Reasons to maintain a definition of protected groundwater equivalent to an USDW during well stimulation and oil and gas development in California

Seth B.C. Shonkoff, PhD, MPH
PSE / UC Berkeley/ LBNL

Dominic C. DiGiulio, PhD
PSE Healthy Energy / Stanford University

Staff Workshop Review of Model Criteria for Groundwater Monitoring in Areas of Oil and Gas Well Stimulation Definition of "Protected Water"

California State Water Resources Control Board

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PSE Bringing science to energy policy

Recommendations for Groundwater Monitoring in California

LAWRENCE LIVERMORE NATIONAL LABORATORY

LLNL-TR-669645

Recommendations on Model Criteria for Groundwater Sampling, Testing, and Monitoring of Oil and Gas Development in California

Bradley K. Esser[1], Harry R. Beller[2], Susan A. Carroll[1], John A. Cherry[3], Jan Gillespie[4], Robert B. Jackson[5], Preston D. Jordan2, Vic Madrid[1], Joseph P. Morris[1], Beth L. Parker[3], William T. Stringfellow[2], Charuleka Varadharajan[2], and Avner Vengosh[6]

[1]*Lawrence Livermore National Laboratory, Livermore, California*
[2]*Lawrence Berkeley National Laboratory, Berkeley, California*
[3]*University of Guelph, Guelph, Canada*
[4]*California State University, Bakersfield, California*
[5]*Stanford University, Stanford, California*
[6]*Duke University, Durham, North Carolina*

June, 2015

Final Report
California State Water Resources Control Board

State of California Contract 14-050-250;
LLNL Work for Others Proposal L15606

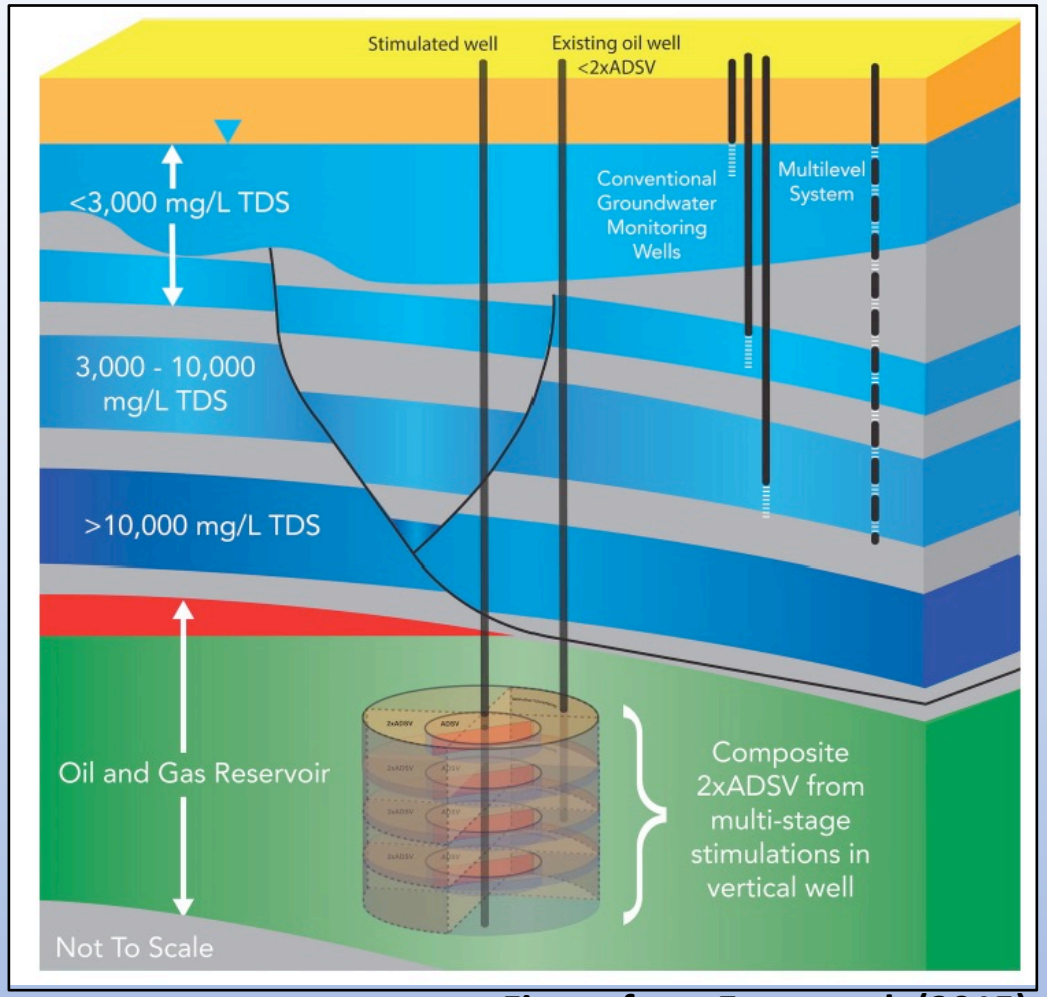

Figure from Esser et al. (2015)

The panel stated monitoring at 10,000 mg/L TDS is appropriate because it aligns with EPA's UIC program and is "technically and economically feasible to desalinate" water at this level of salinity (Esser et al. 2015).

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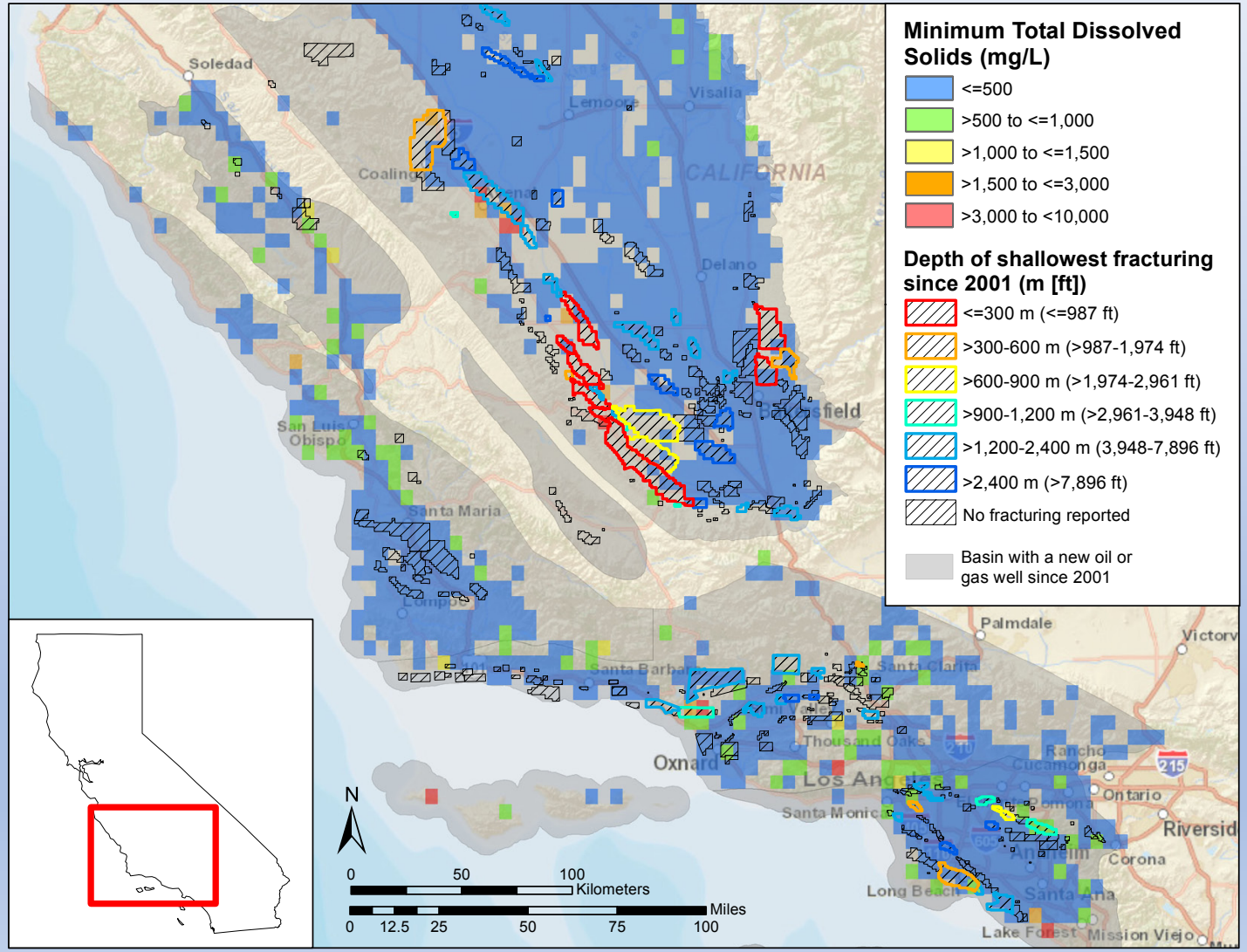
Reasons to maintain at least the current definition of protected water

