Smart Water Systems for Distributed Water Treatment

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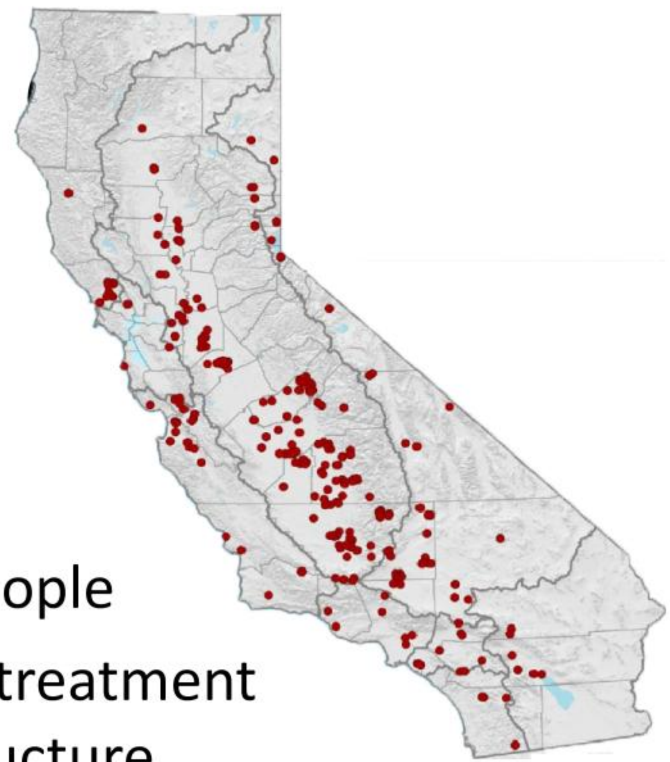
California Contaminated (Potable Water) Groundwater Sources

680 community water systems (CWS)* rely on <u>contaminated</u> groundwater sources



- 265 CWS with water quality violations 2010), affecting ~2.2 million people
- Most violations in Central California (Counties: Kern, Tulare, Madera, Fresno, Stanislaus, Monterey)
- Most violations in rural, disadvantaged communities with CWS serving < 3,300 people
- Diversity of sites, e.g., w.r.t water quality (treatment needs), use capacity, accessibility, infrastructure

*CWS: At least serving 15 connections or 25 yearlong residents.

Source: "Communities that rely on a contaminated groundwater source for drinking water", State Water Resources Control Board Report to the Legislature, January 2013

California Contaminated Groundwater Sources for Drinking Water

Data

- Little or no data are available for state/local small water systems, private domestic wells, and transient non-community water systems.

Monitoring

- Groundwater in many small community water systems is not monitored or monitored sporadically

Small systems

- Treatment and management solutions are also needed for these small water systems

Challenges of Groundwater Treatment in Rural & Disadvantaged Communities

- Small Local Customer Base
  - Lack of resources for capital & infrastructure
  - Water demand highly sensitive to population dynamics
- Unique site-specific conditions
  - Water supply options, quality, and availability
  - Suitability and challenges of treatment technologies
  - Local waste disposal options
- Challenge w.r.t availability of full-time, qualified personnel
  - Operation
  - Monitoring
  - Maintenance
- Limited accessibility to support/expertise
  - Technical
  - Legal (i.e., Regulatory Compliance)
  - Financial

Example: Potable Water Treatment Technologies for Groundwater Nitrate Reduction

Limited	Ion Exchange/ Adorption	Low Pressure RO/ Nanofiltration	Electrodialysis (ED/EDR)	Biological Denitrification	Chemical Denitrification
Type	Removal to waste stream	Removal to waste stream	Removal to waste stream	Biological reduction	Chemical Reduction
Pretreatment	Pre-filter, address scaling	Pre-filter, mitigate mineral scaling	Pre-filter, address hardness	pH adjustment, nutrient/subst. addition, anoxic conditions	pH adjustment
Post Treatment	pH adjustment	pH adjustment, remineralization	pH adjustment, remineralization	Filtration, disinfection, excess substrate removal	pH adjustment, iron/ammonia control
Residuals	High Salinity Brine	Concentrate	Concentrate	Sludge/Biosolids	Media/Sludge
Start/Stop	Fast/Fast	Fast/Fast	Fast/Fast	Slow Init./Fast	Fast/Fast
Water Recovery	97%-99.9%	75-95%	Up to 95%	Nearly 100%	Limited field experience
Barrier protection	No	Yes	No	No	No

Harter et al, "Addressing Nitrate in California's Drinking Water", UC Davis Center for Watershed Sciences, http://groundwaternitrate.ucdavis.edu
Kapoor et al, Nitral removal from drinking water – Review, J. Environ. Engr. 123 (1997) 371

Groundwater Treatment in Rural & Disadvantaged Communities: The Need for a Paradigm Shift

Distributed treatment approach (Engineering design → Scale-down)

- Treatment technologies based on site-specific conditions
- Reconfigurable, mobile or non-permanent installations
- Water use (potable vs. non-potable usage)
  - TAS (treatment-at-Source), POU (point-of-use) or indoor POE (point-of-entry) residential systems

