An Independent Review of Scientific and Technical Information on Advanced Well Stimulation Technologies in California

Noon – 1:00 PM, September 3, 2014

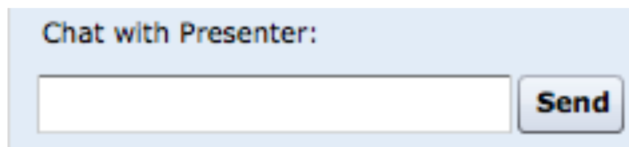
California Council on Science and Technology

BERKELEY LAB

How to Participate

Use the "chat" feature to submit questions in writing.

The chat entry box is in the lower left hand corner of your window. Enter a question and click "send."



If you don't see the chat box, you may need to click on the "show chat" button in the upper left hand corner.

Or you can email questions to cafrac@ccst.us

The moderator will take questions at the end of the presentation.

BLM's Need for the Science Assessment

- In response to a series of legal challenges, the BLM CA requested an independent scientific assessment of well stimulation technologies
- BLM CA needed up-to-date, scientifically accurate information about well stimulation techniques to improve environmental analysis documents
- Information resulting from the science assessment will be used in future oil and gas planning, leasing and development decisions (including the Hollister Field Office Oil and Gas Leasing and Development EIS)

CCST's Independent Review of Scientific and Technical Information on Well Stimulation Technologies in California

- Purpose of the study was to conduct an independent scientific assessment of the potential and impacts of well stimulation technologies in California
- This was an independent scientific expert study
  - An assessment of published literature and analysis of available data
  - No new data collection
  - Interested parties nominated literature to the study

Who Performed the Study

- The CCST's California Well Stimulation Steering Committee provided oversight, scientific guidance and input for the project
- The study analysis was conducted by Lawrence Berkeley National Laboratory (Berkeley Lab) with expertise in Earth Sciences
- Pacific Institute (PI) provided expertise in water issues

Steering Committee Members Were Experts in a Variety of Topics

Expertise	Member
Behavior in fractured rock, energy systems, petroleum reservoirs	Jane Long
Subsurface hydrology, transport in complex subsurface systems	Jens Birkholzer
Life cycle assessment for energy systems, air quality and air emissions from oil and gas production	Adam Brandt
Petroleum geology and resource analysis	Don Gautier
Water resources	Peter Gleick
Methane and measurement of methane leakage	Robert Harriss
Industry well stimulation theory and practice	Dan Hill
Sustainability and general industry practice	Amy Myers Jaffe
CA oil and gas data, geology and hydrogeology, risk analysis	Preston Jordan
Reservoir engineering and geochemistry, enhanced oil recovery and reservoir characterization	Larry Lake
Air, climate and public health impacts of energy production	Seth Shonkoff
Environmental science and engineering	Samuel Traina

Authors

- Jane Long (CCST, Chair)
- Jens Birkholzer (LBNL, Lead)
- Preston Jordan (LBNL, Principal Investigator)
- James Houseworth (LBNL, Principal Investigator)
- Laura Feinstein (CCST, project manager)
- Patrick Dobson (LBNL)
- Dev Millstein (LBNL)
- Matthew Reagan (LBNL)
- William Stringfellow (LBNL)
- Ruth Tinnacher (LBNL)
- Charuleka Varadharajan (LBNL)
- Heather Cooley (PI)
- Kristina Donnelly (PI)
- Matthew Heberger (PI)
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- William Foxall (LBNL)
- Nathaniel Lindsey (LBNL)

California Council on Science and Technology

- CCST is a nonpartisan, impartial, not-for-profit 501(c)(3) corporation established via Assembly Concurrent Resolution (ACR 162) in 1988 by a unanimous vote of the California Legislature

- It is designed to offer expert advice to the state government and to recommend solutions to science and technology-related policy issues.

- CCST is governed by a Board of Directors composed of representatives from its sponsoring academic institutions, from the corporate and business community, as well as from the philanthropic community

The Role of CCST - Science and Technology in the State's Interest

- Not for profit, 501(c)3 comprised of over 200 of California's top talent

- Committed to serving the State in all aspects of science and technology
  - Sustaining institutions: UC, CSU, CCC, Stanford, USC, CalTech
    - Affiliate members: LBNL, LLNL, Sandia, SLAC, NASA Ames, JPL

CCST is comprised of :

16 Board Members

30 Council Members (18 Academia, 8 Industry, 4 DOE/NASA)

136 Senior Fellows

12 Cal Teachers Advisory Council Members

10 S&T Policy Fellows

And includes:

3 Nobel Laureates

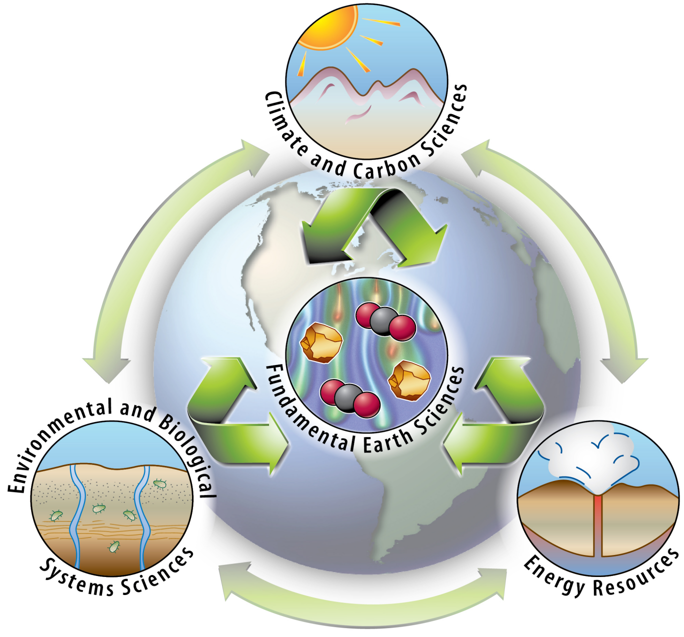
81 National Academies' Members

11 National Medal of Science or Technology

6 National Board Certified Teachers

Lawrence Berkeley National Laboratory

- Discovery science, energy innovation and environmental solutions
- ~$800 Million Budget; 4,200 Employees; 1,000 Students
- 13 Nobel Prizes – most recent in 2011 for the discovery of dark energy
- 70 members of the National Academy of Sciences (~3% of the Academy)
- 10,000 researchers from industry/universities annually use the Lab's unique research facilities.



Earth Sciences at Berkeley Lab

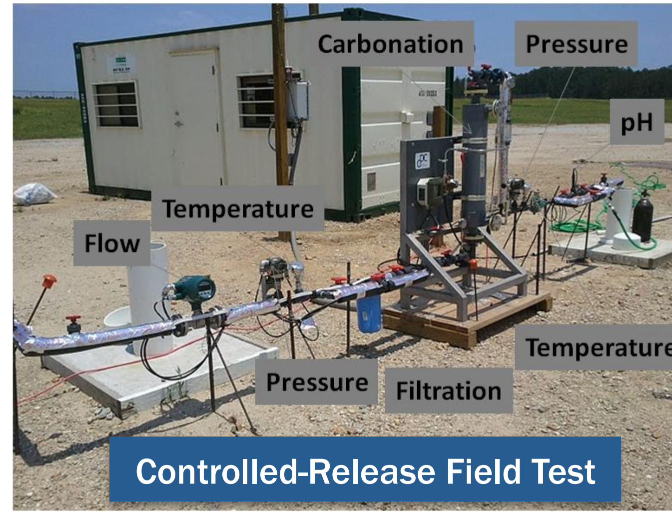
MISSION

...to create new knowledge and capabilities needed to enable sustainable stewardship of **critical environmental systems** and judicious use of the Earth's **natural energy resources.**

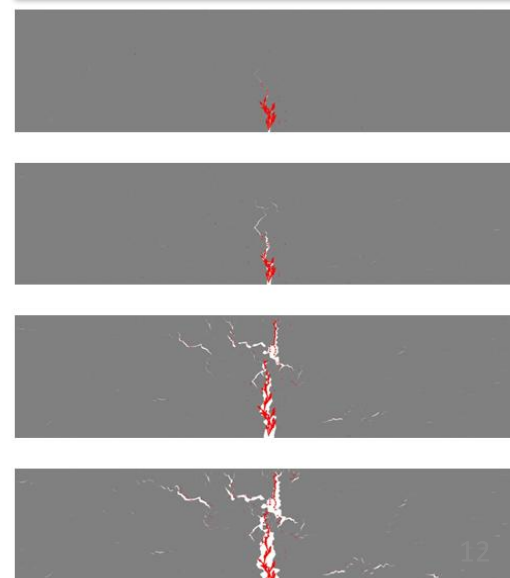
Lawrence Berkeley National Laboratory

Current R&D Examples Related to WST and Impacts

- Coupled modeling of hydraulic fracturing processes
- Reactive geochemistry and multi-scale flow processes in shale
- Hydraulic fracturing pathways and scenario assessment
- Fracturing without water
- Simulation-based induced seismicity hazard assessment
- Best practices for addressing induced seismicity
- Characterization and monitoring, field experiments
- Assessment of leakage on groundwater quality
- Water-energy issues



Simulating Fracture Evolution



Pacific Institute

- Is a tax-exempt 501(c)(3) organization established in 1987.
- Conducts interdisciplinary research to advance environmental protection, economic development, and social equity—in California, nationally, and internationally.
- Has three integrated programs
  - Water,
  - Corporate Sustainability,
  - Community Strategies for Sustainability and Justice.

PACIFIC INSTITUTE

Key Questions Addressed by the Study

- What is past, current and potential future practice in well stimulation technologies including hydraulic fracturing, acid fracturing and matrix acidization in California?
- Where might these technologies allow expanded production of oil onshore in California?
- What are the potential direct environmental hazards of these specific technologies in California?

Relationship between the Three Questions

#1

Well stimulation techniques: past, present, future?

1. High vol fracturing
2. Acid fracturing
3. Matrix acidizing

#2

Expanded oil and gas production in CA because of these technologies? Where? When?

#3

What are direct environmental impacts of these specific technologies?

- Indirect effects of WST enabled production
- Health and environmental impacts of oil and gas production

SB4 study content

Vol I: Geology and Technology

Well stimulation techniques: past, present, future for oil, **gas and offshore**?

1. High vol fracking
2. Acid fracking
3. Matrix acidation

What are alternative practices

Expanded oil and **gas** production on shore and **off shore** in CA because of these technologies?
Where? When?

Vol II: Potential impacts

What are direct **health** and environment impacts of these specific technologies?

Some impacts from production enabled by WST :
Eg production fluid disposal, ecological disruption

Vol III: Case Studies

Case Studies

A. San Joaquin oil and gas
B. Los Angeles
C. Monterey source rock
D. Offshore

The Basis of our Assessment

- Peer reviewed published literature
- Analysis of available data from CDOGGR and other publicly available sources
- Other relevant publications including reports and theses. Make the qualifications of this information transparent
- The expertise of the committee and scientific community to identify issues
- Literature could be nominated to the committee emailed as attachments to CAFRAC@ccst.us and through the following website:
- http://ccst.us/projects/fracking_public/submission-form.php

Study Process

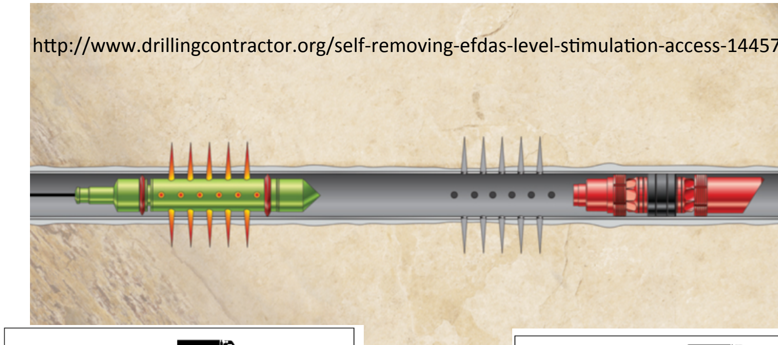
Task	Completed
Project Kick-Off	Sep 2013
Steering committee appointed by CCST	Feb 2014
Public webinars held, literature submissions received from public	Feb 16, 2014
Body of report delivered for steering committee review	March 6, 2014
Executive summary written by steering committee	March 28, 2014
Report reviewed by independent experts	May 14, 2014
Authors and steering committee responded to peer review	June 27, 2014
Report monitors approved responses to peer review	July 22, 2014
Report made available to public	Aug 28, 2014

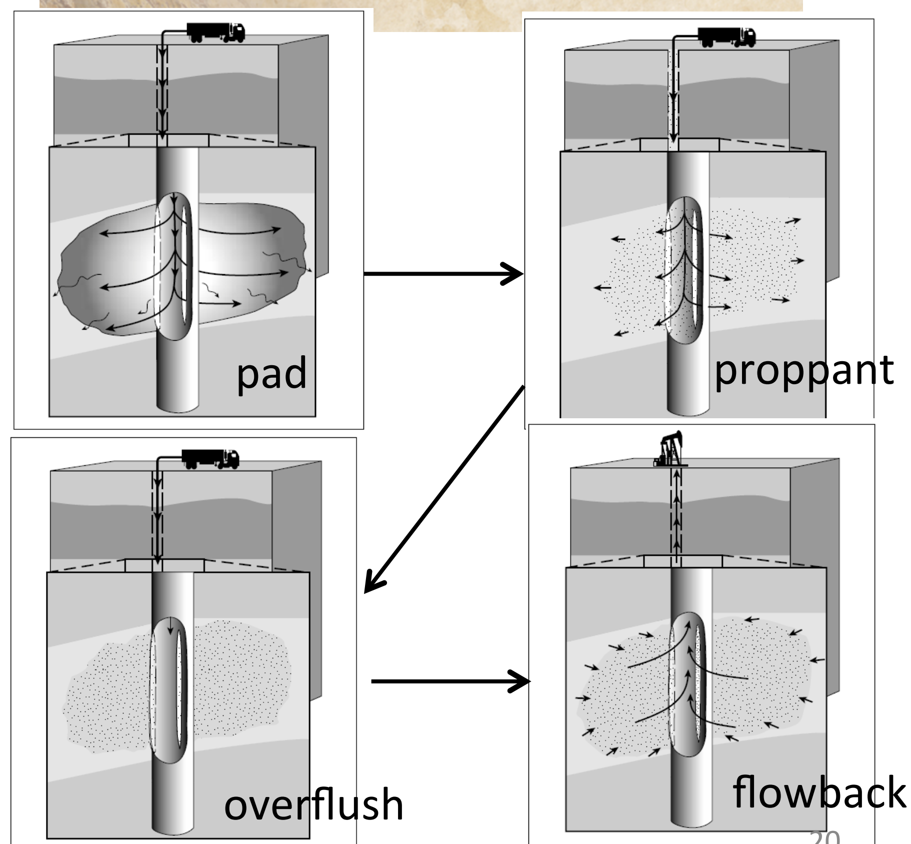
Key Question 1: What are the past, current and potential future practices in well stimulation technologies including hydraulic fracturing, acid fracturing, and matrix acidizing in California?

- Hydraulic Fracturing
  - Proppant fracturing – conductivity of fractures preserved by injecting granular proppant into fractures
  - Acid fracturing – conductivity of fractures preserved by injecting acid. Only known successful field applications have been in carbonate reservoirs.
- Matrix Acidizing
  - Acid opens pores near the well-bore

Typical Hydraulic Fracturing Process

- Isolate stage and perforate
- Pre-flush with HCl to clean out perforations and weaken rock
- Inject fracturing fluid called the "pad" to initiate and propagate fractures
- Add proppant to fluid to retain fracture permeability (or use acid for acid fracturing)
- Overflush after fracturing to displace proppant from well
- Flowback to remove fracturing fluid



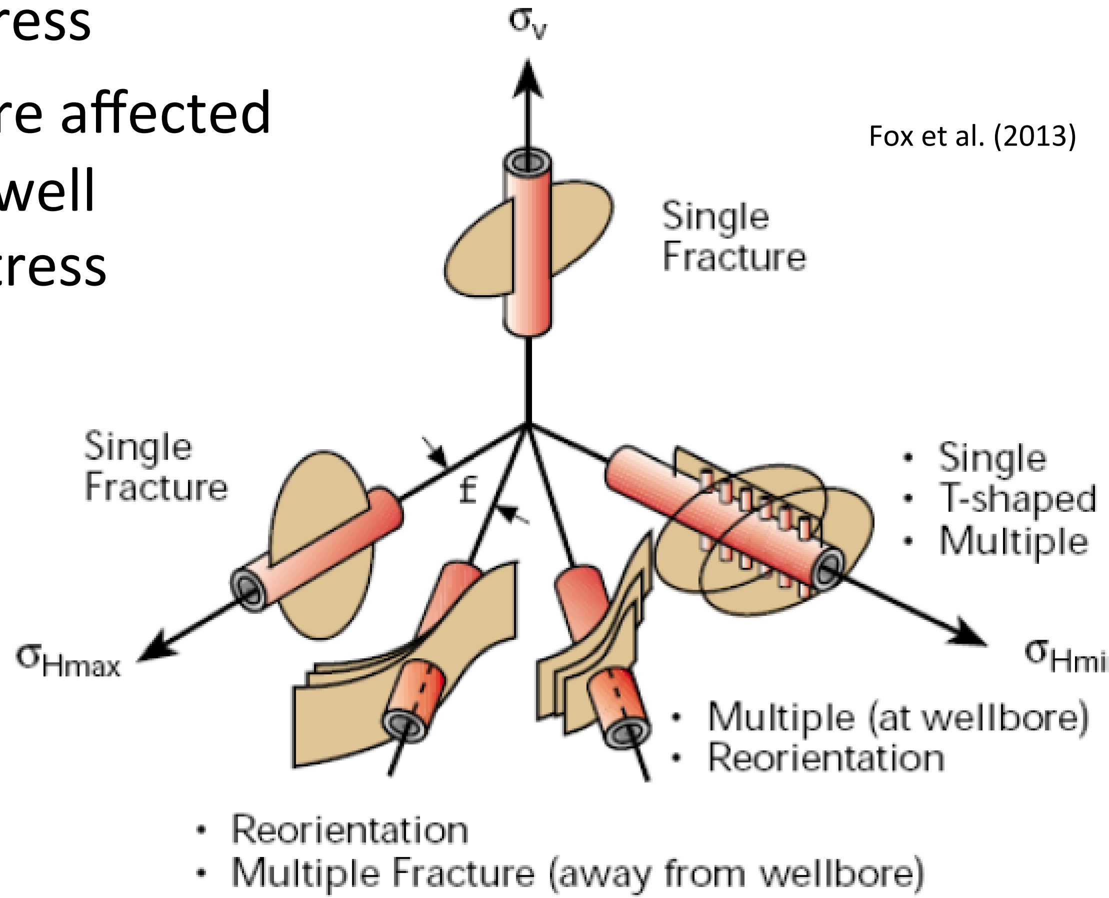


modified from Economides and Nolte (2000)

State of Stress and Rock Properties Determine the Orientation of the Hydraulic Fracture

- Fractures open in the direction of the minimum principal stress
- Fracture characteristics are affected by the orientation of the well relative to the principal stress directions
  - transverse fractures for lower permeability matrix
  - longitudinal fractures for higher permeability matrix

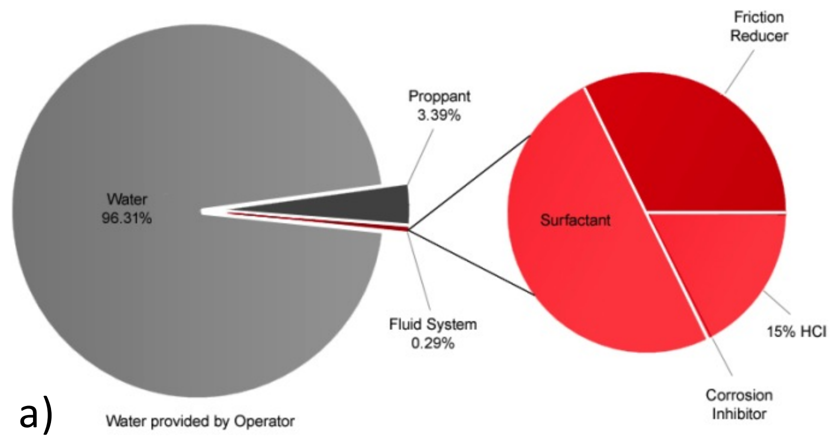
Fox et al. (2013)



Fracturing Fluid Additives and Volumes

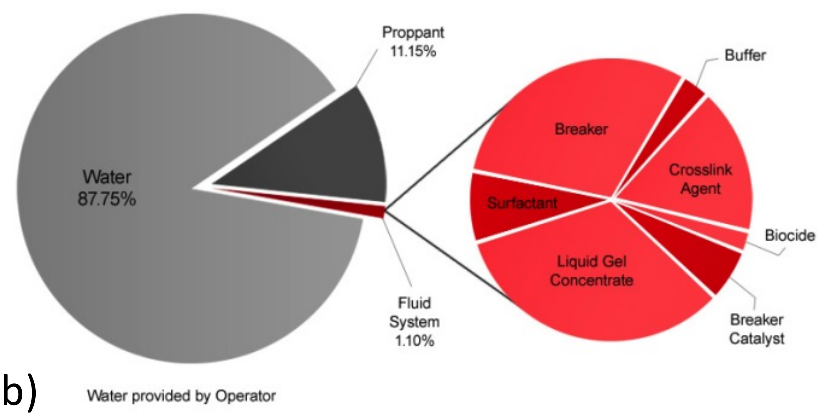
- Slickwater fluids carry the lowest chemical concentration and less proppant
- Slickwater volume per stage typically ~ 1 to 3 x 10^5 gallons
- Each stage ~ 200 to 400 feet, or about 1,000 gal/ft
- Fluid volume injected reduced by about a factor of 2 to 4 for cross-linked gels

a)



Example Slickwater Composition

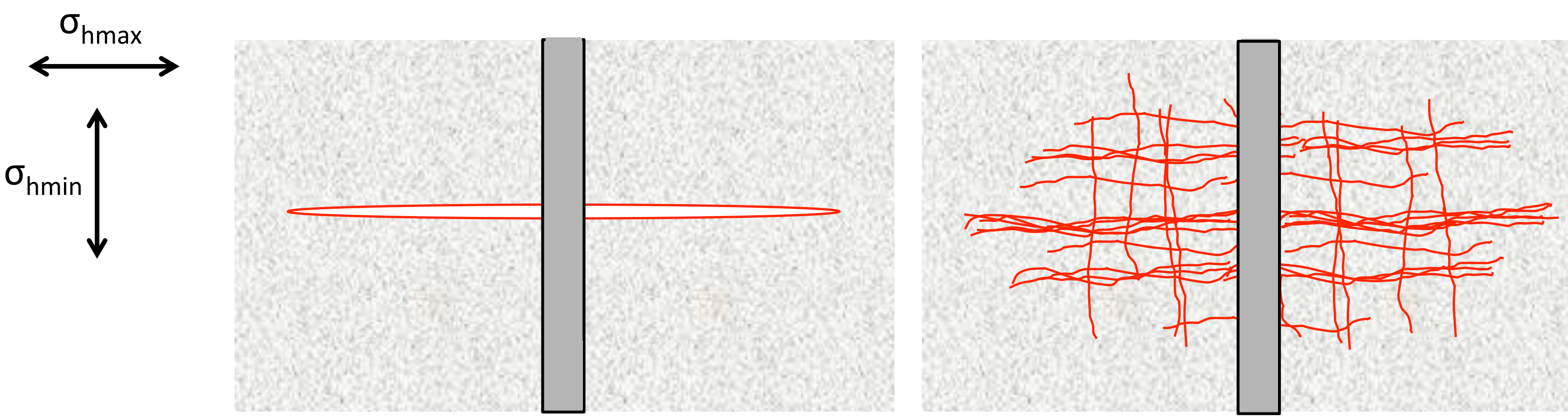
b)



Example Cross-Link Gel Composition

http://www.halliburton.com/public/projects/pubsdata/Hydraulic_Fracturing/fluids_disclosure.html