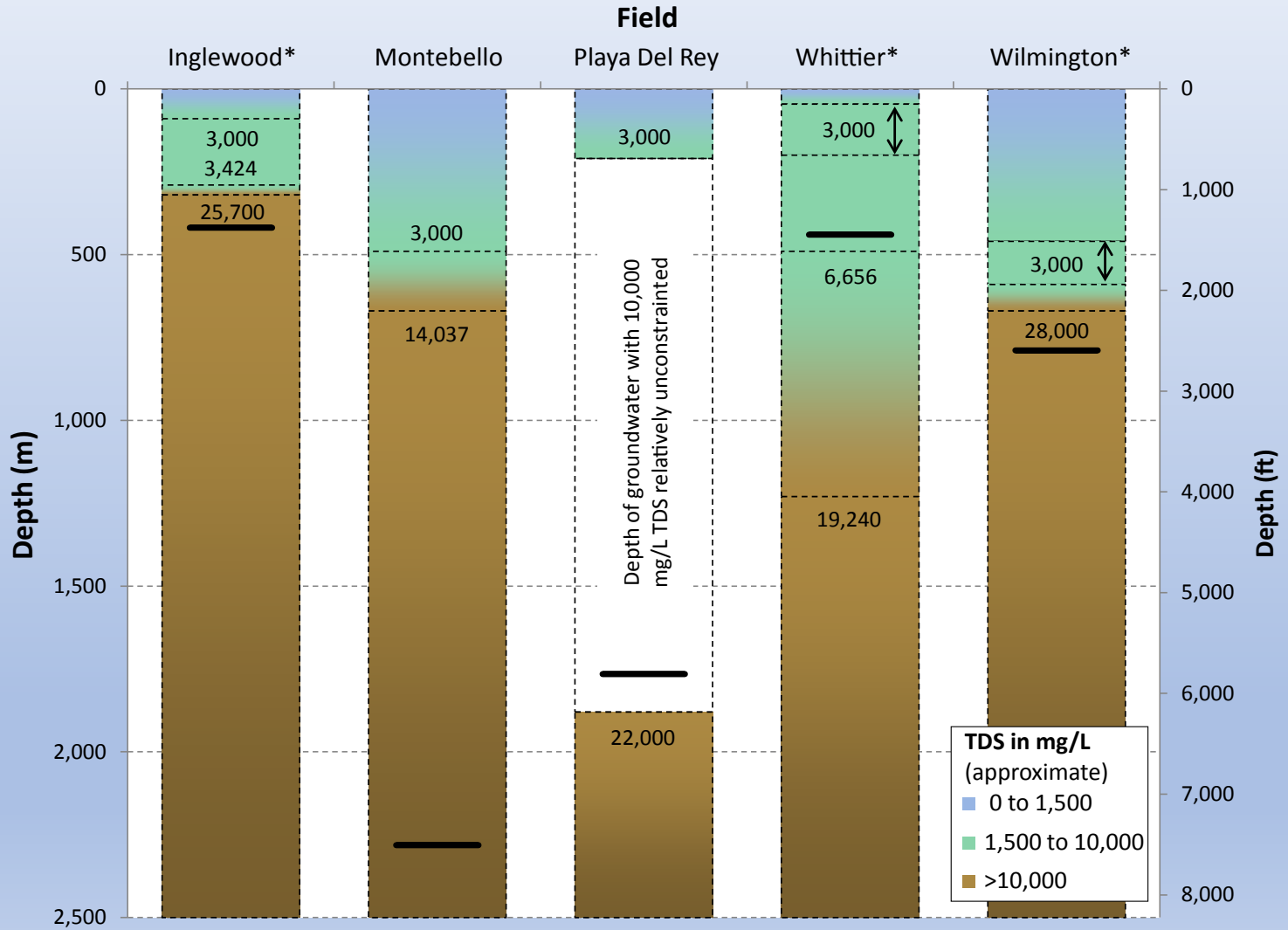
- The current definition of protected groundwater protects brackish (up to 10,000 mg/L TDS) groundwater resources.
- Population growth, drought and climate change in California will necessitate use of brackish groundwater resources.
- California has significant brackish groundwater resources, including that in oil and gas producing areas.
- Desalination of brackish groundwater is: (1) economically and technically feasible, and (2) less energy intensive and produces less brine than desalination of seawater.
- Desalination of brackish groundwater resources in oil and gas producing areas is technically feasible.
- The federal government professional organizations, including API, have recommended the use of a 10,000 mg/L TDS criterion to define protected groundwater during well stimulation.
- Other states have an explicit definition of protected groundwater equivalent to a USDW.
- In the context of drought, population growth and climate change and given that desalinization is possible for water with >10,000 mg/L TDS, California could consider increasing the definition of protected groundwater to a TDS threshold >10,000 mg/L.

Maintaining the current definition of protected groundwater and adequate vertical separation can protect brackish groundwater resources



CCST 2015

Shallow Hydraulic fracturing near brackish groundwater in the Los Angeles Basin



CCST 2015

Population growth, drought and climate change in California will necessitate the increased use of brackish groundwater to supplement freshwater demand.

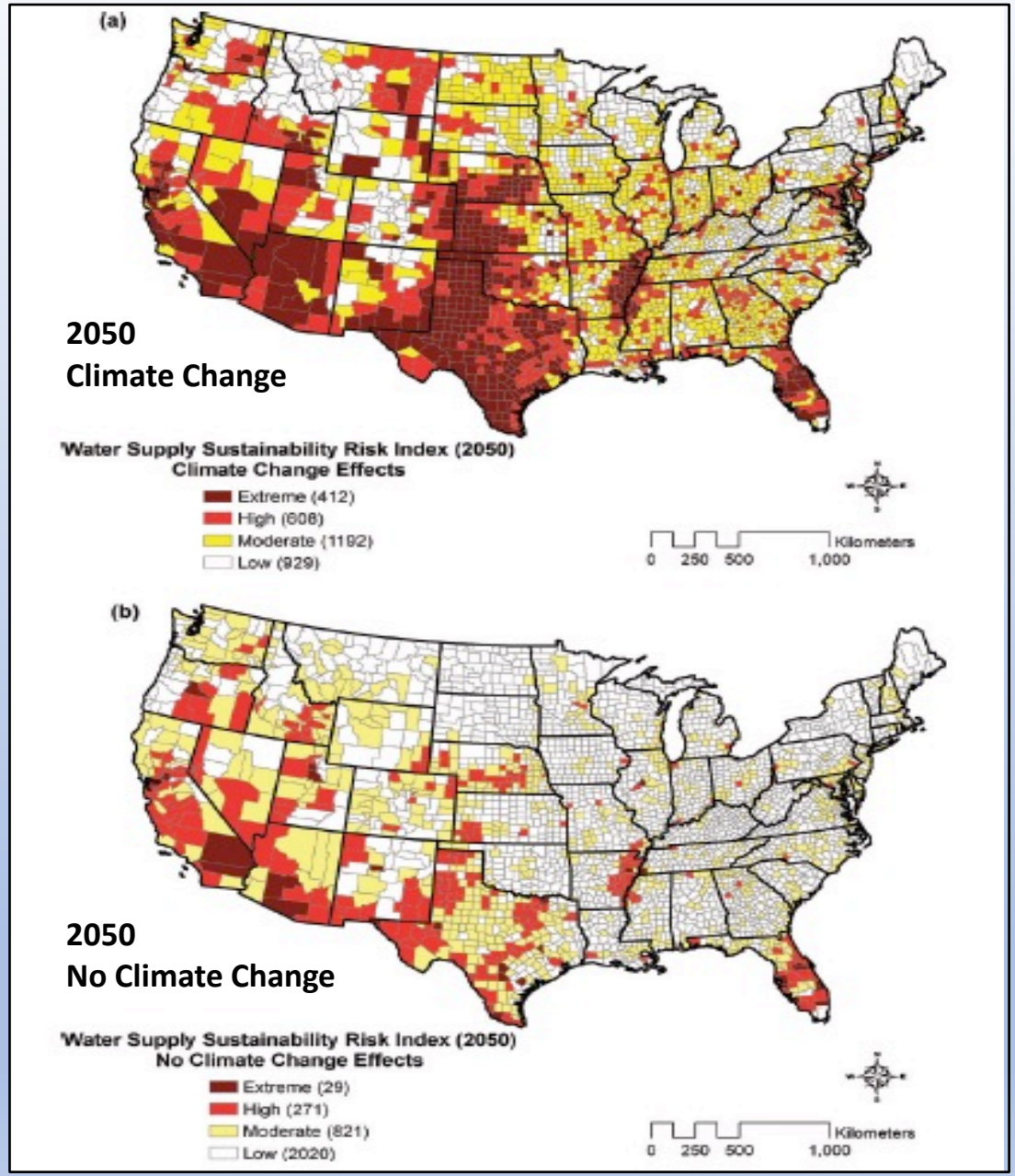
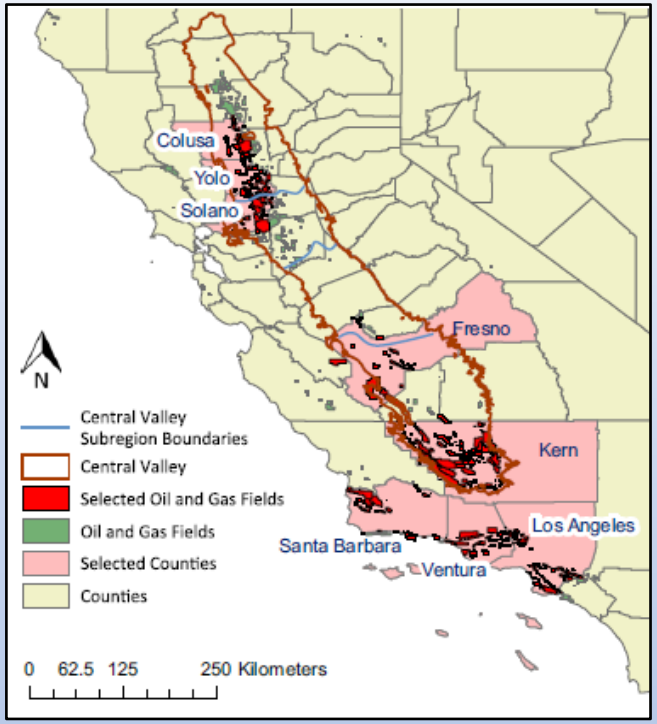
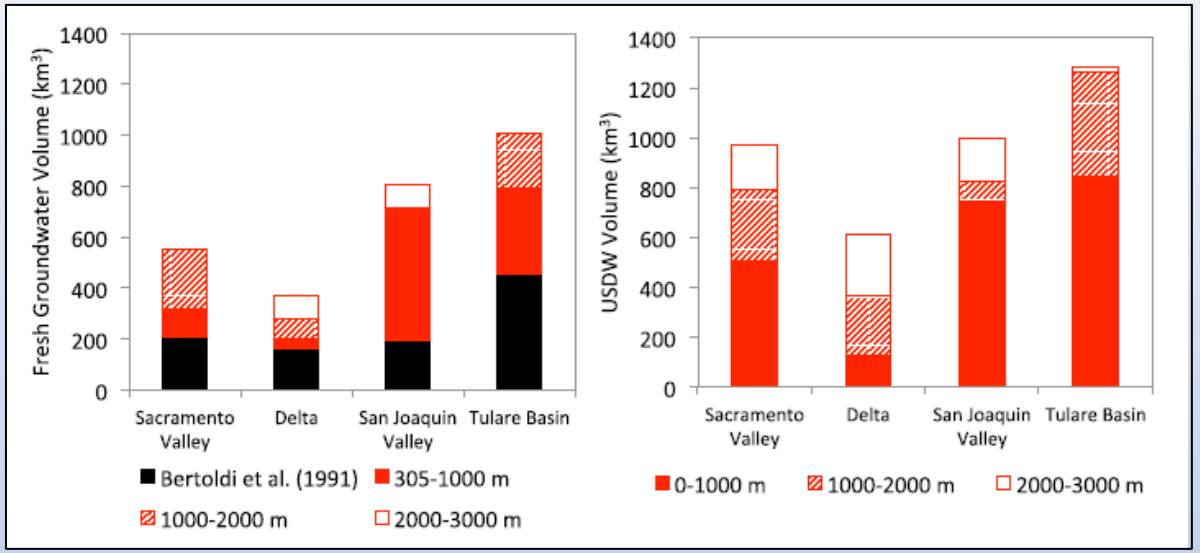