The challenge: Robust, self-adaptive treatment systems

- Autonomous operation handling variability in
  - Raw water quality and supply
  - Production demand
- Fault-tolerant → safe, reliable drinking water quality
- Lower operational and maintenance costs

Infrastructure: Centralized Monitoring and Support Cyberinfrastructure

- Minimize/eliminate need for on-site monitoring & supervision
- Consolidation of :
  - Distributed customer base
  - Asset management
  - Support/expertise (technical, legal, financial)

Example: Potable Water Treatment Technologies for Groundwater Nitrate Reduction

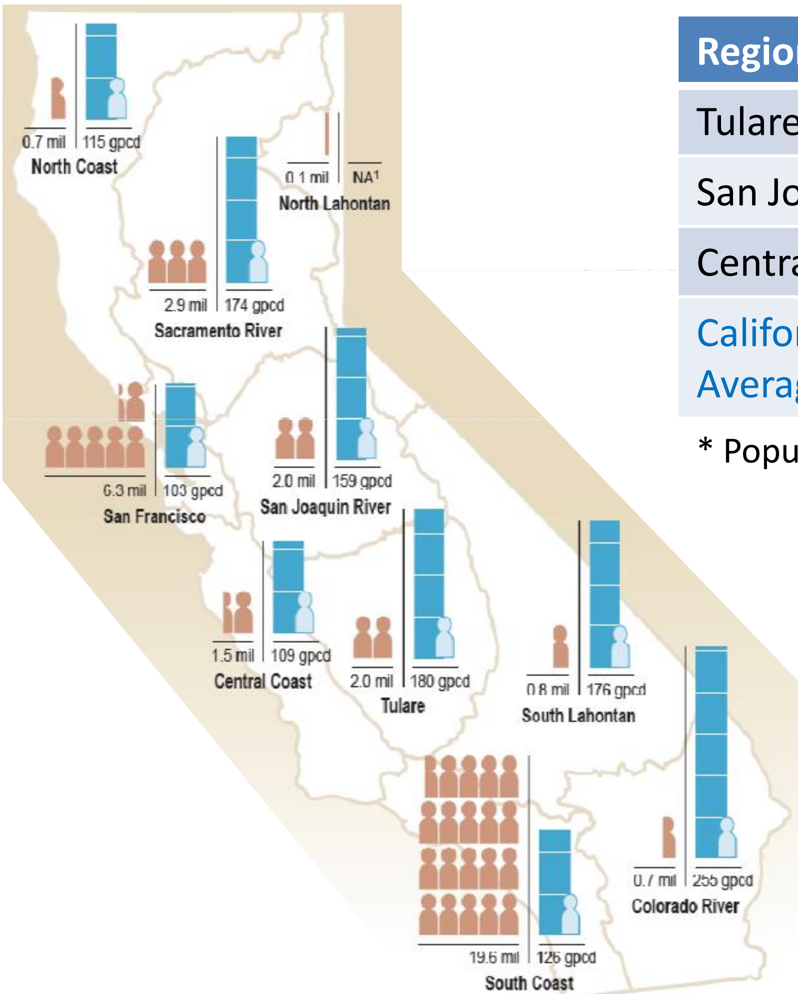
Fixed Bed Ion exchange, Adsorption (e.g., AC), and Low-Pressure RO/Nanofiltration

- Well established for small/POE/POU to large-scale applications
- Suitable for small distributed treatment systems
  - Consistent high quality water (wide range of contaminant removal)
  - Low-moderate operational complexity
  - Ease of automation and remote monitoring
  - Start/stop operation can be matched with demand
  - Commercial off-the shelf components
- Concentrate management maybe a challenge in some locations

Biological/Chemical/Electro-Chemical Denitrification

- Emerging potable water treatment (contaminant specific, not broadly applicable)
- Operational complexity and monitoring needs may require (frequent) on-site expertise
- More suitable for large satellite or centralized treatment
- Potential benefit for satellite treatment of IX/RO brine/concentrate residual

Groundwater Treatment Capacity Needs



California Residential Water Use, Gallons per day

Region	Per Capita	Per Household
Tulare Lake	180	565
San Joaquin	159	474
Central Coast	109	311
California Average*	133 (Range 103-255)	387 (Range 278-711)

* Population-weighted average, single- and multi-family homes

Single-Family Water Use:

(approximate)

Indoor: 47%

Outdoor: 53%

Faucet Use:

(approx. for drinking & cooking)

33 gallon/household/day

< 9% Total Water Use

California Water Plan Update 2009

DeOreo, W. B., et al, California Single-Family Water Use Efficiency Study, Aquacraft, Inc., 2011