Fracturing Fluid Viscosity, Rock Properties and Fracture Complexity

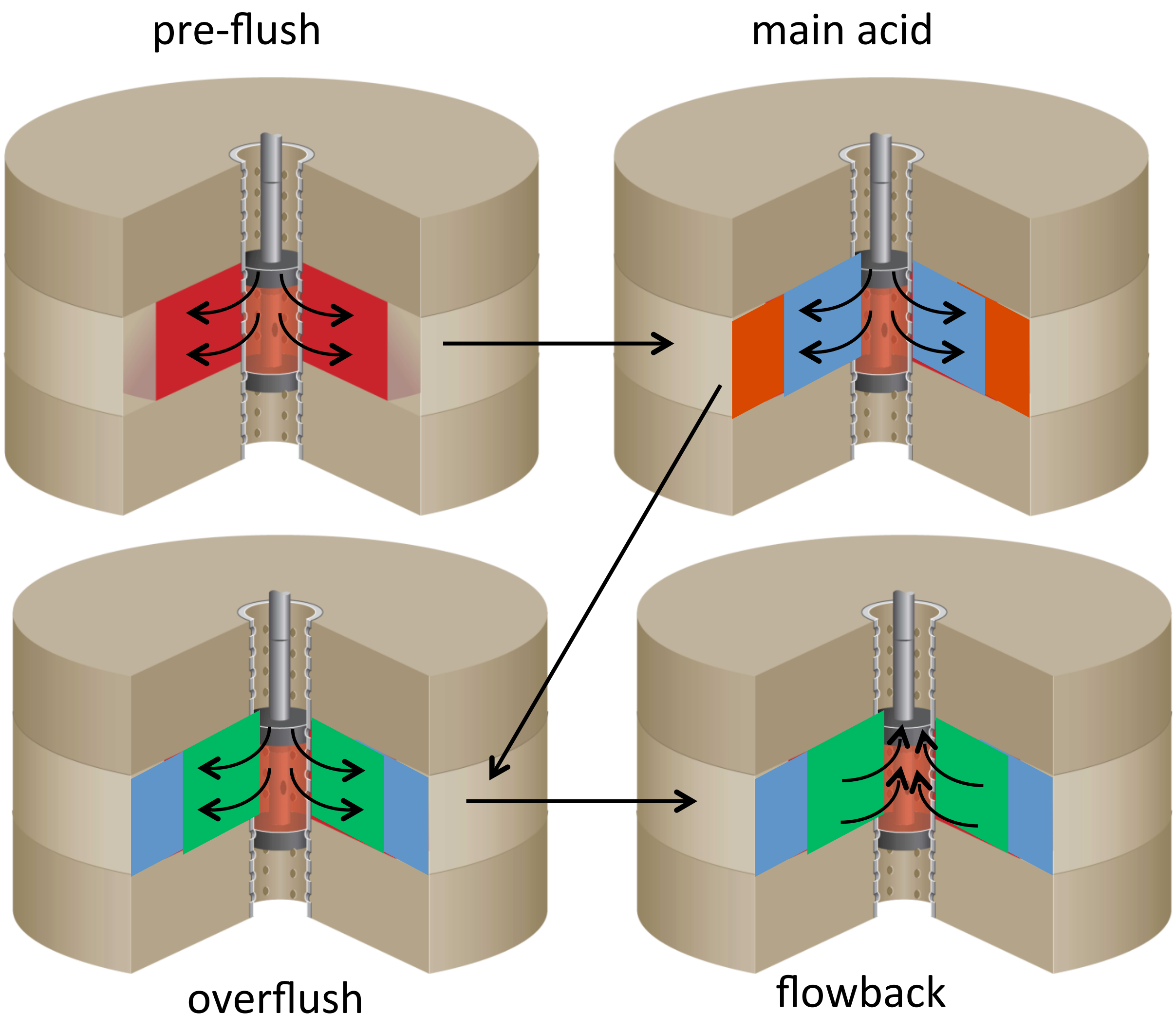


Fracturing Fluid	Higher viscosity cross-linked gel	Lower viscosity slickwater
	Lower injected volume and rate	Higher injected volume and rate
Rock Properties	Higher permeability	Lower permeability
	Less brittle	More brittle
Fracture Geometry	Simpler bi-wing	More complex networks
	Larger fracture aperture	Smaller fracture aperture

Well Stimulation – Matrix Acidizing

- Matrix Acidizing
  - Injection of acidic fluids into a well below fracture pressure to dissolve reservoir rock and/or pore-plugging materials such as drilling muds
  - Generally not effective for low permeability reservoirs
  - Two distinct variants
    - Sandstone acidizing (siliceous reservoirs only)
      - acid treatment intended to dissolve siliceous minerals typically using a combination of HCl and HF
      - typically used to mitigate formation damage very close to well, with some exceptions
    - Carbonate acidizing (carbonate reservoirs only)
      - acid treatment intended to dissolve carbonate minerals typically using HCl
      - used mainly for formation damage mitigation, but can provide limited reservoir stimulation

Typical Sandstone Matrix Acidizing Process



modified from
Samuel
and Sengul (2003)

Typical Sandstone Acidizing Fluids and Volumes

- Four phases
  - acid preflush 5-15% HCl
  - main acid 3-13% HCl with 0.5-3% HF
  - overflush 2-8% ammonium chloride
  - flowback
- Each injection phase 10-250 gal/ft, with lower values for lower permeability and/or high clay content conditions
- Typical additives
  - corrosion inhibitors (0.1-2%)
  - iron control agents (0.1-1%)
  - surfactants (0.1-0.4%)

Key Question 1: WST Practice in California

Conclusion 1: Present-Day WST Practices in CA

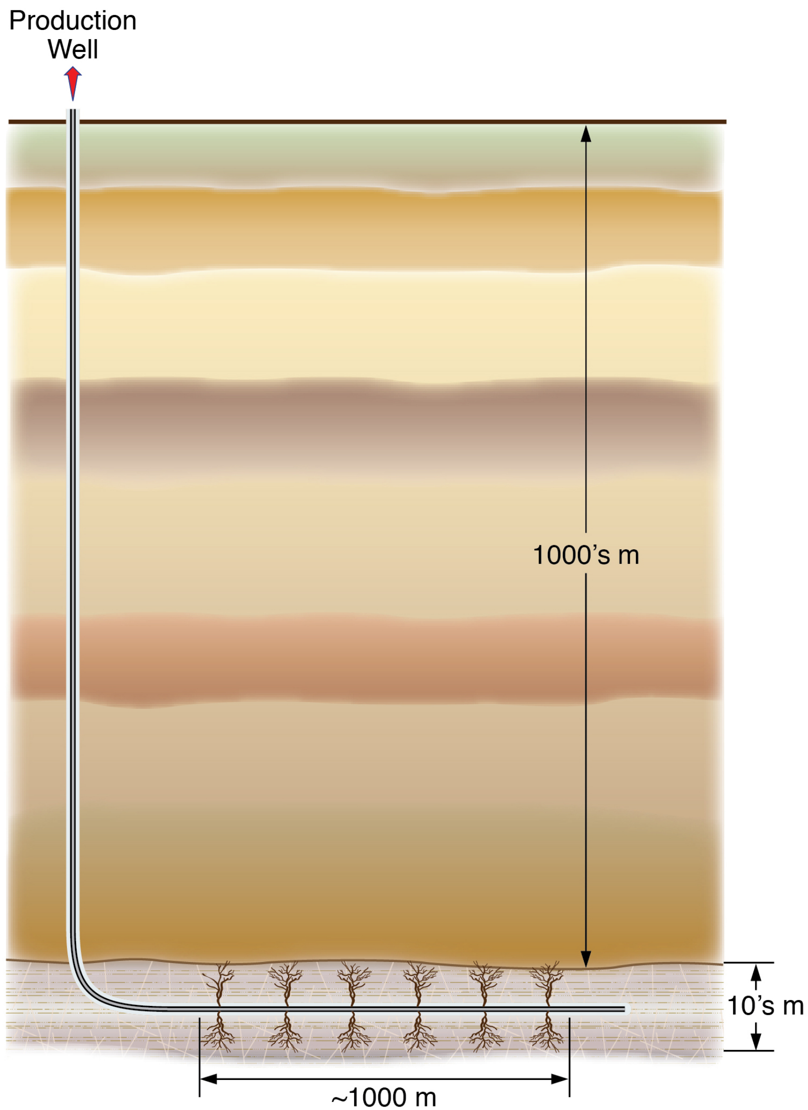
- Available data suggests that present day well stimulation practices in California differ significantly from practices used for unconventional shale reservoirs in states such as North Dakota and Texas.

- Hydraulic fracturing in California tends to
  - use less water per well,
  - use fluids having higher chemical concentrations,
  - occur in shallower and more vertical wells, and
  - target more permeable and weaker rocks.

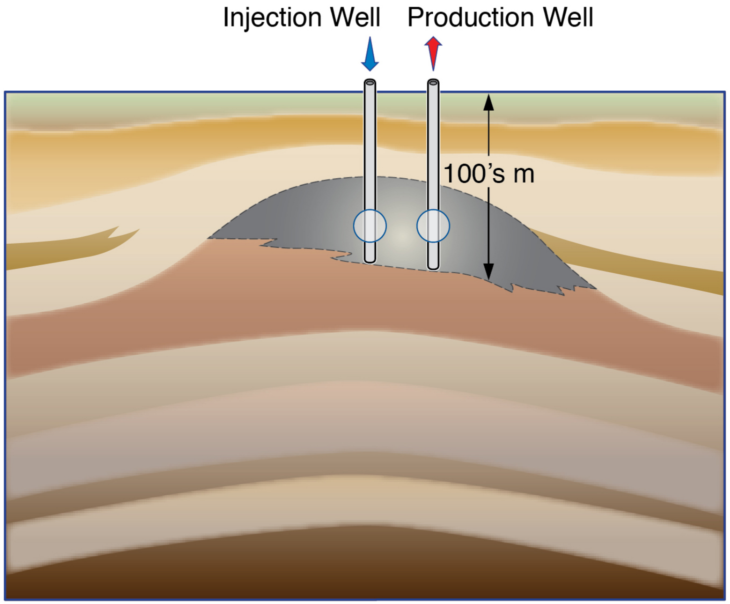
- Therefore the impacts of hydraulic fracturing observed in other states are not necessarily applicable to current hydraulic fracturing practices in California.

Fracked Wells in California Tend to be Vertical

Typical Source Rock Stimulation

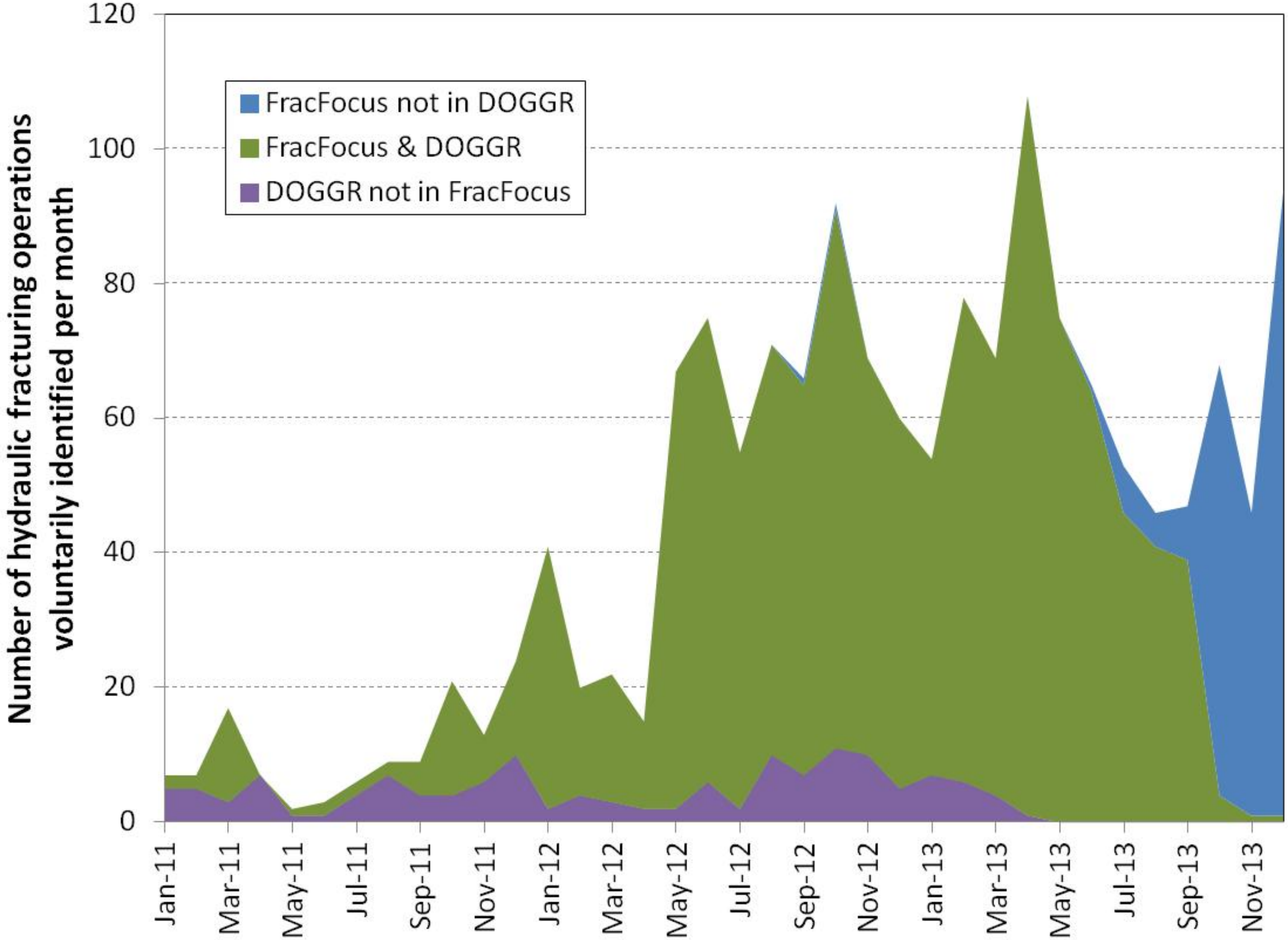


Typical California (Migrated Oil) Stimulation



ESD14-047

Activity - FracFocus and DOGGR



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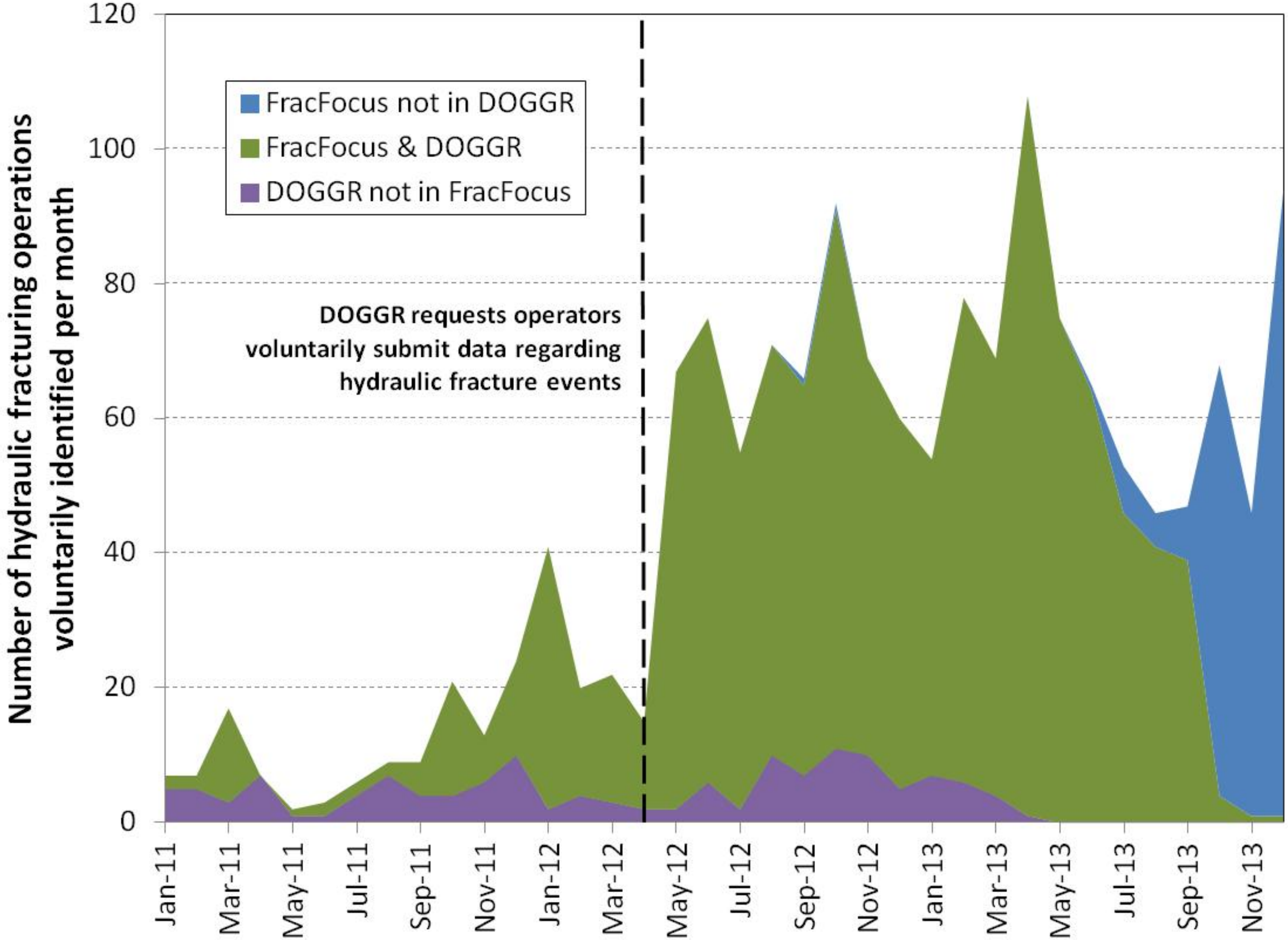

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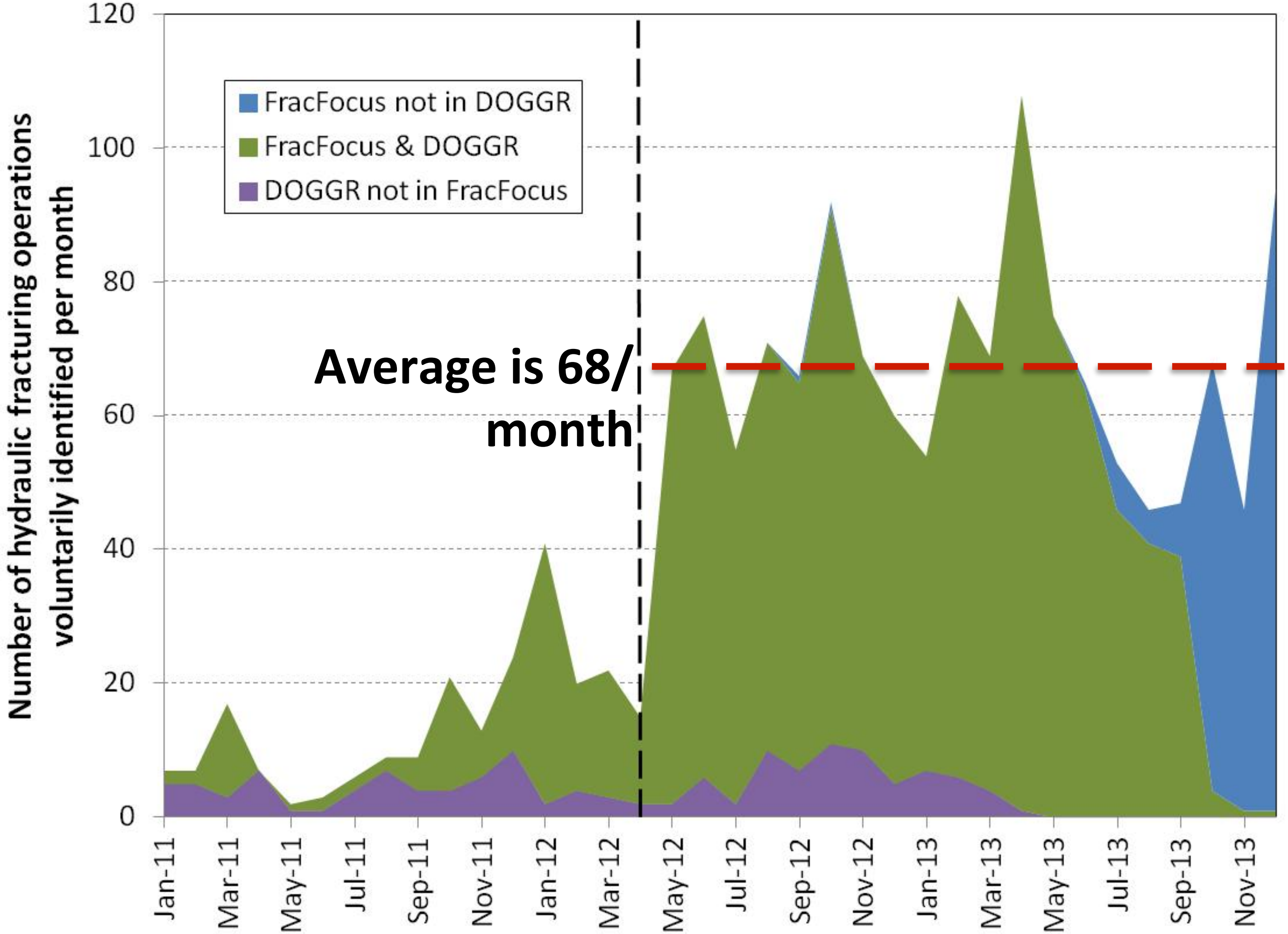
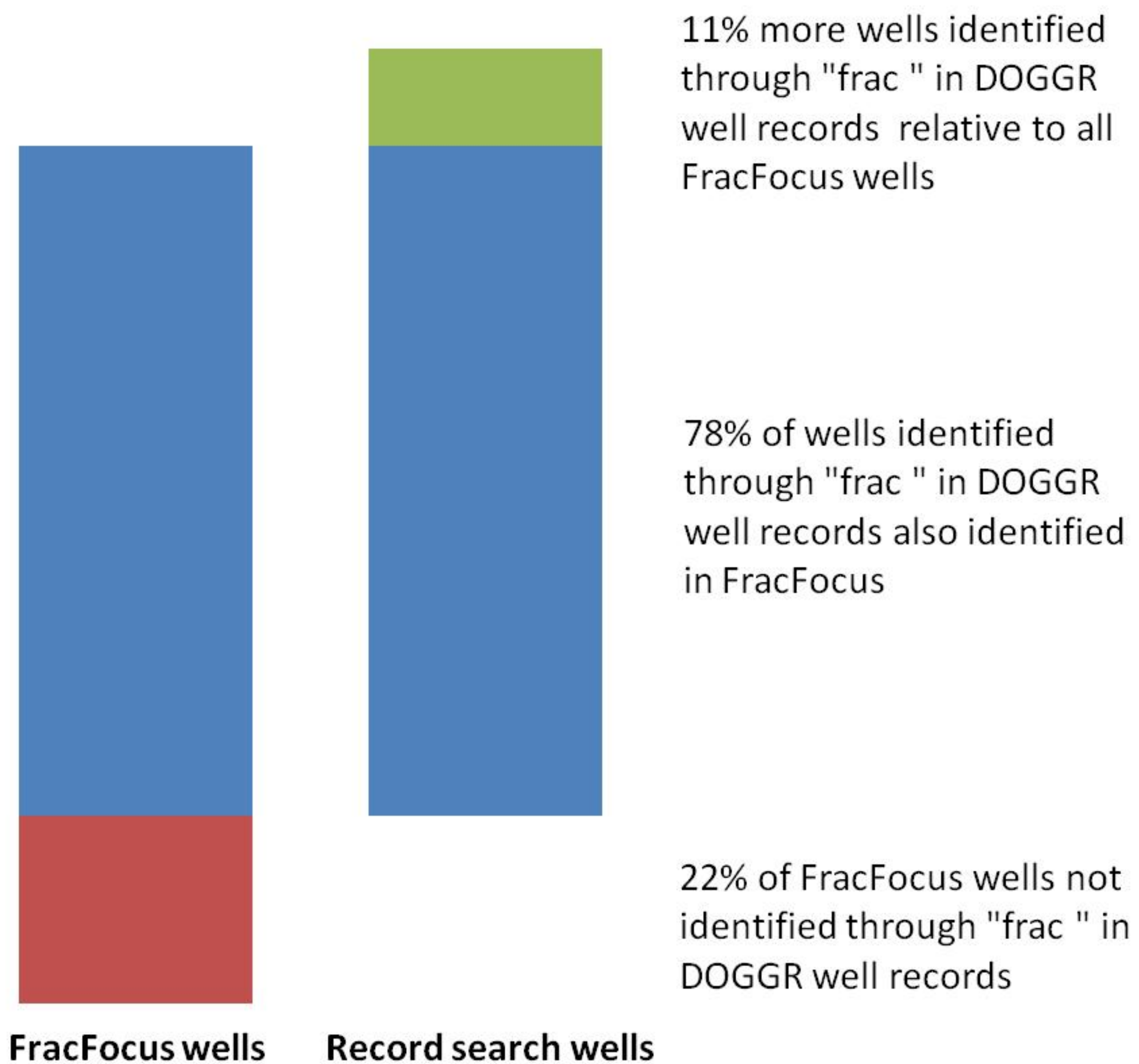
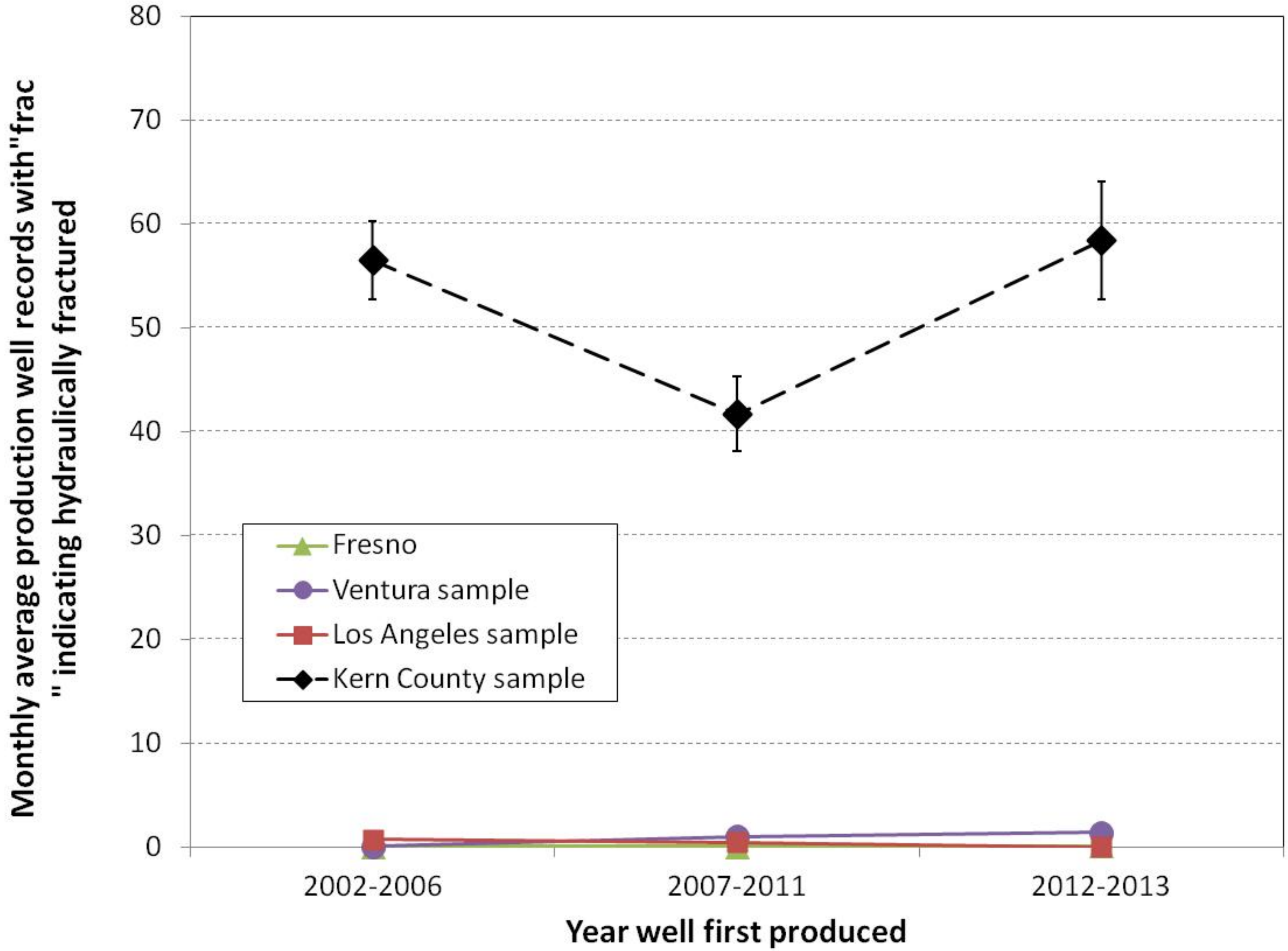


