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

Public Webinar, July 9 2015

CCST
CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

BERKELEY LAB

Web location for this presentation

- In the interest of time, we will not be showing every slide in this deck.

- You can find a full copy of this presentation at

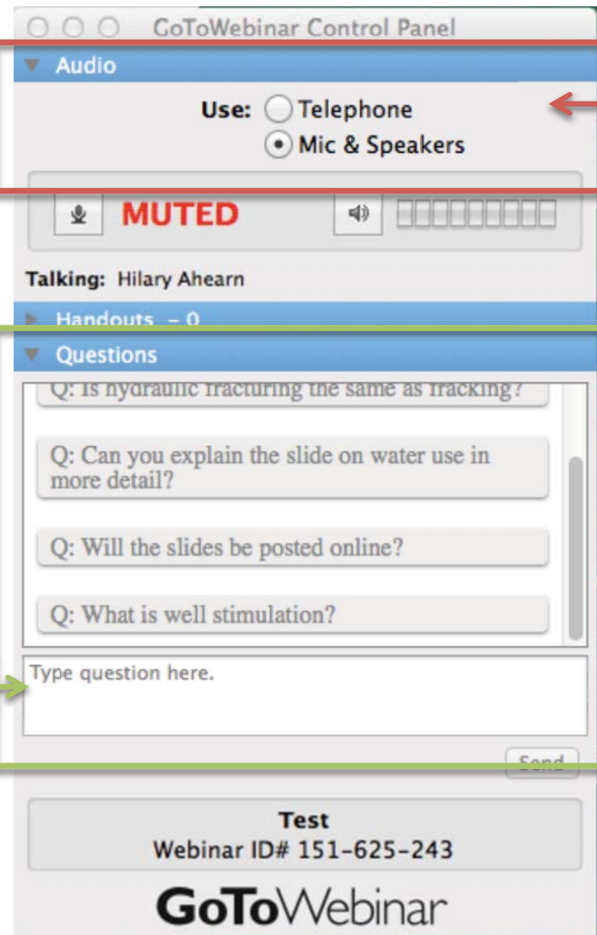
  http://ccst.us/projects/hydraulic_fracturing_public/SB4.php

  (accessible from our home page, http://ccst.us/)

How to Participate

We recommend listening over your computer "Mic and Speakers."

If you experience audio problems, please choose the "telephone" option and call in instead.



Please ask questions by typing them in the "Questions" window in your Control Panel.

We will answer as many questions as possible at the end.

Senate Bill 4 (SB 4)

- Regulates hydraulic fracturing and acid stimulation technologies in California.
- SB 4 also requires the California Natural Resources Agency to conduct an independent scientific study to assess
  - current and potential future well stimulation practices
  - the impacts of well stimulation technologies
  - the gaps in data that preclude this understanding;
  - potential risks associated with current practices;
  - alternative practices that might limit these risks.

Purpose of this briefing

To provide a briefing of the conclusions and recommendations from "*An Independent Scientific Assessment of Well Stimulation in California*" commissioned by the California Natural Resources Agency pursuant to Senate Bill 4 (Pavley) and developed by CCST and LBNL

California Council on Science and Technology (CCST)

- CCST is a nonpartisan, impartial, not-for-profit corporation established via Assembly Concurrent Resolution (ACR 162) in 1988 to provide objective advice from California's best scientists and research institutions on policy issues involving science.

- CCST is dedicated to providing impartial expertise that extends beyond the resources or perspective of any single institution.

- CCST is governed by a Board of Directors and studies are funded by government agencies, foundations and other private sponsors.

California Council on Science and Technology

CCST regularly issues important, peer-reviewed reports authored by the State's foremost technical experts to address some of society's toughest challenges related to water, energy, innovation, and STEM education in California.

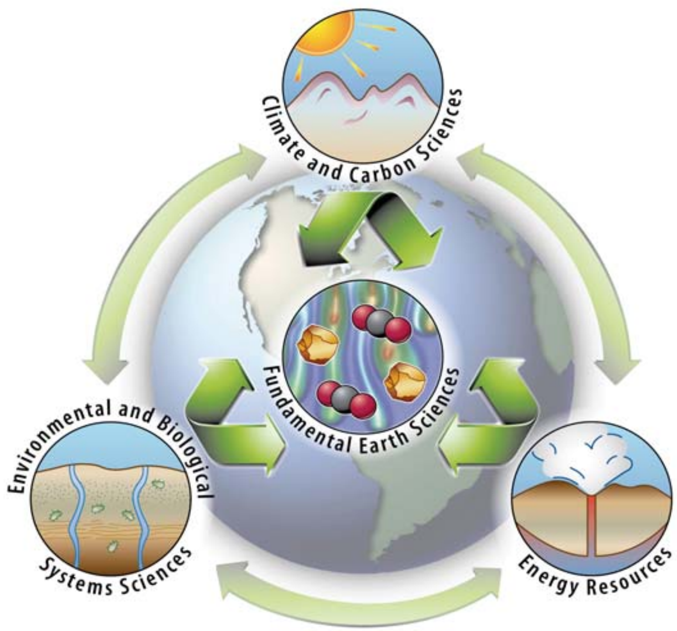
Our role is to oversee a very rigorous process, which includes:

- Convening study teams with an appropriate range of expertise for the task
- Providing a balance of points of view on CCST teams and reports
- Screening for potential conflicts of interest (*point of view is different from conflict of interest)*
- Conducting an extensive and rigorous peer review by experts who were not involved in writing the report, and who also undergo a conflict of interest screening

This process, modeled after the National Academies, ensures the product is credible and responsive to the study charge.

Lawrence Berkeley National Laboratory (LBNL)

- 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 LBNL

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.**

Managed by the University of California for the U.S. Department of Energy

Who Performed the Study

- **The CCST's California Well Stimulation Steering Committee**
  - Provided oversight, scientific guidance and input for the project
  - Together with science team, developed conclusions and recommendations
- **Lawrence Berkeley National Laboratory (LBNL)**
  - Performed the majority of the analysis
- **Subcontractors**:
  - The Pacific Institute
  - PSE Healthy Energy
  - Stanford University
  - Dan Gautier (USGS retired)
  - Scripps Institute of Oceanography
  - CSU Stanislaus Endangered Species Recovery Program
  - University of the Pacific

Steering Committee Members

- Jane C. S. Long (Chair)
- Jens Birkholzer (LBNL Lead)
- Peter Gleick (Impacts to Water)
- Dan Tormey (Impacts of well stimulation technologies, WST, in CA)
- Larry Lake (Petroleum Engineering)
- Seth Shonkoff (Public Health)
- Dan Hill (WST)
- Don Gautier (Petroleum Geology)
- Tom McKone (Risk Assessment)
- William Minner (WST Design and Practice in CA)
- Roger Aines (Geochemistry)
- Amy Myers Jaffe (Environmental Practice in Petroleum, Oil Business)
- Sam Traina (Environmental Engineering)

Ex Officio:

- Laura Feinstein (Project Manager)

The study was produced in three volumes plus a summary

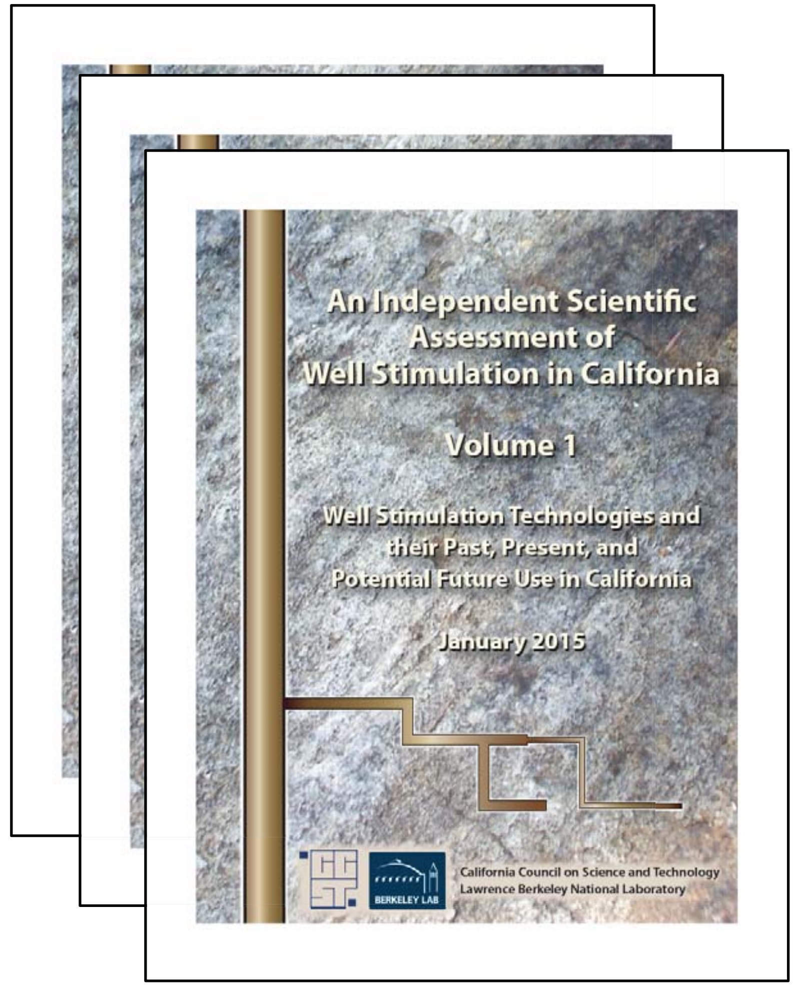
Title	Delivered to CNRA
VOLUME I: Well Stimulation Technologies and their Past, Present and Potential Future Use in California	Jan 1, 2015
VOLUME II: Generic and Potential Environmental Impacts of Well Stimulation Treatments	July 1, 2015
VOLUME III: Case Studies with Selected Evaluations of Environmental and Public Health Risk	July 1, 2015
Summary Report: Vernacular Summary of Major Findings, Conclusions and Recommendations	July 1, 2015

CCST CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

BERKELEY LAB

Detailed Information in Three Report Volumes and Thousands of Document Pages

- Today's presentation provides a short summary of main conclusions and recommendations
- These are derived from a large amount of detailed technical analyses, discussion, and interpretation
- We encourage all stakeholders to go through all volumes and chapters, and utilize underlying technical information going forward
- The science team is available as a resource for information and advice
- Report data can be made available upon request

