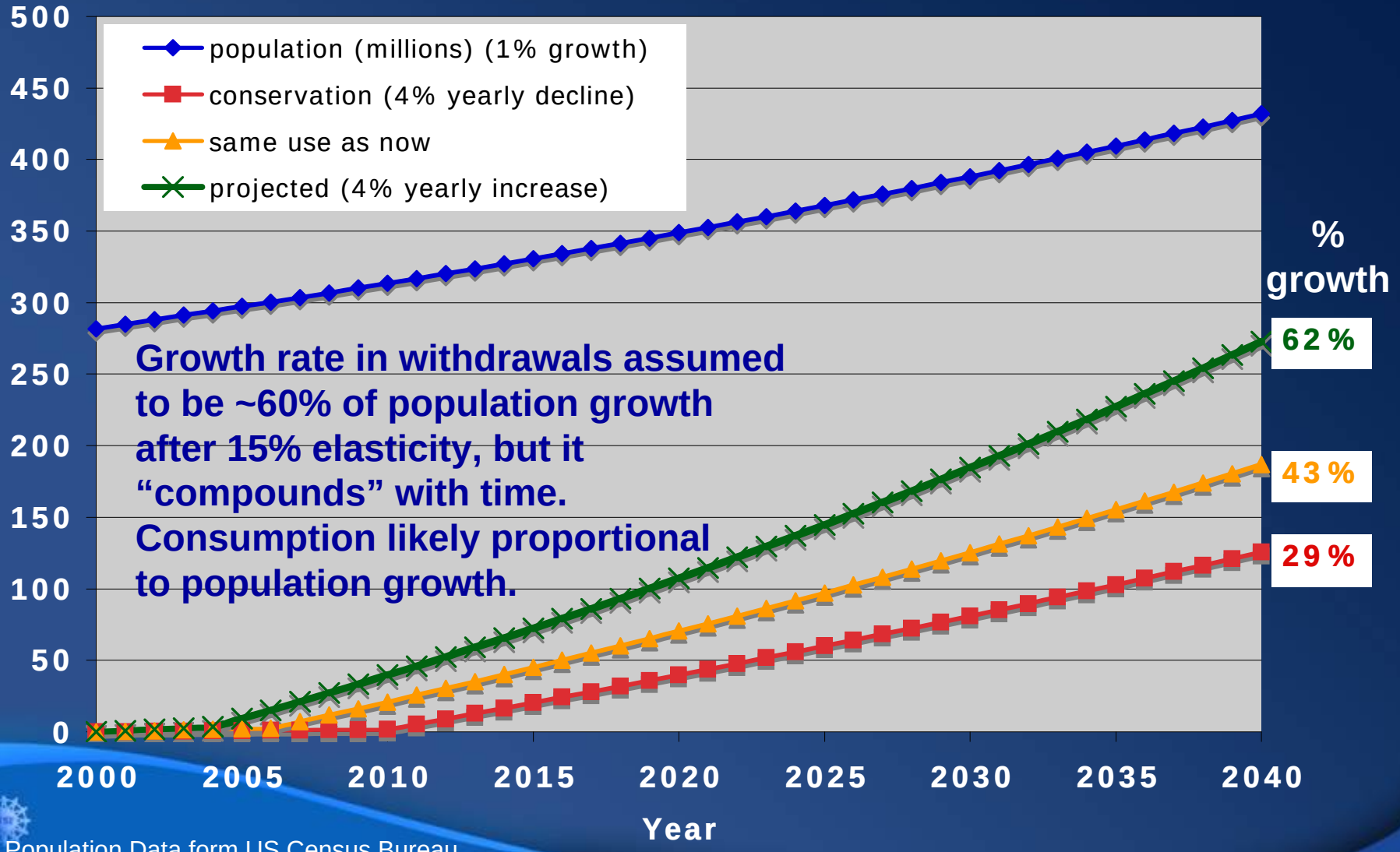
Population 2030



Population Data form US Census Bureau

Water Use Growth With Population

Increase in Million Acre Feet (325,500 gal) of Water Withdrawn



Population Data form US Census Bureau

The Blueprint 2030 forecast share of the revised United States population growth forecast from 2000 to 2030 was 1.14%

2030 Projected % Increase (since 2000)

Averages don't tell the real story:
Growth problems will be local.