Figure from Roy et al. (2012)

Updated Estimates of Fresh and Brackish Groundwater Resources in the Central Valley



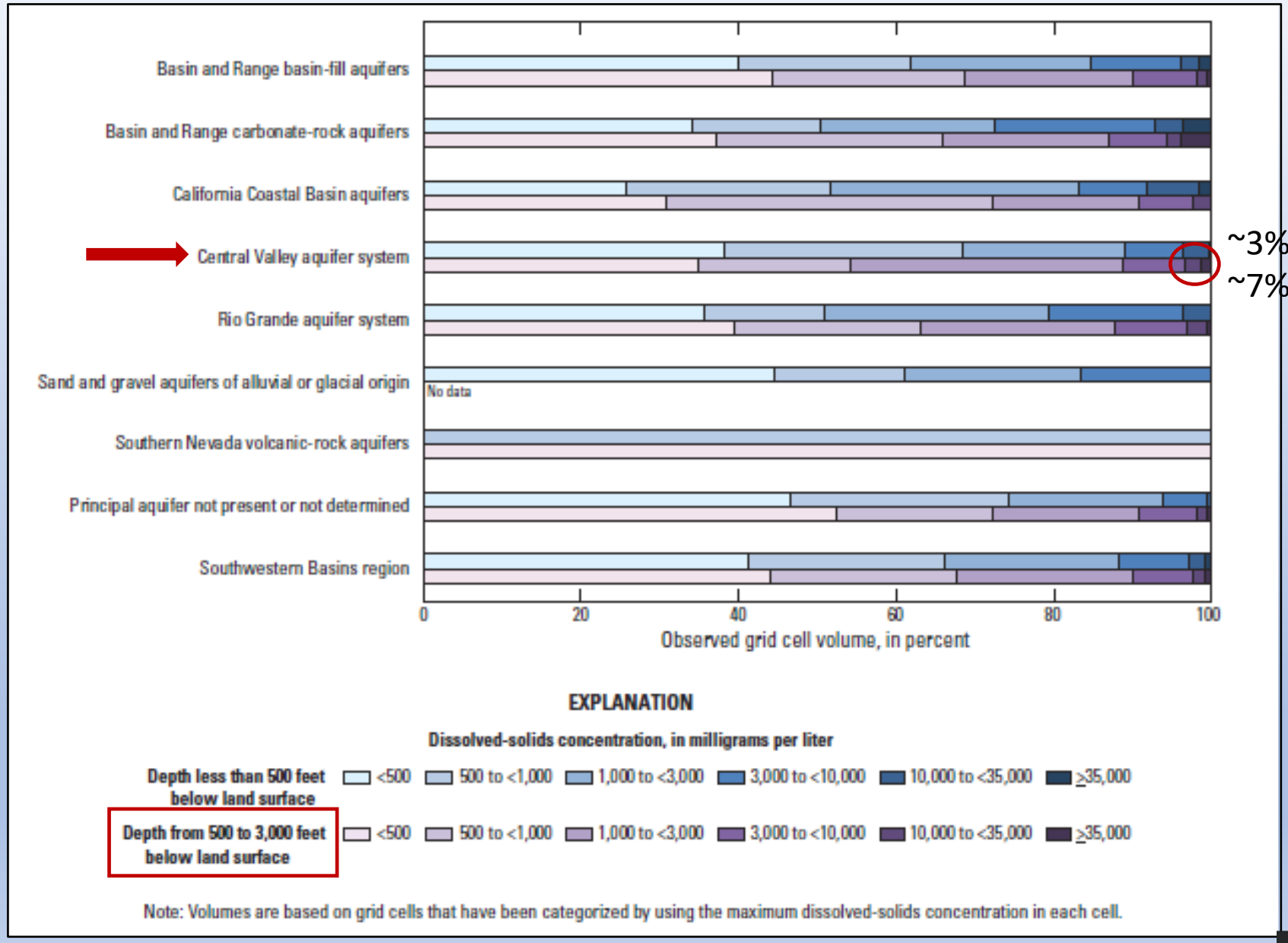


Figures from Kang and Jackson (2016)

Estimated fresh groundwater (<3,000 mg/L TDS to 305m) ~ 1,000 km^3 (Bertoldi et al. 1991)
Fresh groundwater ~ 2,700 km^3 (Kang and Jackson 2016)
Brackish groundwater (3,000 – 10,000 mg/L TDS) ~ 3,900 km^3 (Kang and Jackson 2016)

~60% of groundwater resources are brackish
Tulare Basin, where substantial oil & gas development occurs, contains significant brackish groundwater resources

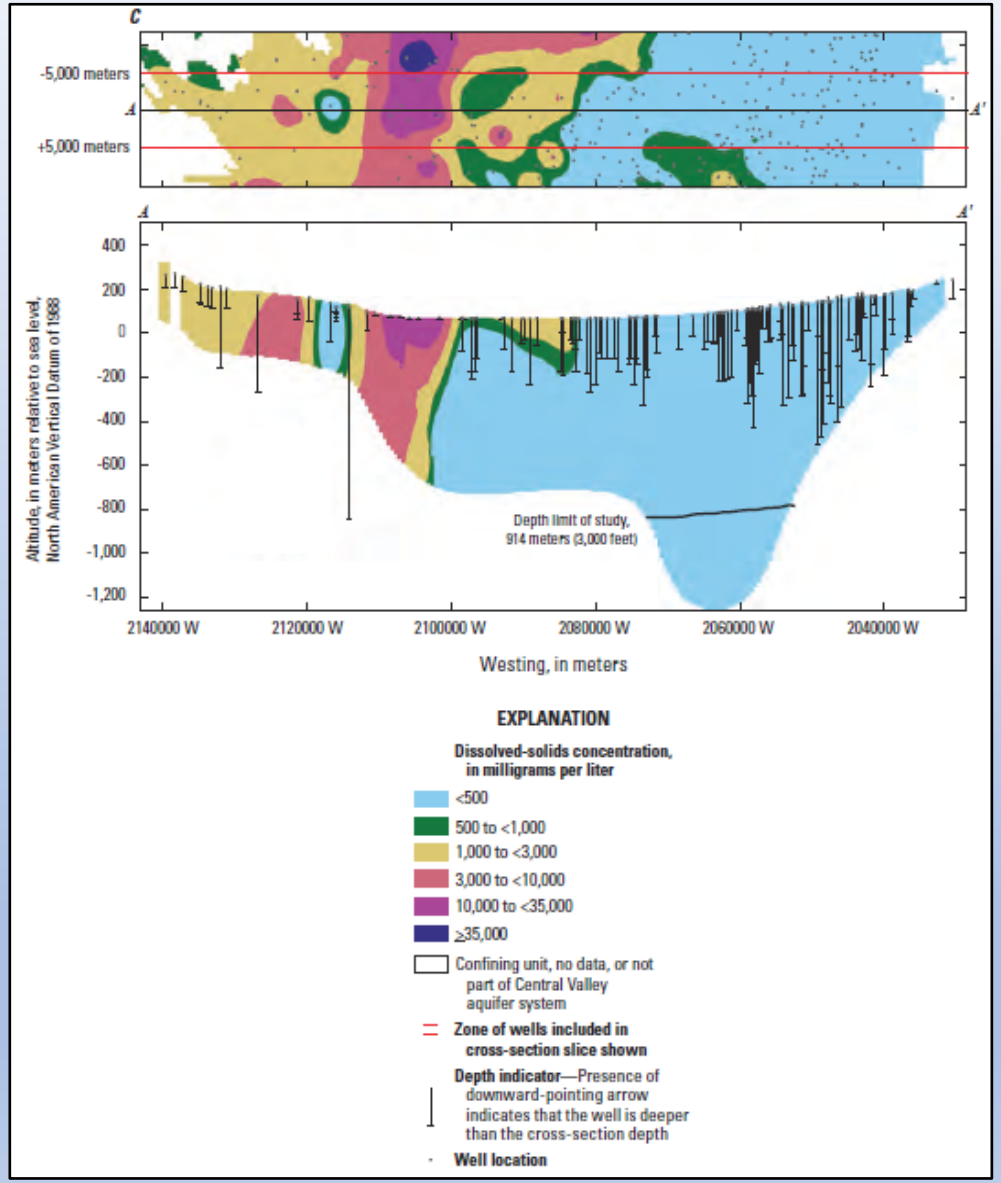
USGS Study on Brackish Groundwater Resources in the U.S.