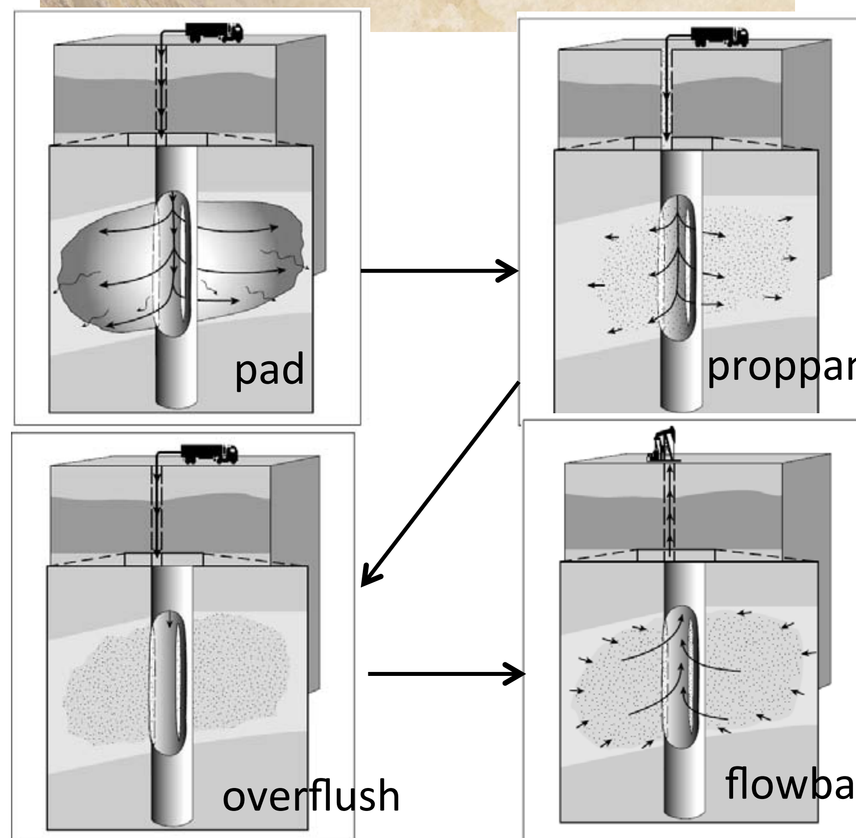


Volume III: Four Case Studies Focus on Specific Places and Issues

- The **Offshore Case Study** evaluates what we know and do not know about the use of stimulation technologies in that environment.
- The **Monterey Formation Case Study** identifies the geographic locations (or "footprint") of the parts of the Monterey Formation that could contain producible oil and gas in "source rock", and examines the implications if new production were to begin in those regions.
- The **Los Angeles Basin Case Study** describes the geologic basis of oil production and its implications for future oil and gas production using technology such as hydraulic fracturing. The second part evaluates sparse information about public health implications of oil and gas development in a densely populated mega-city.
- The **San Joaquin Basin Case Study** evaluates likely future production with hydraulic fracturing in this region and examines the implications of that production.

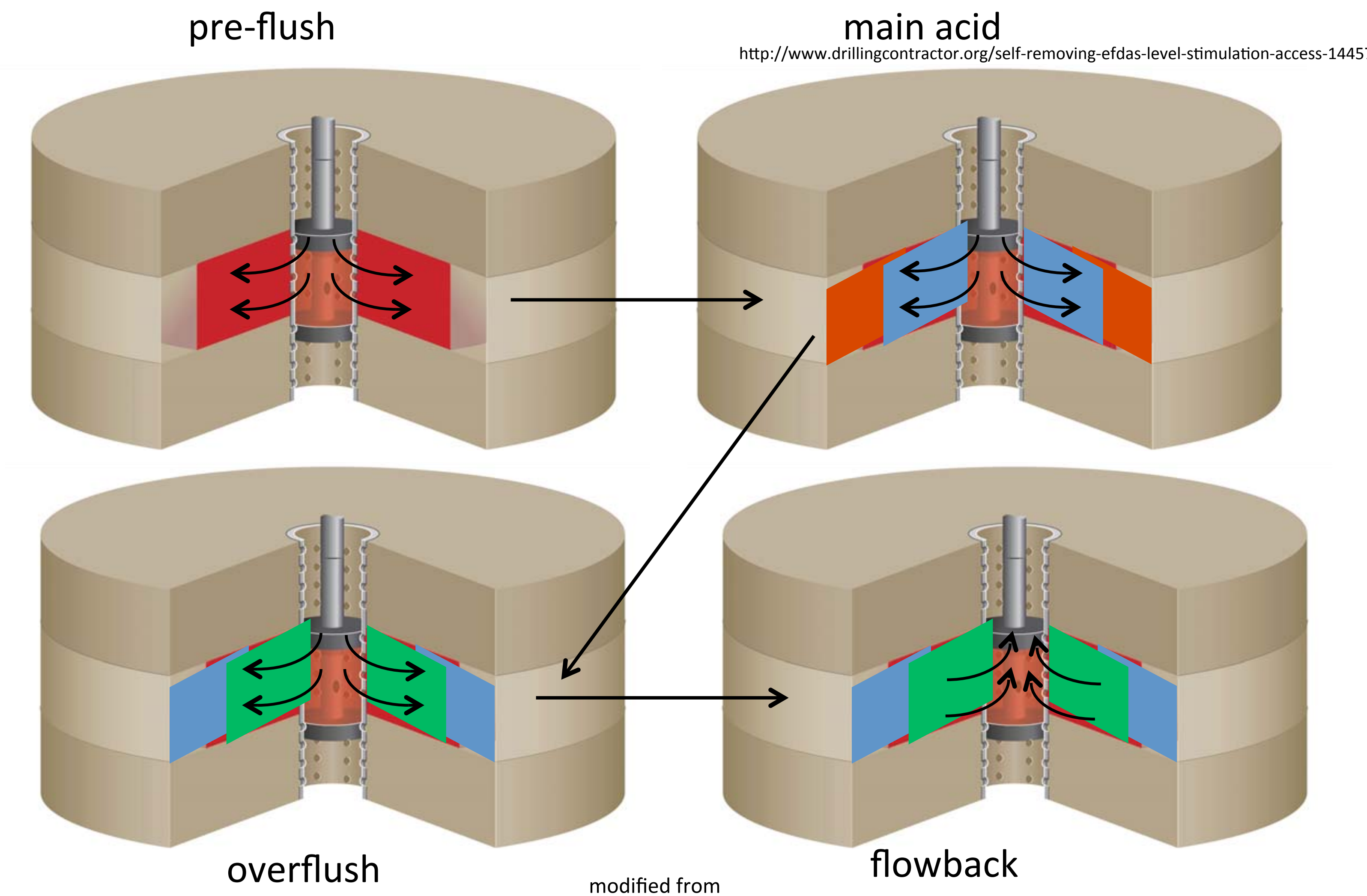
Typical Hydraulic Fracturing Process

- 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)

Typical Sandstone Matrix Acidizing Process



modified from
Samuel and Sengul (2003)

The Basis for Our Assessment

- Prior work for Bureau of Land Management (BLM).
- Peer-reviewed published literature.
- Analysis of available data from California Division of Oil, Gas and Geothermal Resources (CDOGGR) and other publicly available sources.
- Other relevant publications including reports and theses. We state the qualifications of the information used in the report.
- The expertise of the committee and scientific community to identify issues.
- CCST solicited nominations of information from the public.

Principles to improve safety of hydraulic fracturing and acid stimulation in California

1. Maintain, expand and analyze data on the practice of hydraulic fracturing and acid stimulation in California.
2. Prepare for potential future changes in hydraulic fracturing and acid stimulation practice in California.
3. Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation.
4. Manage produced water from hydraulically fractured or acid stimulated wells appropriately.
5. Add protections to avoid groundwater contamination by hydraulic fracturing.
6. Understand and control emissions and their impact on environmental and human health.
7. Take an informed path forward.

Principle 1.
Maintain, expand and analyze data on the practice of hydraulic fracturing and acid stimulation in California.

Principle 1. Maintain, expand and analyze data on the practice of hydraulic fracturing and acid stimulation in California.

- **Conclusion 1.1. Most well stimulations in California are hydraulic fracturing and most hydraulic fracturing occurs in the San Joaquin Valley.**
  - *About 95% of reported hydraulic fracturing operations occur in the San Joaquin Valley, nearly all in four oil fields in Kern County.*
  - *20% of oil and gas production comes from wells treated with hydraulic fracturing.*
  - *Hydraulic fracturing accounts for about 90% of all well stimulations in California;*
  - *Matrix acidizing accounts for only 10% of all WST operations; and acid fracturing operations are practically nonexistent.*
  - *Acid stimulation is not expected to lead to major increases in oil and gas production due to the state's geology.*
  - *Operators of dry gas wells located in the Sacramento Valley rarely use hydraulic fracturing.*
  - *(Volume I, Chapter 3)*

Database Sources on Well Stimulation Practices

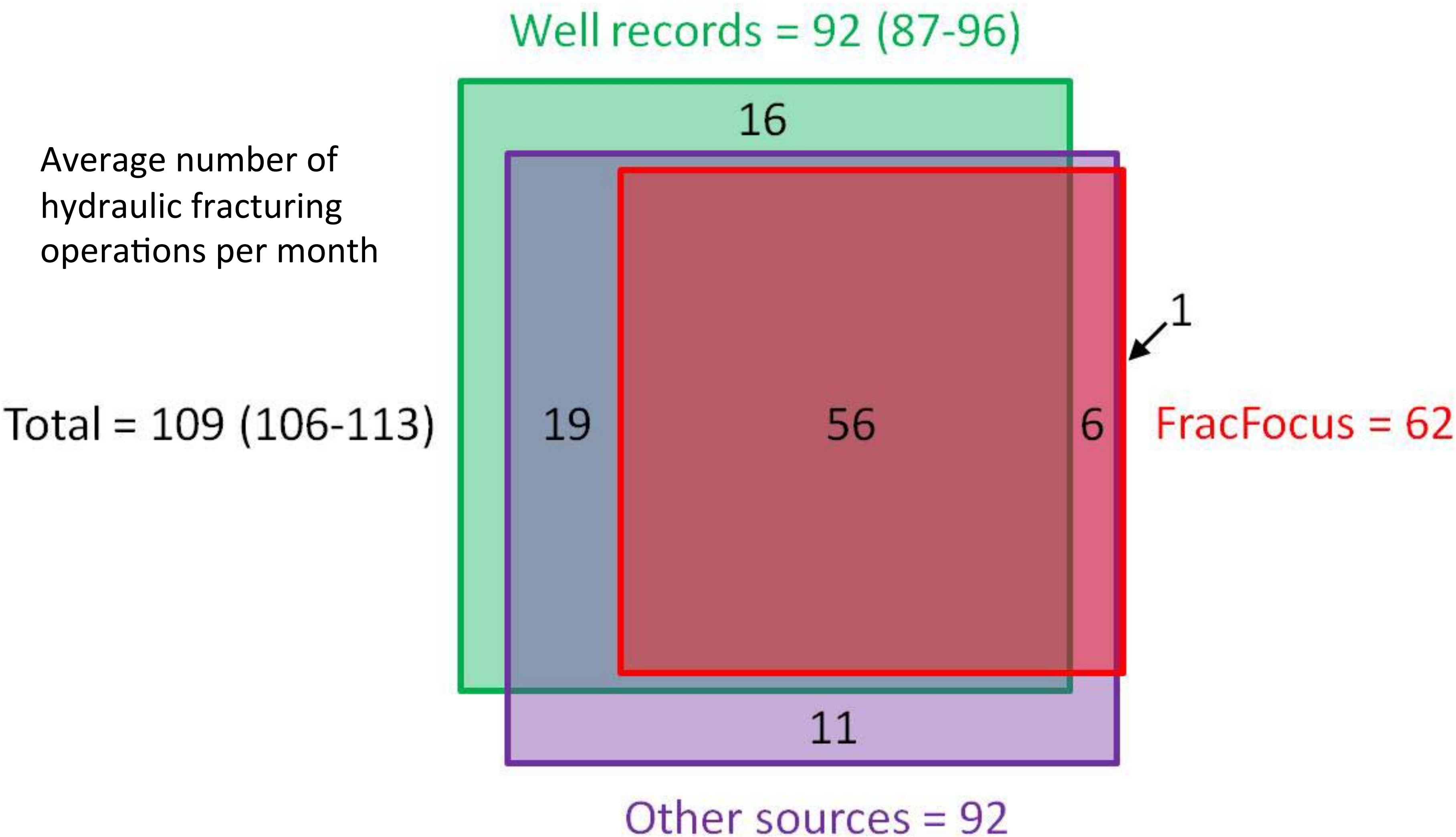
Data source	Years	Required	HF	AF	MA	API #	Location	Date	Volume	Chemicals	Depth
DOGGR disclosures	2014	x	x	x	x	x	x	x	x	x	x
DOGGR notices	2014	x	x	x	x	x	x		x	x	x
SCAQMD	2013-2014	x	x	x	x	partial	x	x	x	x	
CVRWQCB	2012-2013	x	x	x	x	x	x	x	x		TVD
FracFocus	2011-2014	partial	p			x	x	x	x	partial	TVD
Well record search	2002-2013		p			x					
DOGGR GIS well table	all		p			x	x				MD-partial