Population data and projections from U.S. Census Bureau
http://www.census.gov/population/www/projections/stproj.html
http://www.census.gov/popest/datasets.html
Water Use Data from USGS (http://web1.er.usgs.gov/NAWQAMapTheme/index.jsp)
Projections for water use based on Texas Water Use 60 yr projections
(http://www.twdb.state.tx.us/publications/reports/State_Water_Plan/2007/2007StateWa

Trends Making Problems Worse

- Population Growth (>1% per year) and Shifts: Changes and increases demand in water, food, and energy
- Growth of Deserts: More land with scarce water
- Overpumping of Ground Water Aquifers: Unsustainable
- Transfer of Population To Urban Areas: Can't keep up
- Energy, Food, and Water: Cannot generate more energy and food without sufficient water. Cannot get a lot more water without energy
- Contamination of Source Waters: Cross-contamination of surface and aquifers is growing, reducing dilution solutions – *more treatment is needed*
- Snowpack Storage and Glacial Melting: Major river systems with shortages during dry months (Brahmaputra, Ganges, Yellow, Mekong Rivers, Blue Nile, Mt. Kilimanjaro, Andes, Colorado, Rio Grande, Lake Mead, …)

BUT THERE IS HOPE!

Why Water Technology Advancement is Needed

- Federally funded research from 1950's and 60's brought about membrane water treatment systems that have transformed new water treatment systems worldwide.
- New technologies are now being developed that can create a new transformation to the total water infrastructure.
- However, bulk of water innovation is now overseas, with a reverse brain drain underway. Researchers trained in the U.S. are going overseas to conduct R&D and to implement new technologies. Innovation thrust is in Asia, Europe, and the Mideast. Offering huge salaries to U.S. researchers.
- The United States can regain the innovation and competitive lead: We still have the best scientists, engineers, universities, and labs in the world.

Vision for Future of Water Purification

- Move away from homogeneous chemical mixer systems to heterogeneous chemistry systems: catalysts, separators, absorbers, membranes (passive and active), biochemical,…
- Move away from chemical oxidants and reductants to self-generated chemicals: Recovery of chemicals from wastewater – nutrients, ammonia, methane,…
- Move to zero discharge of waste & residuals. 100% reuse
- Less exogenous energy: More use of sunlight and energy from wastewater…quantum confinement.
- Develop bio-inspired processes for detection of contaminants and pathogens (including viruses) in water, and separation of contaminants and salts.

Where is our Water?

Brackish water exist everywhere: Untapped resource

Ground Ice & Permafrost 0.022%

Ice Caps, Glaciers, & Perm. Snow 1.74%

Saline Lakes 0.006%

Saline Groundwater 0.94%

Accessible With Additional Research

Not All Currently Accessible

30% shortfall in 30 yrs

Lakes 0.007%

Rivers 0.0002%

Groundwater 0.76%

Cleaning up contaminated water makes more water accessible

Atmosphere 0.001%

Biological 0.0001%

Swamps 0.0008%

Soil Moisture 0.001%

Total World Water:
332,500,000 mi^3
1.36 billion cubic kilometers

99.23% currently unusable for most humans

There Are Many S&T Opportunities

- We are far from the natural law limits for separating contaminants from water: Lots of room to improve!
- Traditional methods in developed world are capital, energy and chemical intensive
- New materials and systems are being developed that can dramatically drop the cost of treating water
- New communications systems can be used to control and prevent contamination and illness

Siemen's SkyHydrant

To INCREASE the Amount of Clean Water Available to People

There are three major goals:

Goal I. **Increase** potable water supplies, to gain new waters from **reuse** and **desalination** from the *"sea to sink to the sea again."*