FracFocus and Well Record Search



Historic Activity from Well Records



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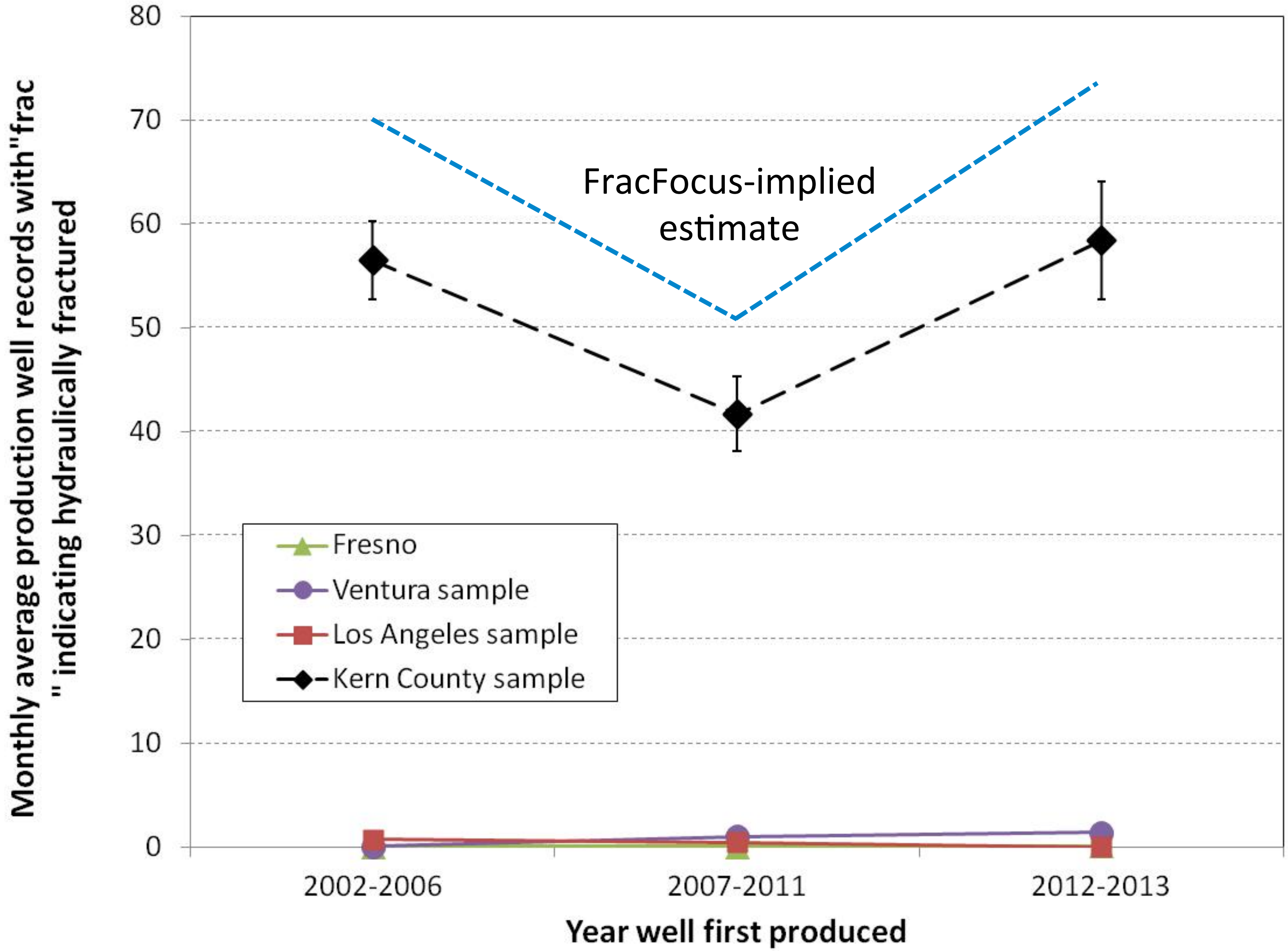

Well Stimulation Activity

- 190 hydraulic fracturing notifications received by DOGGR last December (first mandatory month)

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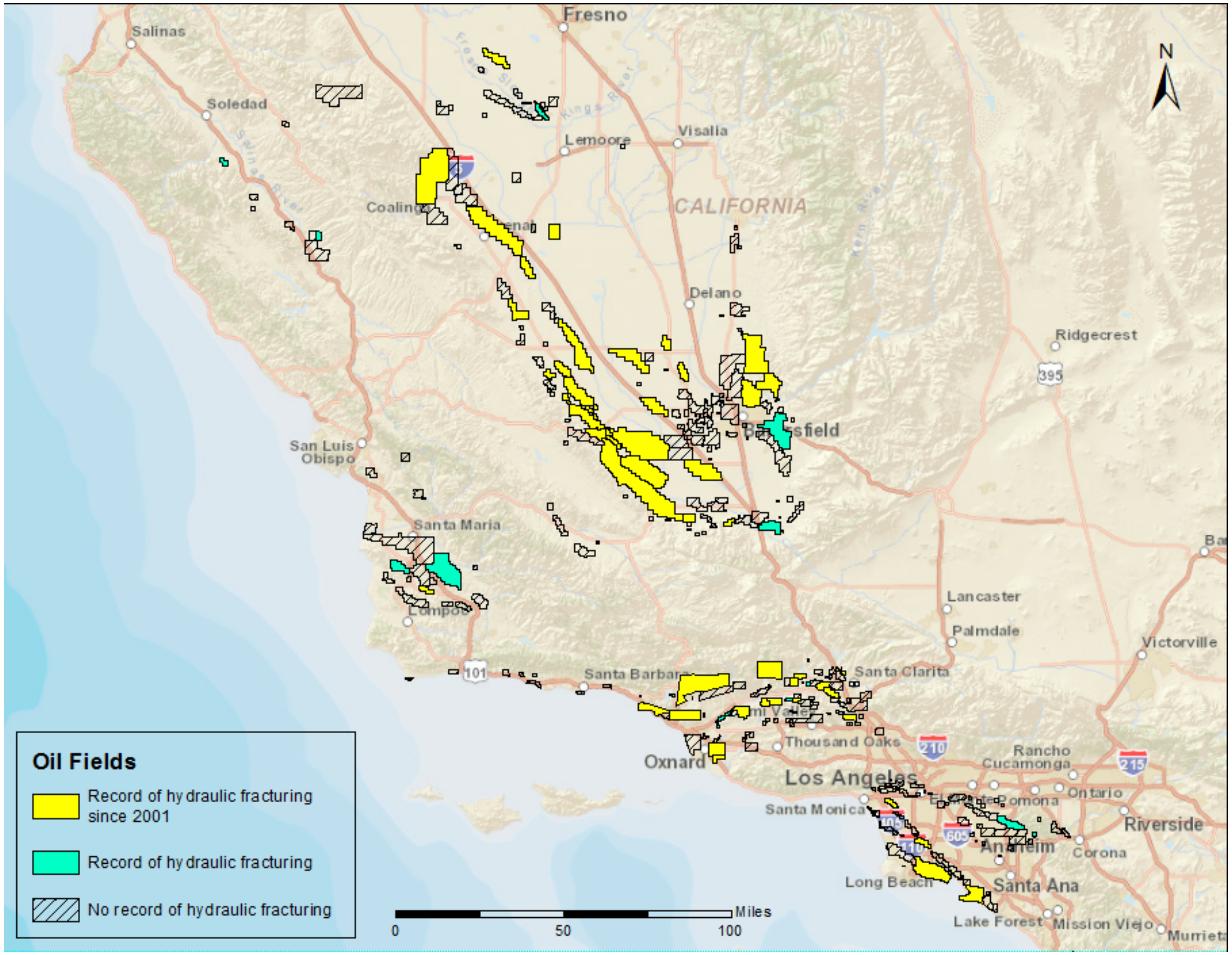
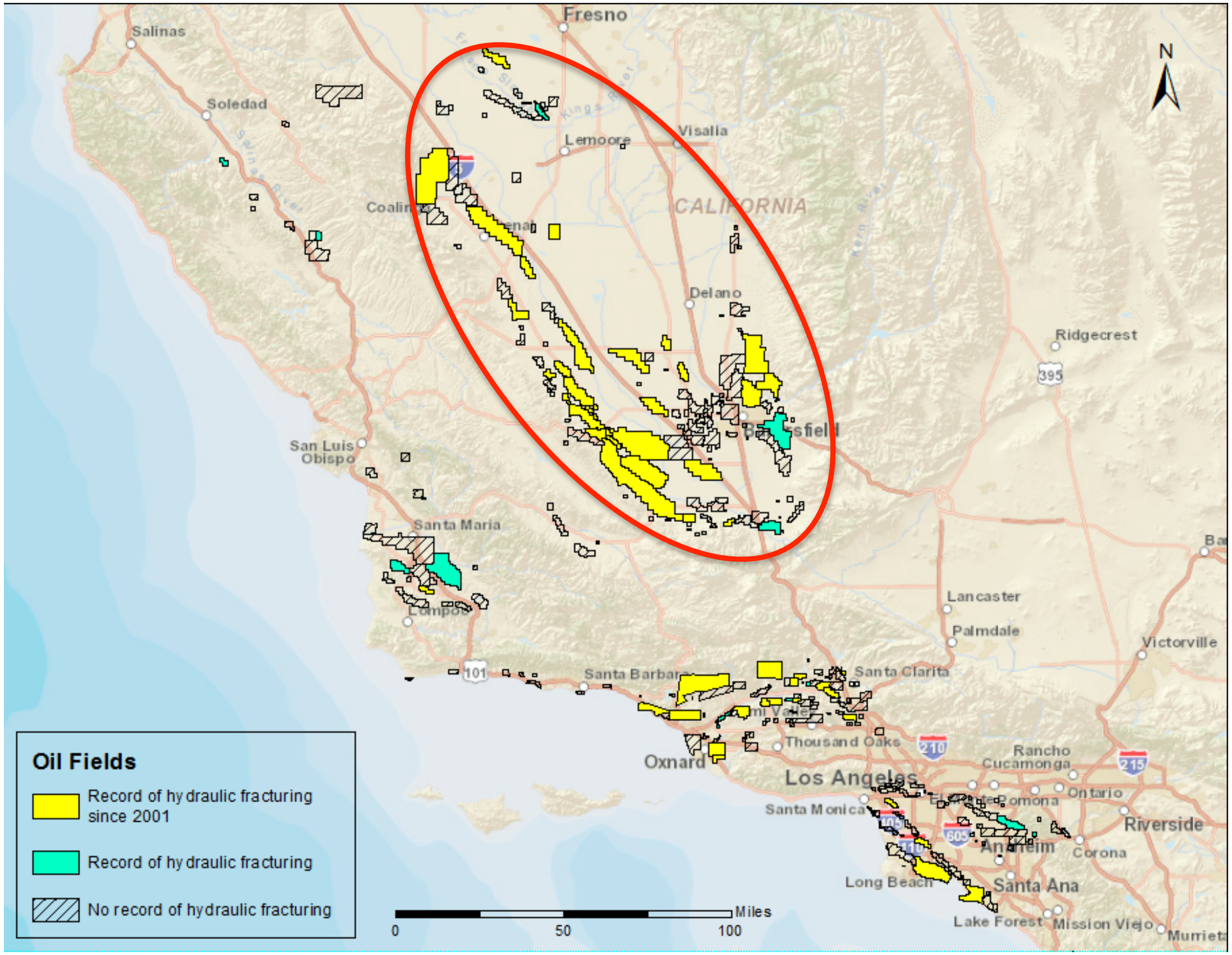
- Suggests 100-150 hydraulic fracturing operations per month
- Notifications indicate about one tenth as many matrix acidizing operations and one hundredth as many acid fracturing operations

Fields With Fracturing Reported



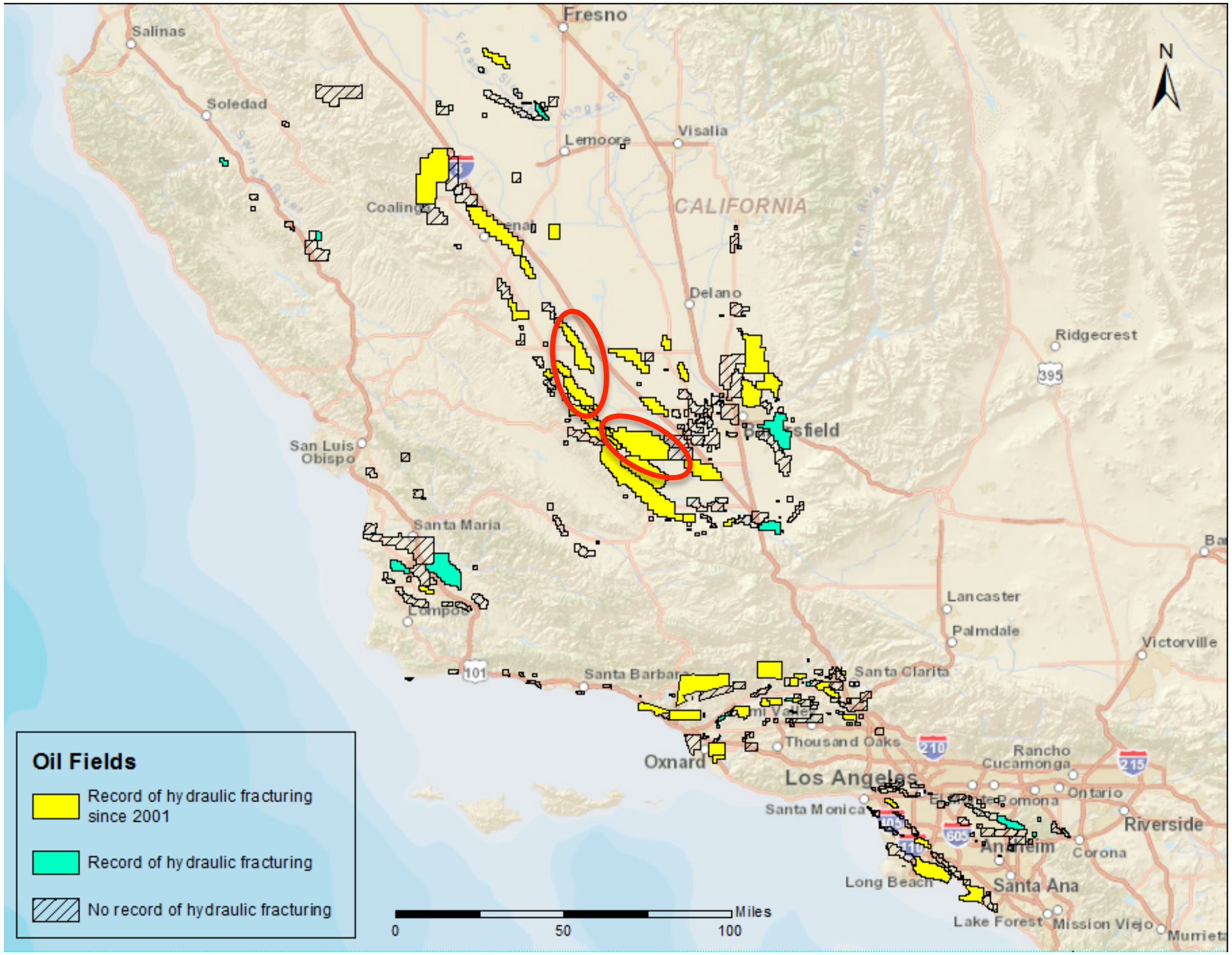
Onshore oil fields with at least one hydraulically fractured well according to DOGGR all well file, DOGGR well record sample search, FracFocus and/or reported in literature

Fields With Fracturing Reported



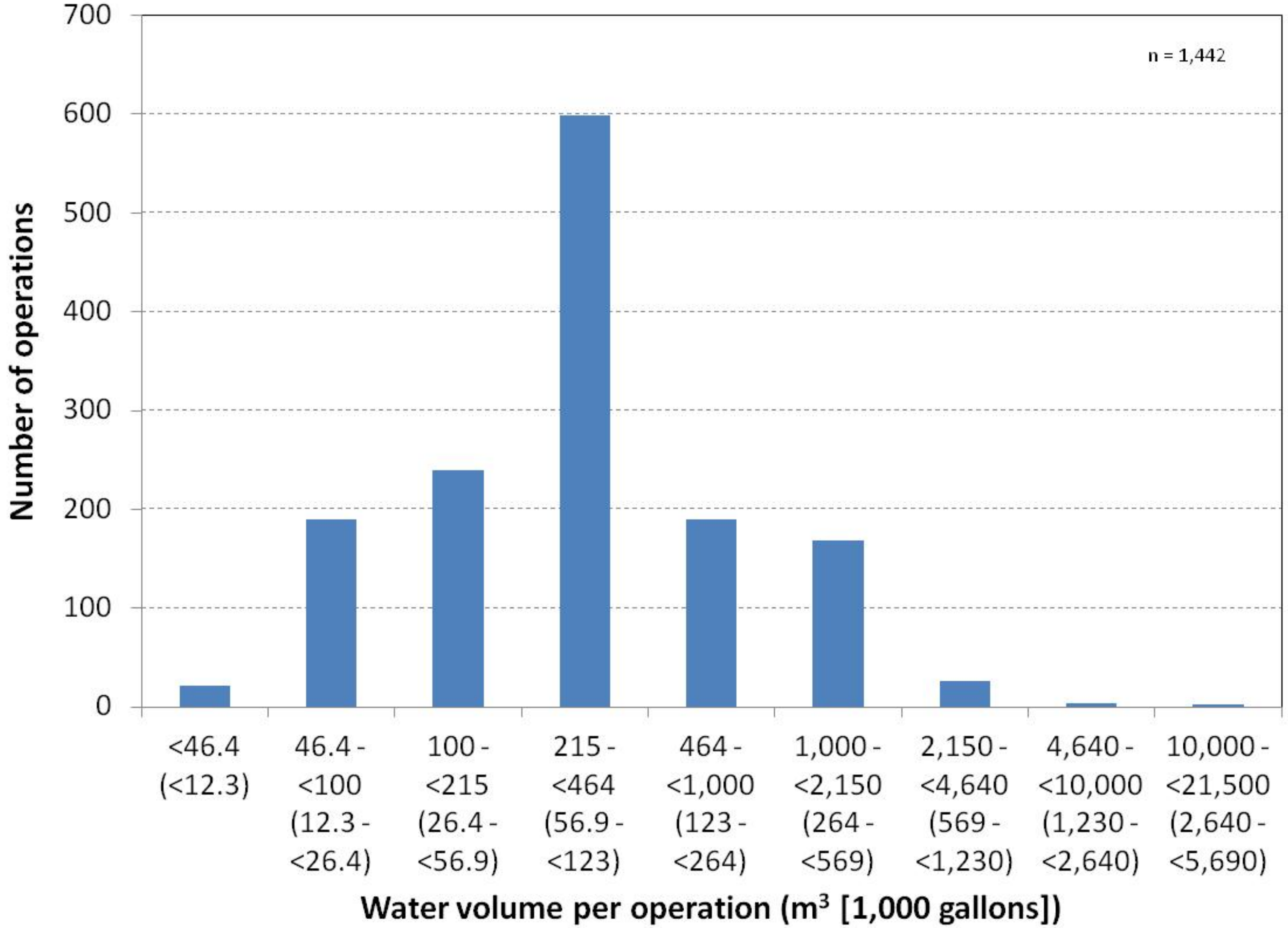
98% of hydraulic fracturing operations in 2012-2013 occurred in the San Joaquin basin according to FracFocus, DOGGR's well layer, and the well record search.