HF = hydraulic fracturing; AF = acid fracturing; MA = matrix acidizing

Department of Oil Gas & Geothermal regulation (DOGGR), Central Valley Regional Water Quality Control Board (CVRWQCB) , South Coast Air Quality Management District (SCAQMD)

Different data sources give similar results for the amount of hydraulic fracturing being done in the state

Average number of hydraulic fracturing operations per month

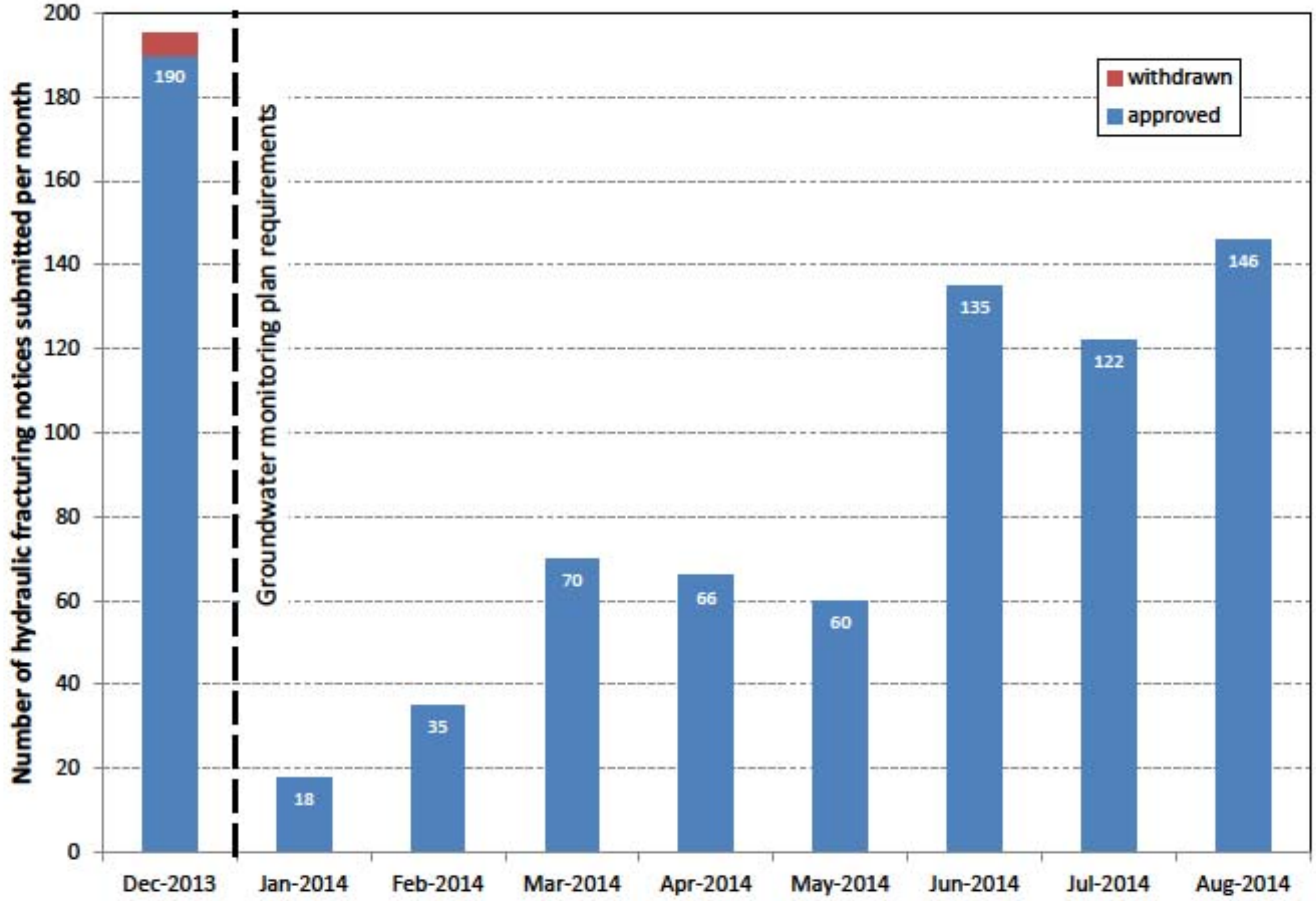


CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

"An Independent Scientific Assessment of Well Stimulation in California," July 2015

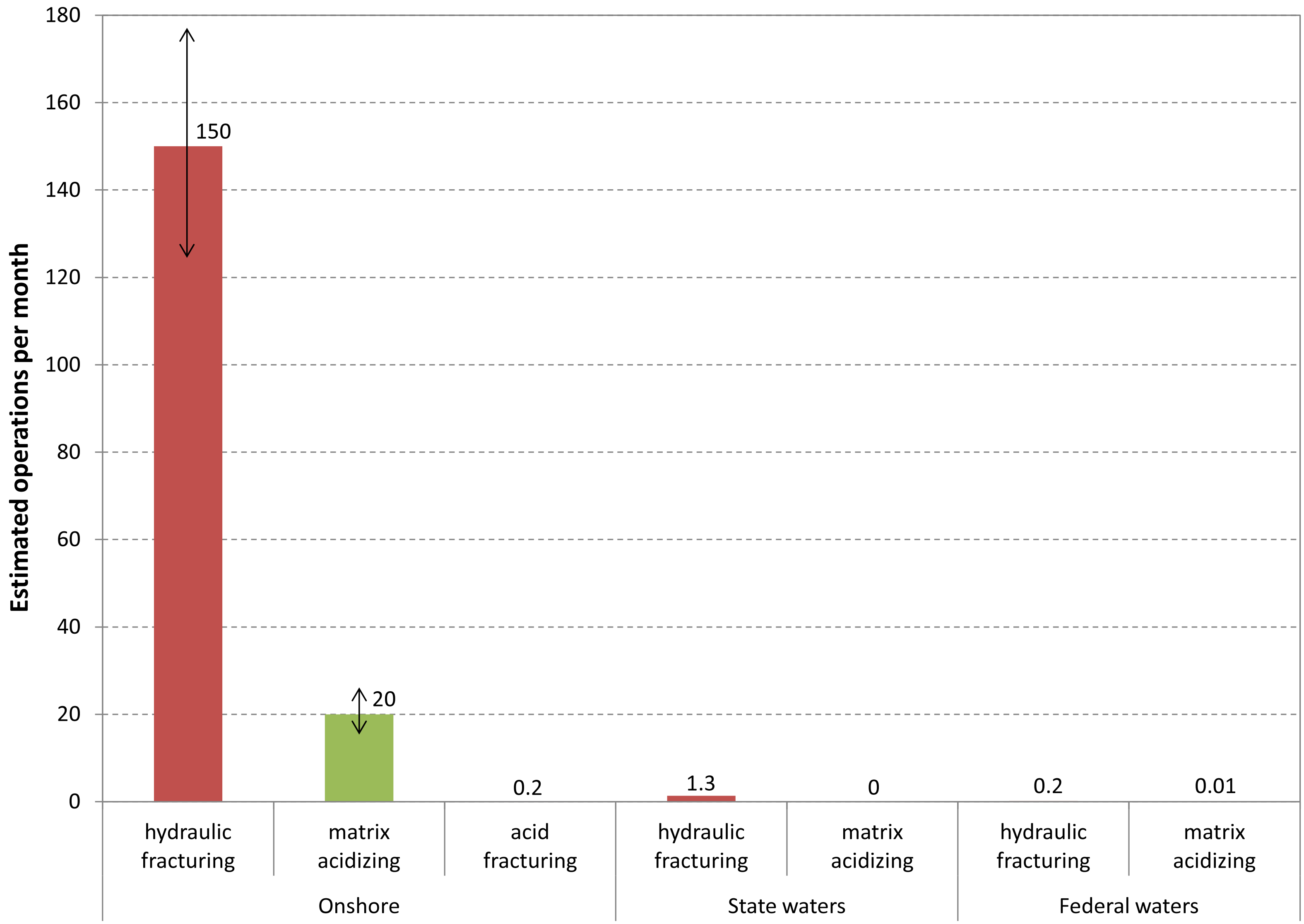
BERKELEY LAB

Hydraulic fracturing notice count suggests more activity than do other data sources