Goal II. **Selectively remove contaminants** from all types of water sources, to get the *"drop of poison out of an ocean of water."*

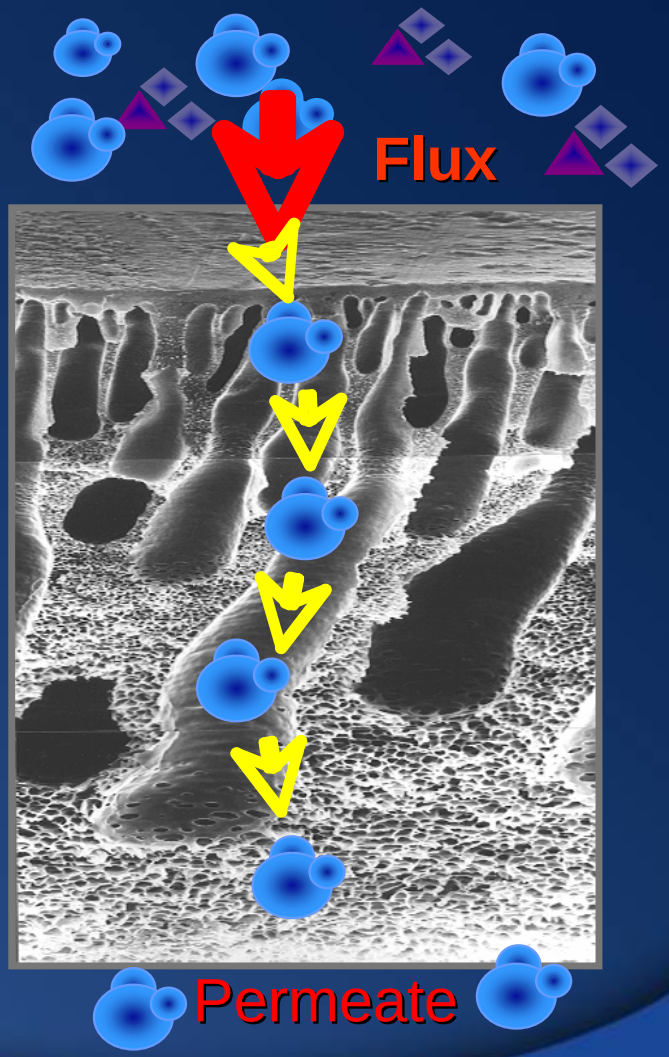
Goal III. **Disinfect** water from current and potentially emerging pathogens **without producing toxic substances**, to *"beat chlorination."*

To Do So, We Need Appropriate Technologies: *Change of Mindset*

- Appropriate technologies does not mean “low-tech,” and “low-cost” does not mean low-quality. Treated water in developed nations can be very low-cost, but is high-quality. High-quality water is needed to prevent illness.
- Appropriate technologies use less energy & chemicals, & do not need highly trained workers to operate effectively.
- Newer technologies can leapfrog current practices in developed world to deliver appropriate solutions for specific problems in different regions in Africa, without having to first duplicate problems in industrial countries such as U.S.