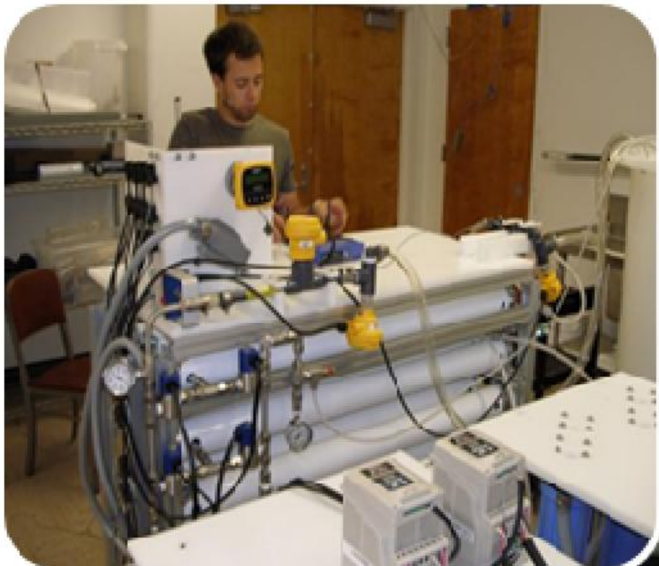
Effect of End-Water Use on Groundwater Treatment Capacity Needs

Basis: 503 GPD per household (California Average + 30 % Allowance)

End Water Use	1 Connection GPD (GPM)	50 Connections GPD (GPM)
Indoor & Outdoor	503 (~0.35)	25,155 (~17.5)
Indoor Only	236 (~0.16)	11,823 (~8.2)
Faucet Only (Drinking & Cooking)	43 (~0.03)	2,145 (~1.5)

- Considerations of water use may improve:
  - Technical feasibility of selected treatment technology (e.g., reduced waste disposal needs)
  - Affordability of water treatment
- Need to consider the long-term benefits of the following:
  - Dual water distribution systems (potable & non-potable)
  - Integration of POU or indoor POE residential treatment systems (may require regulatory update)

Small Scale Water Filtration/RO/NF Systems



UCLA M3 system:
5,000 – 8,000 GPD product

GE RO system (10-20 GPD)
(under the sink)

UCLA COM2RO:
12,000 – 46,000 GPD

100 GPD Media filtration + NF/RO
(Aqua Mini (Sea Recovery)

Example: Containerized Smart Low-Pressure RO/Nanofiltration System

Source Water: 100 ppm contaminant (e.g., nitrate), 750 ppm TDS

Capacity: 25,000 GPD (i.e., ~50 connections, indoor + outdoor use), 85-95% removal

High Cost Estimate:

- System amortized cost: $ 1,400/month (15 yrs @ 3% interest)
- Operation & Maintenance
  - Electricity & Chemicals: $118/month ($0.16 /1000 gal product)
  - Service Fee: $500- $1,600/month ($0.7 - 2.1 /1000 gal product)
- Treatment cost: ~**$40 - $62/month/connection** → **~$25- $40** with product blending

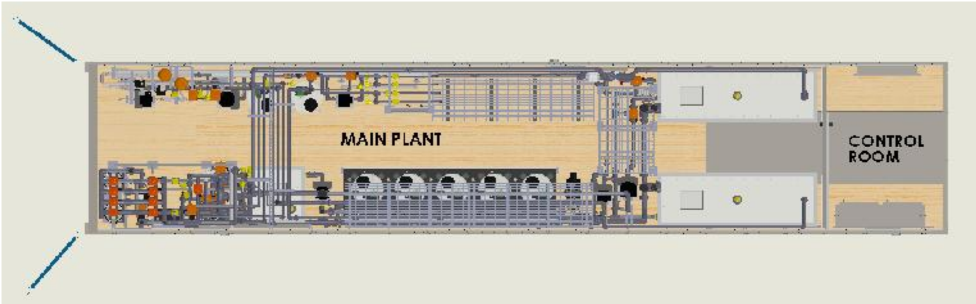
**Meyer, et al, Biological and Ion Exchange Nitrate Removal: Performance and Sustainability Evaluation. Water Research Foundation. 2010.*

UCLA Smart Integrated Membrane Systems (SIMS) Approach for Groundwater Filtration/Decontamination/Desalination

Integrated membrane-based water treatment plant: 45,000 GPD Capacity

- Reconfigurable system to match water treatment needs
- Fully automated for self-adaptive membrane system operation
- Remote monitoring and supervisory control
- Real-time membrane (fouling/scaling) monitoring (MeMo)
- Self-contained and mobile system for rapid deployment
  Fixed-column adsorption/ion-exchange/disinfection capabilities
- Opportunities for leveraging/integrating new technology components

Initial Deployment planned for 4th quarter of 2013 (Panoche, RRR, Tulare Lake)