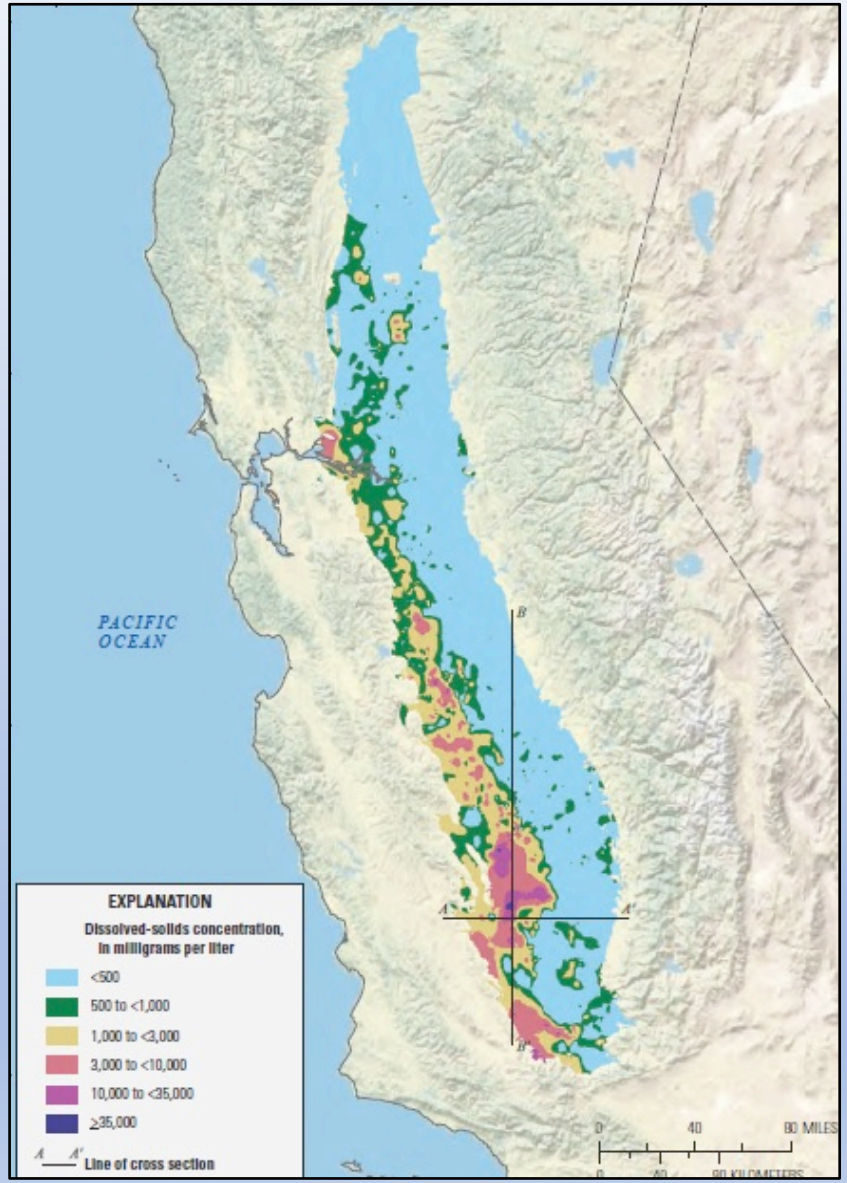


~3% saline
~7% brackish

Figure from Stanton et al. (2017)

USGS Study on Brackish Groundwater Resources in the U.S. Geostatistical Mapping of a Portion of the San Joaquin Valley

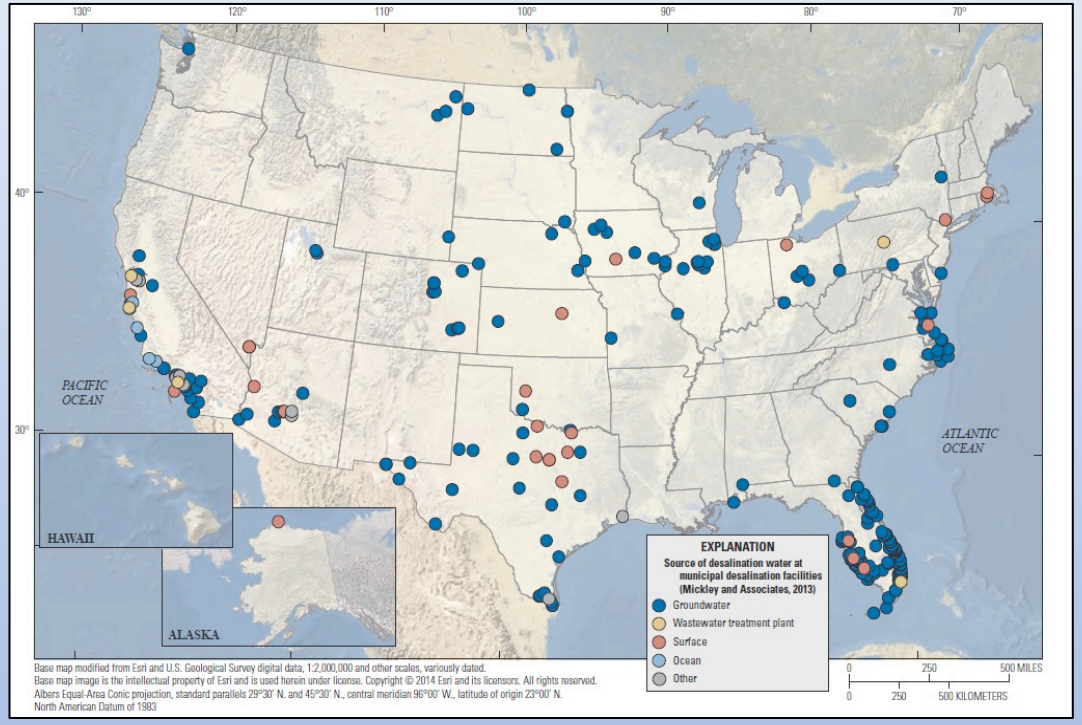


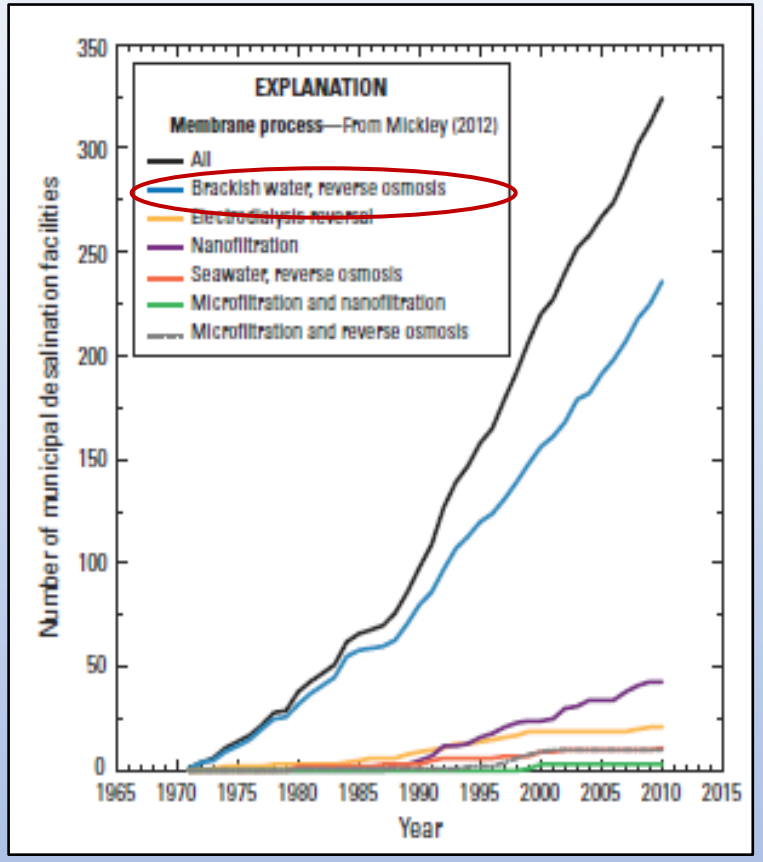


Figures from Stanton et al. (2017)

Increased Desalination of Brackish Water Could Assist in Meeting Increasing Freshwater Demand

649 plants in 2010 – 67% municipal, 18% industry, 9% power, 6% other





Most desalination plants for brackish groundwater.
Most desalination is by reverse osmosis.
Less costly than seawater.
Less brine production than seawater.
Costs continue to decrease.

Treatability and energy requirements dependent on geochemical composition (Ahdab et al. 2018, McMahon et al. 2016).

Figures from Stanton et al. (2017)

There is an Increasing Trend in Comprehensive Sustainable Groundwater Management (e.g., Desalination + Aquifer Storage and Recovery) That is Applicable to California

San Antonio (H_2Oaks Center)

- Opened early 2017
- 99.9% dissolved solids removal
- 12 million gallons per day
- Reverse osmosis
- 1 gallon brine produced per 10 gallons treated
- Brine disposed in underlying saline aquifer (not USDW receiving aquifer exemption)