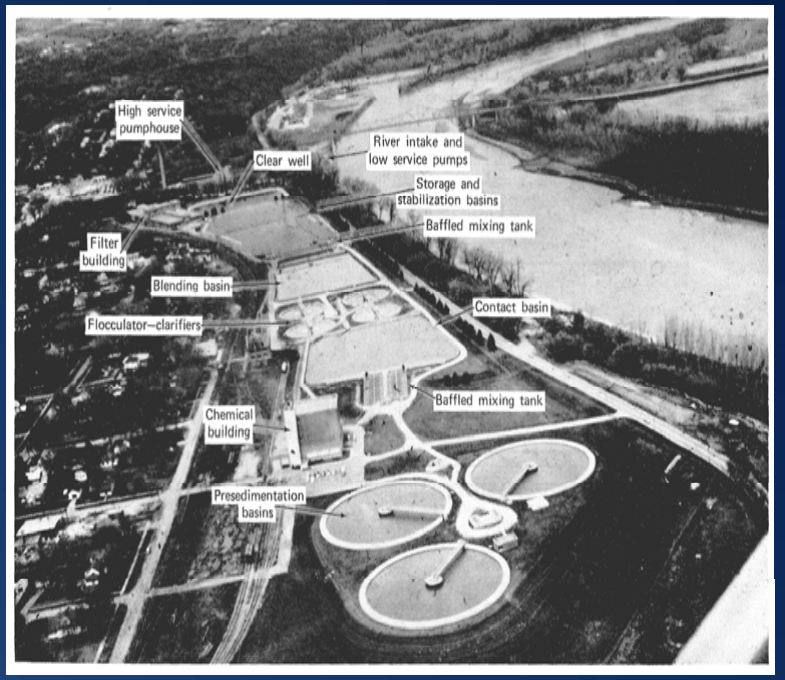
Using Saline Waters

- Current methods to remove salt from water (desalinate) need large amounts of capital, energy, and chemicals.
- Current methods are prone to fouling, scaling, and/or corrosion, and cost a lot to operate, needing lots of maintenance and trained workers
- Inland salt waters are full of hard salts, and disposal of brine is very expensive.
- However, new methods are being developed to reduce all these problems, making certain saline source water, particularly found in mining, relatively inexpensive to recover.



Issues With Current Treatment Methods

- The lack of reliable electrical power, fuels, and chemicals prevent traditional water treatment methods being used in many parts of the developing world.
- Current methods destroy the energy and chemical content in the wastewater. New technologies extract energy and chemicals from wastewater, making it a resource rather than a harmful waste.



Missouri River Water Treatment Plant

- Current treatment increases total dissolved salts in water and carbon dioxide released to the atmosphere. More salts require even more chemicals for downstream waters. Treatment along with agricultural runoff, leads to salting of land with irrigated waters, diminishing food production.

Needs highly trained workers.

Distribution System Issues

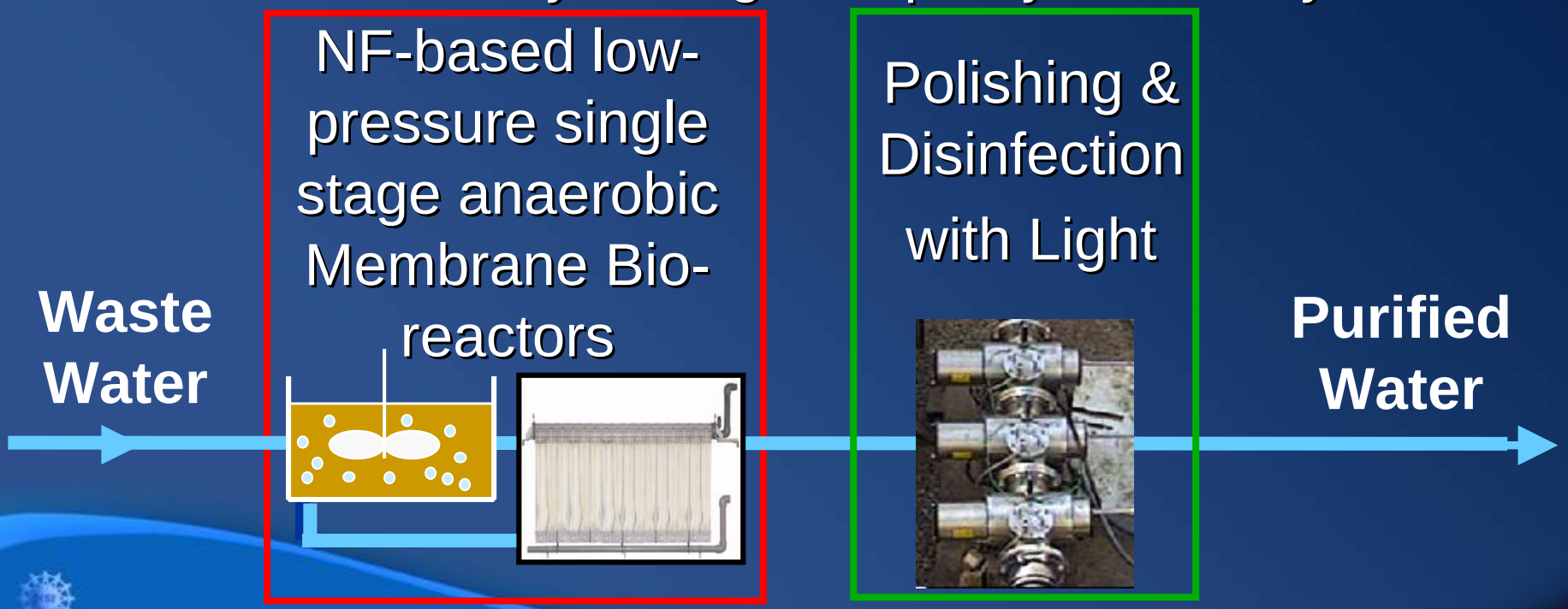
- Distributions systems expensive to install and maintain. They are failing all over the world due to age and neglect.
- Distribution systems can be a source of transmitting disease. New pipes connected to an older system, particularly in peri-urban areas, rapidly degrade and cause disease.