Concentrate Residual Management

Cost of Conventional Methods

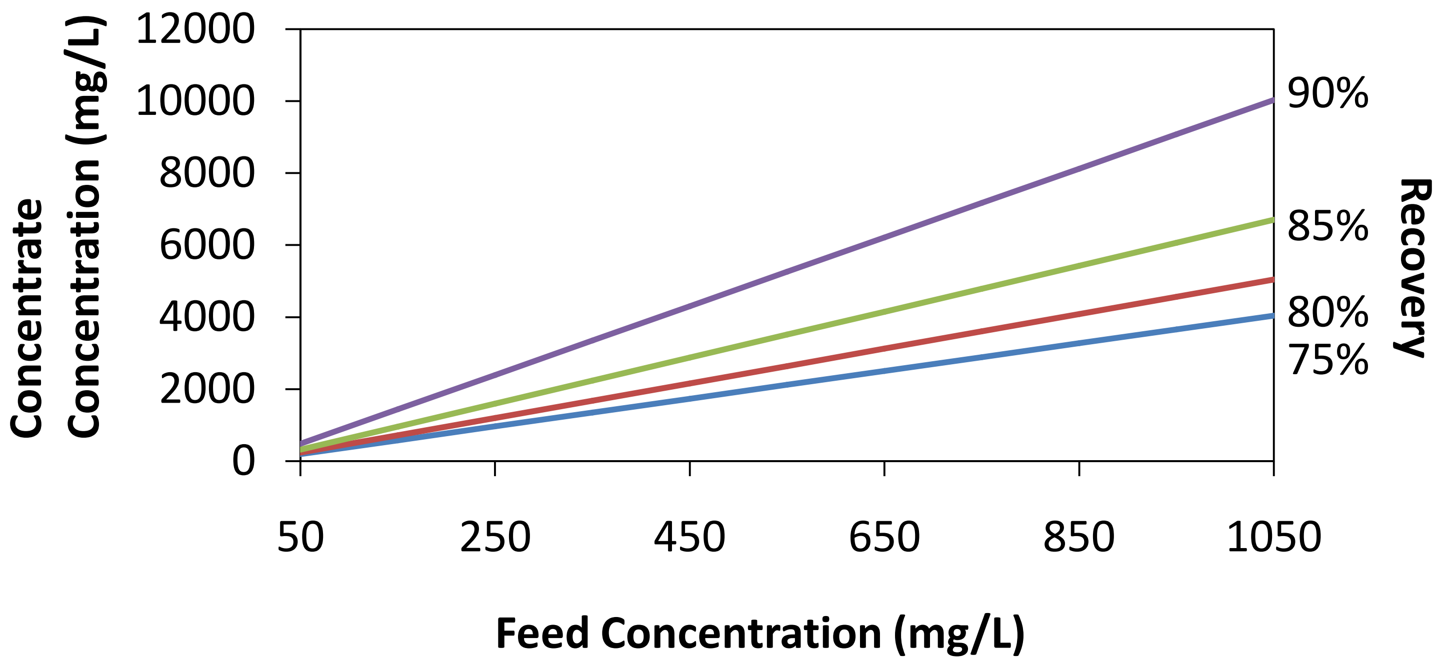
Method	Average ($/kgal)	Range ($/kgal)
Evaporation Ponds	15.9	7-27
Solar Ponds	39.3	8-88
Well Injection	30.5	13-111
Sewer	7.9	6-11

Meyer, et al, Biological and Ion Exchange Nitrate Removal: Performance and Sustainability Evaluation. Water Research Foundation. 2010.

Potential reduction of concentrate management costs:

- Satellite plants for RO/NF/IX waste treatment/water reuse
- Use of concentrate for agricultural purposes
- Blending of concentrate with source water