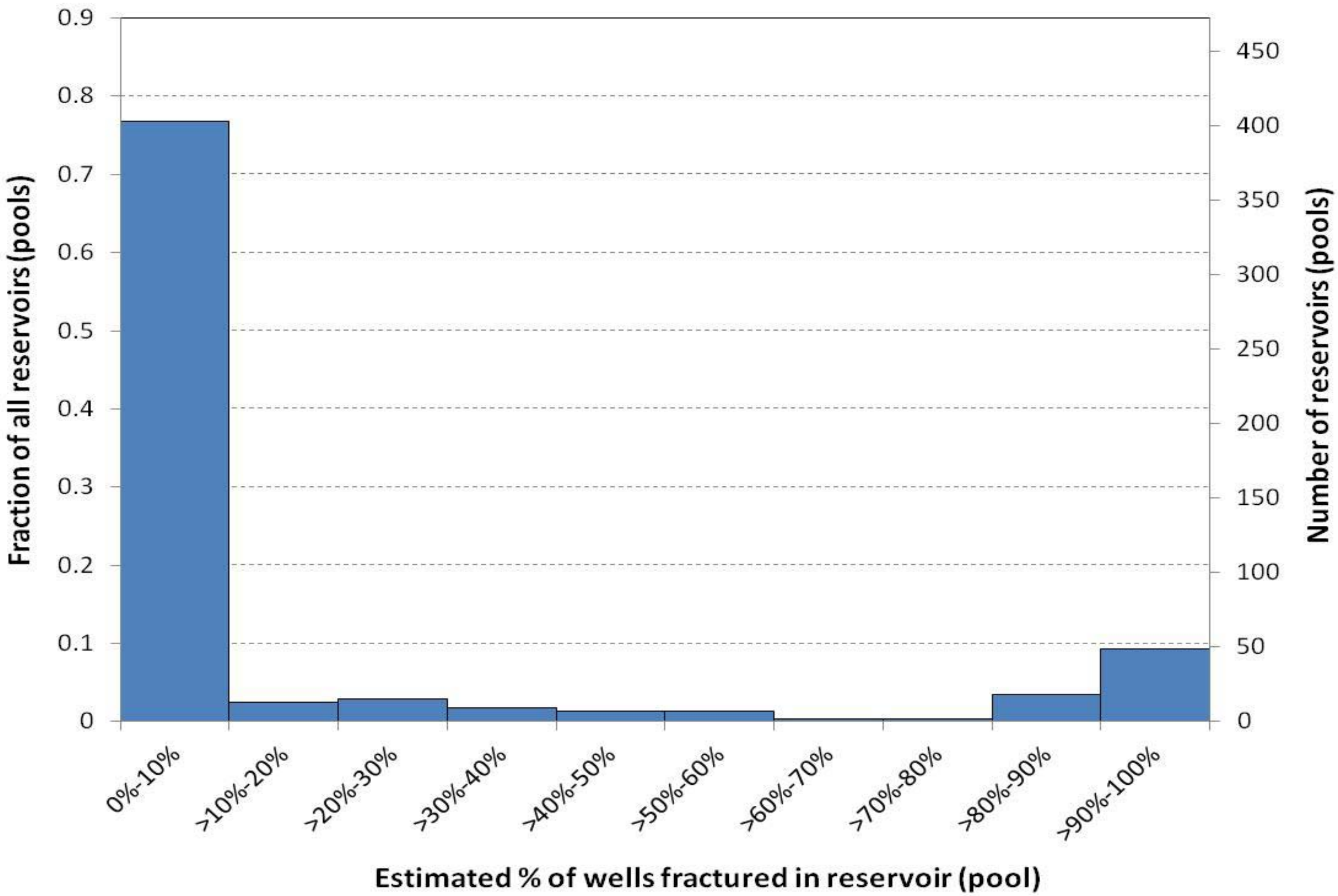


"An Independent Scientific Assessment of Well Stimulation in California," July 2015

Almost all stimulation activity is hydraulic fracturing of oil wells onshore

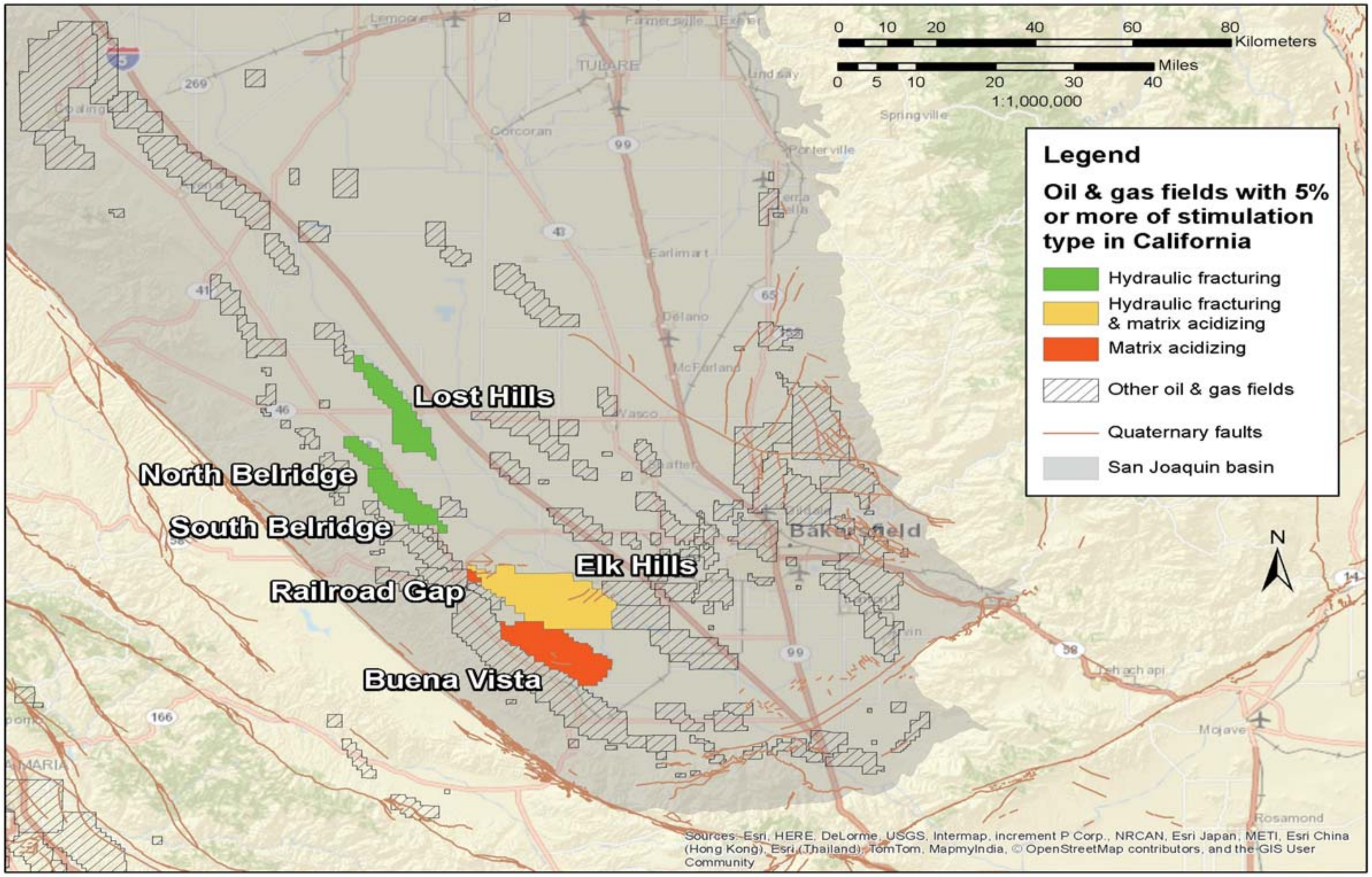


Most pools are either highly fractured or not fractured



"An Independent Scientific Assessment of Well Stimulation in California," July 2015

Nearly all hydraulic fracturing and matrix acidizing occurs in six fields in the San Joaquin Valley

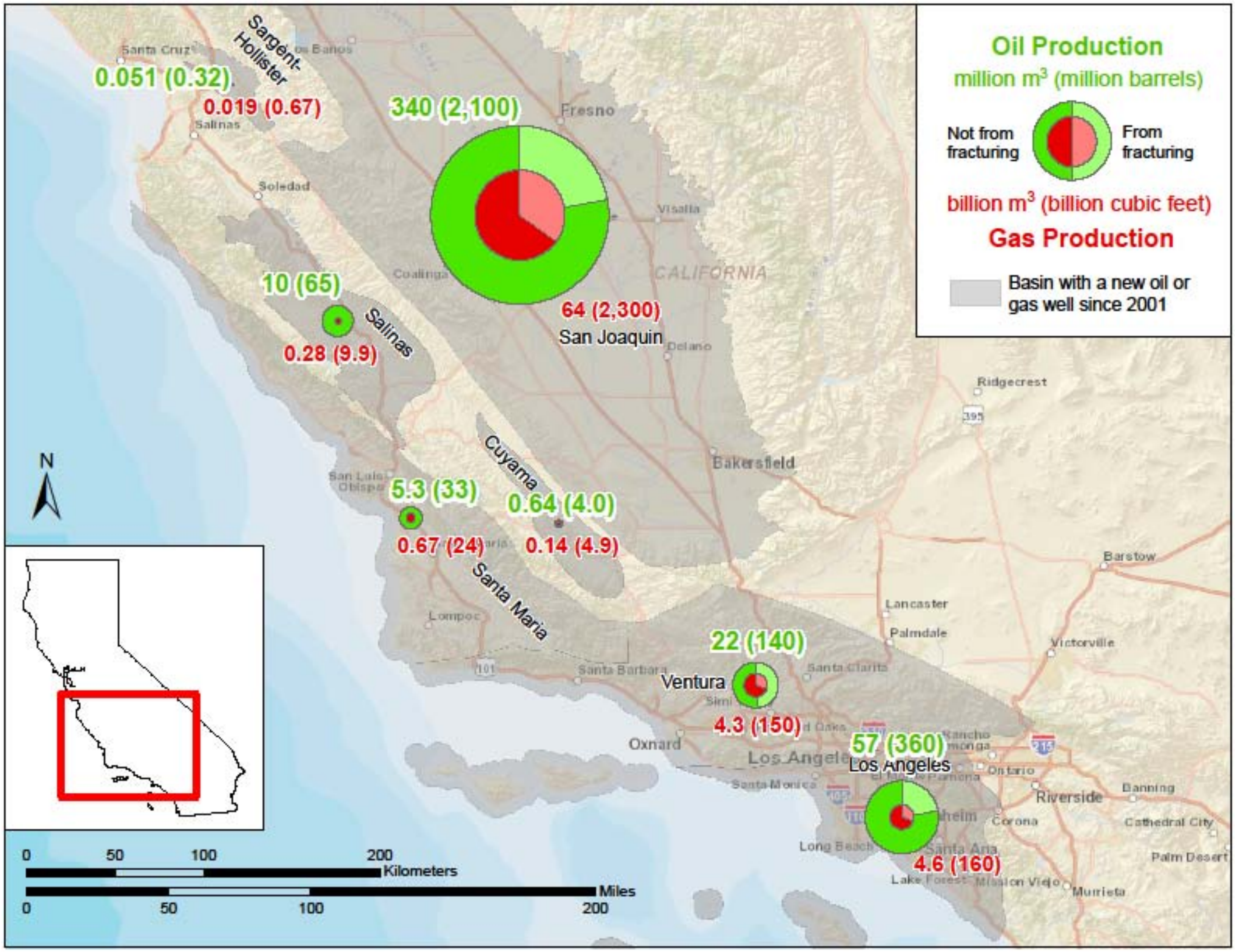


CCST CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

"An Independent Scientific Assessment of Well Stimulation in California," July 2015

BERKELEY LAB

Hydraulic fracturing facilitated about 20% of oil and gas production in CA during 2001-2013 study period