Hard water struvite

- Point-of-source and point-of-use treatment systems can be much lower cost. Point-of-use treatment can prevent disease of contaminated distribution systems.
- But these Point-Systems need the efficacy of large controlled systems, without oversight of trained personnel. Robustness needed similar to the air break and chlorine.

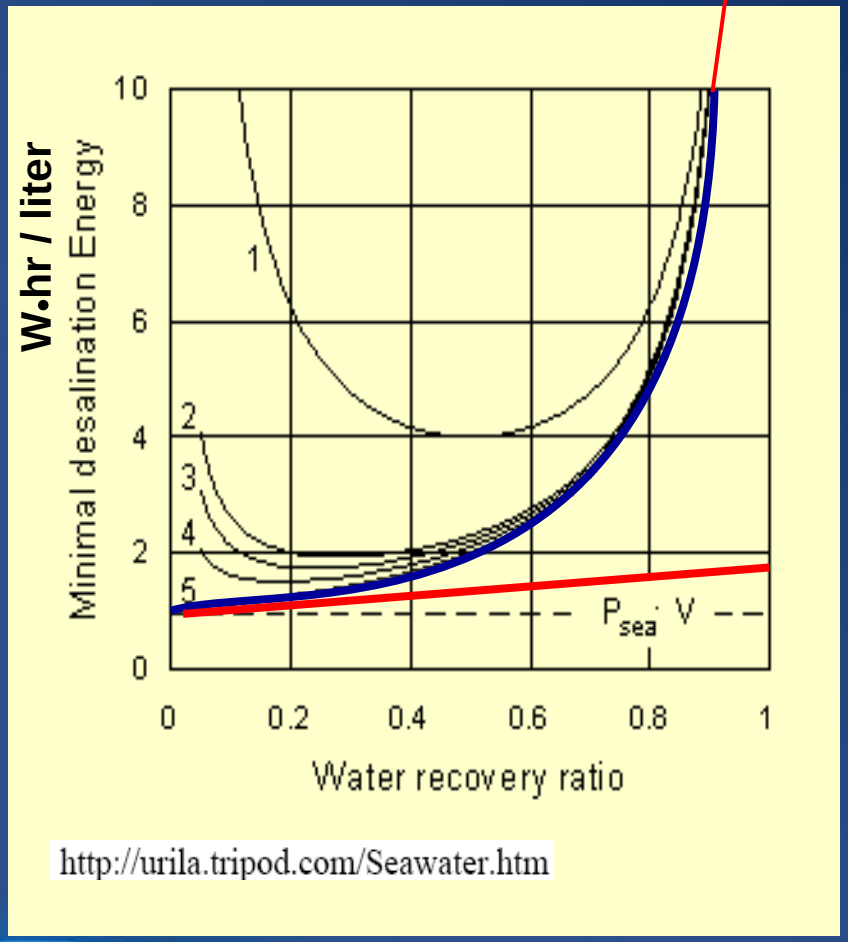
Recovery and Reuse of Water Creates an ENORMOUS RESOURCE