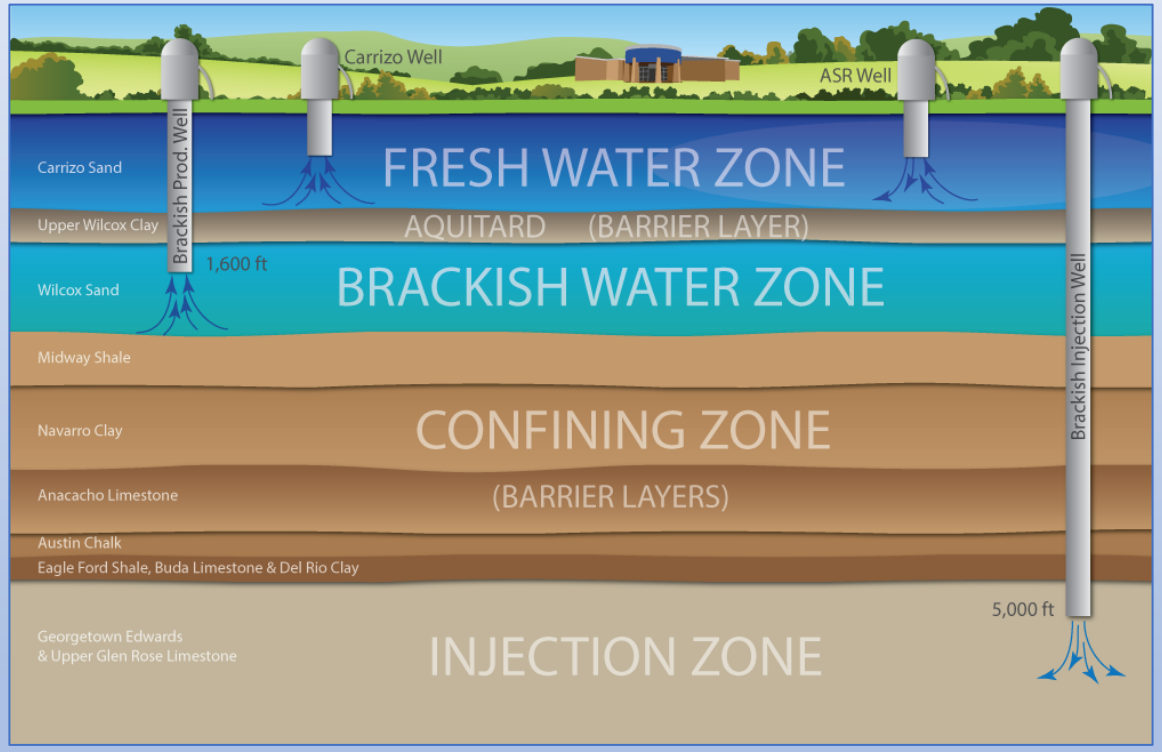
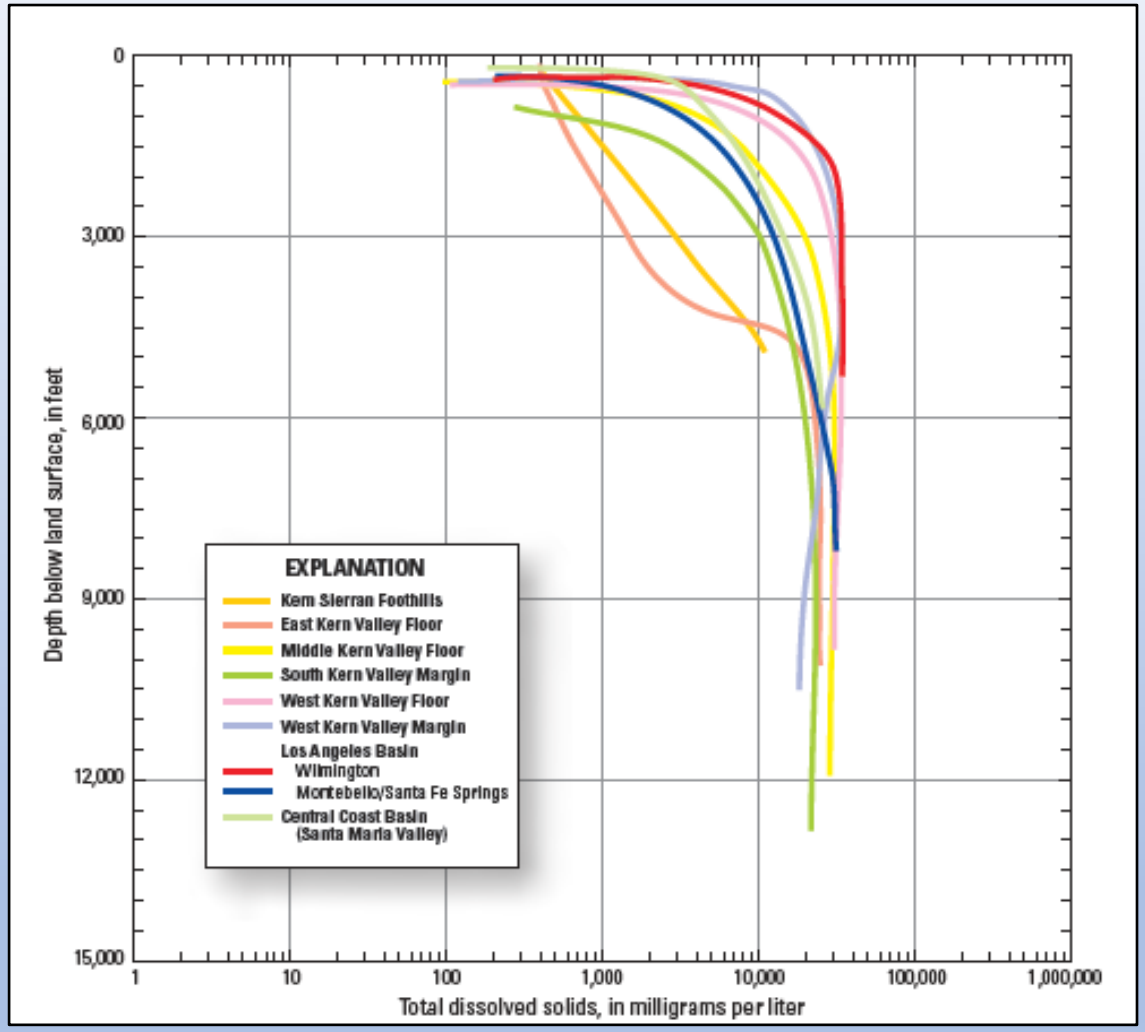
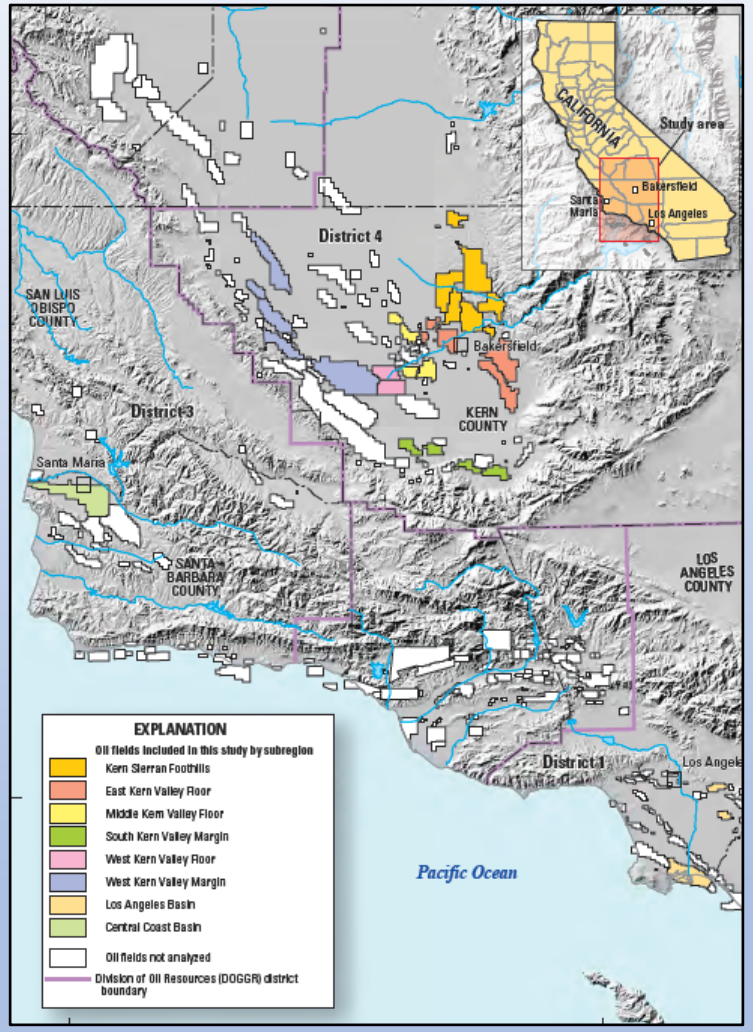


Figure from http://www.saws.org/Your_Water/WaterResources/Projects/desal.cfm

USGS Study on Salinity Mapping in Central and Southern California in Oil and Gas Producing Areas



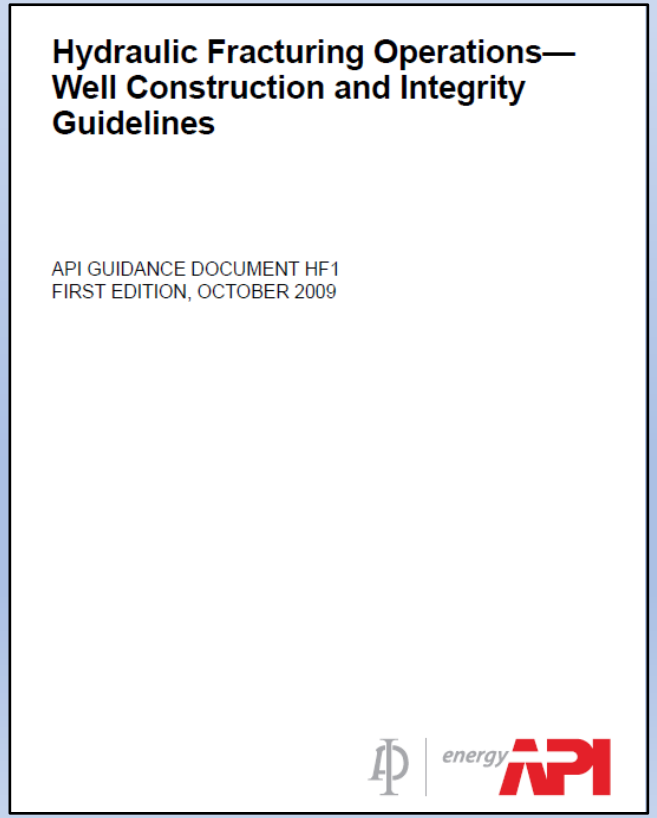


Water well and produced water concentrations used to delineate depths of fresh and brackish groundwater resources.