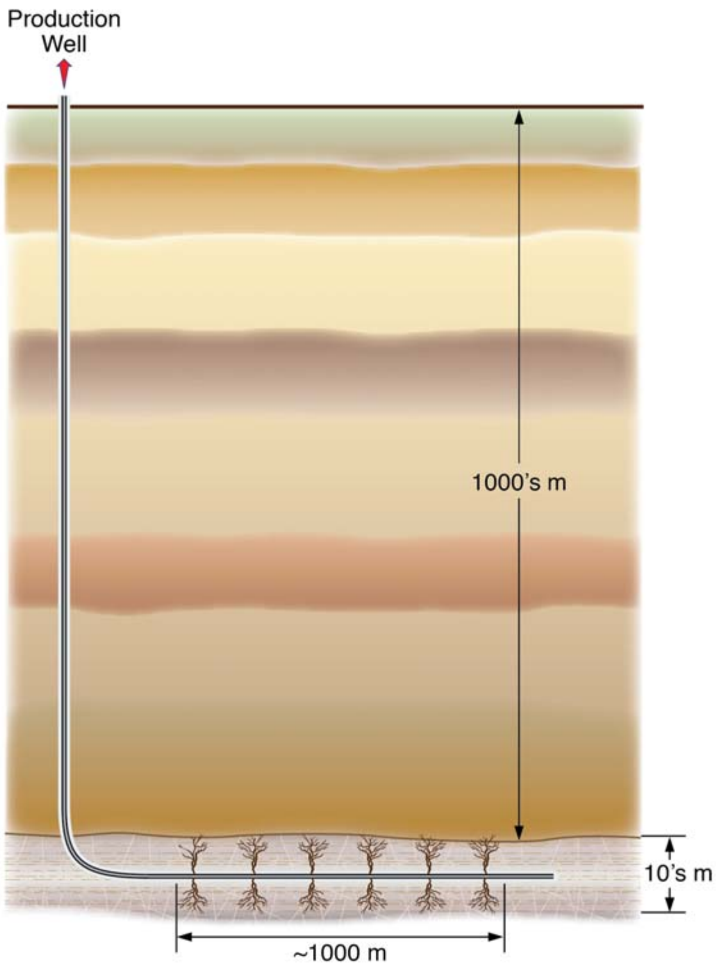
“An Independent Scientific Assessment of Well Stimulation in California,” July 2015

Principle 1. Maintain, expand and analyze data on the practice of hydraulic fracturing and acid stimulation in California

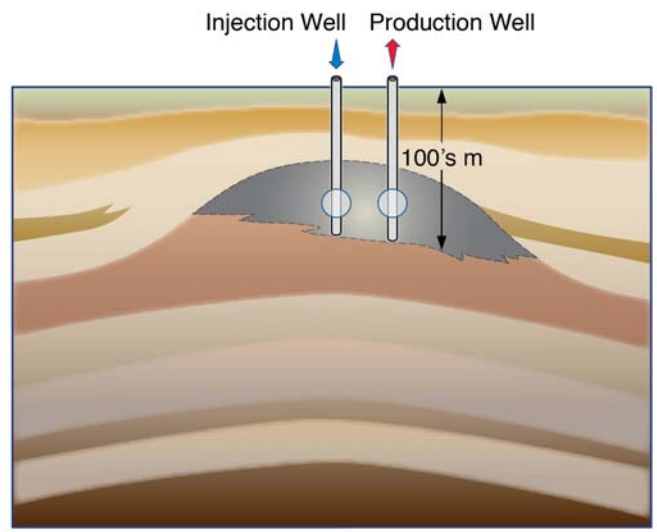
- **Conclusion 1.2. The California experience with hydraulic fracturing differs from that in other states.**
  - *Present-day hydraulic fracturing practice and geologic conditions in California differ from those in other states*
  - *Very little long-reach horizontal high volume fracturing*
  - *Recent experiences with hydraulic fracturing in other states do not necessarily apply to current hydraulic fracturing in California.*

Stimulated wells in California tend to be vertical

Typical Source Rock Stimulation



Typical California (Migrated Oil) Stimulation



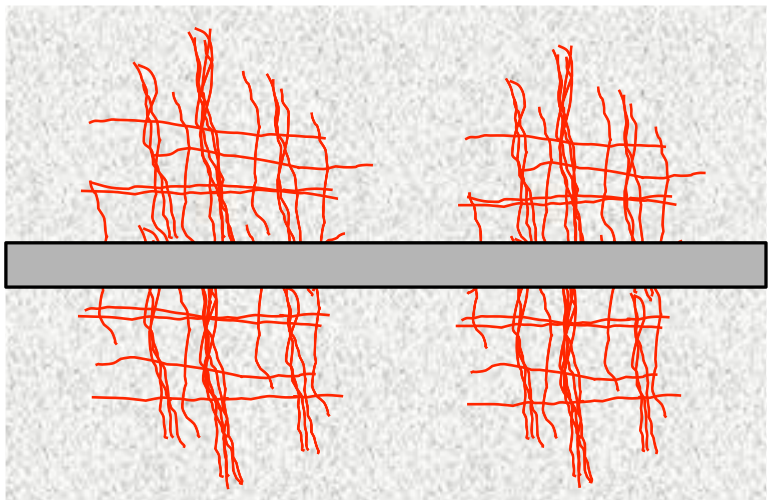
ESD14-047

CCST CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

BERKELEY LAB

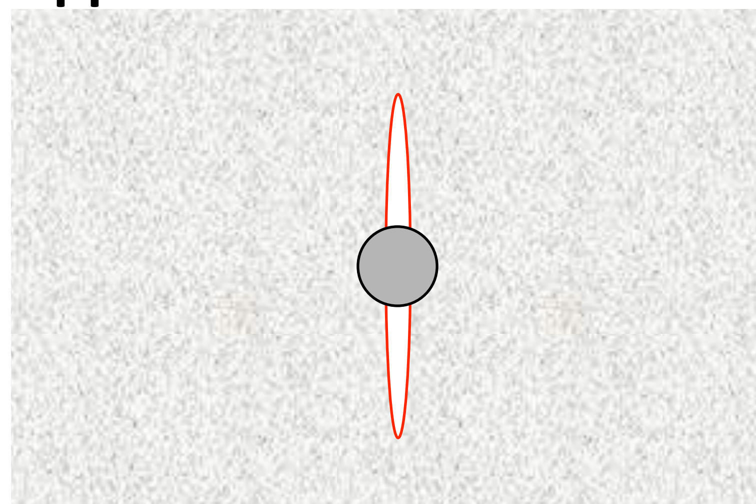
CA hydraulic fractures: smaller and simpler

High Volume – Horizontal Well Application



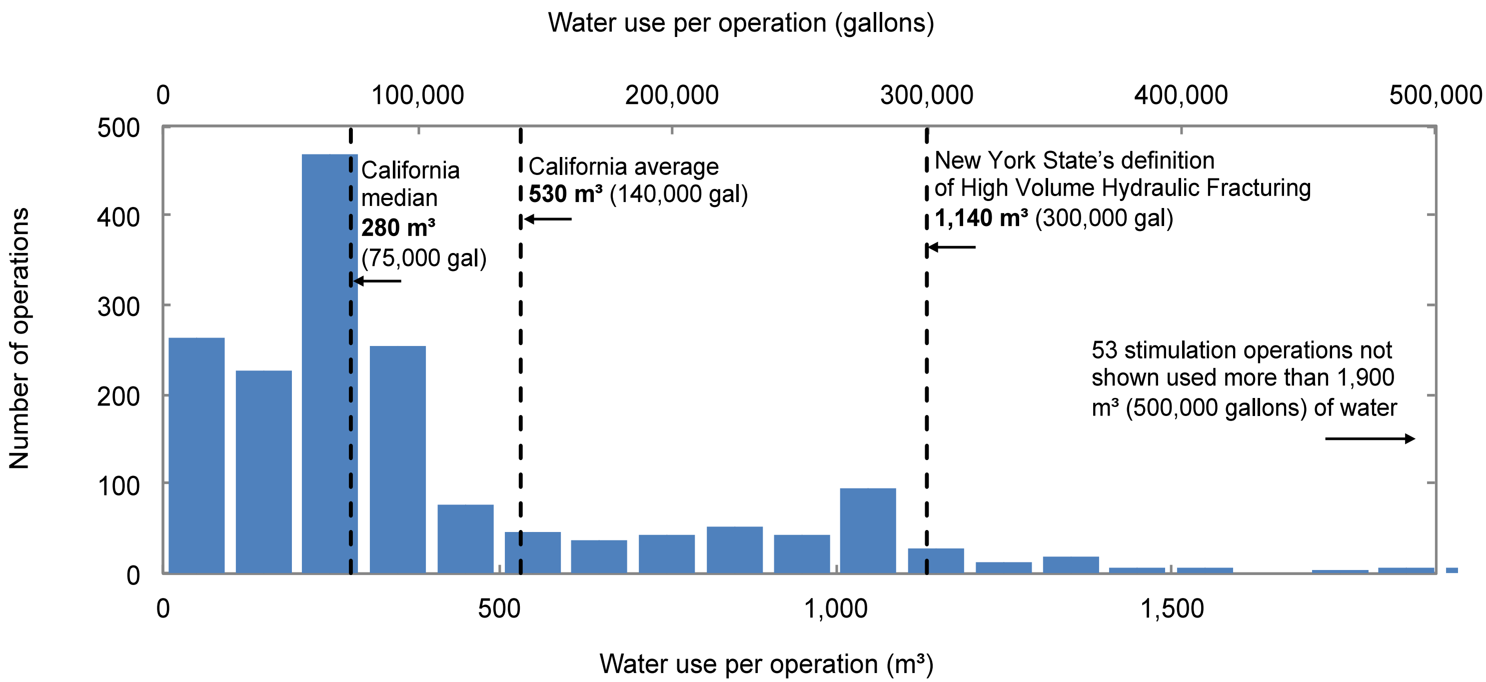
- Larger volumes of water
- Slick-water (detergents) additives
- Complex fracture networks
- (Banned in New York)

Typical California Vertical Well Application



- Smaller volumes of water
- Gel-based (Guar gum) additive
- Simpler fractures with larger aperture