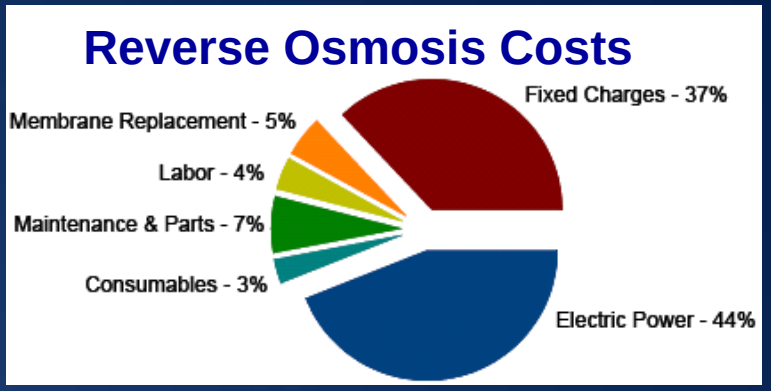
- Can be used for Point-of-Discharge to recharge aquifers
- Membrance Bio-reactors can generate energy when cleaning water, rather than consuming energy
- Ensures absolutely the highest quality and safety



Reverse Osmosis: State-of-the-art

Least amount of energy possible





For water with 34,000 ppm TDS:

- 50% water recovery
  - min Elec. 1.77 W hr/liter
  - best Elec. 2.22 W•hr/liter
- 80% water recovery
  - min Elec. 5 W hr/liter
  - best Elec. 8.40 W•hr/liter

But Physical Limit is only 0.8 W•hr/liter for full recovery (no residual)

To Directly Reuse Water, We Need to Know How to Take Toxic Compounds Out

- Small hydrocarbon molecules can taste and smell bad, and cause water to be colored.
- Low levels of toxic compounds such as heavy metals (As, Pb, Hg, U, Cd), pesticides, herbicides, petroleum distillates, and disinfection byproducts are hard to know if they are in water, and to remove in a high background of organics and potable compounds.
- We must make absolutely sure pathogens are not in the product water.