Figures from Metzger and Landon (2018)

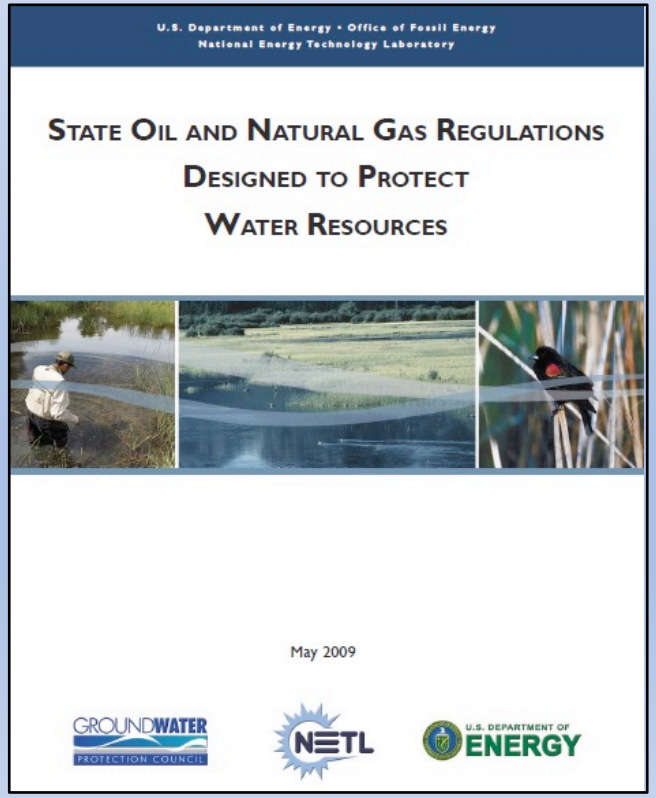
American Petroleum Institute (API)

"At a minimum, it is recommend that surface casing be set at least 100 ft below the deepest USDW encountered while drilling the well…If intermediate casing is not cemented to the surface, at a minimum the cement should extend above any exposed USDW or any hydrocarbon bearing zone." (API 2009)



Groundwater Protection Council (GWPC)

"Hydraulic fracturing in oil or gas bearing zones that occur in non-exempt USDW's should either be stopped, or restricted to the use of materials that do not pose a risk of endangering ground water and do not have the potential to cause human health effects." (GWPC 2009)



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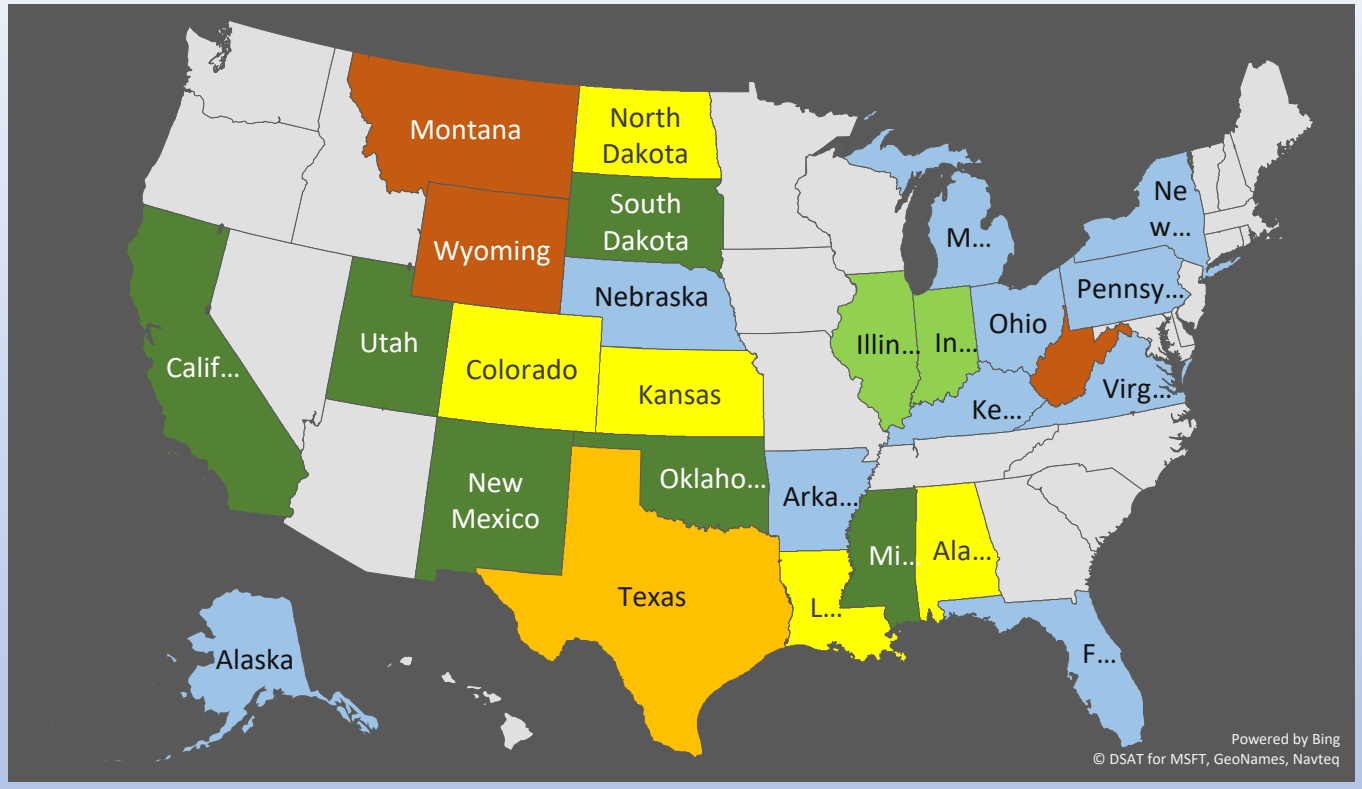
Produced Water < 10,000 mg/L TDS

Figure from DiGiulio et al. (2018)

Data (n=18,762) from the USGS National Produced Waters Geochemical Database (Blondes et al. 2014)

Oil and gas development in 27 states but development in brackish groundwater primarily in 17 states.

Definitions of protected groundwater during well stimulation in 17 states having significant brackish groundwater resources



Interpretation of regulations from DiGiulio et al. (2018)

- USDW or equivalent to USDW
- USDW limited to CBM (IN) or horizontal wells (IL)
- Undefined or geographically dependent (KS, CO)
- 3,000 mg/L TDS
- Protection removed
- O&G state not considered in our analysis

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Conclusions

Maintaining a definition of protected groundwater during well stimulation and other forms of oil and gas development using a criteria established for an USDW is reasonable and defensible.

California should maintain current standards to join other states in having explicit criteria for protection of groundwater equivalent to that of an USDW during well stimulation.

California should implement similar requirements for groundwater monitoring during all oil and gas development, not only for well stimulation.

In the context of drought, climate change and population growth and given that desalinization is possible for water with >10,000 mg/L TDS, California could consider increasing the definition of protected groundwater to a TDS threshold above 10,000 mg/L.

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References

Ahdab, Y.D., Thiel, G.P., Bohlke, J.K., Stanton, J., Lienhard, J.H. 2018. Minimum energy requirements for desalination of brackish groundwater in the United States with comparison to international datasets. *Water Research* 141, 387-404.

American Petroleum Institute. API Guidance Document HF1, Hydraulic Fracturing Operations – Well Construction and Integrity Guidelines, First Edition, October 2009.

Bertoldi, G.L., Johnson, R.H., Evenson, K.D. 1991. Ground Water in the Central Valley, California. A Summary Report, U.S.G.Gs Survey Professional Paper, Vol 1401-A.

Blondes, M.S., Gans, K.D., Thordsen, J.J., Reidy, M.E., Thomas, B., Engle, M., Kharaka, Y., Rowan, E. U.S. Geological Survey National Produced Waters Geochemical Database v2(Provisional). 2014. U.S. Geological Survey

DiGiulio, D.C.; Jackson, R.B. 2016. Impact to Underground Sources of Drinking Water and domestic wells from production well stimulation and completion practices in the Pavillion, Wyoming Field. *Environmental Science & Technology* 50, 4524-4536.

DiGiulio, D.C.; Shonkoff, S.B.C.; Jackson, R.B. 2018. The Need to Protect Fresh and Brackish Groundwater Resources During Unconventional Oil and Gas Development. *Current Opinion in Environmental Science & Health*, 3, 1-7.

Esser, B.K.; Beller, H.R.; Carroll, S.A.; Cherry, J.A.; Gillespie, J.; Jackson, R.B.; Jordon, P.D.; Madrid, V.; Morris, J.P.; Parker, B.L.; Stringfellow, W.T.; Varadharajan, C.; Vengosh, A. 2015. Recommendations on Model Criteria for Groundwater Sampling, Testing, and Monitoring of Oil and Gas Development in California. Lawrence Livermore National Laboratory, LLNL-TR-669645, Final Report, California State Water Resources Control Board

Federal Register, Vol. 80, No. 58, March 26, 2015, Part III, Department of the Interior, Bureau of Land Management, 43 CFR Part 3160, Oil and Gas; Hydraulic Fracturing on Federal and Indian Lands; Final Rule.

Ferguson, G., McIntosh, J.C., Perrone, D., Jasechko, S. 2018. Competition for shrinking window of low salinity groundwater. *Environmental Research Letters* 13, 114013

Groundwater Protection Council. State Oil and Natural Gas Regulations Designed to Protect Water Resources, 2009.

Jackson, R.E.; Lowry, E.R.; Pickle, A.; Kang, M.; DiGiulio, D.C; Zhao, K. 2015. The Depths of Hydraulic Fracturing and Accompanying Water Use Across the United States. *Environmental Science & Technology* 49 (15), 8969–8976.

References

Kang, M., Jackson, R.B. 2016. Salinity of deep groundwater in California: Water quantity, quality, and protection. *Proceedings of the National Academy of Science* 113(28), 7768-7773

Maupin, M.A.; Kenny, J.F.; Hutson, S.S.; Lovelace, J.K.; Barber, N.L.; Linsey, K.S. Estimated Use of Water in the United States in 2010. U.S. Geological Survey, Circular 1405, 2014.