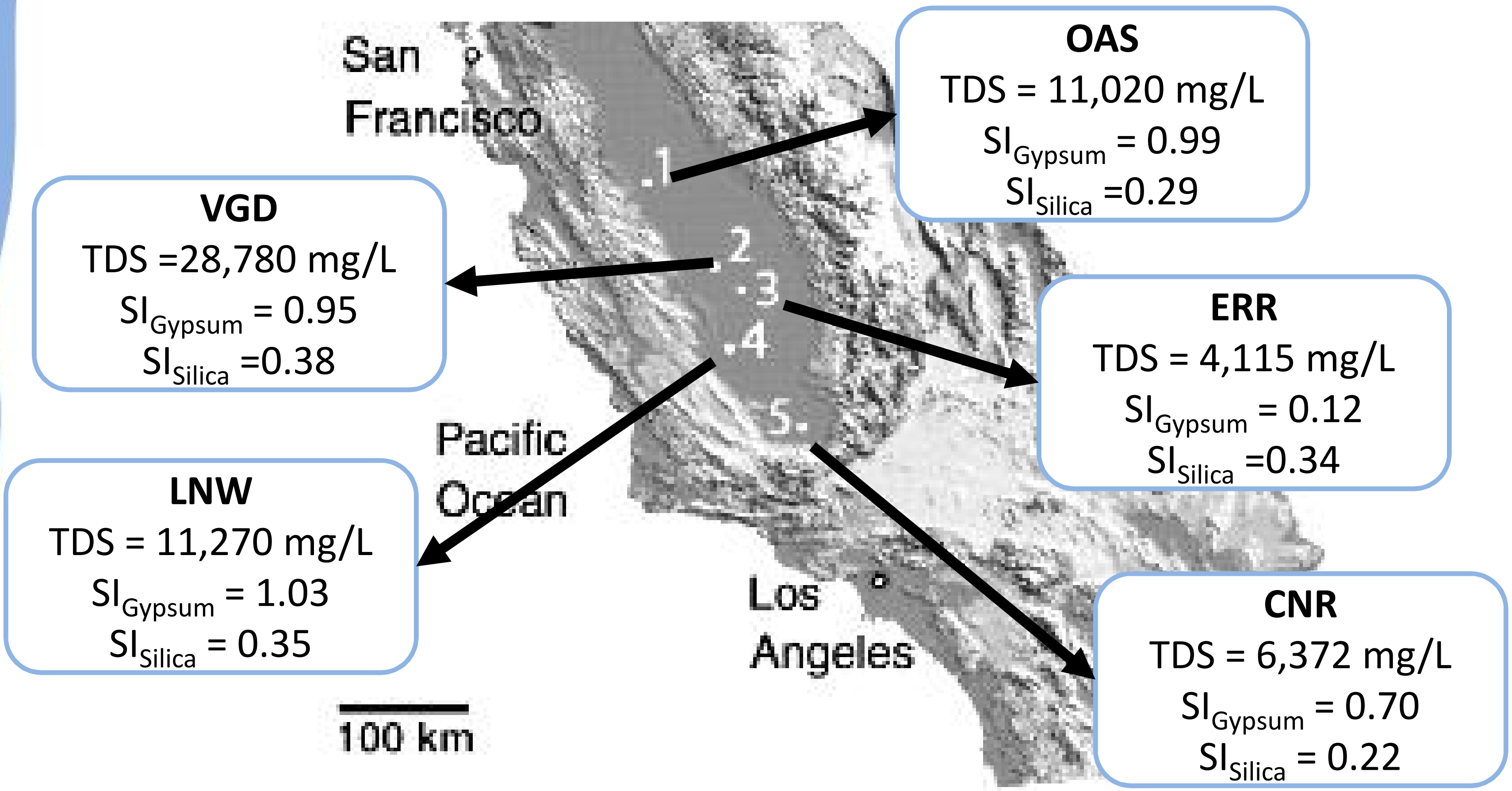
Product Recovery and Concentrate Management



- Depending on feed composition the RO concentrate may be of sufficiently low concentration (w.r.t target contaminant) to reduce the cost disposal and/or allow water reuse
- Potential for satellite treatment via denitrification*
  - Biological Denitrification: $1.13 - 1.56 / 1000 gallon
  - Chemical Denitrification: $ 0.88 - 2.24 / 1000 gallon

**Harter et al, "Addressing Nitrate in California's Drinking Water", UC Davis Center for Watershed Sciences, http://groundwaternitrate.ucdavis.edu*

Membrane Scaling Diagnostics of SJV Drainage Water: Geographical Variability of Source Water Quality