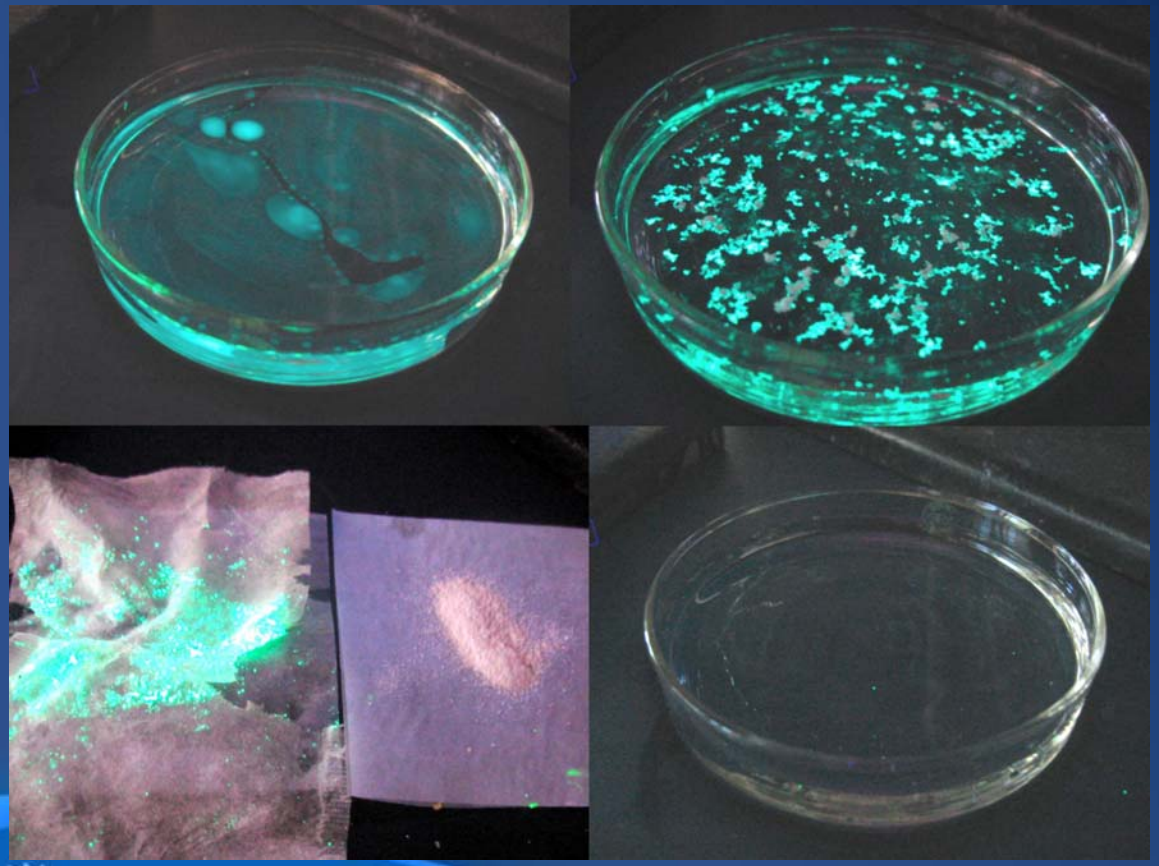
Speciation Matters!

Methyl mercury thousands of times more toxic than elemental mercury.

Nitrosoamines: Carciogenic

Removing Petroleum Byproducts from Water

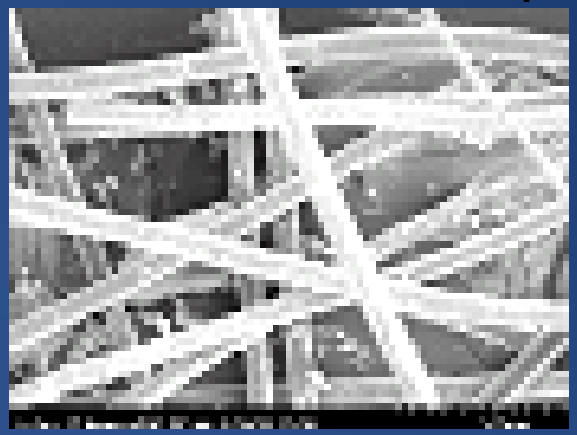
"Organic–Inorganic Hybrid Materials that Rapidly Swell in Non-Polar Liquids: Nanoscale Morphology and Swelling Mechanism," Burkett, Underwood, Volzer, Baughman, and Edmiston, Chemical Materials 2008