Metzger, L.F., Landon, M.K. (2018). Preliminary Groundwater Salinity Mapping Near Selected Oil Fields Using Historical Water-Sample Data, Central and Southern California, U.S. Geological Survey Scientific Investigations Report 2018-5082, 2018.

McMahon, P.B., Böhlke, J.K., Dahm, K.G., Parkhurst, D.L., Anning, D.W., Stanton, J.S. Chemical Considerations for an Updated National Assessment of Brackish Groundwater Resources. *Groundwater* 2016, 54(4), 464-475.

Roy, S.B.; Chen, L.; Girvetz, E.H.; Maurer, E.P.; Mill, W.B.; Grieb, T.M. Projecting water withdrawal and supply for future decades in the U.S. under climate change scenarios. *Environmental Science & Technology* 2012, 46(5), 2545-2556.

Stanton, J.S., Anning, D.W., Brown, C.J., Moore, R.B., McGuire, V.L., Qi, S.L., Harris, A.C., Dennehy, K.F., McMahon, P.B., Degnan, J.R., and Böhlke, J.K., 2017, Brackish Groundwater in the United States: U.S. Geological Survey Professional Paper 1833, 185 p., https://doi.org/10.3133/pp1833.

Stephens, M.J., Shimabukuro, D.H., Gillespie, J.M., Chang, W. 2018. Groundwater salinity mapping using geophysical log analysis within the Fruitvale and Rosedale Ranch oil fields, Kern County, California, USA. *Hydrogeology Journal* doi.org/10.1007/s10040-018-1872-5

U.S. Department of Interior, Bureau of Land Management. BLM Proposed to Rescind Rule on Hydraulic Fracturing, available at https://www.blm.gov/node/13073

U.S. District Court for the District of Wyoming. Order on Motions for Preliminary Injunction, Case No. 2:15-CV-043-SWS. Petitioners: States of Wyoming, State of Colorado and Intervenor-Petitioners: State of North Dakota, State of Utah, and Ute Indian Tribe vs. U.S. Department of the Interior. Respondents, Sierra Club, Earthworks, Western Resource Advocates, Conservation Colorado Education Fund, the Wilderness Society and Southern Utah Wilderness Alliance. Intervenor-Respondents: Independent Petroleum Association of American and Western Energy Alliance. Filed September 30, 2015. Available at http://www.wyd.uscourts.gov/pdfforms/orders/15-cv-043%20130%20order.pdf

References

U.S. Environmental Protection Agency. Evaluation of Impacts to Underground Source of Drinking Water by Hydraulic Fracturing of Coalbed Methane Reservoirs, Office of Water, Office of Ground Water and Drinking Water (4606M), EPA 816-R-04-003, June 2004.

U.S. Environmental Protection Agency. Permitting Guidance for Oil and Gas Hydraulic Fracturing Activities Using Diesel Fuels: Underground Injection Control Program Guidance #84, Office of Water, EPA 816-R-14-001, February 2014

U.S. Environmental Protection Agency. Hydraulic Fracturing for Oil and Gas: Impacts from the Hydraulic Fracturing Water Cycle on Drinking Water Resources in the United States (Final Report). Washington, DC, EPA/600/R-16/236F, 2016

Thank You

Seth B.C. Shonkoff, PhD, MPH
sshonkoff@psehealthyenergy.org
sshonkoff@berkeley.edu

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Backup Slides

A Clear Explicit Definition of Protected Groundwater is Necessary to Protect Groundwater Resources

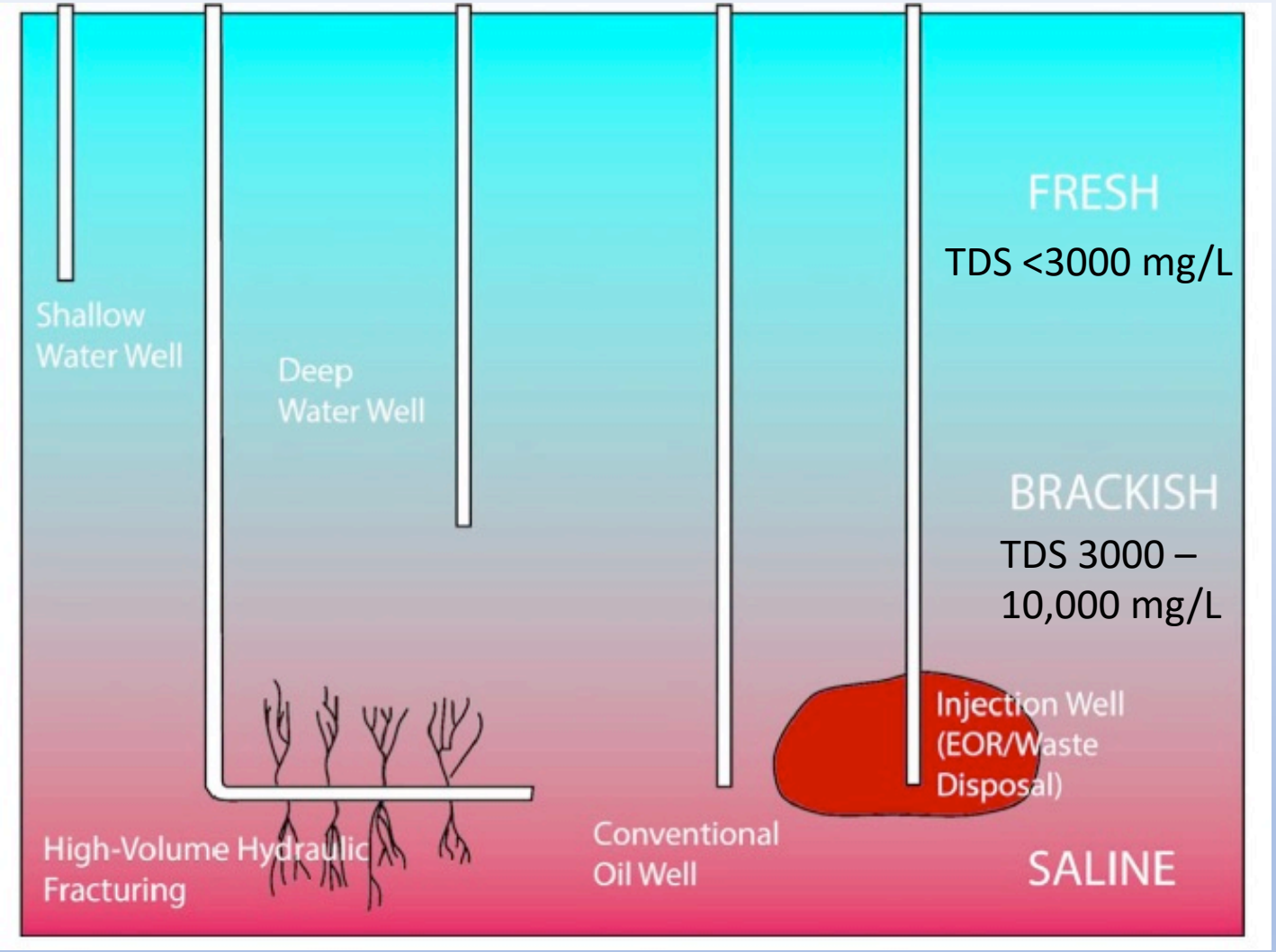


Figure from Ferguson et al. (2018)

California currently protects brackish groundwater during well stimulation in effect limiting well stimulation to formations containing saline groundwater.

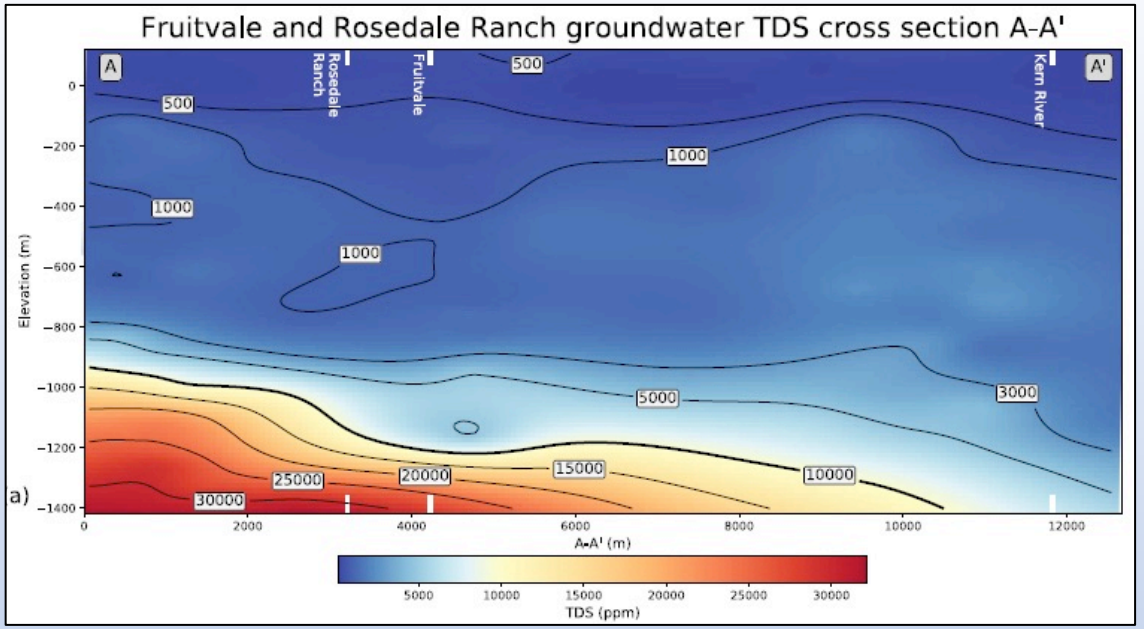
Maximum Allowable TDS Levels for Water Distribution and Protection of Water Resources in California