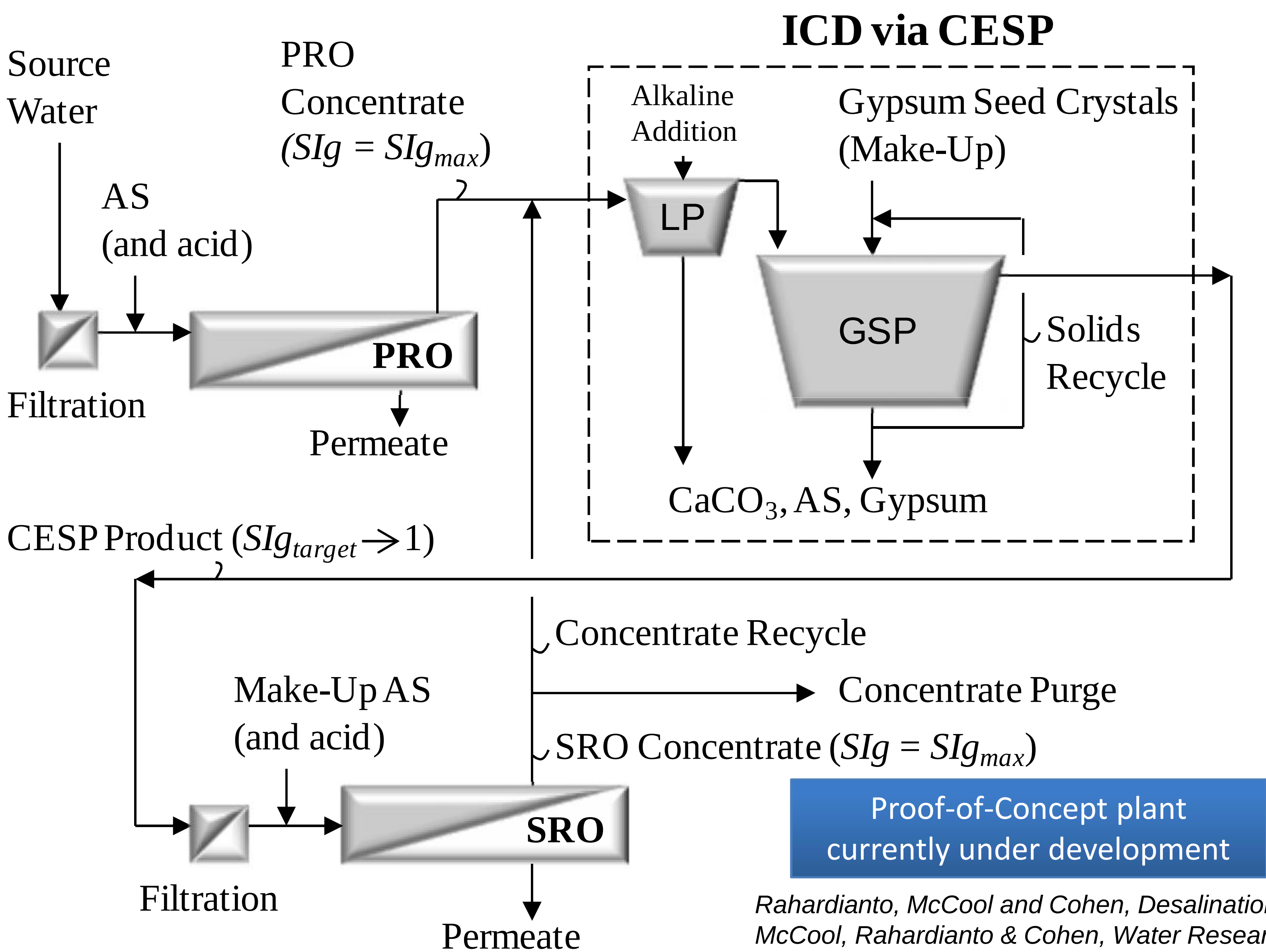


Distributed vs. Centralized RO Treatment Plant

Source waters are spatially distributed over varying distances, with varying water quality (and scaling tendency)

McCool et al, Feasibility of reverse osmosis desalination of brackish agricultural drainage water in the San Joaquin Valley Desalination 261 (2010) 240-250

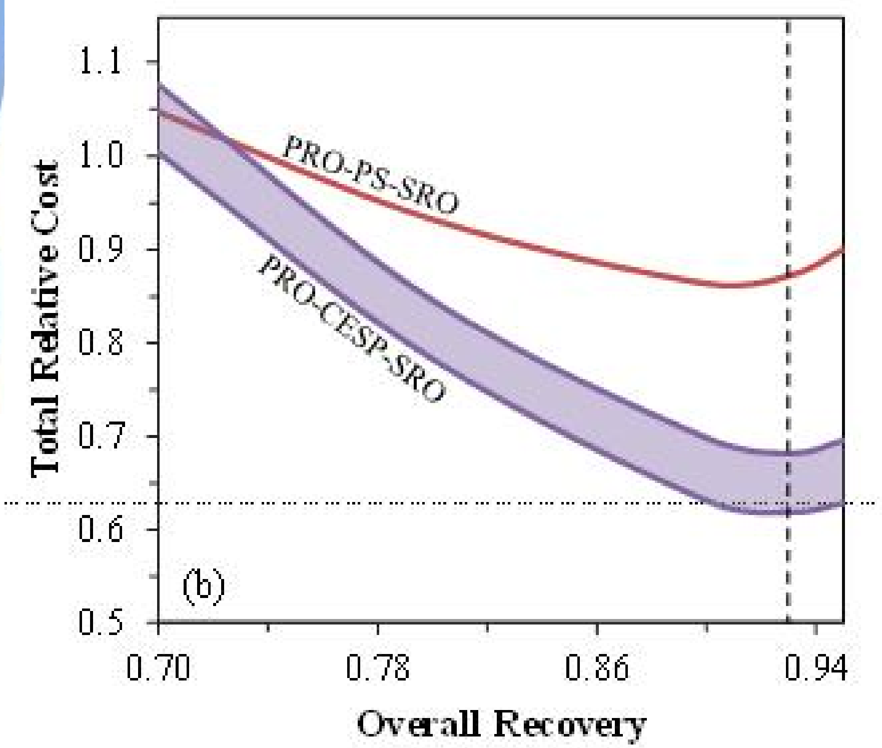
High Recovery (>90%) Brackish Water Desalination