Fields With Fracturing Reported

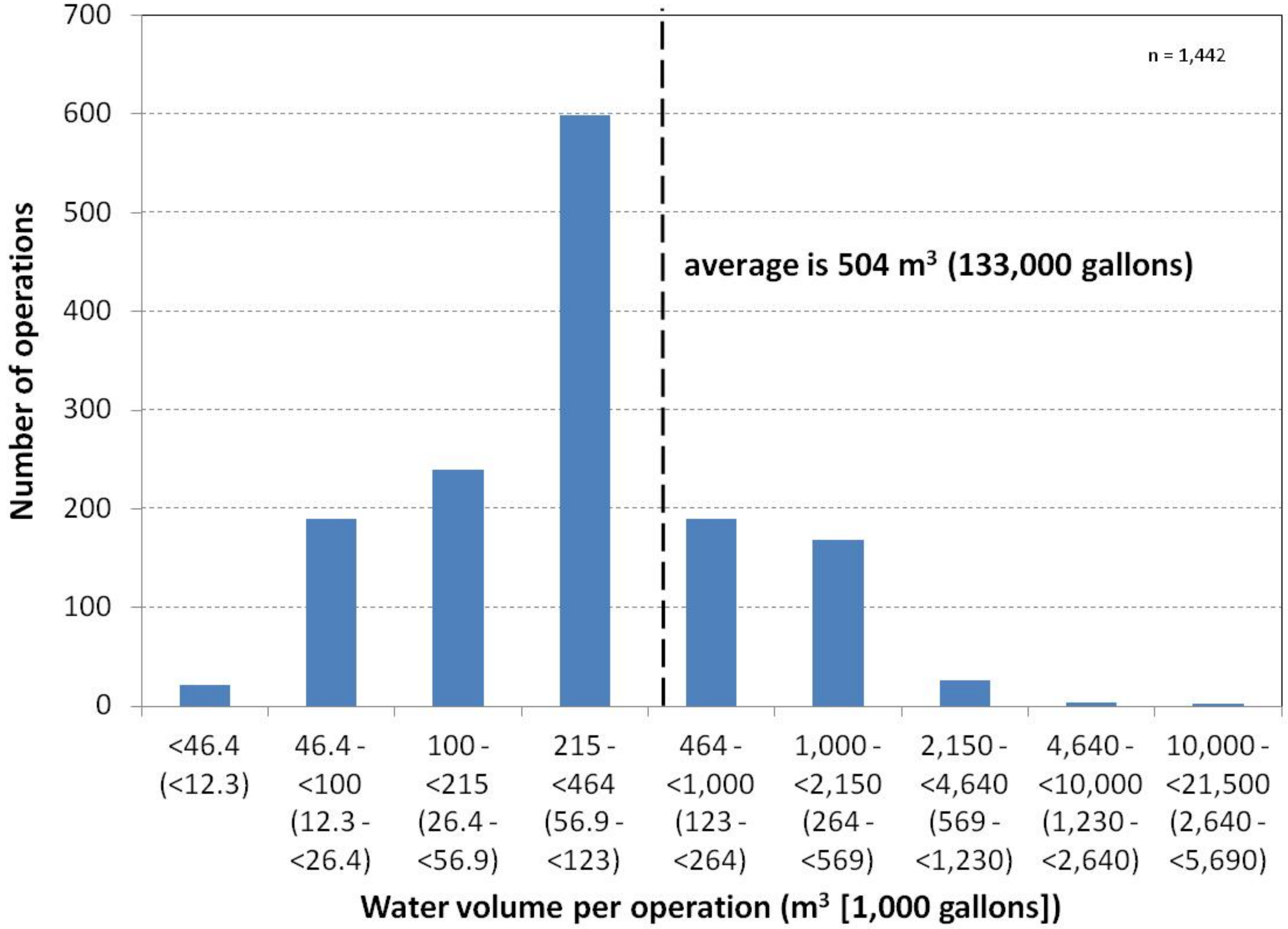


Over 85% of hydraulic fracturing operations in 2012-2013 occurred in four fields on the west side of the San Joaquin Valley: South Belridge, Elk Hills, Lost Hills and North Belridge according to FracFocus, DOGGR's well layer and the well record search results

FracFocus Water Volume



FracFocus Water Volume



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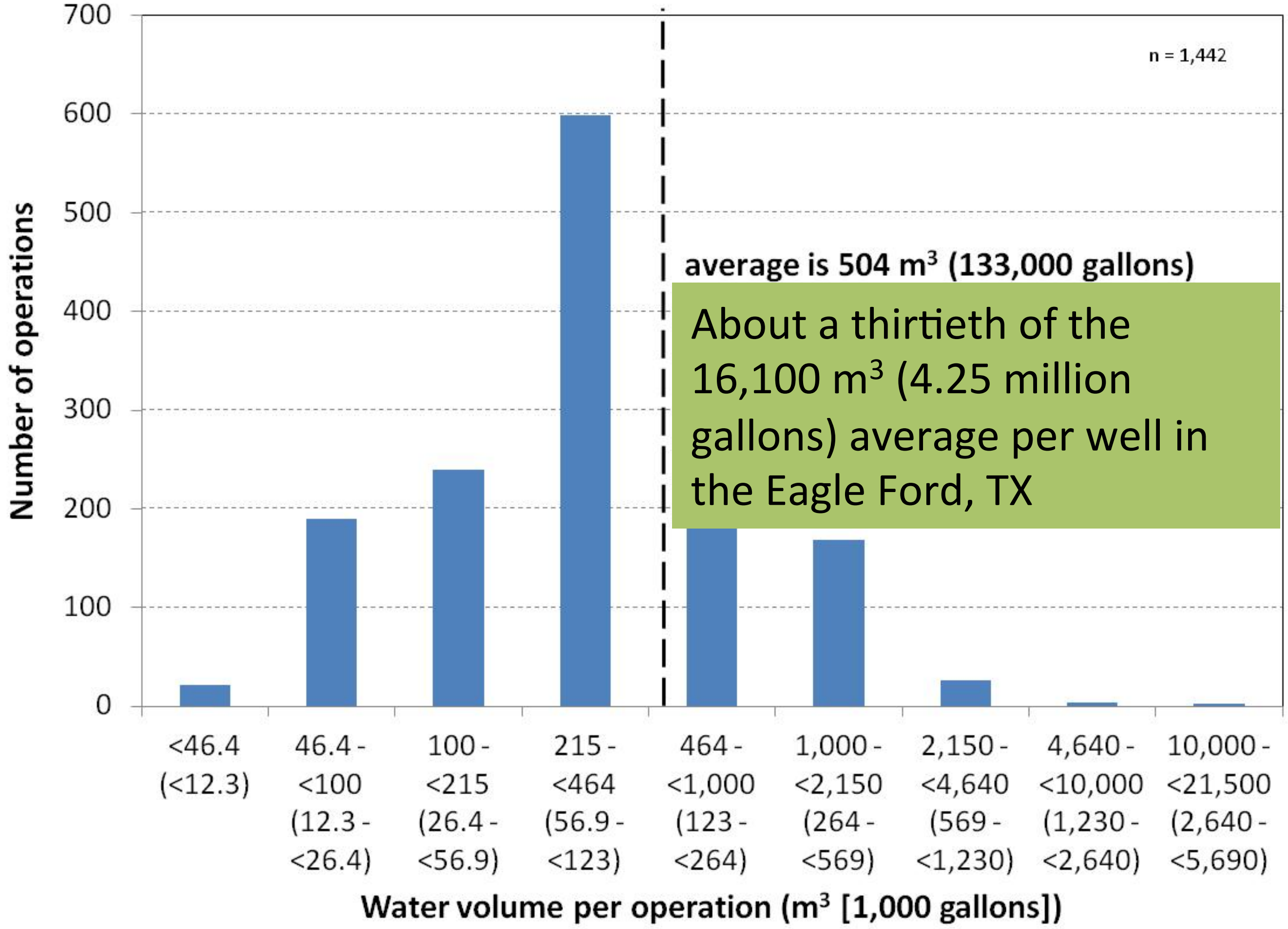
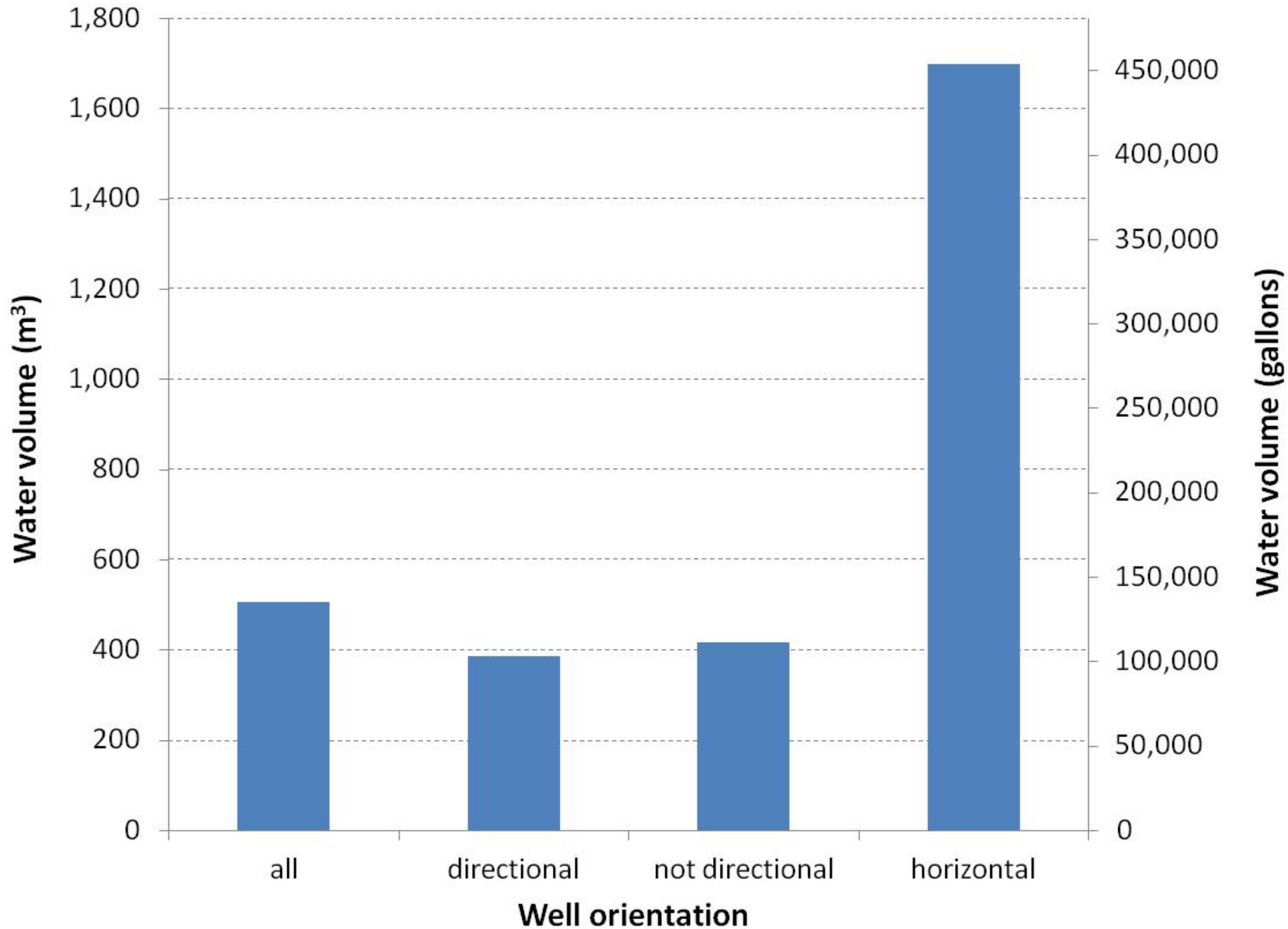


FracFocus Volume by Well Direction



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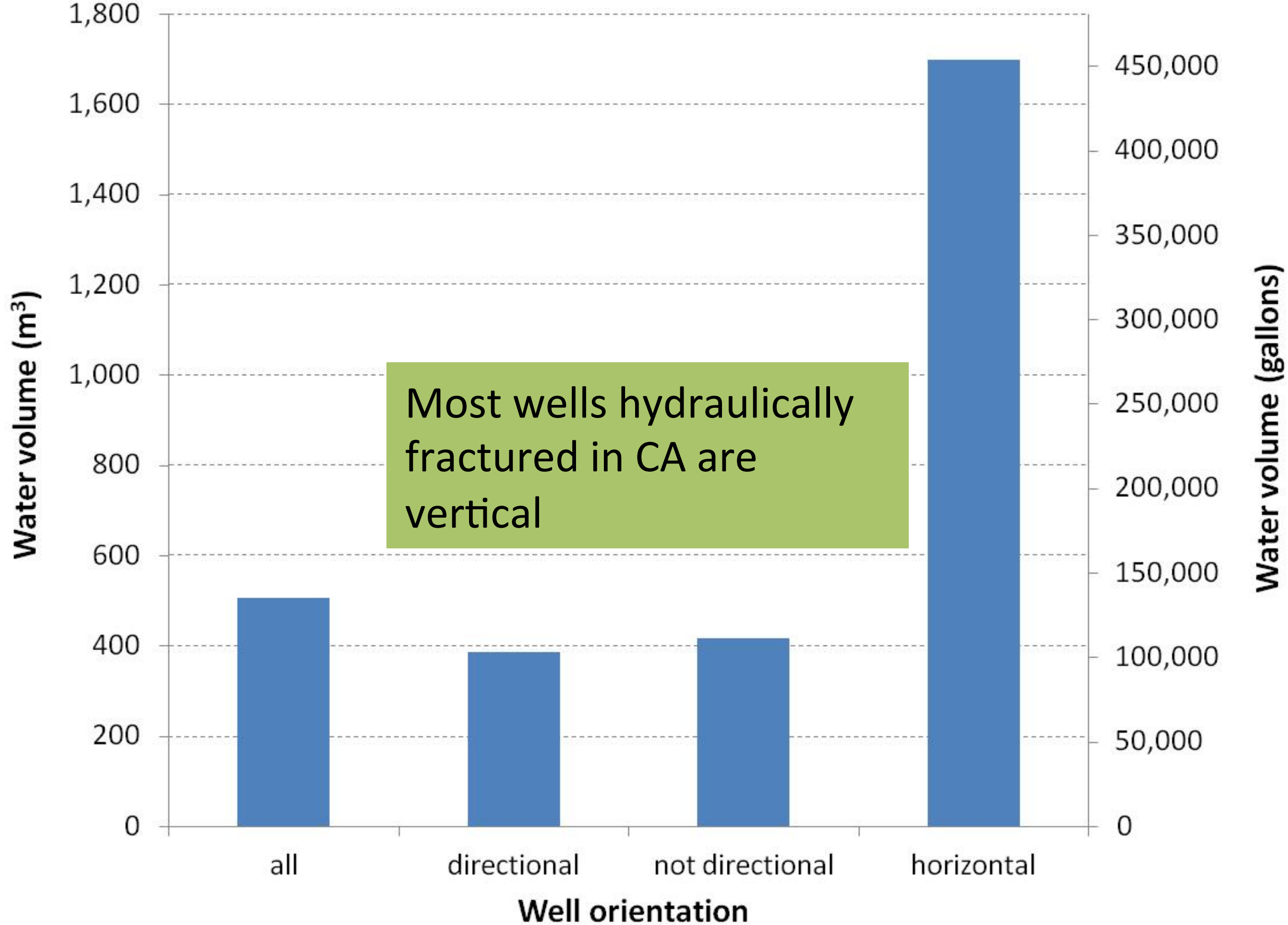
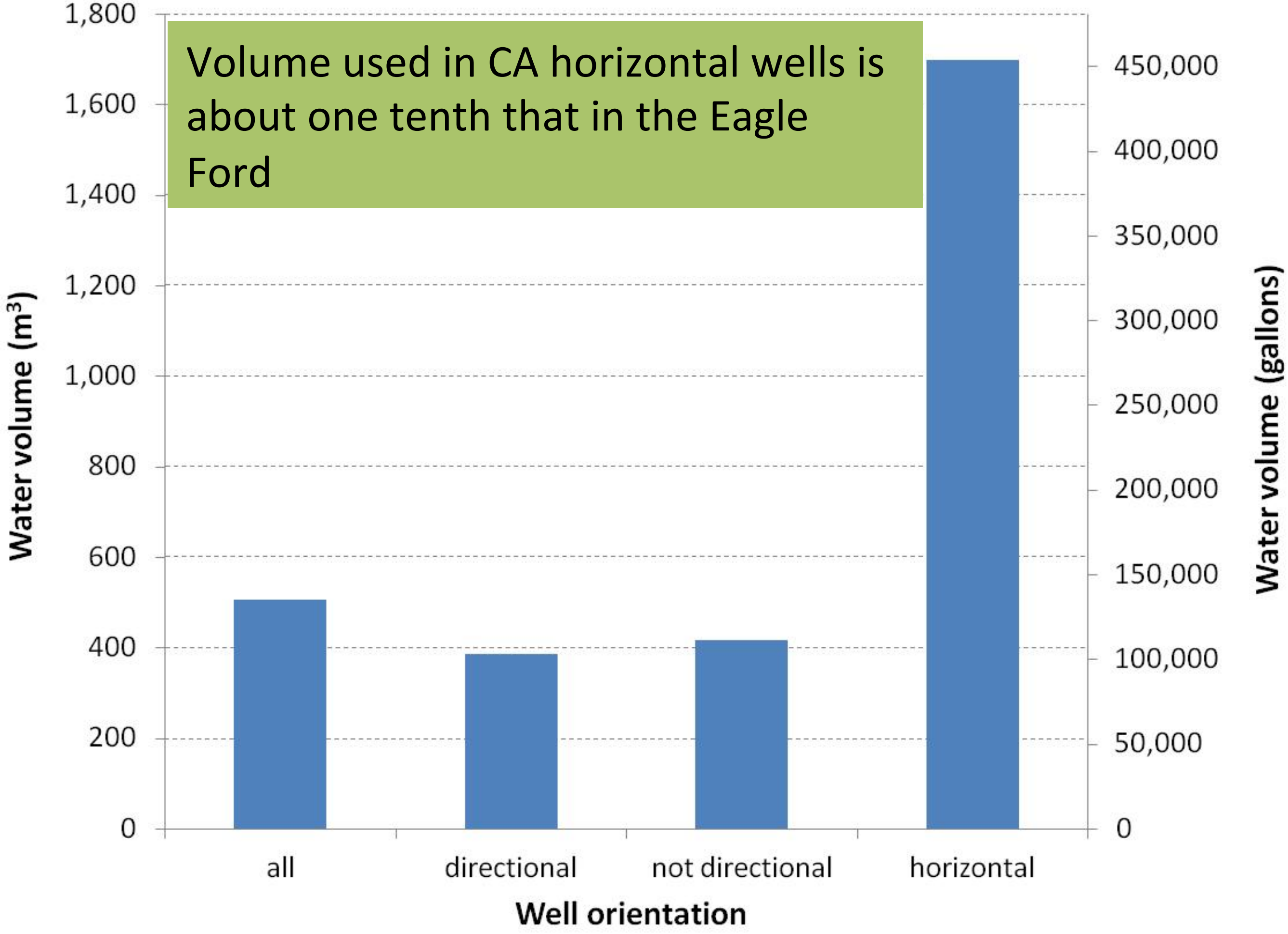


FracFocus Volume by Well Direction



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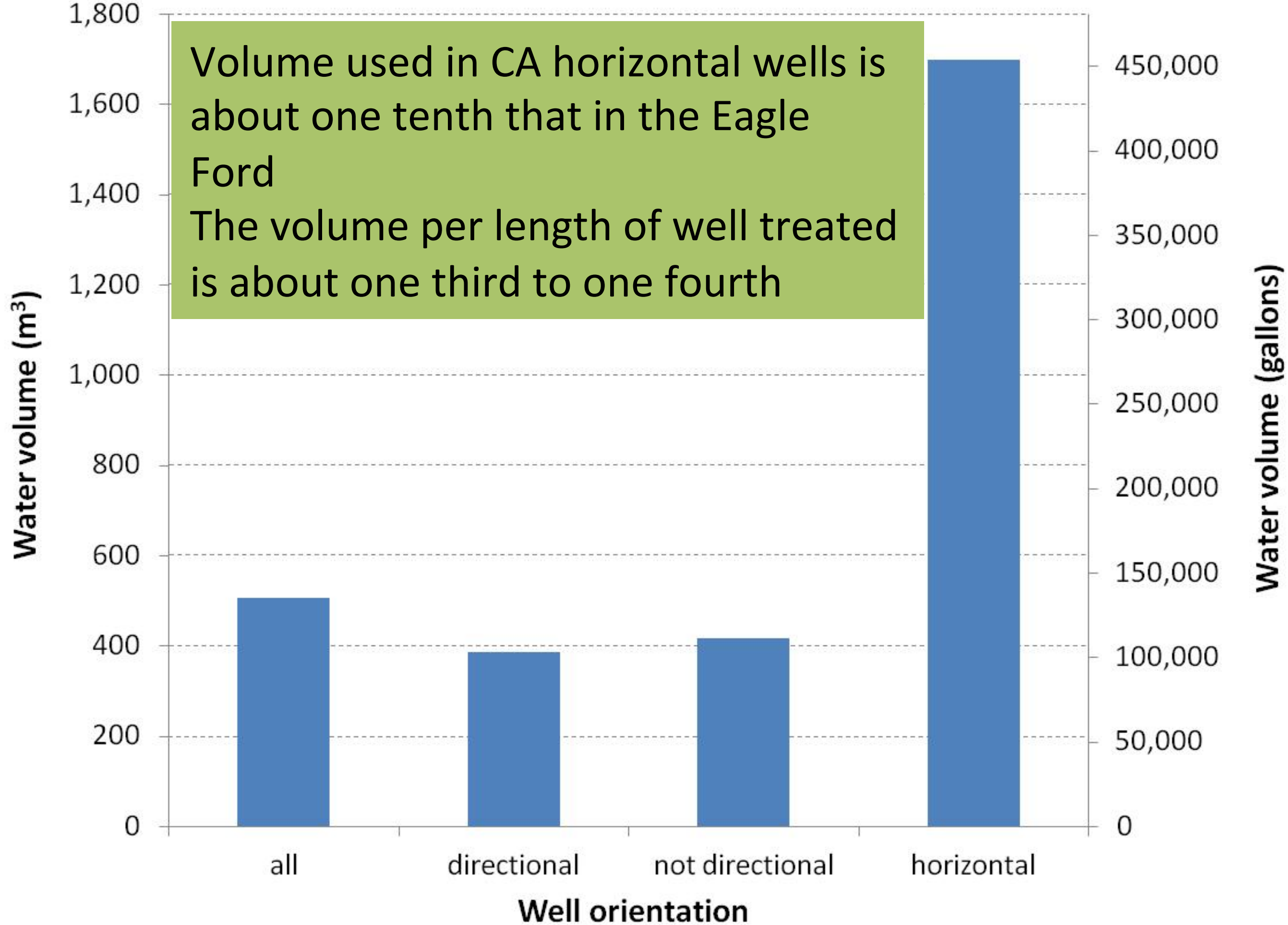

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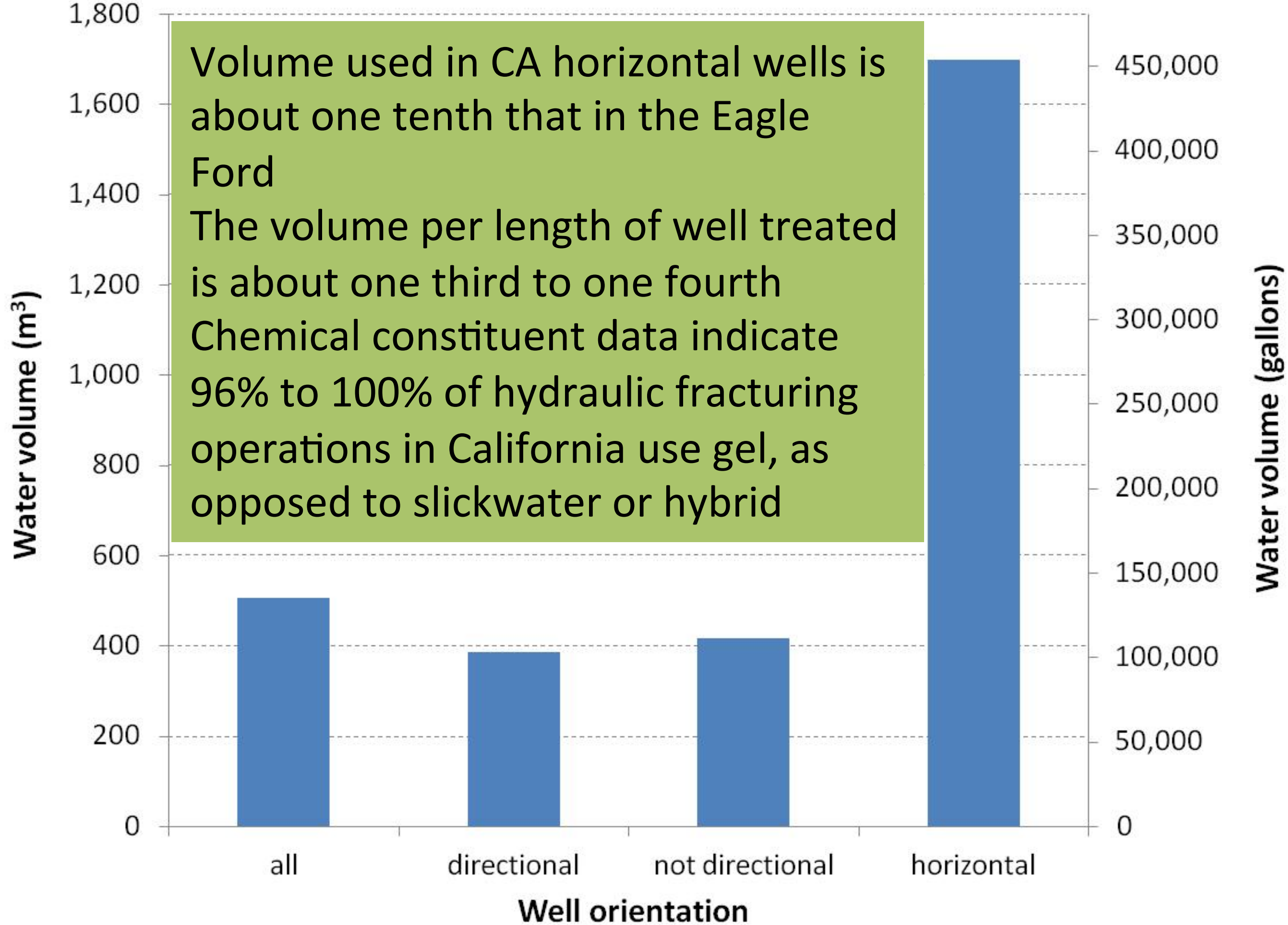