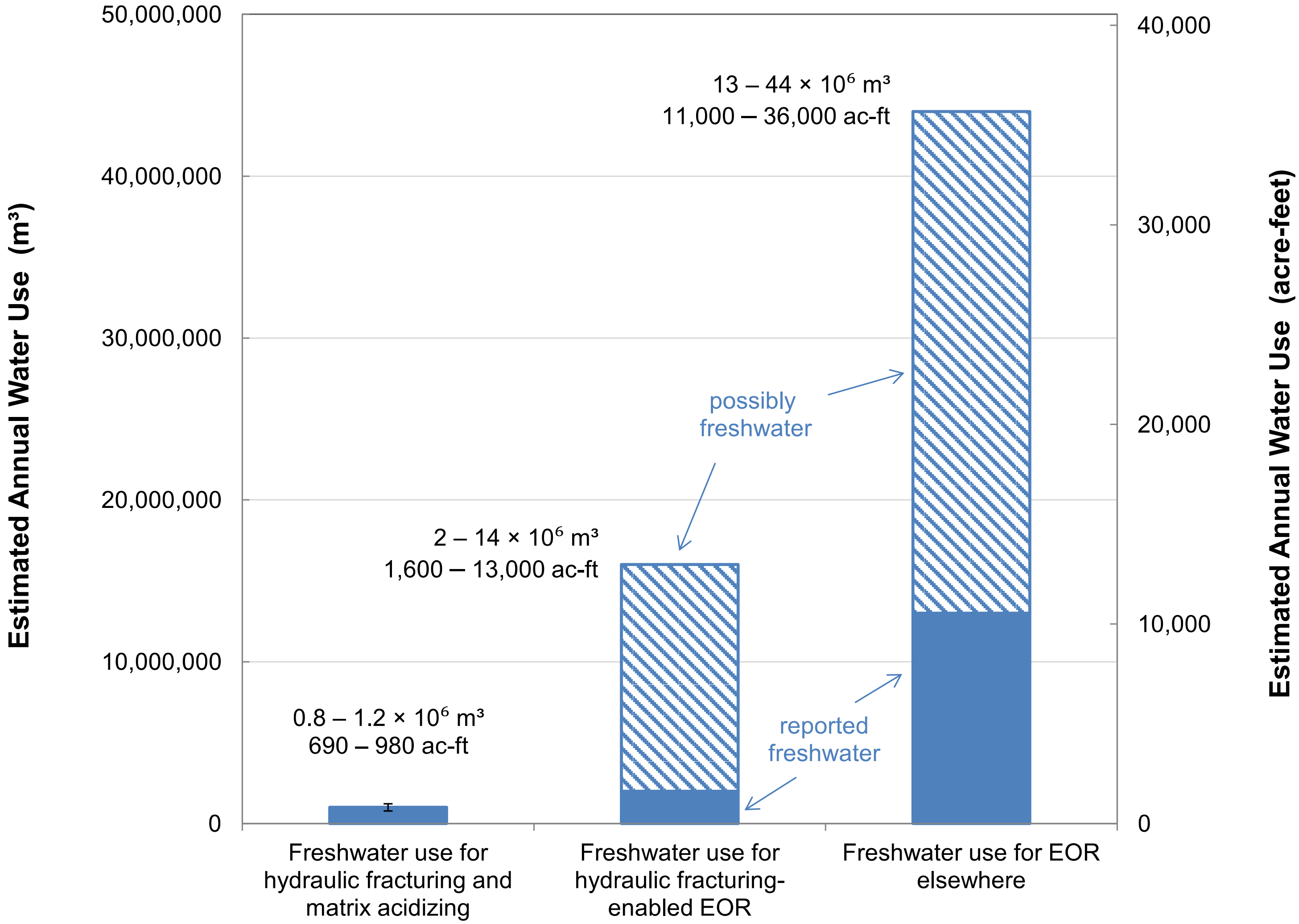
What is high-volume hydraulic fracturing (HVHF)?



The cutoff for what is called "high-volume" hydraulic fracturing is arbitrary. New York State's cutoff of 300,000 gallons and above is larger than more than 90% of California operations.

"An Independent Scientific Assessment of Well Stimulation in California," July 2015

EOR uses more fresh water than hydraulic fracturing



"An Independent Scientific Assessment of Well Stimulation in California," July 2015

Principle 1. Maintain, expand and analyze data on the practice of hydraulic fracturing and acid stimulation in California

- **Conclusion 1.3 Hydraulic fracturing in California does not use a lot of fresh water compared to other states and other human uses.**
  - *Well stimulation in California uses nearly an estimated 800 acre-feet (about a million m^3) of water per year, which is less than 0.2% of all water uses in regions with stimulation*
  - *Most of this water is from fresh water resources, and most fracturing takes place in water-scarce regions*
  - *Enhanced oil recovery in hydraulically fractured fields uses up to 14 x more water than hydraulic fracturing*

An average California household uses about 1 acre-foot per year

Principle 1. Maintain, expand and analyze data on the practice of hydraulic fracturing and acid stimulation in California

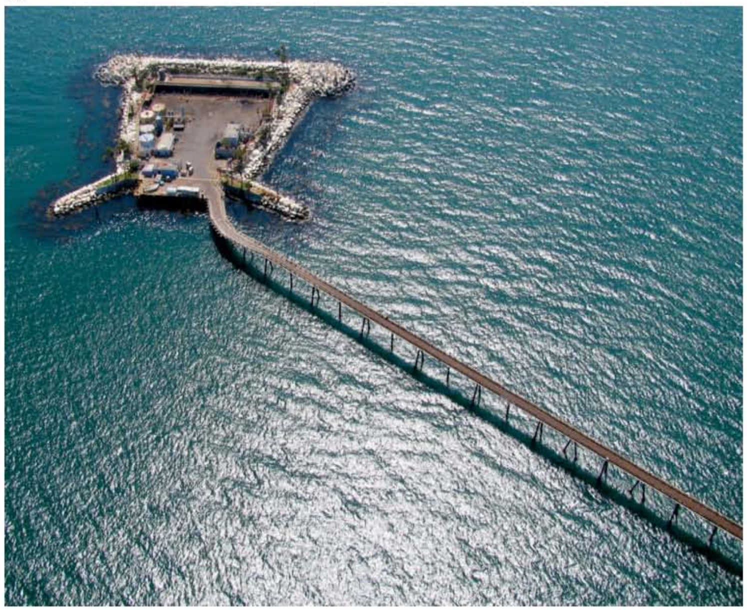
- ***Recommendation 1.1: Identify opportunities for water conservation and reuse in the oil and gas industry.***
  - *There may be opportunities to reduce freshwater consumption or increase the beneficial use of produced water.*
  - *An assessment of water data for the entire oil and gas industry should identify and regularly update opportunities for water efficiency and conservation. (Volume I, Chapter 3; Volume III, Chapter 5)*

Principle 1. Maintain, expand and analyze data on the practice of hydraulic fracturing and acid stimulation in California

- **Conclusion 1.4. A small number of offshore wells use hydraulic fracturing.**
  - *California operators currently use hydraulic fracturing in a small proportion of offshore wells.*
  - *We expect offshore hydraulic fracturing to remain incidental.*
  - *Policies currently restrict oil and gas production offshore, but if these were to change in the future, production could likely occur without well stimulation technology for the foreseeable future.*

State water practice is similar to hydraulic fracturing onshore, Federal records are not up to SB 4 standards

a



Rincon Offshore Artificial Island
in State Waters

b

Platform Heritage in Federal Waters

Principle 1. Maintain, expand and analyze data on the practice of hydraulic fracturing and acid stimulation in California

- **Conclusion 1.5. Record keeping for hydraulic fracturing and acid stimulation in federal waters does not meet state standards.**
  - *U.S. EPA's National Pollutant Discharge Elimination System (NPDES) permits that regulate produced water discharge from offshore platforms do not effectively address hydraulic fracturing fluids.*
  - *The limited publicly available records disclose only a few stimulations per year.*

Principle 1. Maintain, expand and analyze data on the practice of hydraulic fracturing and acid stimulation in California

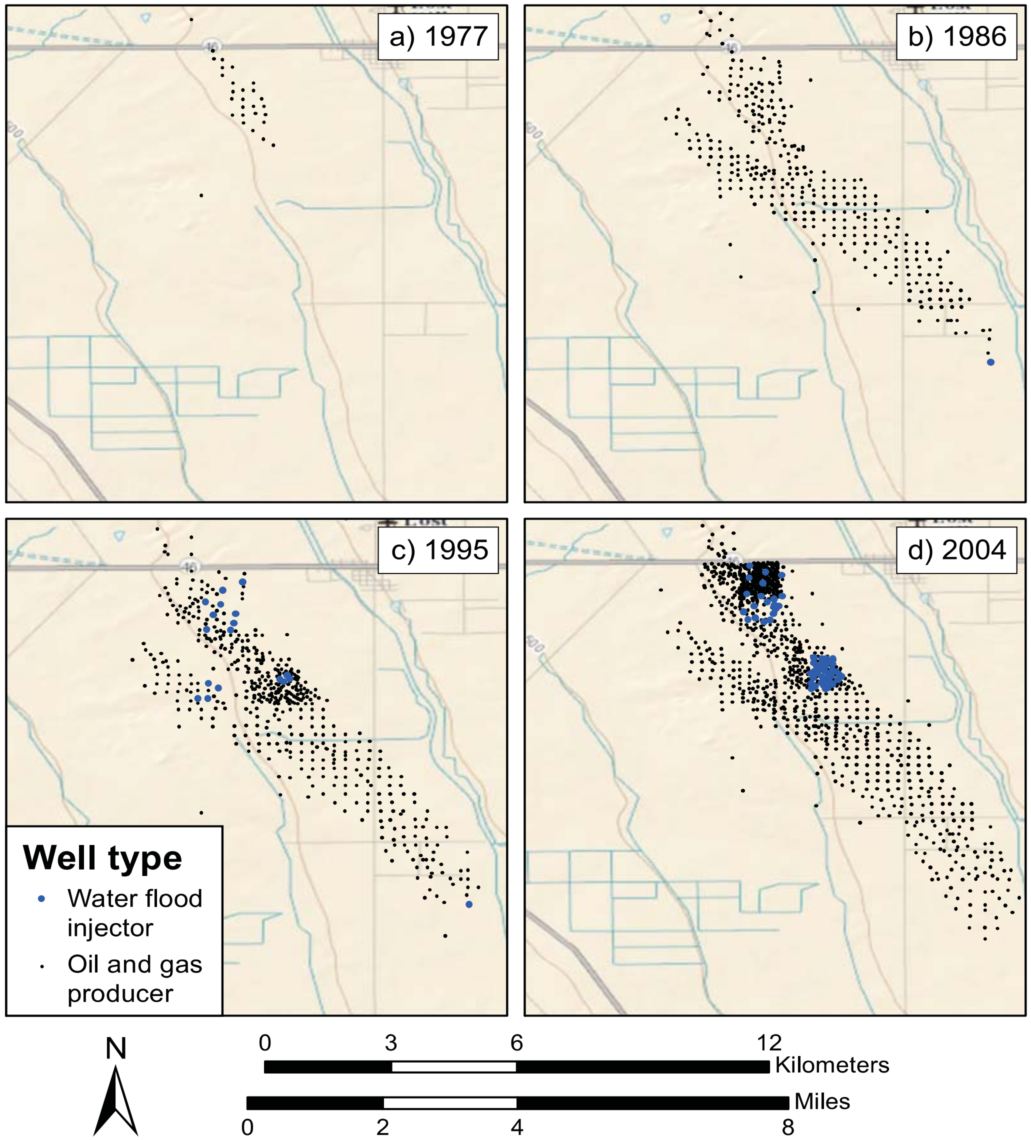
- ***Recommendation 1.2: Improve reporting of hydraulic fracturing and acid stimulation data in federal waters.***
  - *California should request that the federal government match the requirements of SB 4.*
  - *The U.S. EPA should conduct an assessment of ocean discharge of produced water from hydraulic fracturing operations.*

Principle 2.
Prepare for potential future changes in hydraulic fracturing and acid stimulation practice in California.