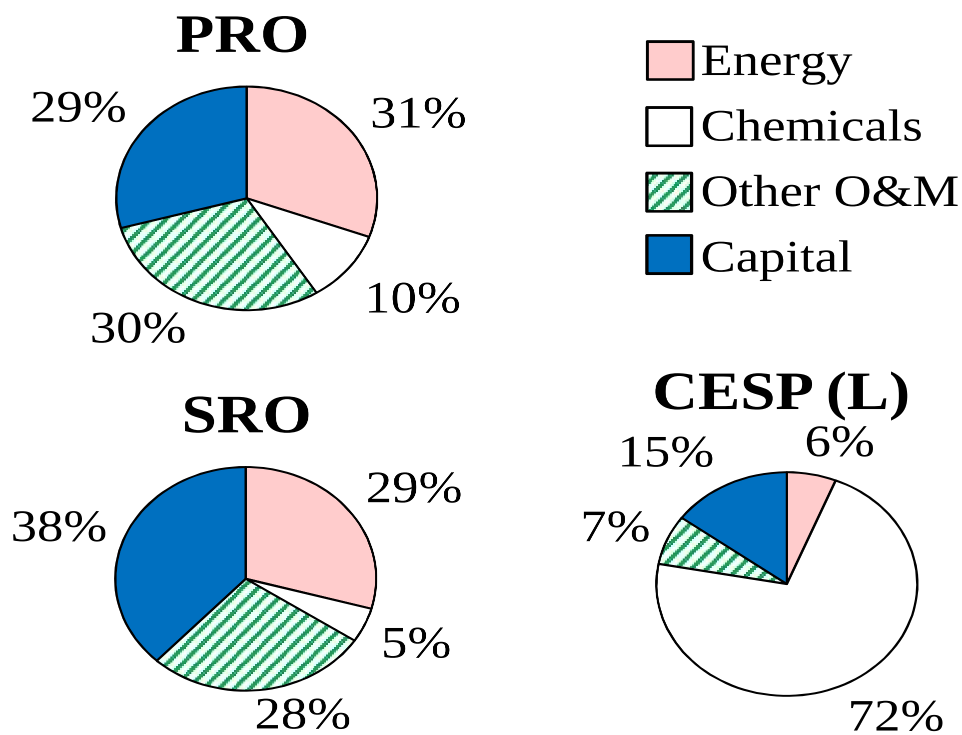
Proof-of-Concept plant currently under development

Rahardianto, McCool and Cohen, Desalination, 2011
McCool, Rahardianto & Cohen, Water Research, 2012