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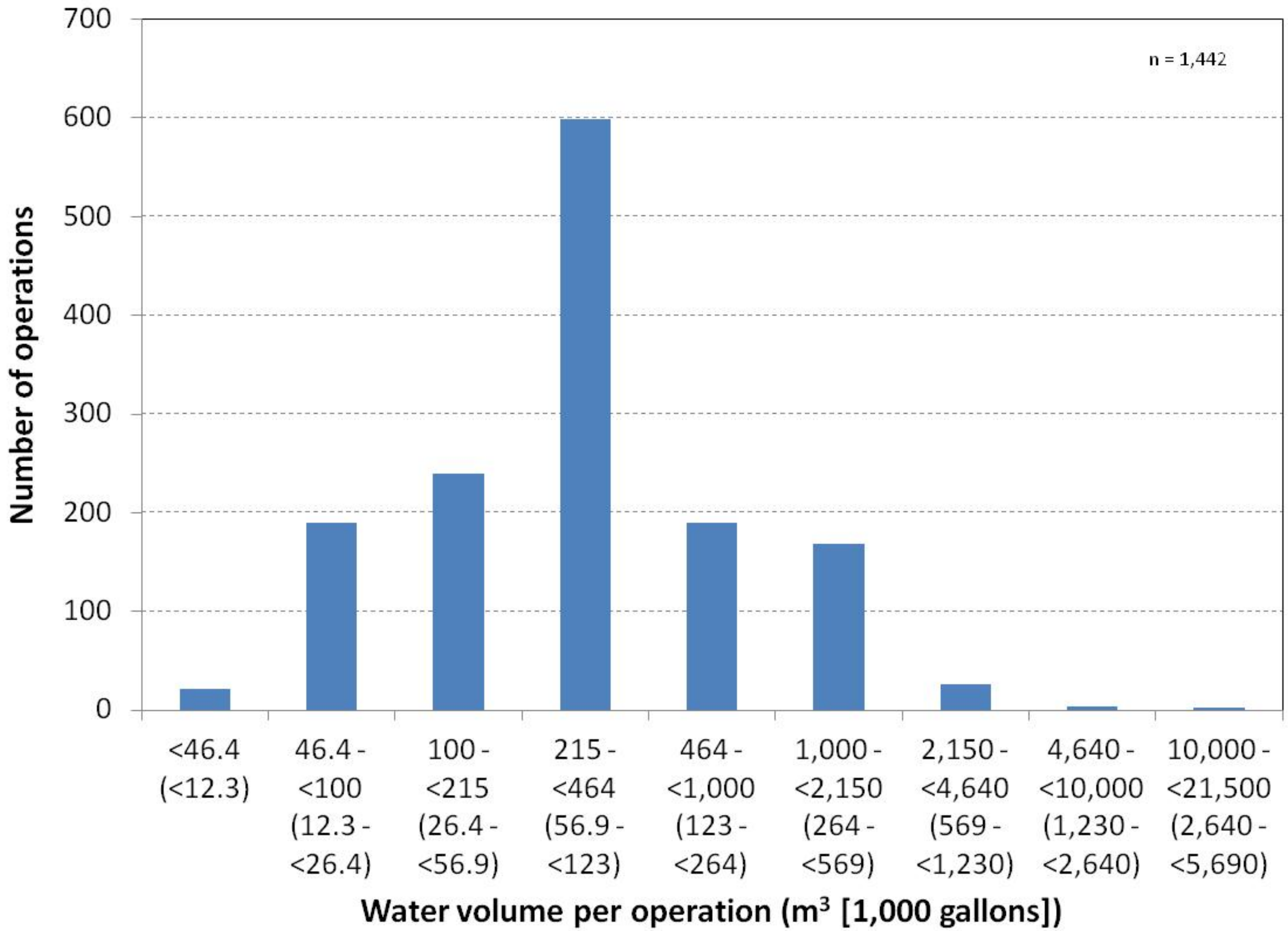

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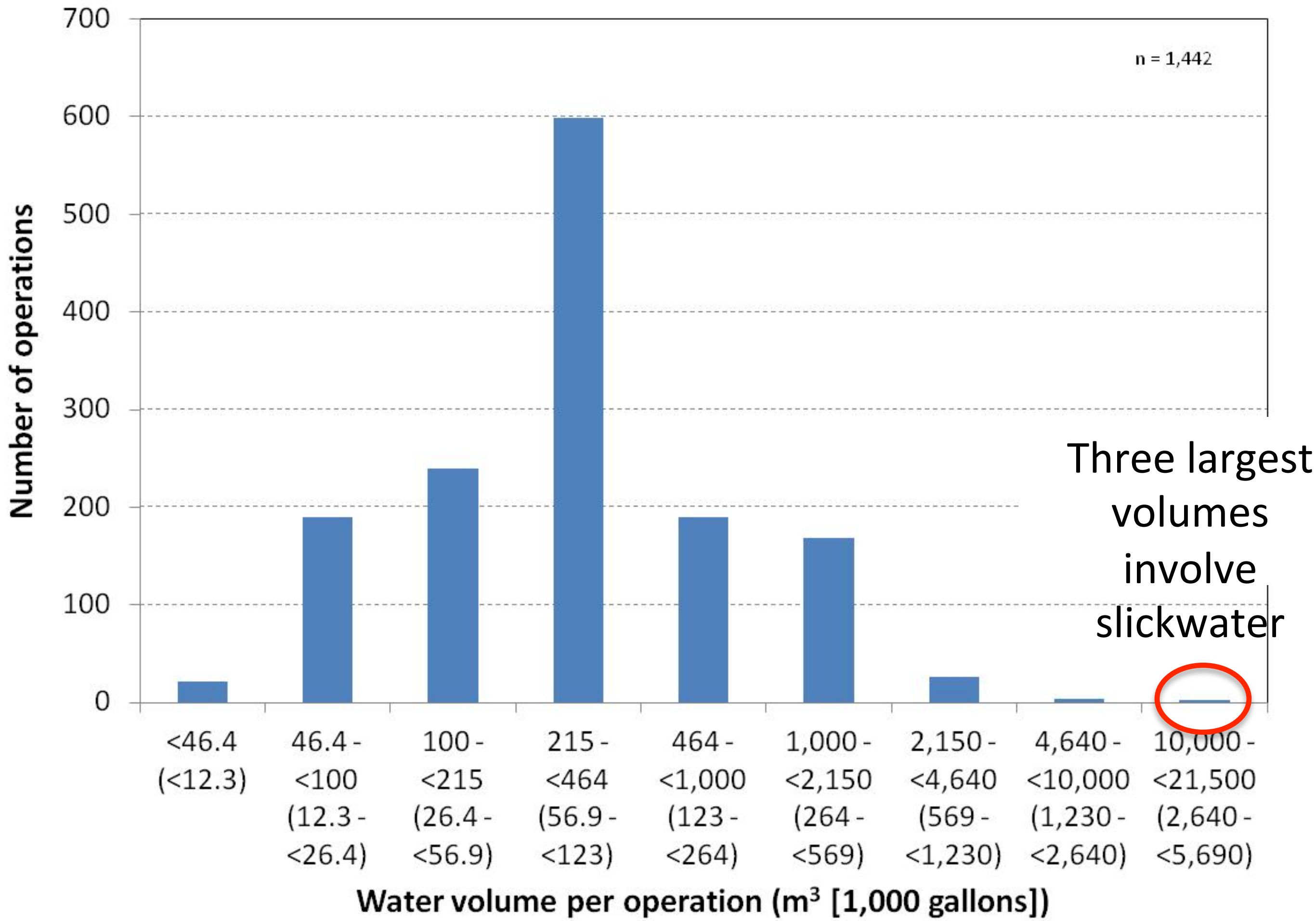
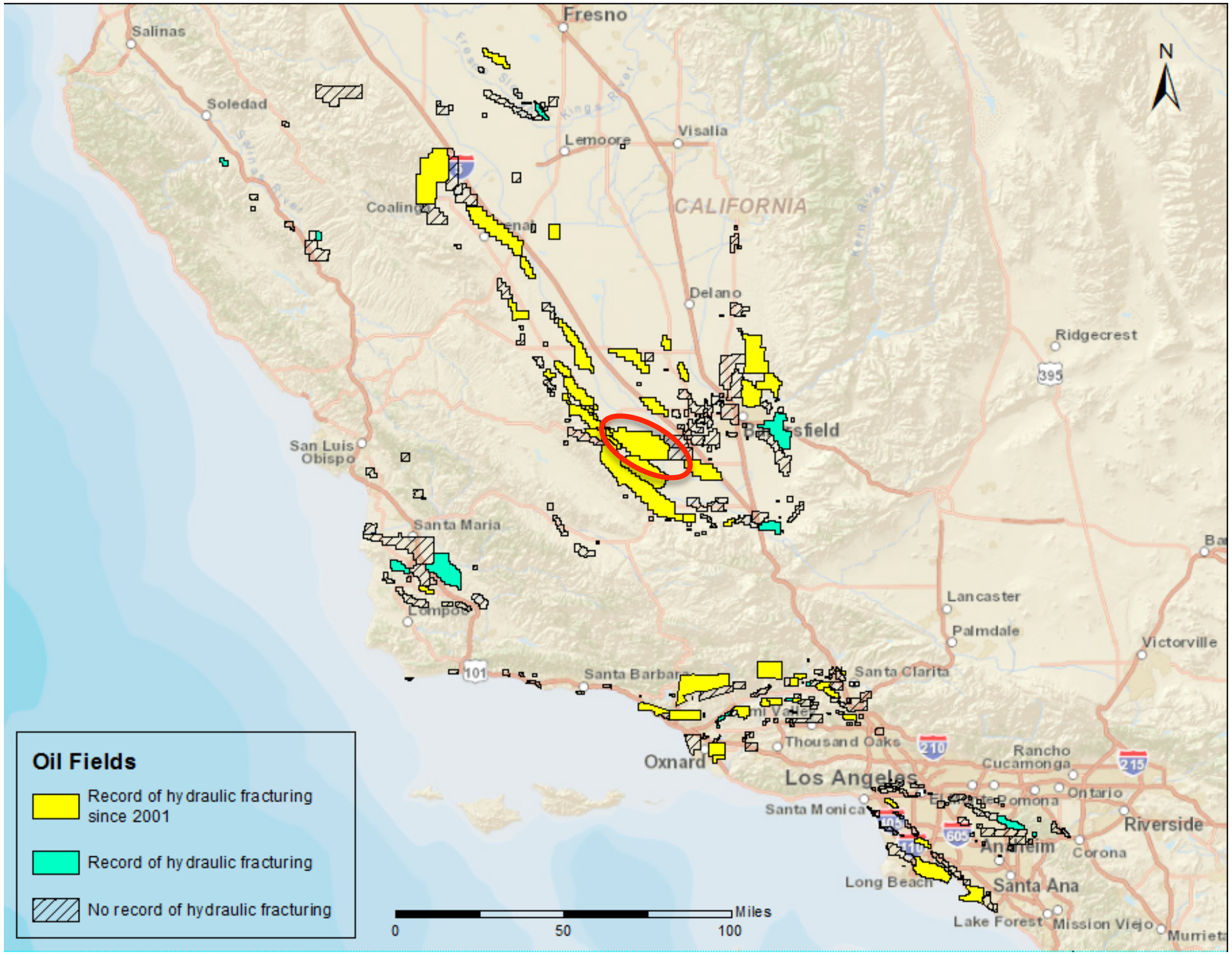


Key Question 1

Conclusion 2: Acid Fracturing and Matrix Acidizing

- Acid fracturing is a small fraction of reported WST to date in California.
- Acid fracturing is usually applied in carbonate reservoirs, and these are rare in California. Matrix acidizing has been used successfully but rarely in California.
- **These technologies are not expected to lead to major increases in oil and gas development in the state**

Field With Acid Stimulation



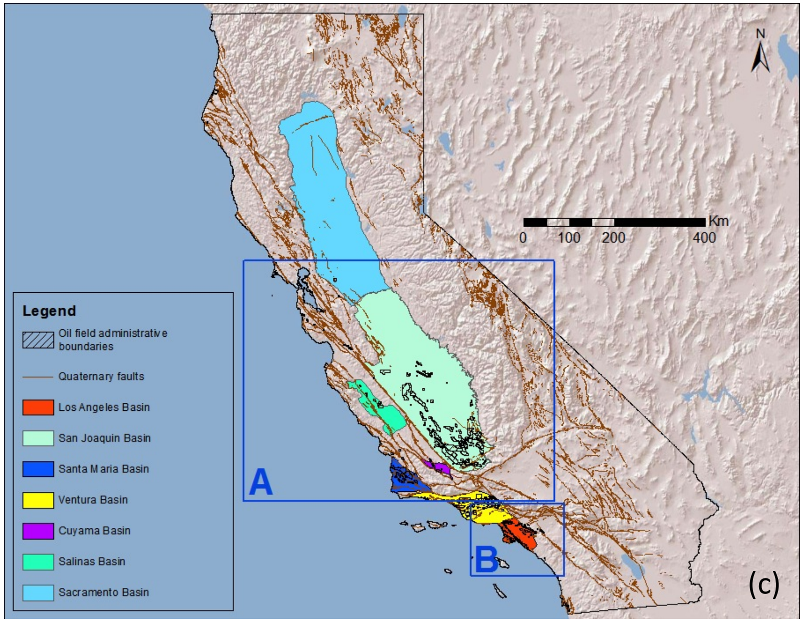
Acid stimulation notices (both matrix and fracturing) are all for operations in the Elk Hills Field. Matrix acidization reported in two additional fields further in the past in the literature

Acid Stimulation Water Volumes

- Notices indicate the matrix acidization stimulations use about a third the water volume per well as hydraulic fracturing
- Notices indicate the few acid fracturing stimulations use a water volume similar to hydraulic fracturing
- Notices indicate acid stimulations use sandstone acid

Key Question 2: Where will well stimulation technologies allow expanded production of oil onshore in California?

- Estimates of CA oil resources that might be produced using WST
- Assessment of prior resource estimates



Key Question 2

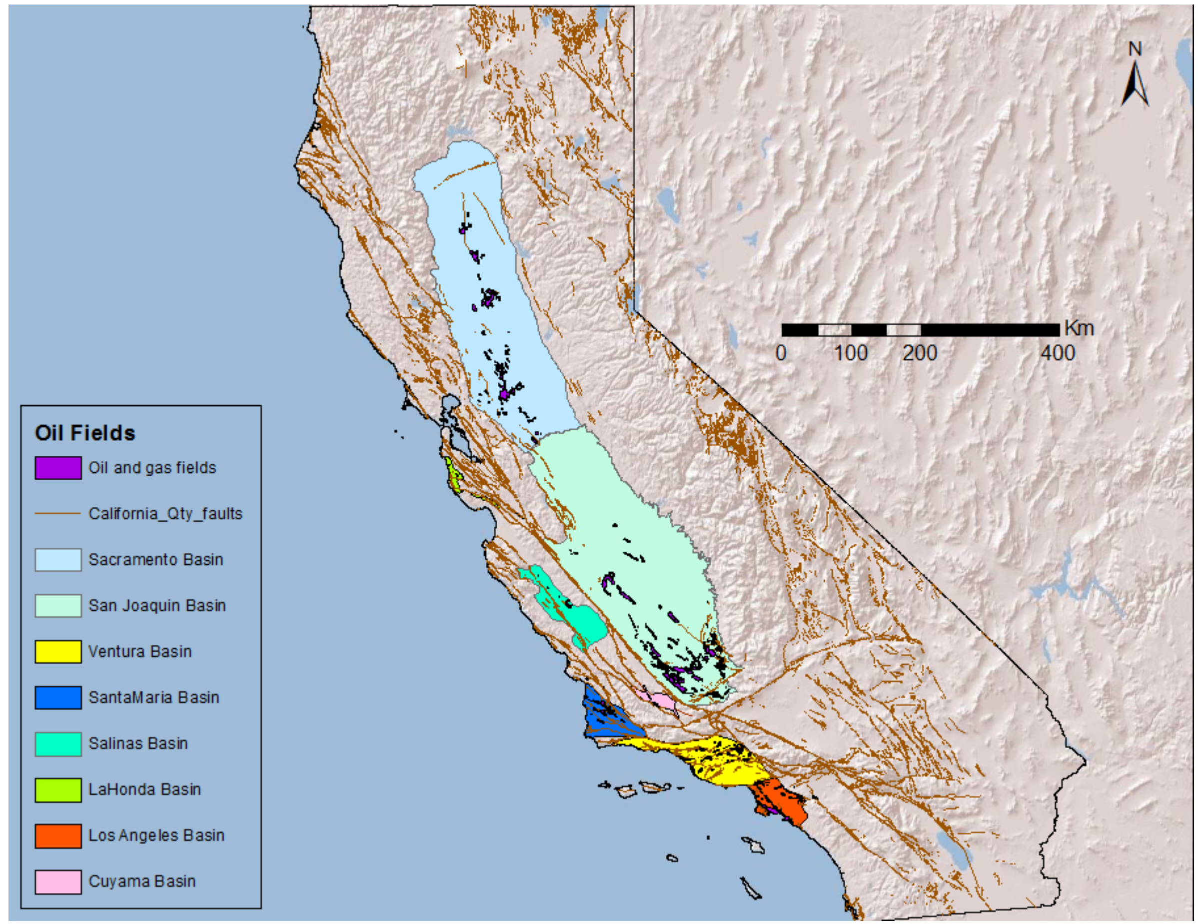
Conclusion 3: Future WST Prospects in CA

Credible estimates of the potential for oil recovery in and near 19 existing giant fields in the San Joaquin and Los Angeles basins indicate that almost 10 billion barrels of additional oil might be produced but would require unrestricted application of current best-practice EOR technology. Some of this production may involve WSTs.

2011 Energy Information Administration (EIA) estimate of about 15 billion barrels of technically recoverable oil from new plays in the Monterey Formation source rock (which has low permeability and would require WSTs) is highly uncertain. This estimate was revised downward by EIA in 2014 to 0.6 billion barrels.

Where are major sedimentary basins in CA?

- Sedimentation and basin evolution controlled by active tectonics
- Mixture of marine (biogenic) and terrigenous (detrital) sediments



Future Well Stimulation Targets

- USGS has estimated that 9.7 billion barrels could be recovered from 19 largest oil fields in LA and San Joaquin basins using known EOR techniques
  – High degree of certainty about technical potential
- Conditions needed to produce oil from deep shales
  – In the oil window
  – Oil must be retained
  – Technology available to produce it
  – **Very uncertain**

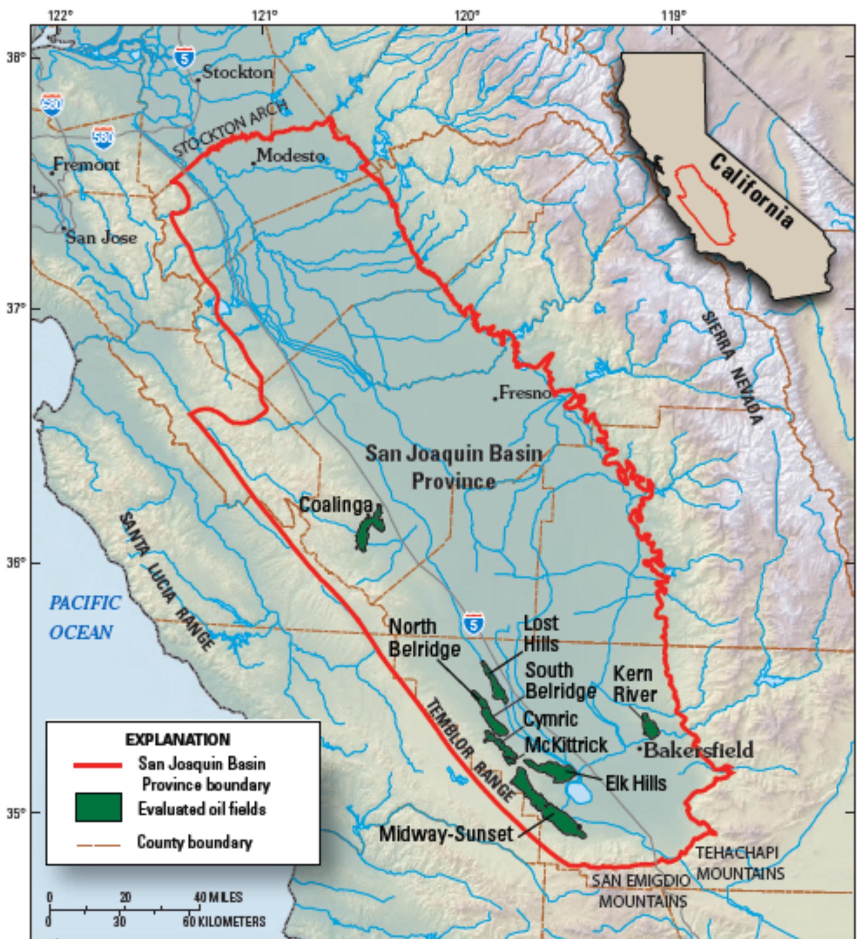
Additional Oil from Existing Fields

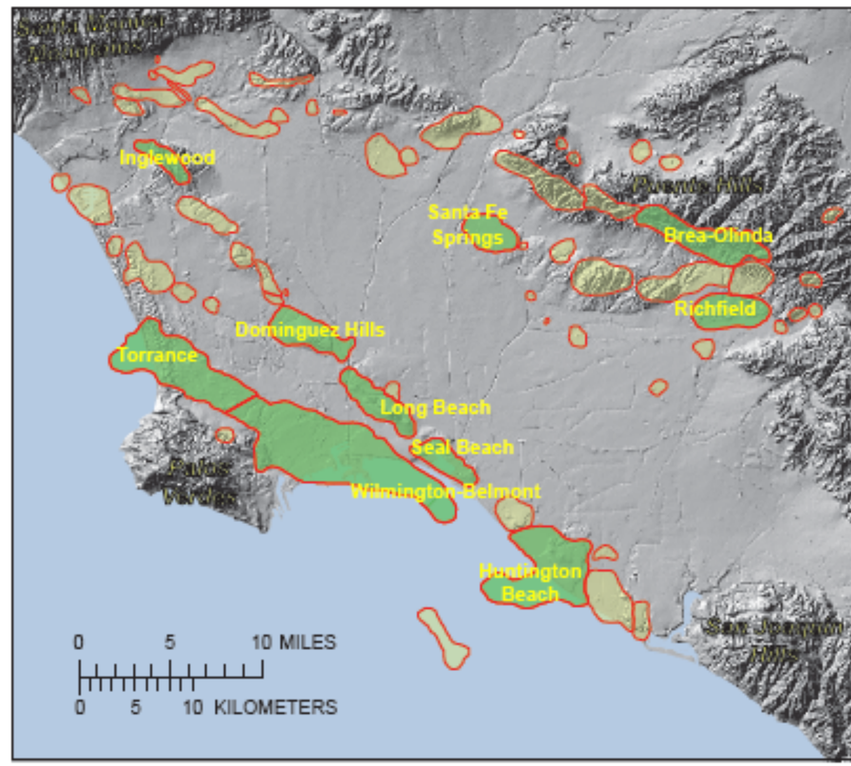
- Redevelopment of old LA basin fields: application of modern technology
- Heavy and extra-heavy oil: Wider application of thermal recovery technology
- **Oil from diatomite: closely spaced vertical wells with fracturing** and waterflood or steam
- Oil in naturally fractured porcelanite and chert reservoirs: **acidizing** and vertical wells
- Diagenetically trapped oil at the opal-CT/quartz boundary: horizontal wells