Principle 2. Prepare for potential future changes in hydraulic fracturing and acid stimulation practice in California.

- **Conclusion 2.1. Future use of hydraulic fracturing in California will likely resemble current use.**
  - *Future use of hydraulic fracturing will most likely expand production in and near existing oil fields in the San Joaquin Basin that currently require hydraulic fracturing.*

Growth in the number of hydraulically fractured wells operating over time in the Cahn pool in the Lost Hills field

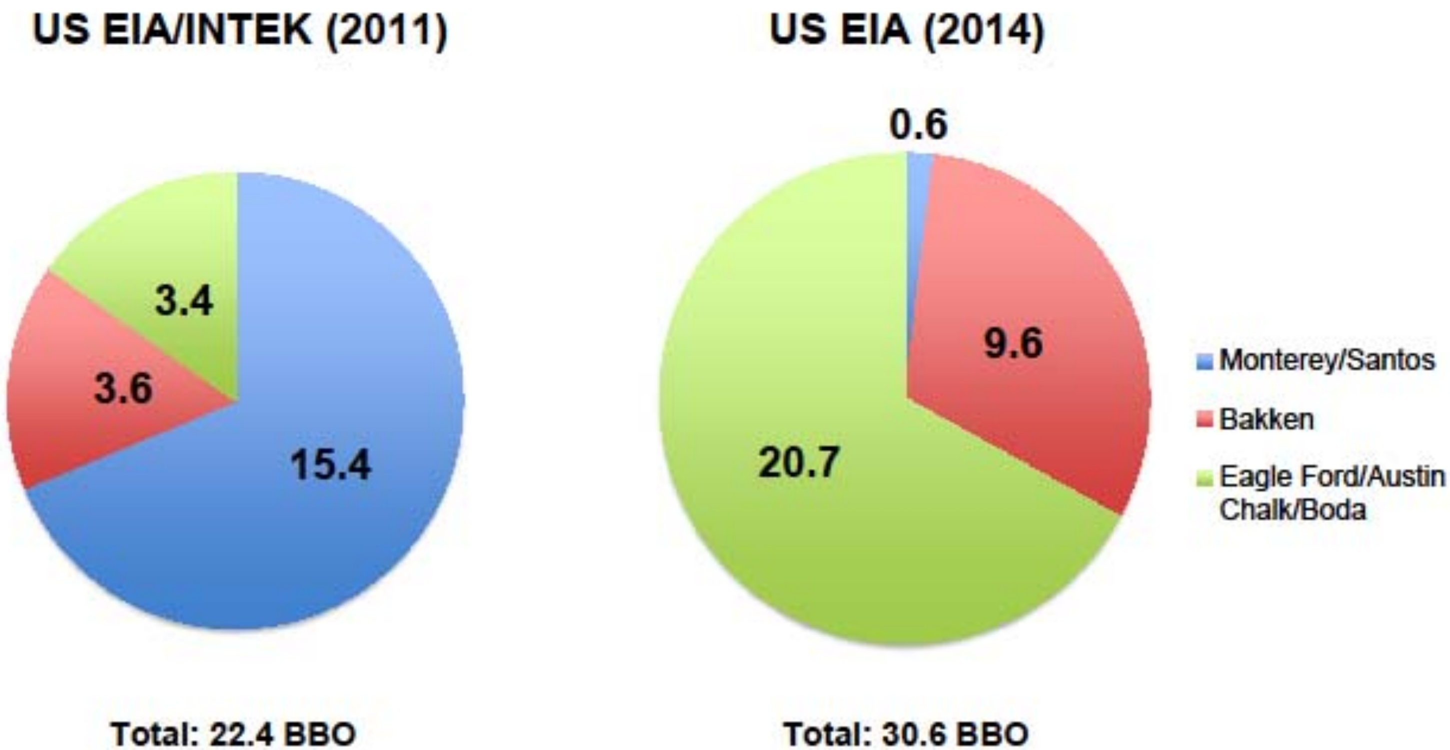


"An Independent Scientific Assessment of Well Stimulation in California," July 2015

Principle 2. Prepare for potential future changes in hydraulic fracturing and acid stimulation practice in California.

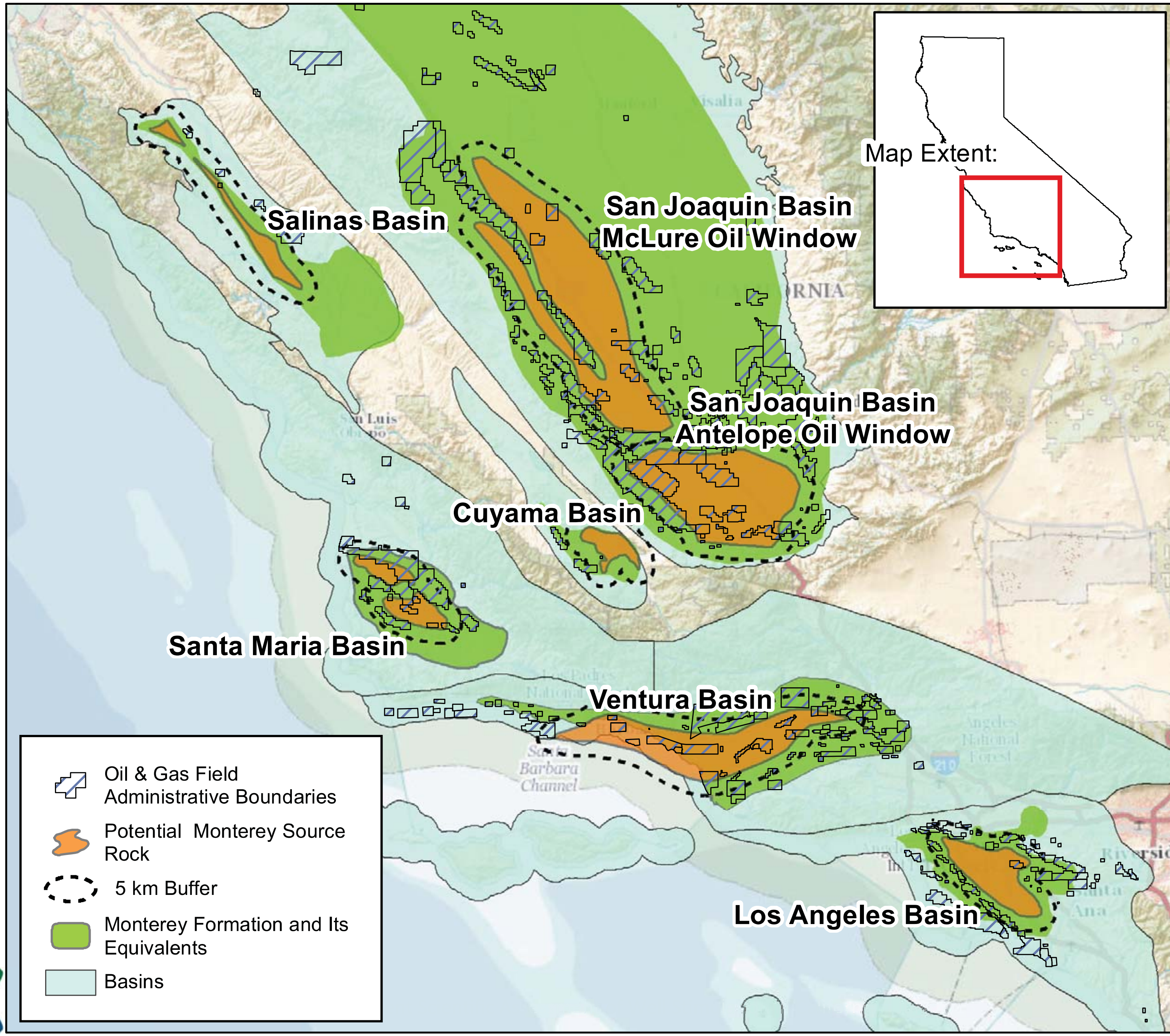
- **Conclusion 2.2. Oil resource assessment and future use of hydraulic fracturing and acid stimulation in the Monterey Formation remain uncertain.**
  - *In 2011, EIA estimated 15 billion barrels of recoverable shale-oil resources in Monterey source rock → Concern about the potential environmental impacts of widespread shale-oil development using hydraulic fracturing*
  - *In 2014, EIA downgraded the 2011 estimate by 96%.*
  - *Neither estimate can be considered reliable.*
  - *The footprint of the "oil window" of the Monterey Formation expands existing regions of oil and gas production rather than opening up entirely new oil and gas producing regions.*
  - *Significant unconventional gas resources probably do not exist in California.*

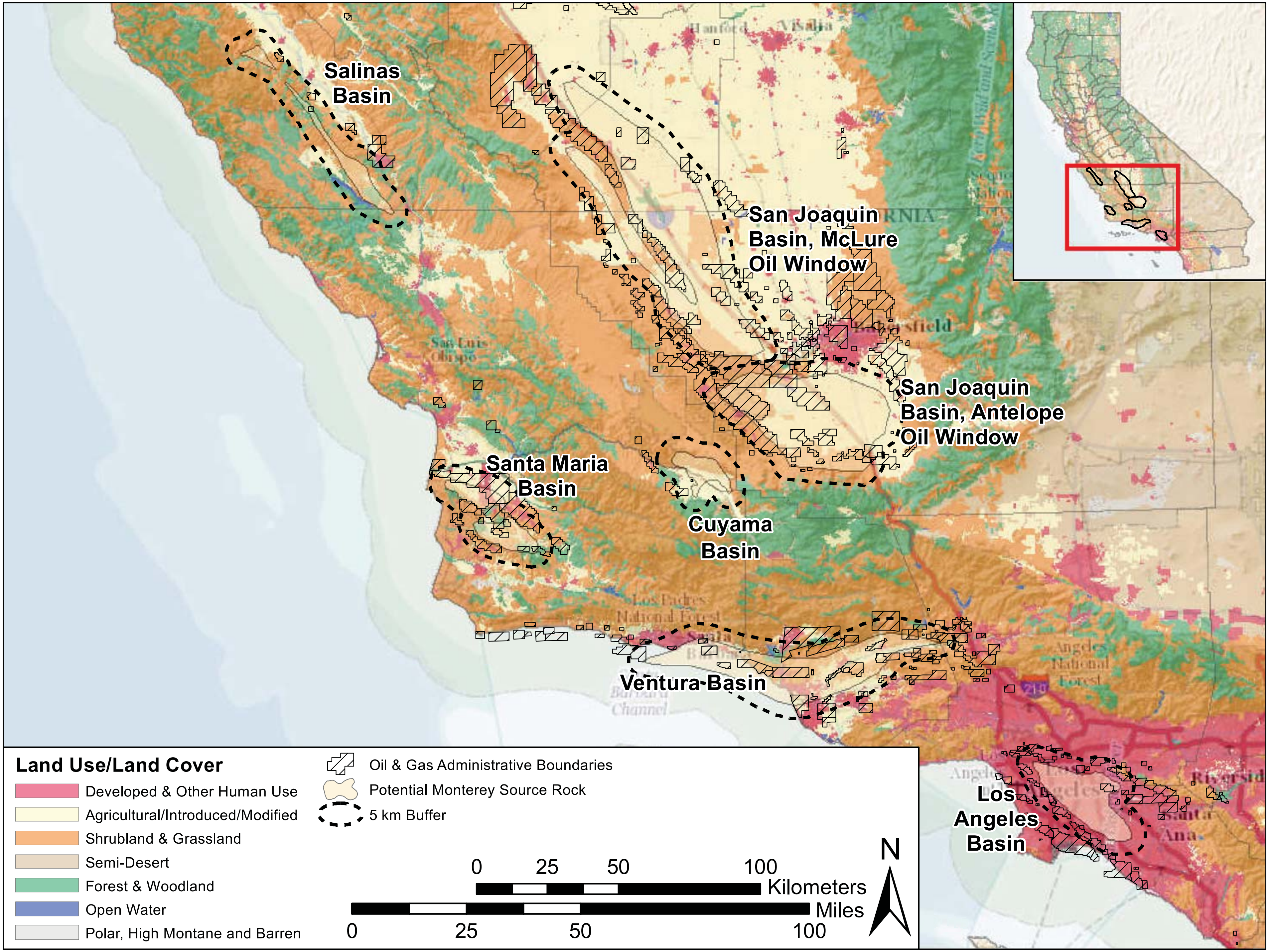
Energy Information Administration (EIA) Estimates of Technically Recoverable Oil Shale