Maximum TDS (mg/L)	Distribution/ Resource	Applicability to O&G Industry	Enforceability	Overseeing Agencies
500	Municipal water supply	None	SMCL, recommended	EPA, SWRCB
1,000	Municipal water supply	None	SMCL, upper limit, CA Code Reg., Title 22, § 64449	SWRCB
1,500	Municipal water supply	None	SMCL, short term limit, CA Code Reg., Title 22, § 64449	SWRCB
3,000 to undefined	Surface water and groundwater	Land disposal, produced water ponds	SWRCB Resolution No. 88-63 as modified by Res No. 2006-0008, Beneficial use as a domestic or municipal water supply. Maximum TDS levels for agricultural and other beneficial use are undefined.	SWRCB
Undefined	"Freshwater"	Conventional O&G Development	PRC § 1722.22 for casing requirements	DOGGR
10,000	groundwater	Well stimulation	USDW, CA Water Code § 10783(k)(2)	DOGGR, SWRCB
10,000	groundwater	UIC Program	UDSW, protected unless exempted, 40 C.F.R. 144.3	EPA, DOGGR
10,000	groundwater	O&G development on federal or tribal land	Onshore Oil & Gas Order No. 2, 53 Federal Register 46798	BLM, DOGGR, SWRCB

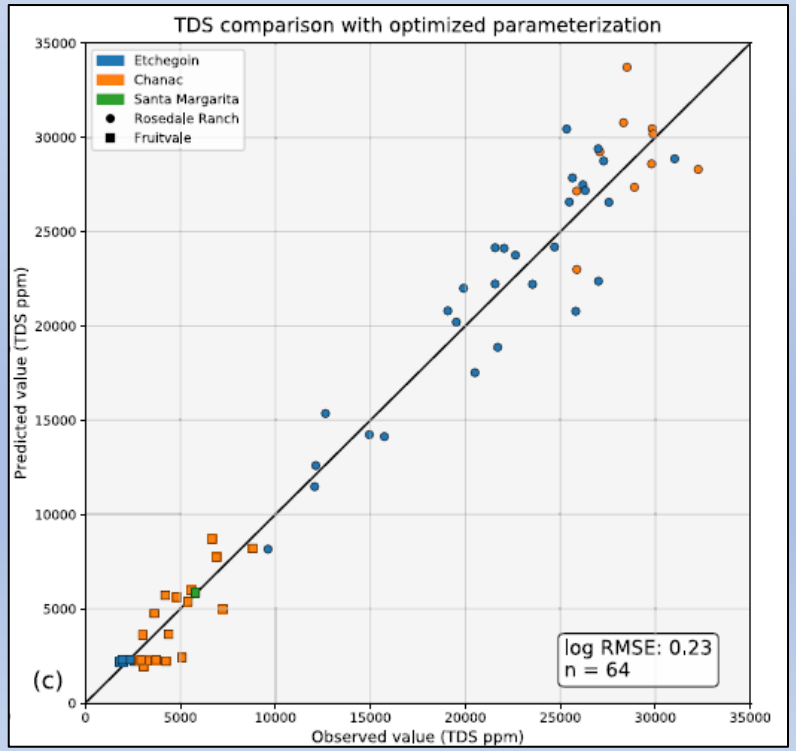
USGS Study on Mapping TDS in Fruitvale and Rosedale Ranch Areas.

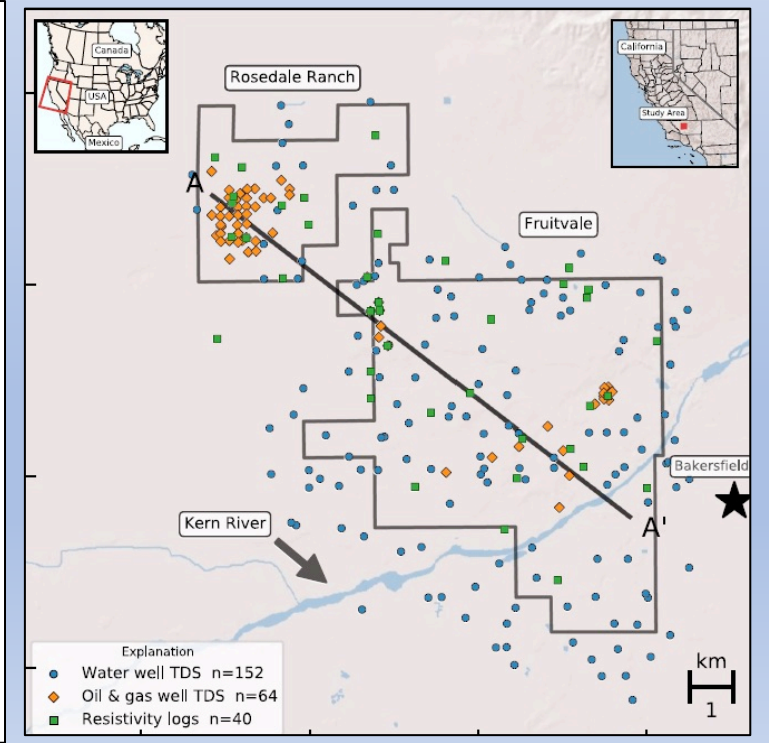
Water well samples, produced water samples, formation resistivity logs, Archie's Equations with optimized parameters, temperature and HCO^-_3 correction, and geostatistical methods were used to delineate TDS levels.

Use of resistivity logs to estimate TDS has considerable uncertainty but reasonable estimates of TDS can be made.



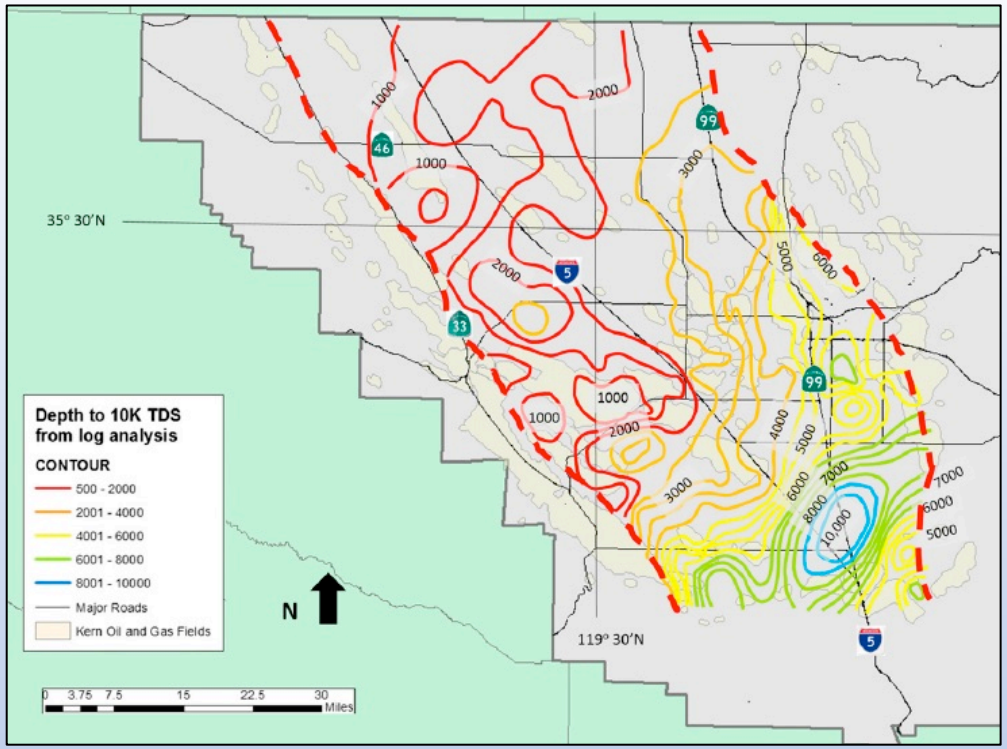
Figures from Stephens et al. (2018)

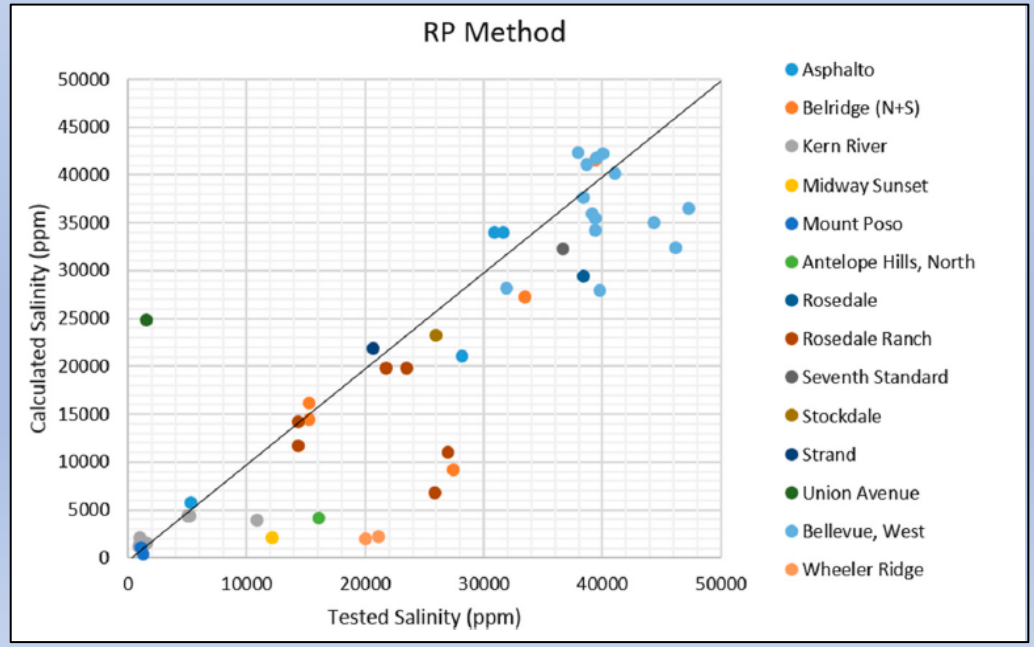




Estimation of Depths (ft) to 10,000 mg/L in Southern San Joaquin Valley

Produced water samples, formation resistivity logs, Humble approximation of Archie's Equations, assumption of porosity at 30% used to delineate TDS levels.





Figures from Gillespie et al. (2017)