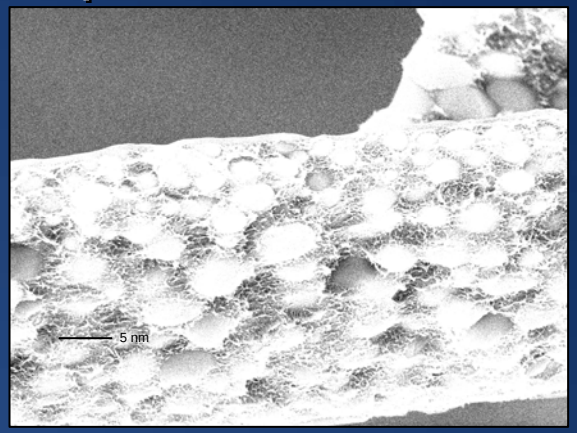


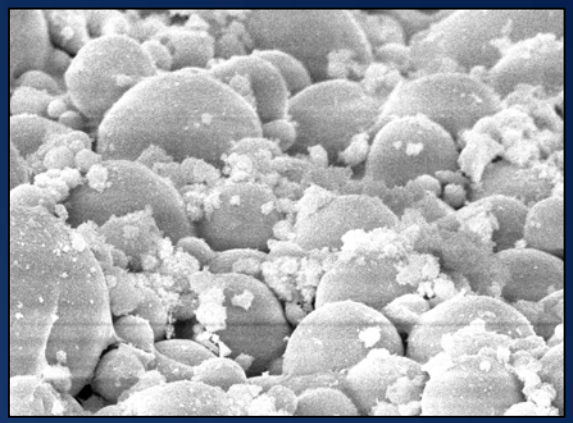
New low-cost absorbable glass can remove virtually all petroleum byproducts like benzene, distillates, and oil from water. Can be used over and over again. Large numbers of people are sickened by these compounds.

Cleansing Water of Organics with Sunlight

Templated porous structures and fibers







Ta_2O_5 – SiO_2 composites 17 days of aging with nodules 1-3 μm in diameter

Ndiege, Chandrasekharan, and Shannon, UIUC

Can use low-cost treated silica (sand) to remove all organic compounds from water at high rates using free sunlight. Can remove carciogens, toxic compounds, and pathogens too, all without using chlorine.

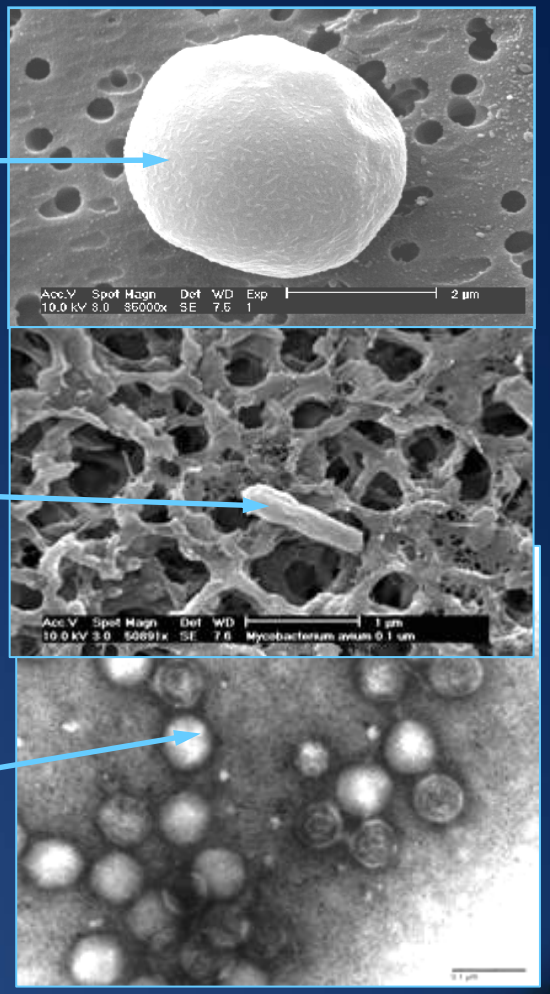
Disinfection of Hard to Treat Pathogens, Without Intensive Chemical Treatment

- Use of materials to trap pathogens, including viruses
- Use particles, catalysts, and photocatalysts with plentiful, free light to kill pathogens in water
- Disinfect water WITHOUT using chlorine or other powerful oxidants that can themselves form toxic compounds

Cryptosporidium parvum

Mycobacterium avium

Adenoviruses



Benito Mariñas, UIUC

We can Change How Clean Drinking Water & Sanitation is Done

- Prioritize S&T solutions in the world with joint meetings of researchers, practitioners, and governments at all levels.
- Implement testing, with formative and summative analysis of efficacy of each technology.
- Put new appropriate technologies into practice.
- Help build the science and technology capacity in the United States.
- Work with universities and national agencies.

Questions and More Information

For more information, contact:

"Mark A. Shannon"
mshannon@illinois.edu

WaterCAMPWS:
http://WaterCAMPWS.org