(courtesy of USGS)

From USGS study

Current Technology Could Add 4.9 to 15.6 BBO (Mean Estimate of 9.4 BBO) From Just 19 Giant San Joaquin and L.A. Basin Fields

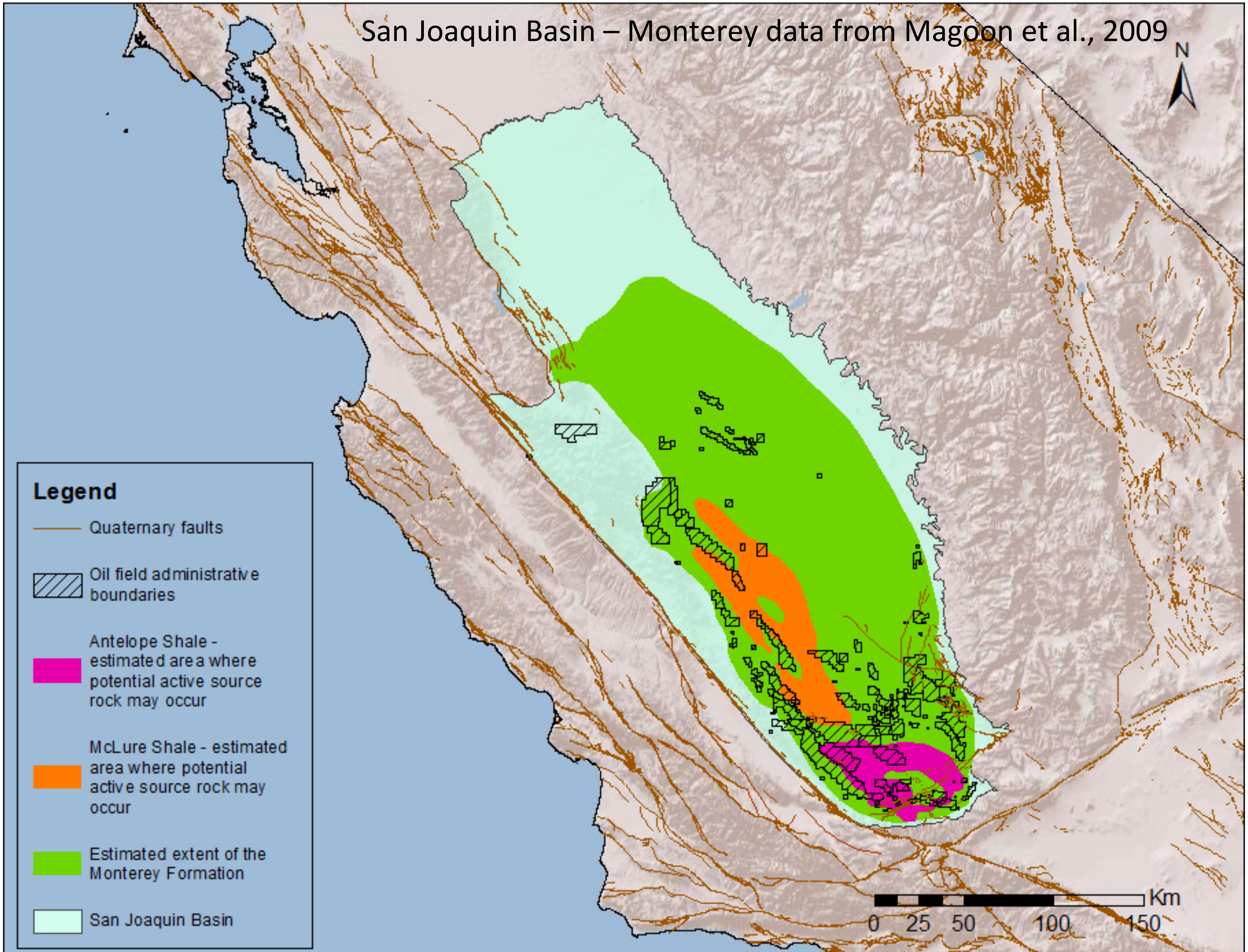




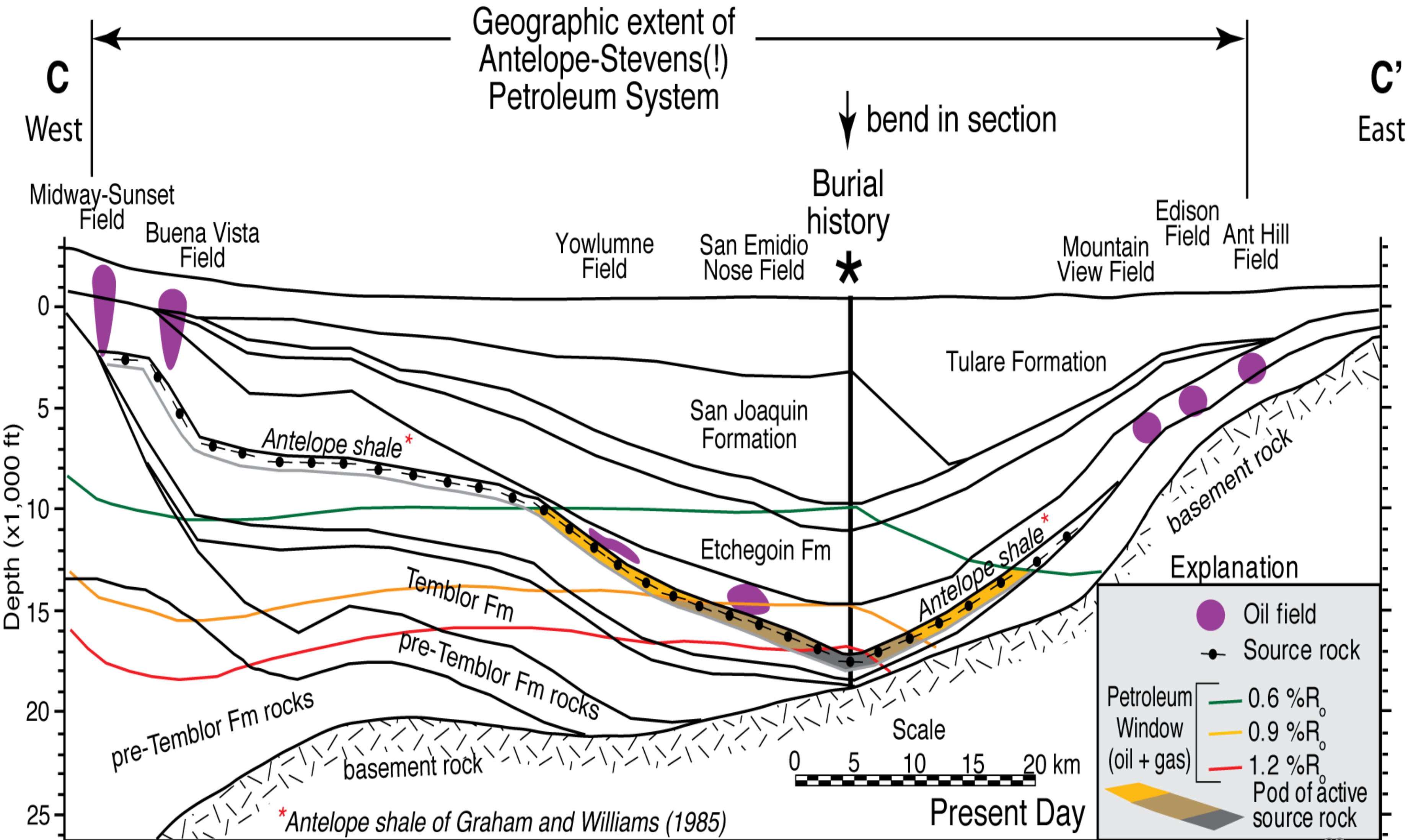
Oil source rocks in CA – potential oil shale targets

- Monterey Formation
- Soda Lake Shale, Vaqueros Formation
- Tumey Formation
- Kreyenhagen Formation
- Moreno Formation

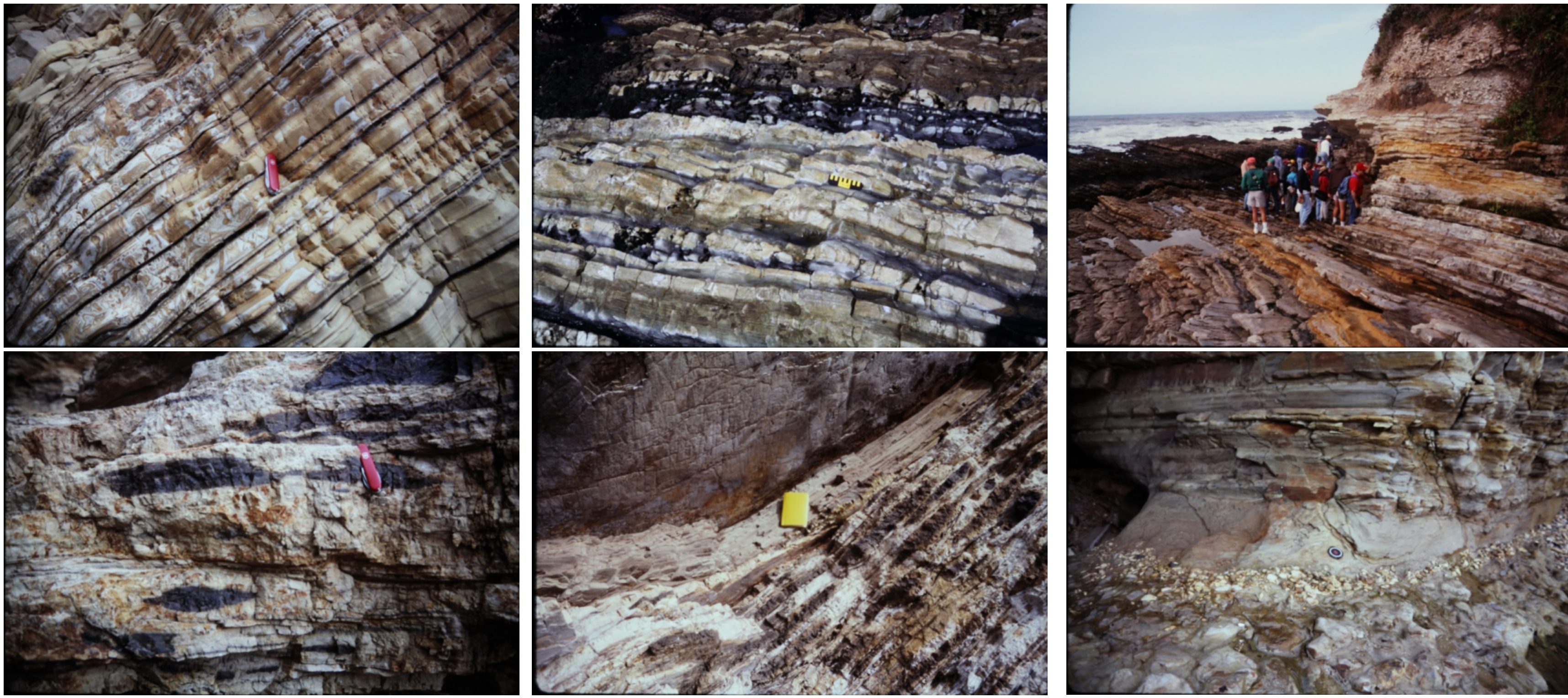
Conventional vs. Unconventional Resources



Migrated vs Source Oils in SJV



Lithologic Variability in the Monterey



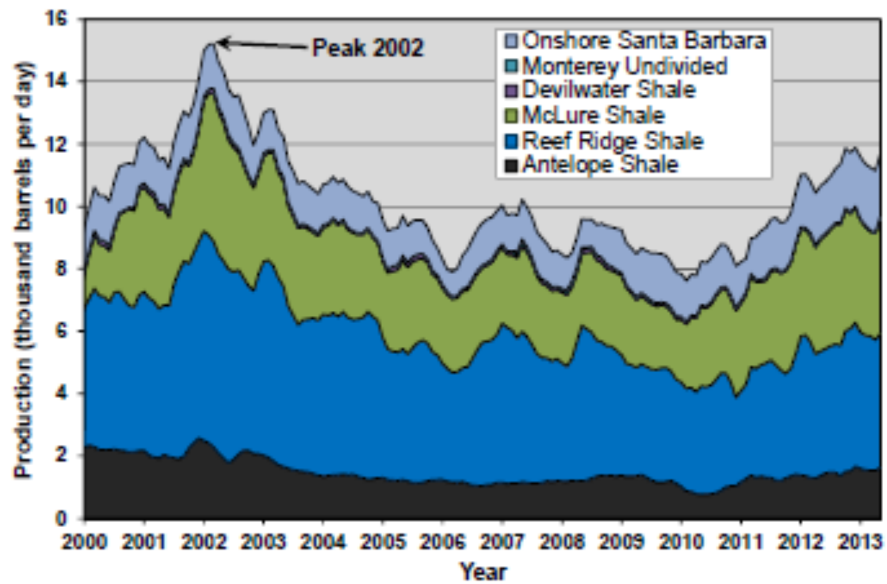
Siliceous shale, diatomite, porcelanite, dolomite, and organic shale are main constituents, with interfingering turbidite sandstones

EIA estimates

	INTEK (2011)	EIA (2014)
Areal extent (mi^2)	**1752**	**192**
Wells/mi^2	**16**	**6.4**
Production/well (Kbbl oil)	**550**	**451**
Total recoverable oil (Bbbl oil)	**15.4**	**0.6**

2011 EIA-INTEK Report: Review of Emerging Resources: U.S. Shale Gas and Shale Oil Plays

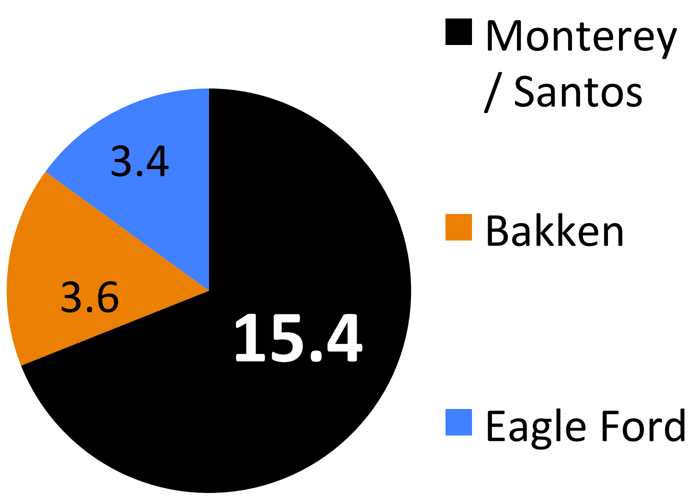
- Claims the Monterey is the largest shale oil formation in U.S. at 15.4 billion barrels (64 % of the total shale oil)
- Estimate requires well productivities 4-5 times greater than currently observed (Hughes, 2013)
- Estimate has been drastically reduced by EIA in 2014 to 0.6 billion barrels (smaller area, lower production rates)



Oil production from Monterey shale reservoirs (Hughes, 2013)

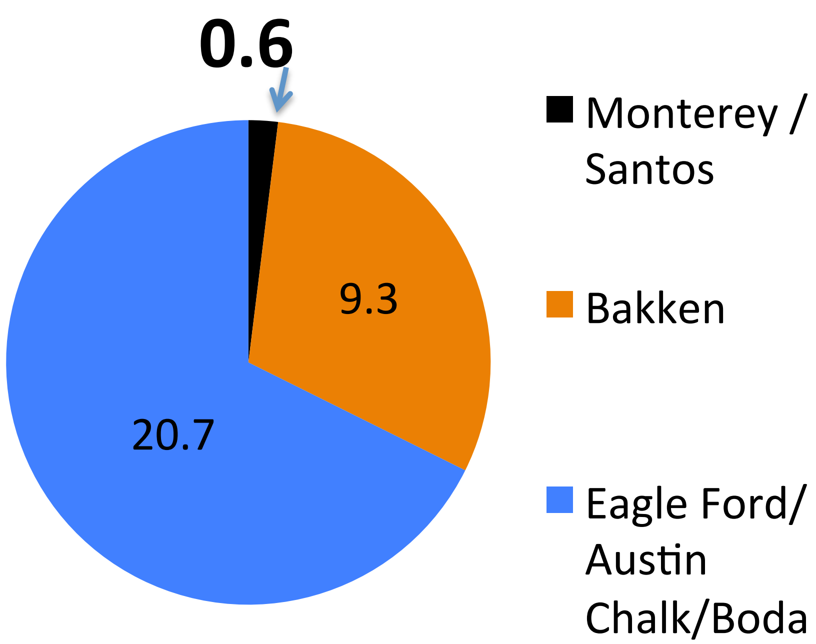
Estimates of Technically Recoverable Oil Shale Resources (EIA)

EIA/INTEK (2011)



Total: 22.4

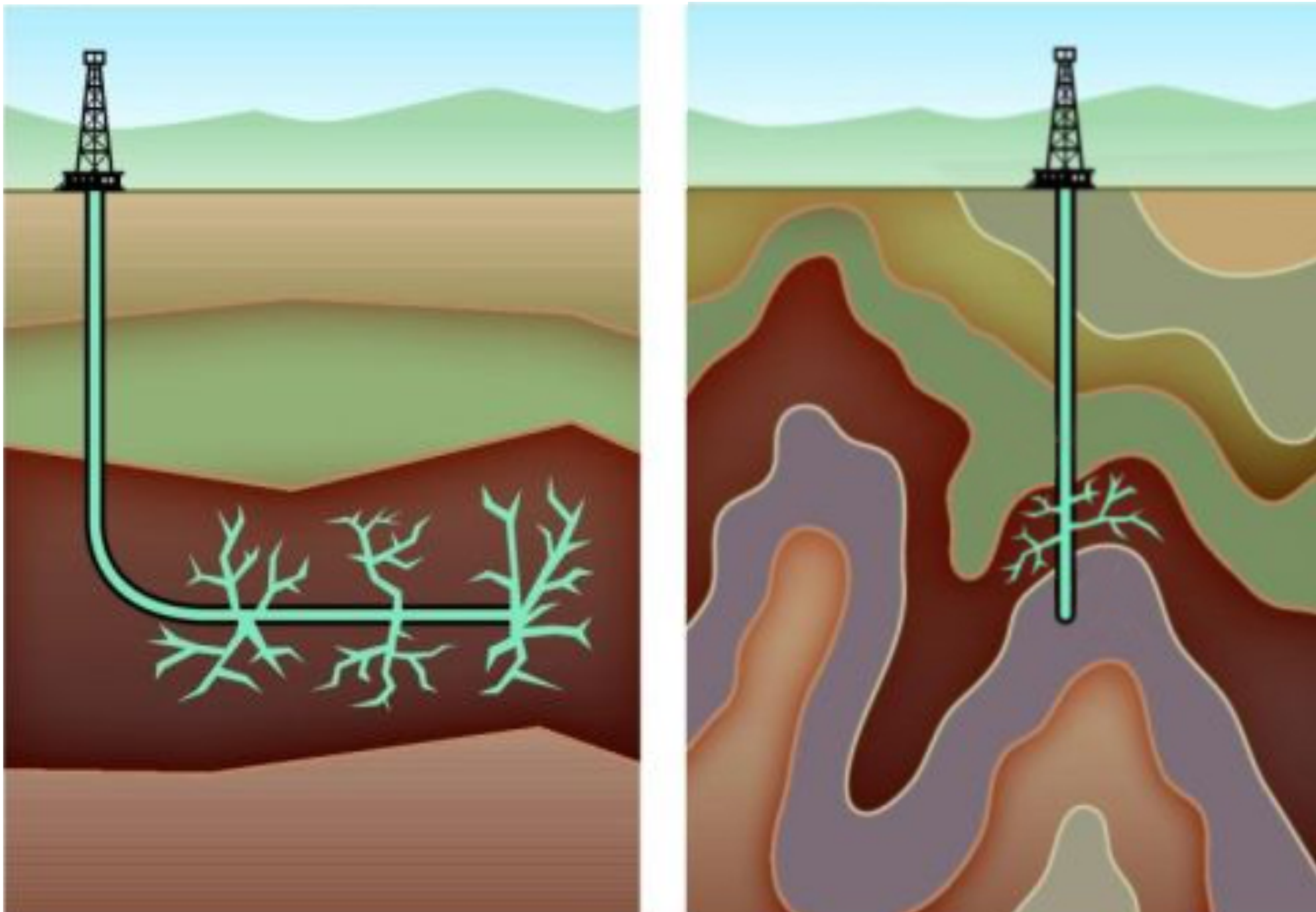
EIA (2014)



Total: 30.6

(Unproved estimates – BBO)

Monterey Geology is More Complex



Key Question 3: What are the potential environmental hazards of well stimulation technologies in California?

- Water supply
- Water quality and toxicity of fracturing fluids
- Potential releases into water
- Air quality and greenhouse gas emissions
- Seismic risk
- Comments on indirect impacts:
  - Expanded production impacts

Key question 3

Conclusion 4: Water Demand for WST

While current water demand for WST operations is a small fraction of statewide water use, it can contribute to local constraints on water availability, especially during droughts.

Data Sources for Water Quantities

- FracFocus Database
- Skytruth Database
- DOGGR notices of intent
  - December 2013 to January 2014 only
- Government reports

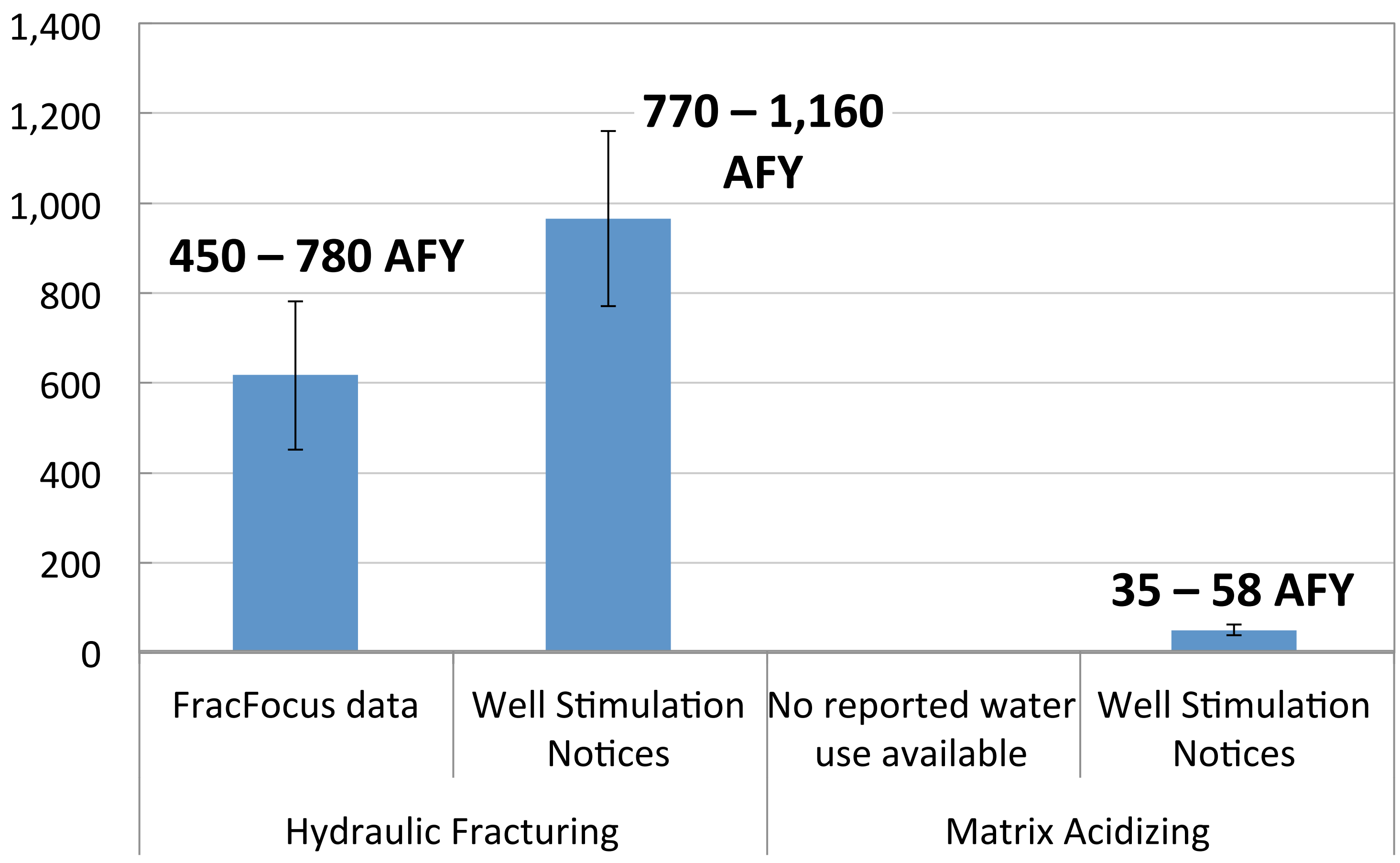
Intended Water Sources

- Information from notice of intent
  - May not represent actual use
- Freshwater most commonly reported rather than produced water
- Purchased from local water agencies, on-site wells as alternative source

Water Volume Statistics Per Well

	FracFocus Voluntary Reports (2011–2013)	Hydraulic Fracturing Notices (Dec. 2013 - Jan 2014)
Number of Records:	1,478	213
Gallons water used		
Minimum	6,000	63,000
Maximum	4,400,000	470,000
Average	130,000	210,000

Projected Annual Water Use, acre-feet per year



Key question 3

Conclusion 5: Use of Chemicals for WST

- Information from the voluntary industry database, FracFocus
- Of the chemicals reported for WST treatments in California for which toxicity information is available, most are considered to be of low toxicity or non-toxic.
  - However, a few reported chemicals present concerns for acute toxicity
  - These include biocides, corrosion inhibitors, and mineral acids
  - Potential risks posed by chronic exposure to most chemicals used in WST are unknown at this time

Key question 3

Conclusion 5: Use of Chemicals for WST

The list of chemicals used in hydraulic fracturing is dependent on voluntary industry disclosure. A number of stimulation-fluid constituents are toxic and therefore could potentially pose a hazard to humans. However, most chemicals were non-toxic or show low-toxicity.