Cost of AD Water Salinity Management Relative to PRO

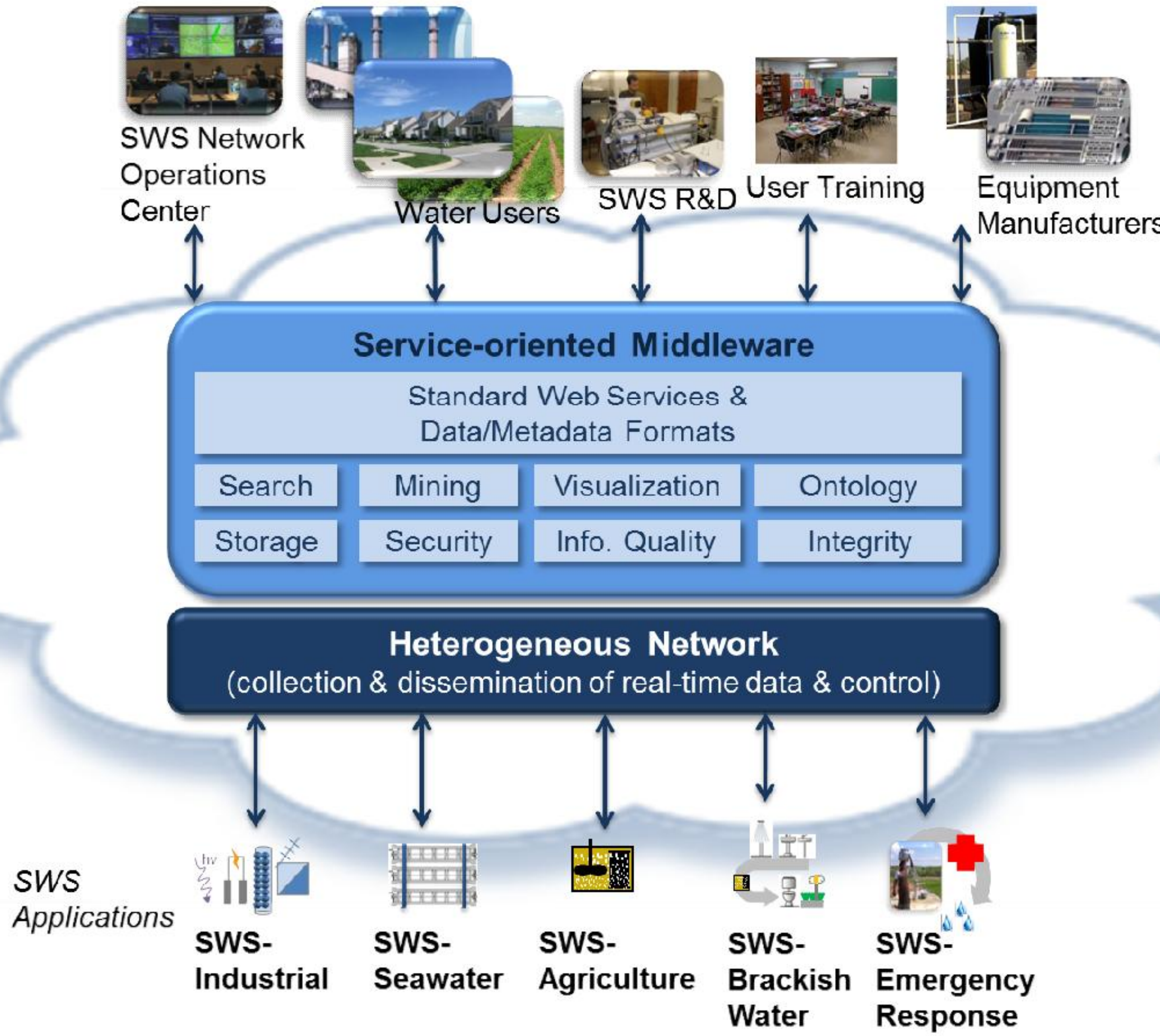


With brine disposal cost of 1.10 $/m^3
(PRO cost = 1.09 $/m^3–product)



PRO (with brine disposal): ~$1350 per Acre-foot
PRO-CESP-SRO: ~ $780 PER Acre-foot

Distributed Smart Water systems: Autonomous, Self-Adaptive & Fault Tolerant Operation



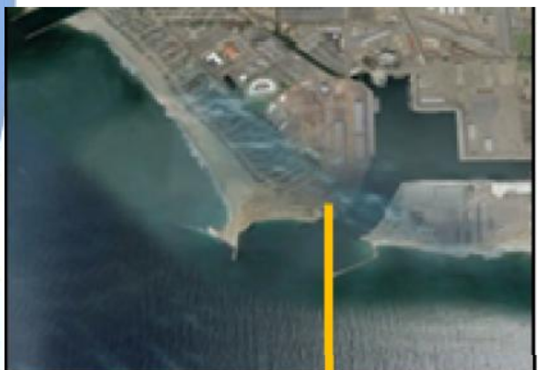
Pilot/Demonstration Activities: CoM2RO Treatment and Recycling of Cooling Tower Blow Down Water at the UCLA Co-Gen Plant

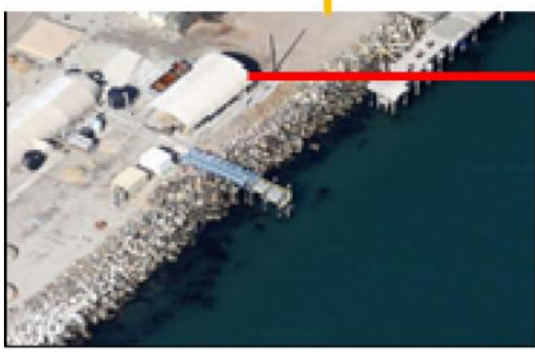
- Process models
- Control and optimization
- Soft sensors
- Membrane characterization
- Software design
- Advanced system design concepts

- Disposal of up to ~66,000-152,000 gallons/day
- Water unit price= $7.6/1000 Gallons
- 1,000-2,000 mg/L TDS
- Turbidity= 1.4-14 NTU
- Annual savings to UCLA ~$90K

UCLA Self-Adaptive MF/UF/RO Seawater Desalination System (US Naval Base at Port Hueneme)

Seawater Desalination: COM2RO in operation at Port Hueneme since August 2012





Shipboard and inland water treatment and desalination

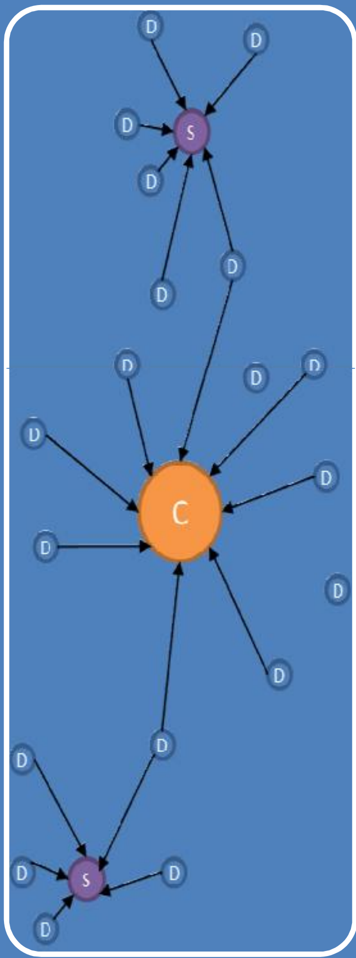
Self-adaptive RO, UF and coagulation-assisted UF

Water production cost:
\$0.50 - \$1/m³
(includes capital cost)

Permeate production capacity:
Seawater: Up to~18,000 GPD (69 m^3/day)
Brackish water: up to ~46,000 GPD (176 m^3/day)

Treatment Technologies for Groundwater Treatment in Rural Communities

Challenges and objectives:



- Meet local water quality and supply needs
- Remote system monitoring, expert supervision and control, fault detection and isolation → reduce need for onsite O&M
- Disposal/management of discharge water
- New paradigm of distributed system management and control
  - Cyberinfrastructure for distributed systems
  - Engage the public and other stakeholders through transparency of system monitoring, operability, and rapid expert response

QUESTIONS?