- Significant data gaps concerning WST chemicals were identified
- Composition of WST fluids in California are different from other areas, due geology & oil application (vs. natural gas in other locations)

Chemistry of WST Fluids

- WST additives
  - List of chemicals used in more than 2% of CA wells
    - FracFocus
- Matrix acidizing additives
  - Complete list from notice of intent
    - Limited data
- Ranked by mammalian oral acute toxicity
  - Starting point for hazard analysis
  - Globally Harmonized System of Classification and Labelling of Chemicals (GHS)
    - Five classes, 1 = most toxic, 5 = least toxic

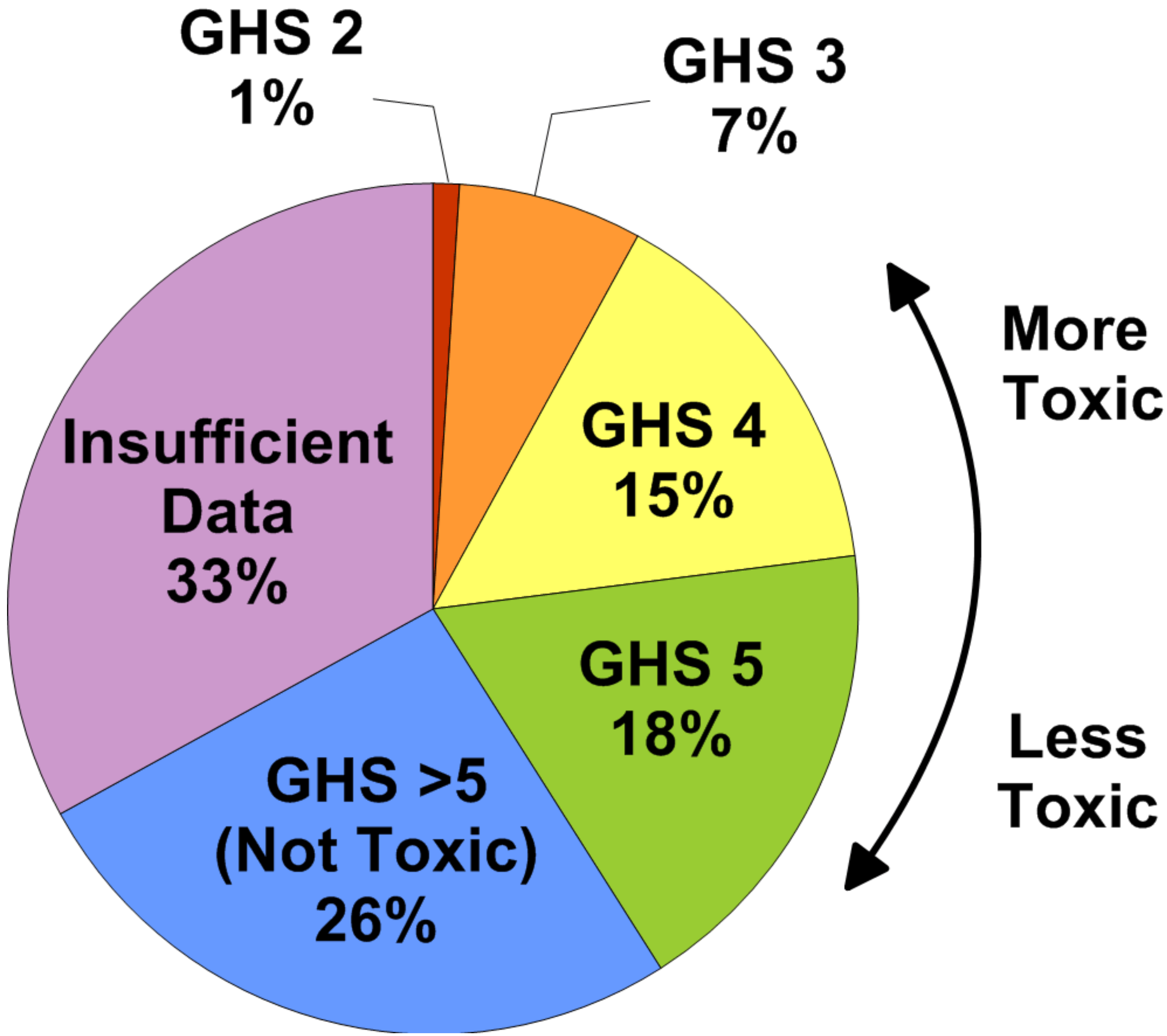
Toxicity Analysis

Table 5-6. *Grouping of chemicals found in hydraulic fracturing fluids in more than 2% of California hydraulic fracturing jobs based on GHS Categories for oral toxicity data (GHS category 1: most toxic; category 5: least toxic)*

GHS Category	Number and Percent of Chemicals					
	Oral Rat LD_{50}		Oral Mouse LD_{50}		Oral Rabbit LD_{50}	
	[ ]	[%]	[ ]	[%]	[ ]	[%]
1	0	0%	0	0%	0	0%
2	1	1%	1	1%	0	0%
3	7	7%	2	2%	2	2%
4	15	15%	13	13%	6	6%
5	17	18%	12	12%	2	2%
> 5	25	26%	12	12%	9	9%
No/insufficient data	32	33%	57	59%	78	80%
TOTAL	97	100%	97	100%	97	100%

Mammalian Toxicity of WST Chemicals

ranked in the global harmonized system



WST Additive Knowledge Gaps

- Lack of physical, chemical and biological information on chemicals
  - 1/3 missing basic toxicological characterization
  - Further hazard & risk analyses needed
    - Chronic toxicity, synergistic effects etc.
    - Environmental toxicity
- Reliance on voluntary disclosures
  - Potentially incomplete information
  - Data quality undocumented

Potential Releases into Water

- Surface release pathways
  - Spills and leaks
  - Management and disposal of wastewater
  - Stormwater runoff
- Subsurface release pathways
  - Formation of high permeability pathways
  - Leakage from wells

Key question 3

Conclusion 6: Subsurface Releases

- There are no publicly recorded instances of subsurface release of contaminated fluids into potable groundwater in California, but a lack of studies, consistent and transparent data collection, and reporting makes it difficult to evaluate the extent to which this may have occurred.
- Existing wells are generally considered as the most likely pathway for subsurface transport of WST and subsurface fluids (water, brines, gas).

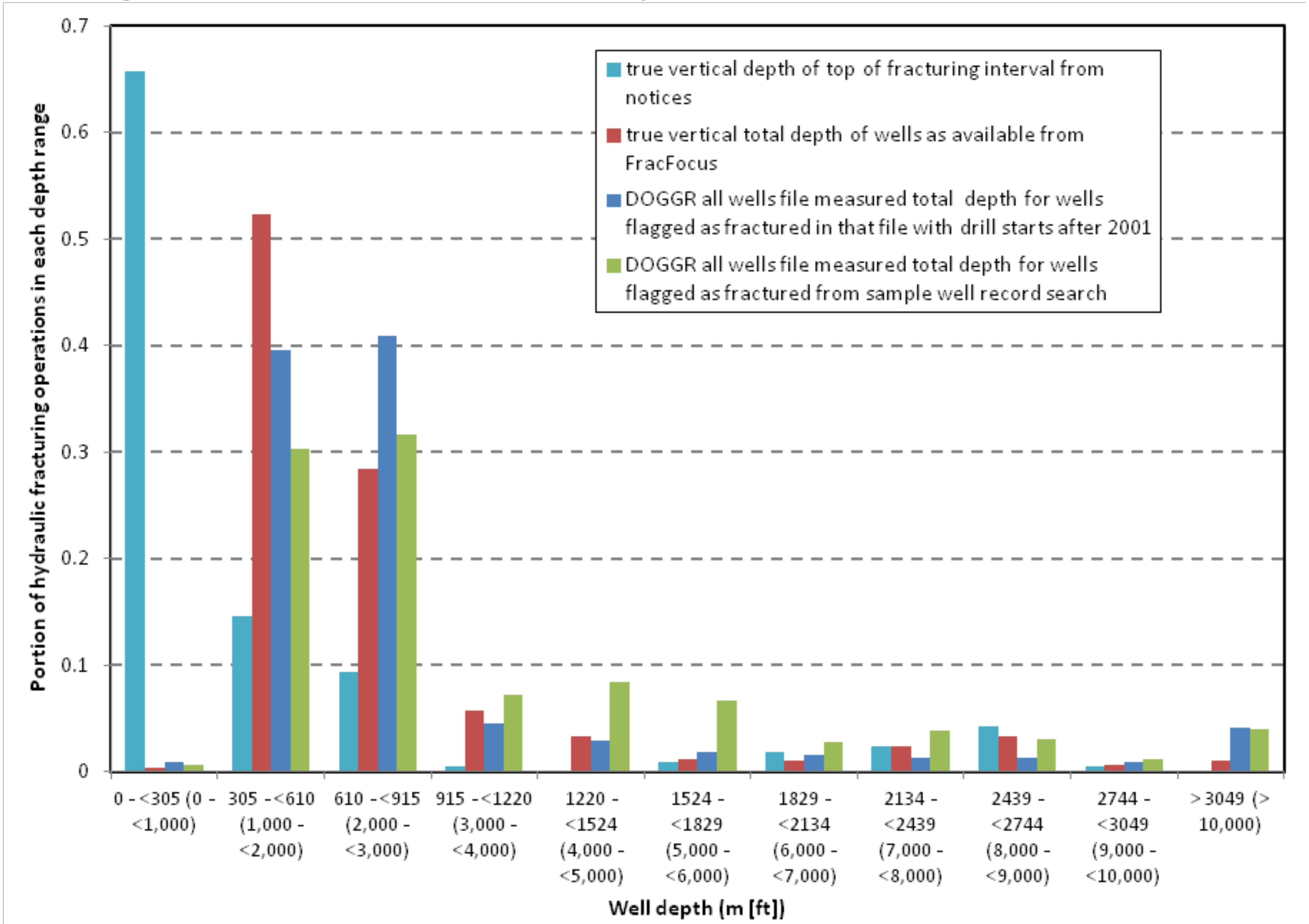
Conclusion 6 cont'd

- More than half of the hydraulic fracturing has occurred in many fields at a depth less than 600 m (2000 ft)
- 600 m (2000 ft) is likely the maximum distance for vertical propagation of hydraulic fractures, although the maximum vertical length of a fracture may be less than this in shallow formations because of the different stress conditions.
- This presents an inherent risk for fractures to intersect nearby aquifers if they contain usable water.

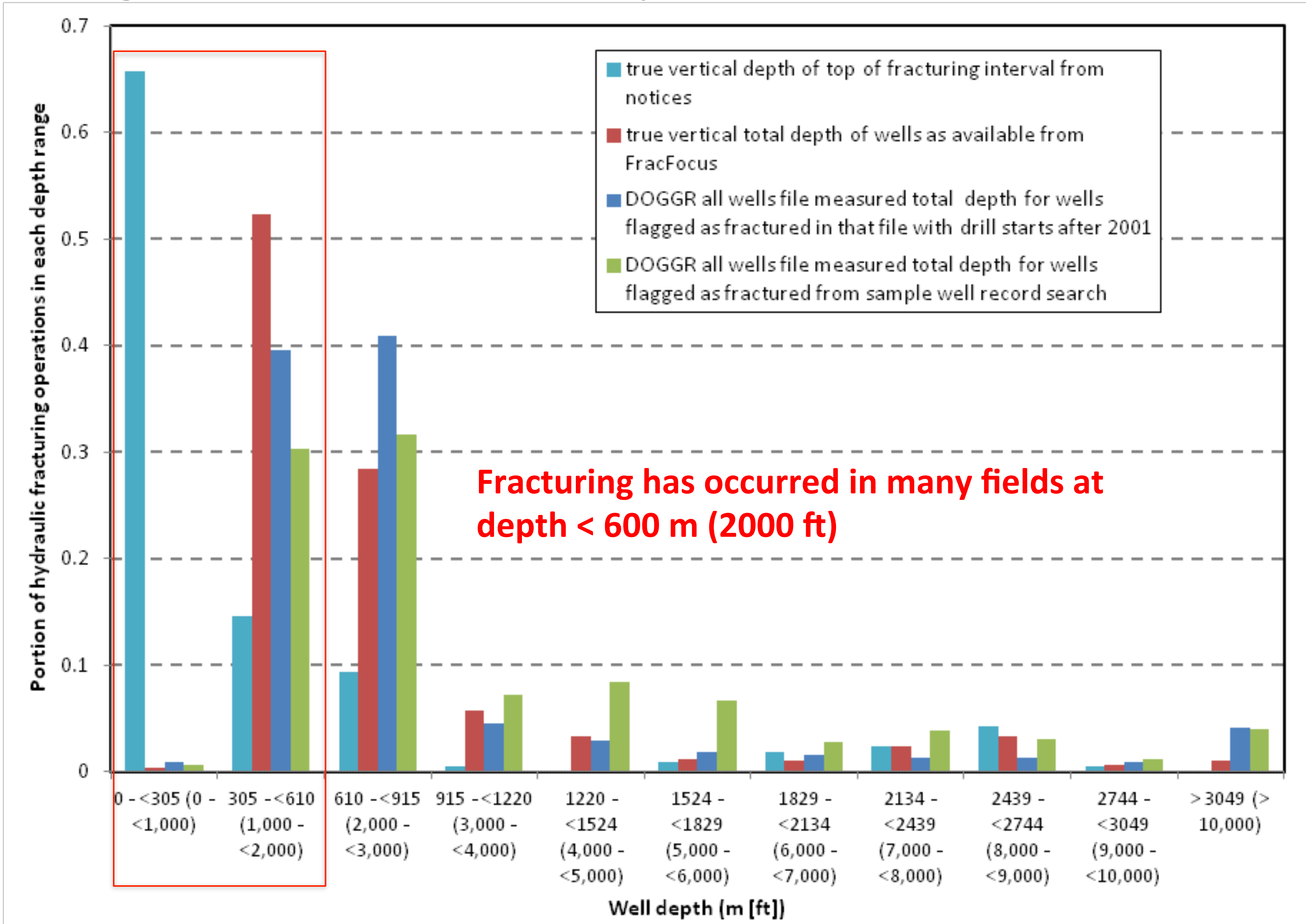
Conclusion 6 cont'd

- California needs to develop an accurate understanding about the location, depth, and quality of groundwater in oil and gas producing regions in order to evaluate the risks of WST operations to groundwater.
- This information on groundwater must be integrated with additional information to map the actual extent of hydraulic fractures to assess whether and where water contamination from WST activities have been or will be a problem.

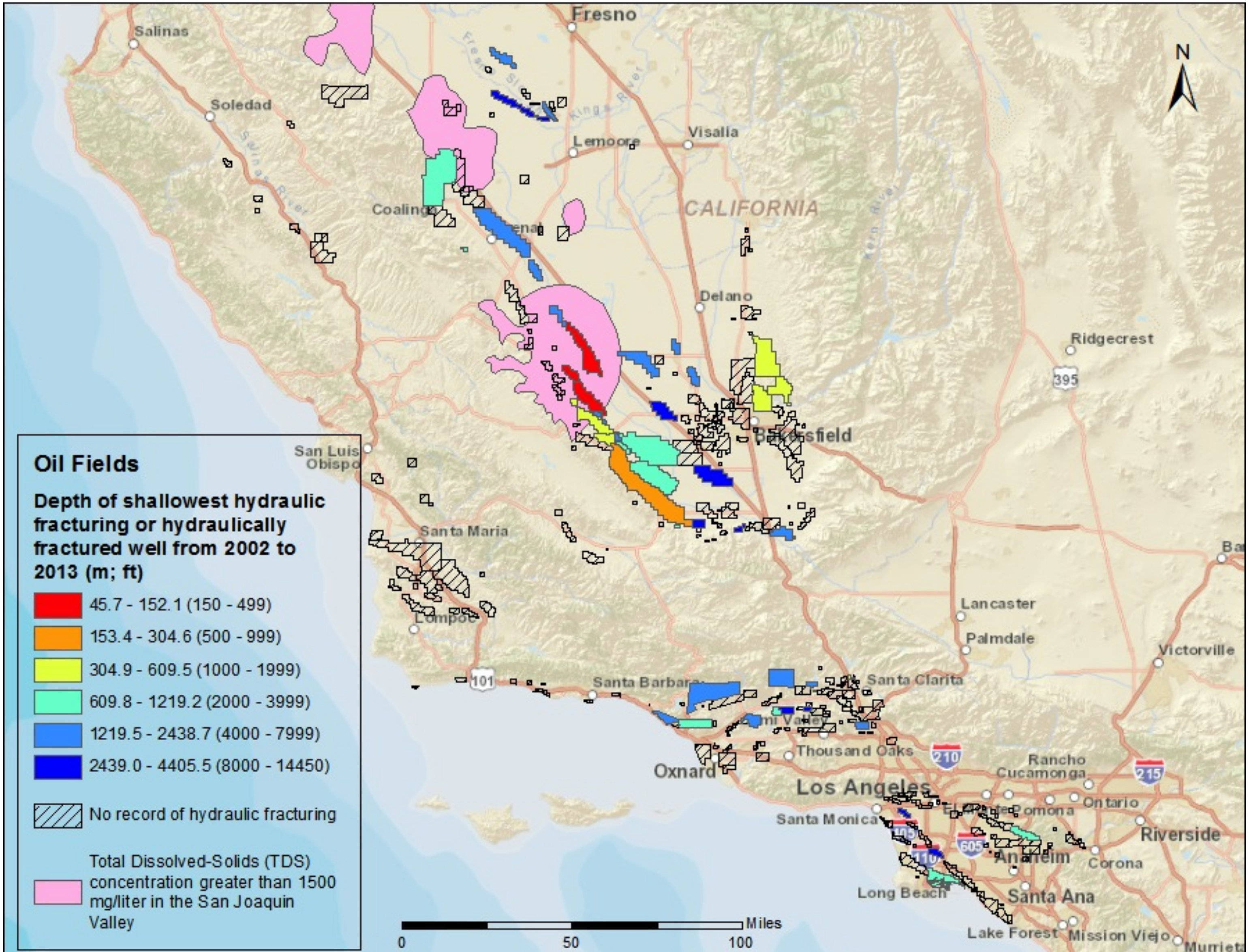
Portion of hydraulic fracturing operations vs. depth range (DOGGR data is only for wells drilled after 2001)



Portion of hydraulic fracturing operations vs. depth range (DOGGR data is only for wells drilled after 2001)



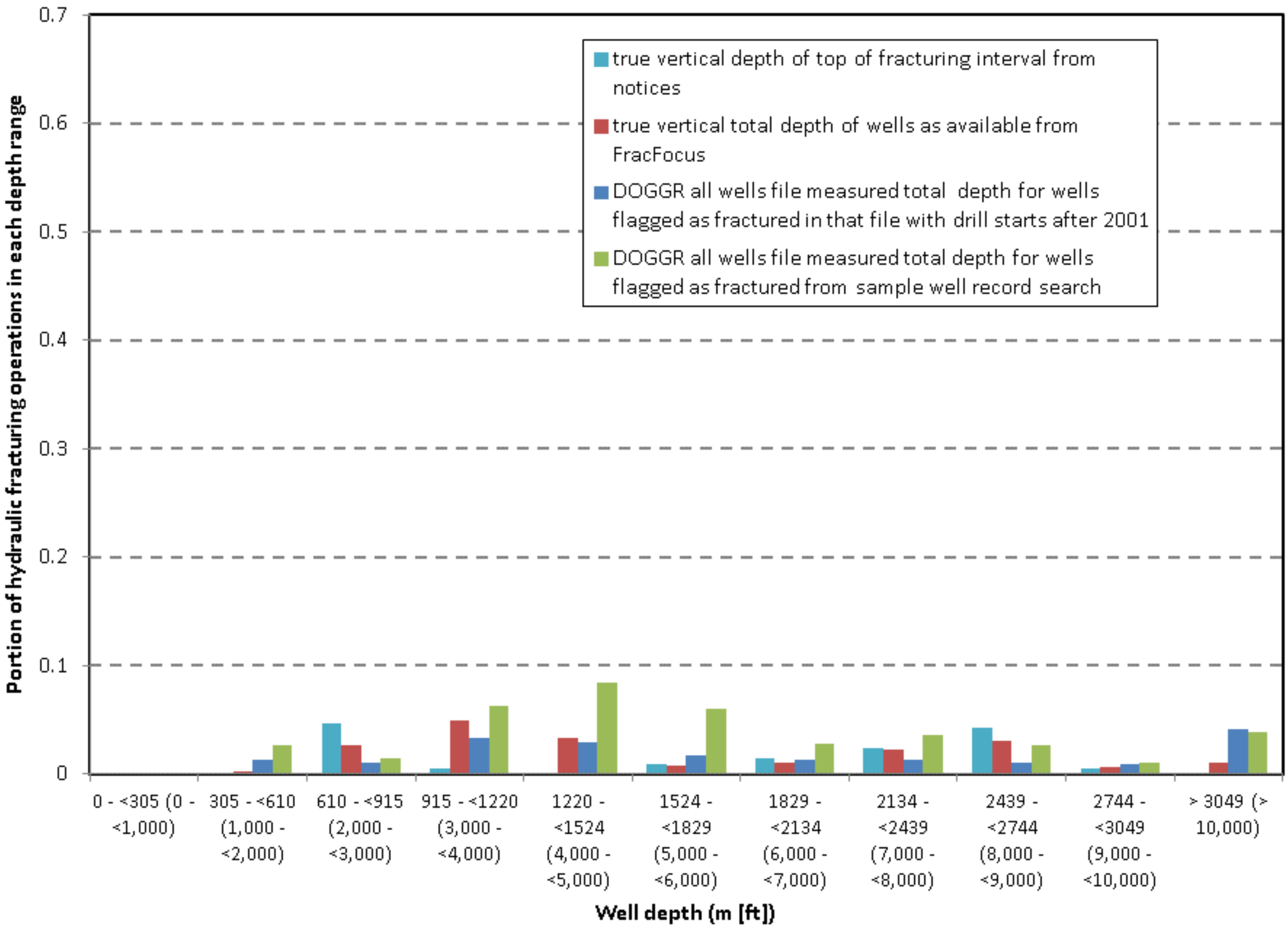
Shallowest hydraulic fracturing depth from the well stimulation notices or hydraulically fractured well depth in each field



Groundwater TDS Thresholds

Total Dissolved Solids (mg/l)	Thresholds
500	Fed EPA: secondary standard California recommended for drinking water
1,000	California upper for drinking water
1,500	California short term for drinking water
3,000	California suitable for use (protected)
10,000	Fed Safe Drinking Water Act: protected groundwater

Portion of hydraulic fracturing operations vs. depth with overlying groundwater with less than 1,500 mg/L TDS



Key question 3

Conclusion 7: Flowback and Produced Water

- California needs to monitor the quality of flowback/produced water and review regulations on the appropriate use of flowback/produced water, based on its quality and the intended uses
- A lack of baseline data on groundwater quality is a major impediment to identifying or clearly assessing the key water-related risks associated with hydraulic fracturing and other well stimulation techniques

Key question 3

Flowback and Produced Water

In California, produced water and flowback water are co-mingled and managed together. Current practice could allow flowback water to be mixed with produced water for use in irrigation and for the disposal of oil and gas wastewater into unlined pits.

Produced water used for irrigation in Cawelo water district

Source: Lauren Sommers

Unlined pits in Kern County

Source : Google Earth

Key question 3

Conclusion 8: Air Quality

- Estimated marginal emissions of NO_x, $PM_{2.5}$, VOCs from activities directly related to WST appear small compared to oil and gas production emissions in total in the San Joaquin Valley, where the vast majority of hydraulic fracturing takes place.
- However, the San Joaquin Valley is often out of compliance with respect to air quality standards and as a result, possible emission reductions remain relevant.

Pollutant emissions from WST

Key Emission Sources

1. Exhaust from diesel engines (pumps and trucks)
2. Flaring of vented gasses during WST and completion
3. Vaporization of hydrocarbons and fugitive emissions

Key Point California WST: "About a thirtieth of the 16,100 m^3 (4.25 million gallons) average stimulation fluid volume per well in the Eagle Ford, TX"

→ Low fluid volumes lead to relatively little pumping, trucking, venting, flaring, and vaporization associated with WST.

Example bottom-up emission estimate:
Given 4 WST operations per day in the SJV, and frac focus volume estimates:

- WST Pumping emits (kg/day): NO_x: 320, $PM_{2.5}$: 16
- Oil and Gas total off-road diesel equipment(kg/day): NO_x: 16,000, $PM_{2.5}$: 500

Key Question 3

Conclusion 9: GHG Emissions

- Fugitive methane emissions from the direct application of WST to oil wells are likely to be small compared to the total greenhouse gas emissions from oil and gas production in California.
- This is because current California oil and gas operations are energy intensive. However, all greenhouse gas emissions are relevant under California's climate laws, and many emissions sources can be addressed successfully with best-available control technology and good practice.

Estimated greenhouse gas emissions from oil and gas production in 2007

Process	Constituent	Total Statewide, 10^6 metric (short) tons CO_2e
Venting (from well workovers)	CH_4	0.07 (0.08)
Venting (from well completions)	CH_4	NOT ESTIMATED
Oil and Associated Gas Production Total	CH_4	1.07 (1.18)
Oil and Associated Gas production and processing total	CH_4	2.1 (2.31)
Oil and Gas CO_2 + CH_4 total (mostly generating steam)	$CO_2 + CH_4$	18.6 (20.5)

Adapted from CARB 2007 oil and gas survey (Detwiler, 2013)

Emissions uncertainty and controls

Estimates of methane emissions from oil and gas production facilities are highly uncertain

- Even if fugitive methane from production is underestimated by 5X (as suggested as possible by Jeong et al. 2014) methane still only accounts for <1/3 total production related CO_2e emissions

~70% of natural gas produced in CA is from oil wells

- Reduced Emission "Green" Completions can successfully control methane emissions
- Green completions are required for gas wells, but not oil wells, starting in 2015

Key question 3

Conclusion 10: Seismic Risk

- Hydraulic fracturing rarely involves large enough volumes of fluids injected at sufficient rate to cause induced seismicity of concern.
- Current hydraulic fracturing practices for oil and gas production in California is not considered to pose a significant seismic hazard.
- In contrast, disposal of produced water from oil and gas production in deep injection wells has caused felt seismic events in several states.
- Expanded oil and gas production due to extensive hydraulic fracturing activity in California would lead to increased injection volumes for disposal if not handled through an expansion of water treatment and re-use systems, which could increase seismic hazards.

Induced Seismicity as a WST Impact

Large increase in WST-related induced seismicity cases since 2010

- building damage
- temporary or permanent shut down of operations
- public alarm

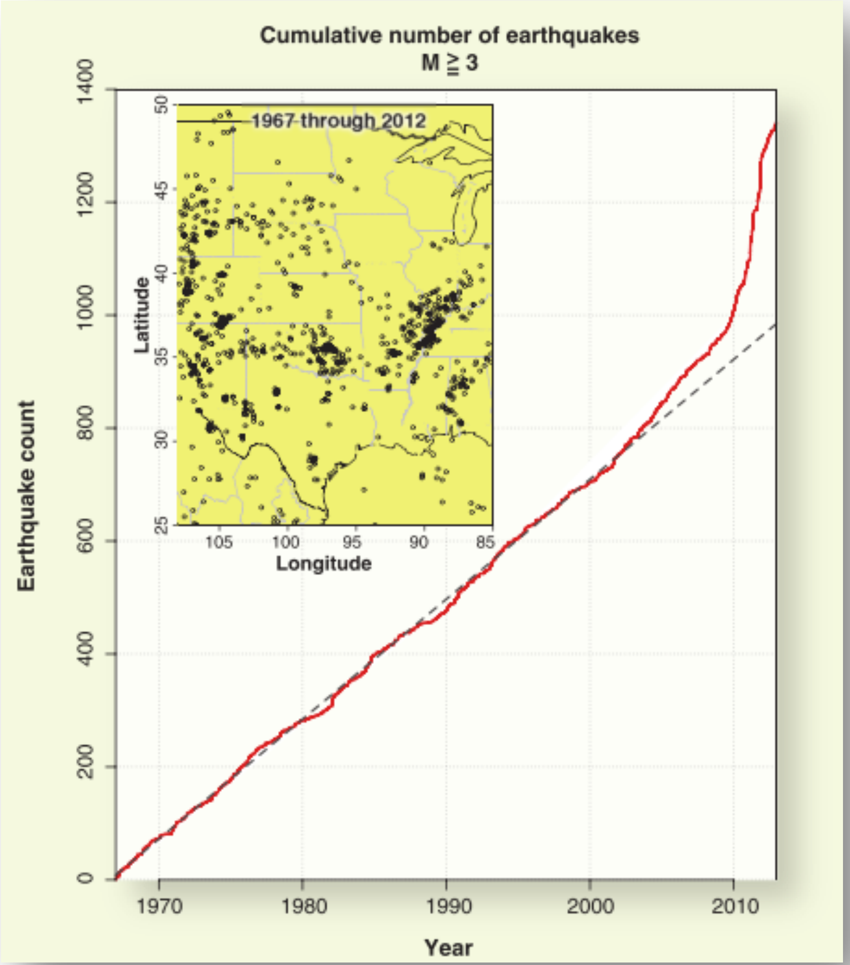
M_{max} from hydrofracture creeping up…currently M3.6

M_{max} from wastewater disposal…at least M5

California

Only one documented case to date, but…

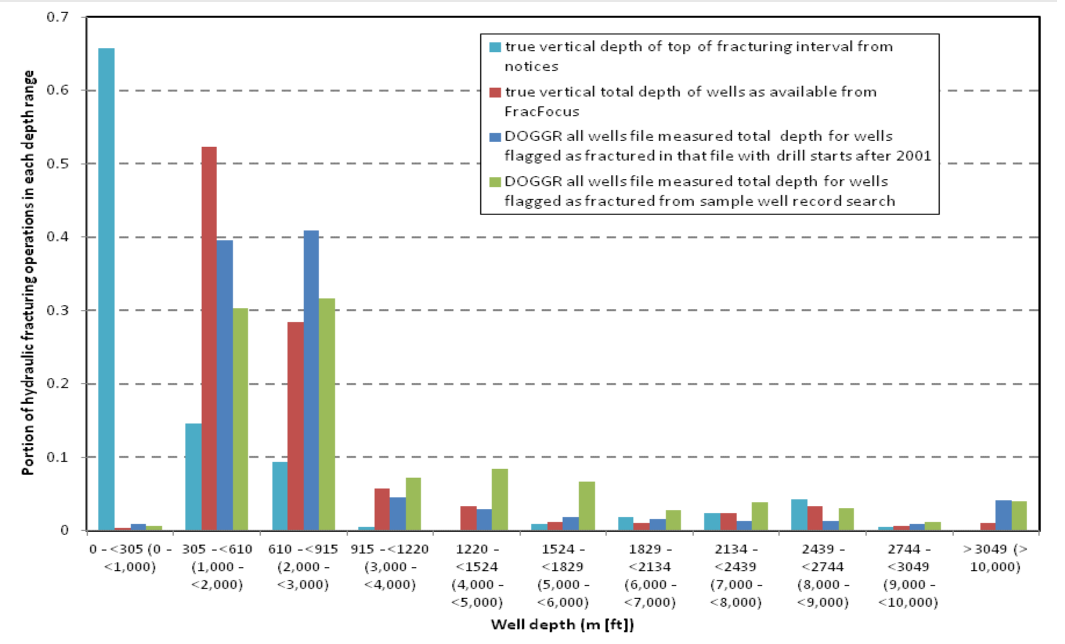
- high rate of natural seismicity, many active faults
- perceived potential for triggering large earthquakes



Ellsworth (2014)

Induced Seismicity Potential in California

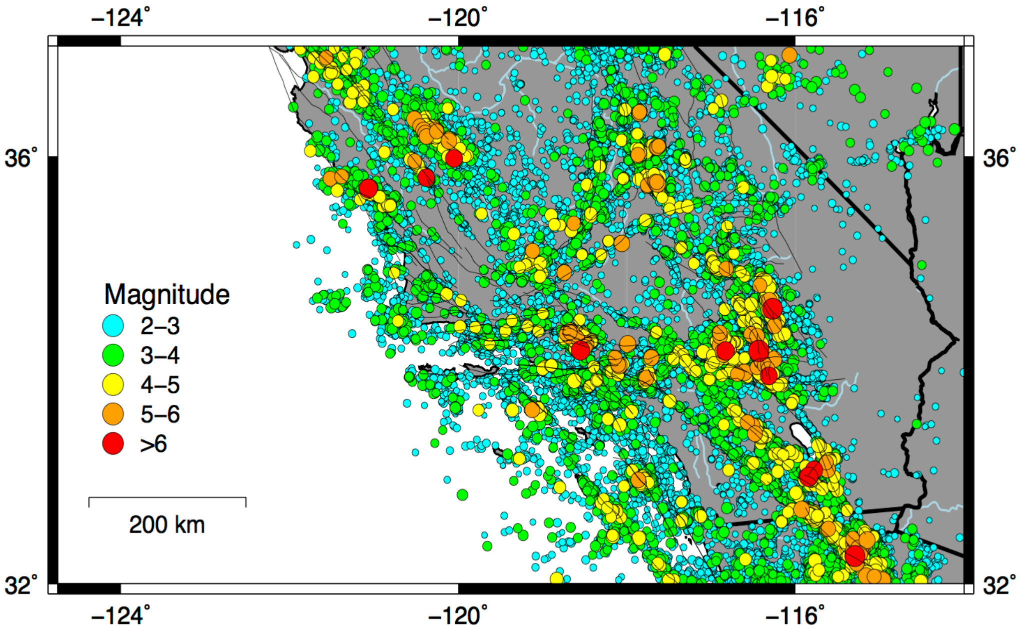
- To date, **hydraulic fracturing** in California has used lower volumes and taken place at shallower depths than in other regions in the US



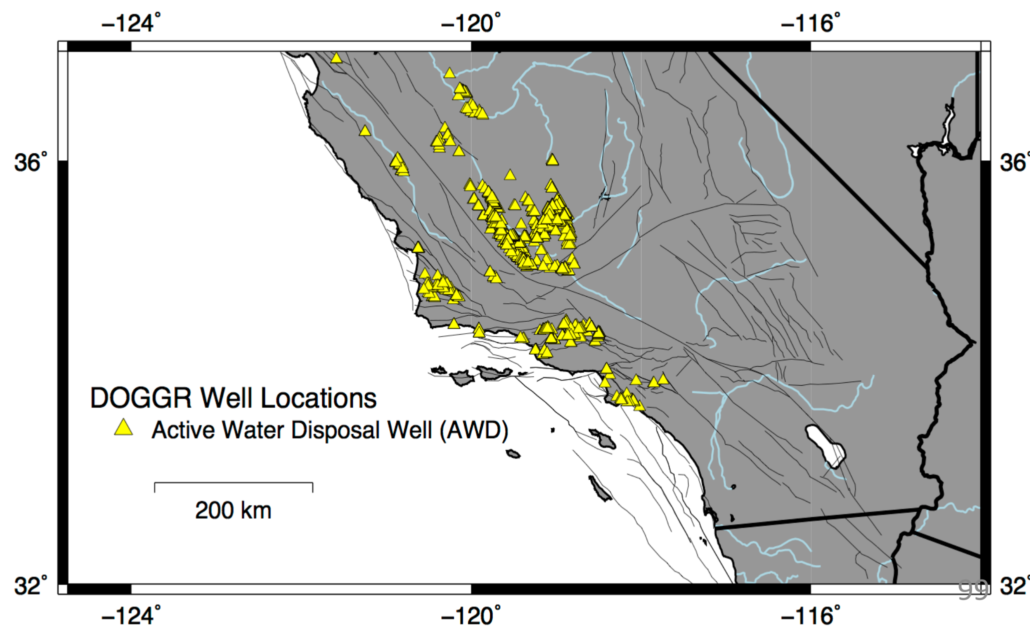
- Overall **wastewater disposal** volume per well in California is ~4 times less and takes place 4,700–7,700 ft shallower than disposal into, e.g., Barnett Shale wells associated with induced seismicity

- **Evaluation of the relationship, if any, between wastewater injection and seismicity and faulting in California is needed to provide better estimates of potential incremental hazard levels due to induced seismicity**

California Seismicity and Wastewater Disposal Wells

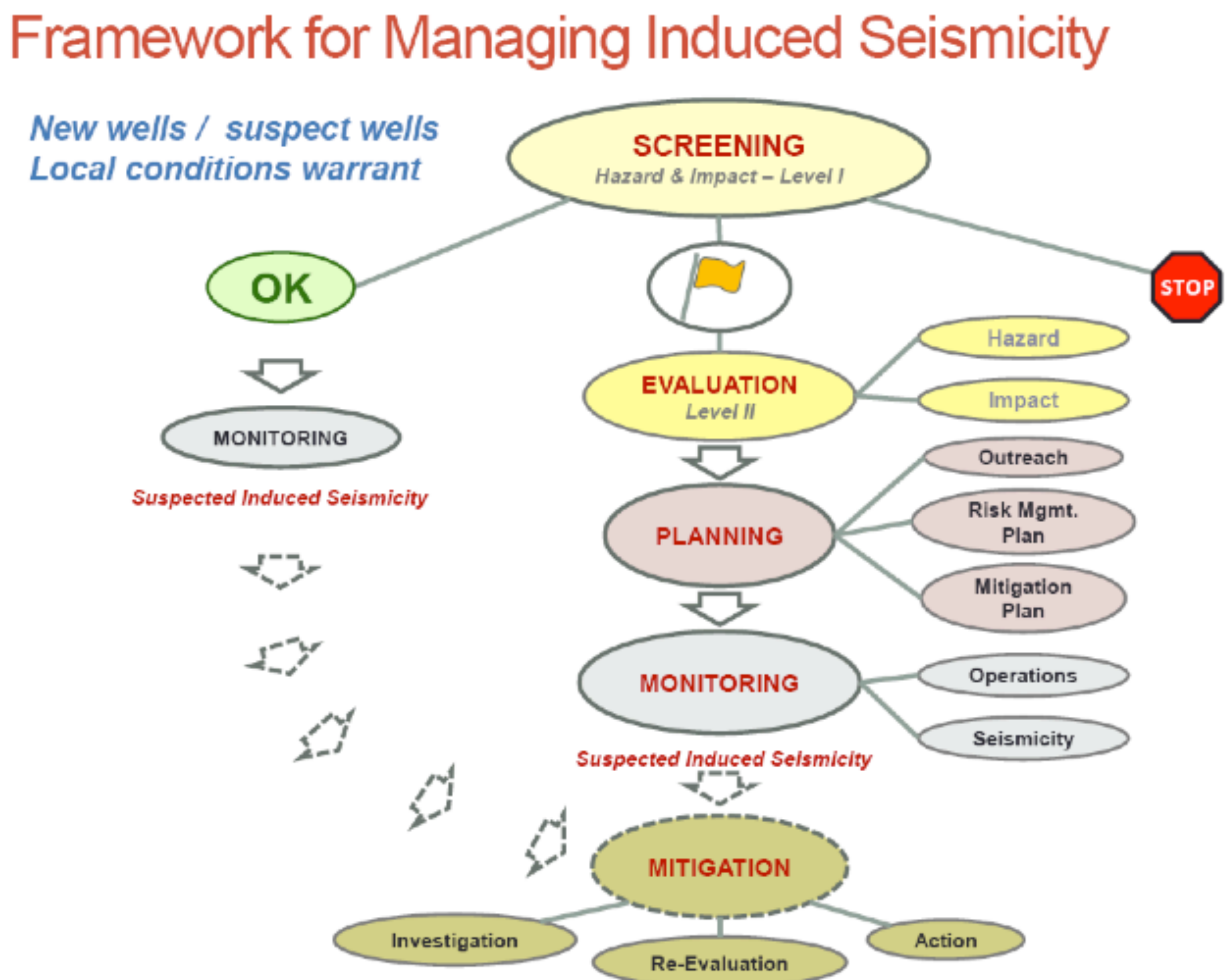


High-precision earthquake locations 1981-2011 from Hauksson et al. (2012)



Locations of 1509 active water disposal wells from DOGGR with UCERF3 FM3.1 faults (Field et al., 2014)

Induced seismicity risk assessment methods and mitigation protocols/best practices



Conclusion 11: Direct vs Indirect Effects

The primary impacts of WST on California's environment will be indirect impacts due to WST-enabled increases and expansion in production.

Impacts of WST-enabled production will vary depending on whether this production occurs in existing rural or urban environments or in regions that have not previously been developed for oil and gas — as well as on the nature of the ecosystems, wildlife, geology and groundwater in the vicinity.

Take away messages

Well stimulation in California is different than other states.

- Differences in the geology of the petroleum reservoirs.
- Generally, hydraulic fracturing in California tends to be performed in shallower wells which are vertical as opposed to horizontal, requires much less water, but uses fluids with more concentrated chemicals than hydraulic fracturing in other states.
- Consequently, the experiences with hydraulic fracturing in other states do not necessarily apply to current hydraulic fracturing in California.

The most likely scenario for future oil recovery is expanded production in and near existing oil fields in the San Joaquin and Los Angeles basins in a manner quite similar to the production practices of today.

- The vast majority of well stimulation currently occurs in the San Joaquin Valley,
- Expanded production in similar reservoirs in the San Joaquin Valley would also likely use this technology,
- Current production in the Los Angeles Basin does not depend heavily on well stimulation and,
- Similar future production could likely occur without these technologies.

EIA estimates are highly uncertain

- The 2011 EIA report suggested 15 billion barrels of recoverable oil from the Monterey source rock,
- The 2014 correction by EIA reduced the estimate to 0.6 billion barrels,
- **The study's review of resource projections from deep source rocks in the Monterey Formation developed by EIA concluded that both these estimates are highly uncertain,**
- Investigators found no reports of successful production from deep source rocks.

Current hydraulic fracturing operations in California require a small fraction of statewide water use.

- In California a hydraulic fracturing operation can consume between 130,000 to 210,000 gallons per well on average,
- 100-150 well stimulations are conducted per month,
- Current total annual water use for well stimulation in California is 450 – 1,200 acre-feet (146.6 million gallons – 391 million gallons),
- hydraulic fracturing can contribute to local constraints on water availability given the extreme drought in the state.

California needs to develop an accurate understanding about the location, depth and quality of groundwater in oil- and gas-producing regions in order to evaluate the risk of well stimulation to groundwater.

- More than half of the stimulated oil wells in California have shallow depth (less than 2,000 feet).
- Shallow hydraulic fracturing poses a potential risk for groundwater if fractures can intersect nearby usable aquifers.
- There are no publicly reported instances of potable water contamination from subsurface releases in California
- A lack of studies, consistent and transparent data collection, and reporting make it difficult to evaluate the extent to which it may have occurred.

The toxicity of chemicals used in hydraulic fracturing warrants further review now that disclosure is required.

- Most of the chemicals reported in FracFocus are not considered to be highly toxic,
- A few of these chemicals, especially the biocides and corrosion inhibitors, are acutely toxic to mammals,
- No information could be found about the toxicity of about a third of the chemicals,
- Few of the chemicals have been evaluated to see if animals or plants would be harmed by chronic exposure. Moreover, data acquired from FracFocus may not be complete or always accurate.

Well stimulation technologies, as currently practiced in California, do not result in a significant increase in seismic hazard.

- The pressure increases from hydraulic fracturing are too small and too short in duration to be able to produce a felt, let alone damaging, earthquake,
- Only one minor, anomalous earthquake (which occurred in 1991) has been linked to hydraulic fracturing to date,
- Expanded oil production for any reason, including expanded use of hydraulic fracturing would lead to increased injection volumes for disposal, and this could increase seismic hazards.

In California, for industry practice of today, the direct environmental impacts of well stimulation practice appear to be relatively limited.

- If these well stimulation technologies enable a significant increase in production in the future, the primary impacts on California's environment will likely be caused by the increase in production activities in general.
- Impacts of increased production will vary
  - Where this production occurs
    - in existing areas (both rural and urban)
    - in regions that have not previously been
  - The nature of the ecosystems, geology, and groundwater in the vicinity.

SUMMARY

- Hydraulic fracturing in California has mostly been different from the high-volume hydraulic fracturing (using long-reach horizontal wells) conducted elsewhere
- Consequently, the experiences in other states are largely not applicable to California.

SUMMARY cont'd

- The likelihood of finding major new shale plays similar to what has occurred in other states is quite uncertain.
- However, about 5 to 16 billion barrels of additional oil could be produced through the application of currently used technology in existing oil fields.
- New production in and around existing production sites in Monterey diatomite reservoirs in the San Joaquin Basin would likely also be amenable to production with hydraulic fracturing.
- New production in and around existing fields that currently does not depend on well stimulation technologies (WST), such as in the Los Angeles Basin, could well continue to be produced without WST in the future.

SUMMARY cont'd

- Current water demand for well stimulation operations in California is a small fraction of statewide water use, but drought conditions may mean this is locally significant.
- Most of the chemicals reported for hydraulic fracturing treatments in California are not considered to be acutely toxic, but a few reported chemicals do present concerns for acute toxicity.

SUMMARY cont'd

- Groundwater contamination from hydraulic fracturing has not been observed in this state, but there is a lack of data about the location and quality of groundwater resources, lack of knowledge about existing wells which might provide leakage paths, and inconsistent monitoring of potential groundwater impacts
- In some cases, hydraulic fracturing is taking place in shallow wells, in regions where the quality and location of the groundwater is not specified.

SUMMARY cont'd

- Hydraulic fracturing as currently practiced in California does not present a risk for induced seismic events of significance.
- Protocols similar to those that have been developed for other types of injection wells, such as for geothermal injections, can be applied to limit this risk.

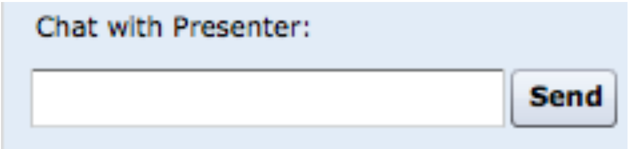
SUMMARY cont'd

- The direct emissions of hydraulic fracturing are a small component of total air pollution and methane, but emissions are relevant under California's climate regulations.
- If the future brings significantly increased production enabled by WST, the primary impacts of WST on California's environment will be indirect impacts, i.e. those due to increases and expansion in production.

How to Participate

Use the "chat" feature to submit questions in writing.

The chat entry box is in the lower left hand corner of your window. Enter a question and click "send."



If you don't see the chat box, you may need to click on the "show chat" button in the upper left hand corner.

Or you can email questions to cafrac@ccst.us

The moderator will take questions at the end of the presentation.