Both estimates of the Monterey oil shale play are highly uncertain

Model Parameters	US EIA/INTEK (2011)	US EIA (2014)
Areal extent (mi^2)	1,752.0	192.0
Wells/mi^2	16.0	6.4
Production/well (Kbbl1 oil)	550.0	451.0
Total recoverable oil (Bbbl2 oil)	15.4	0.6


Map Extent:
Salinas Basin
San Joaquin Basin
McLure Oil Window
San Joaquin Basin
Antelope Oil Window
Cuyama Basin
Santa Maria Basin
Ventura Basin
Los Angeles Basin
Oil & Gas Field
Administrative Boundaries
Potential Monterey Source
Rock
5 km Buffer
Monterey Formation and Its
Equivalents
Basins
BERKELEY LAB



Salinas Basin
San Joaquin Basin, McLure Oil Window
San Joaquin Basin, Antelope Oil Window
Santa Maria Basin
Cuyama Basin
Ventura Basin
Los Angeles Basin
Land Use/Land Cover
Developed & Other Human Use
Agricultural/Introduced/Modified
Shrubland & Grassland
Semi-Desert
Forest & Woodland
Open Water
Polar, High Montane and Barren
Oil & Gas Administrative Boundaries
Potential Monterey Source Rock
5 km Buffer
0 25 50 100 Kilometers
0 25 50 100 Miles
N

Principle 2. Prepare for potential future changes in hydraulic fracturing and acid stimulation practice in California.

- ***Recommendation 2.1: Assess the oil resource potential of the Monterey Formation.***
  - *Request a comprehensive, science-based and peer-reviewed assessment of source-rock ("shale") oil resources in California*
- ***Recommendation 2.2 Keep track of exploration in the Monterey Formation.***
  - *Track well permits for future drilling in the "oil window" of the Monterey source rocks (and other extensive source rocks, such as the Kreyenhagen)*

Principle 3.
Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation.

The Stimulation Life-Cycle	Site Prep, Drilling and Completion	Hydraulic Fracturing or Acid Stimulation	Fluid Recovery	Production
Activity	Build access roads, construct and install well pads, prepare site for drilling Drill and complete wells with steel and cement casings	Improve the reservoir through hydraulic fracturing or acid treatment	Capture, store, treat and dispose of returned well cleanout and stimulation fluids	Pump, store and transport oil and gas Re-inject, reuse or dispose of produced water which could contain stimulation chemicals
Typical Duration	Weeks	Hours	Days	Years
Examples of Possible Impacts	Disruption to wildlife and vegetation	Stimulation chemicals toxicity and risk profile Water supply required to create hydraulic fractures Water contamination from leaks and spills of stimulation fluids Air pollution from machines used in stimulation Induced seismicity from hydraulic fractures Occupational health	Water contamination from leaks, spills and inappropriate disposal of fluid recovery fluids Air pollution from fluid recovery that contains volatile petroleum chemicals from the reservoir	Use of produced water containing stimulation chemicals for irrigation Groundwater contamination from inappropriate disposal Induced seismicity from disposal of produced water Toxic air pollution from production that could affect human health

Direct and indirect impacts considered

Issue	Possible Direct Impact	Possible Indirect Impact
Stimulation Chemicals	Hazardous materials into the environment.	N/A
Water Use[1]	Stimulation uses fresh water supply.	EOR
Water Supply	Stimulation chemicals in produced water used in irrigation	Additional produced water
Water Contamination	Releases of stimulation chemicals contaminate of fresh water supply.	N/A
Air pollution	Equipment, retention ponds and tanks could contain off-gas VOCs.	Oil and gas development activities cause emissions.
Induced Seismicity	Hydraulic fracturing could cause earthquakes.	Injection of wastewater from stimulated wells could cause earthquakes.
Human Health	Releases of stimulation chemicals could affect public health.	Proximity to any oil production could affect public health.
Wildlife and Vegetation	Contamination by stimulation chemicals.	Habitat loss and fragmentation, water use for EOR.

Principle 3. Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation.

- **Conclusion 3.1. Direct impacts of hydraulic fracturing appear small but have not been investigated in detail.**
  - *Direct impacts appear small, but*
  - *Limited data precludes adequate assessment of these impacts*
  - *Good management and mitigation measures can address the vast majority of potential direct impacts of well stimulation.*

Principle 3. Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation

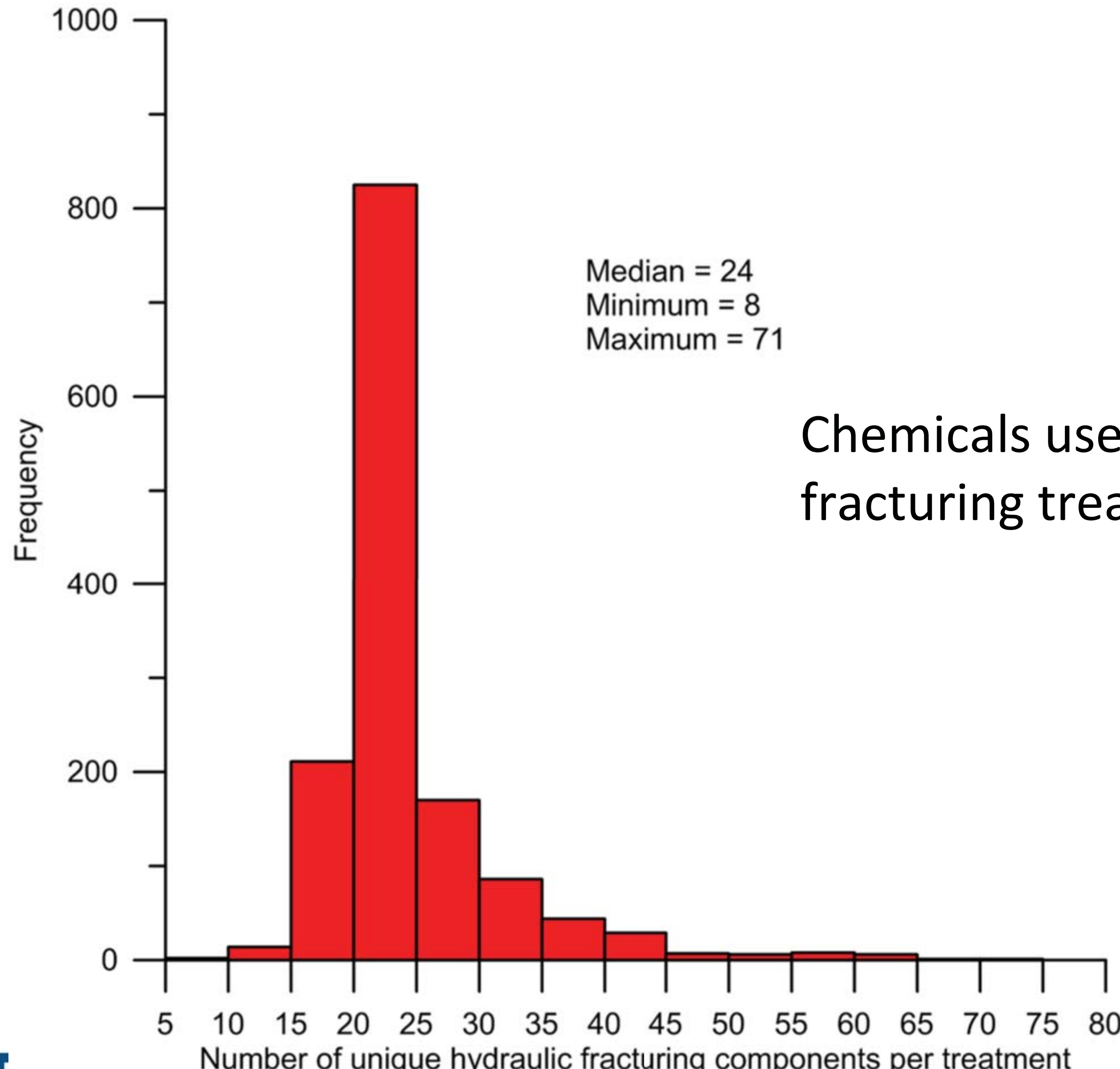
Recommendation 3.1. Assess adequacy of regulations to control direct impacts of hydraulic fracturing and acid stimulations.

- *Reduce the use of highly toxic or harmful chemicals, or those with unknown environmental profiles*
- *Control emissions, leaks and spills*
- *Dispose of produced waters that contain stimulation chemicals appropriate*
- *Devise appropriate treatment and testing for any produced waters intended for beneficial reuse*
- *Avoid shallow hydraulic fracturing near protected aquifers*

Principle 3. Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation

- **Conclusion 3.2. Operators have unrestricted use of many hazardous and uncharacterized chemicals in hydraulic fracturing.**
  - *California operators have reported the use of over 300 chemical additives, many of which have unknown toxicity and environmental characteristics (e.g., biodegradability, migration characteristics)*
  - *The unrestricted use of hazardous chemicals with unknown risk profiles underlies all significant potential direct impacts.*
  - *Biocides, quaternary ammonium compounds, etc. present larger environmental hazards because of their toxicity, frequent use, or use in large amounts. Chemicals were ranked according to the hazard they present to health where data allows*
  - *No negative impacts have been found in California, but no agency has systematically investigated possible impacts*
  - *Application of green chemistry principles would reduce potential risk to the environment or human health.*

How many stimulation constituents in California



Chemicals used per fracturing treatment

"An Independent Scientific Assessment of Well Stimulation in California," July 2015

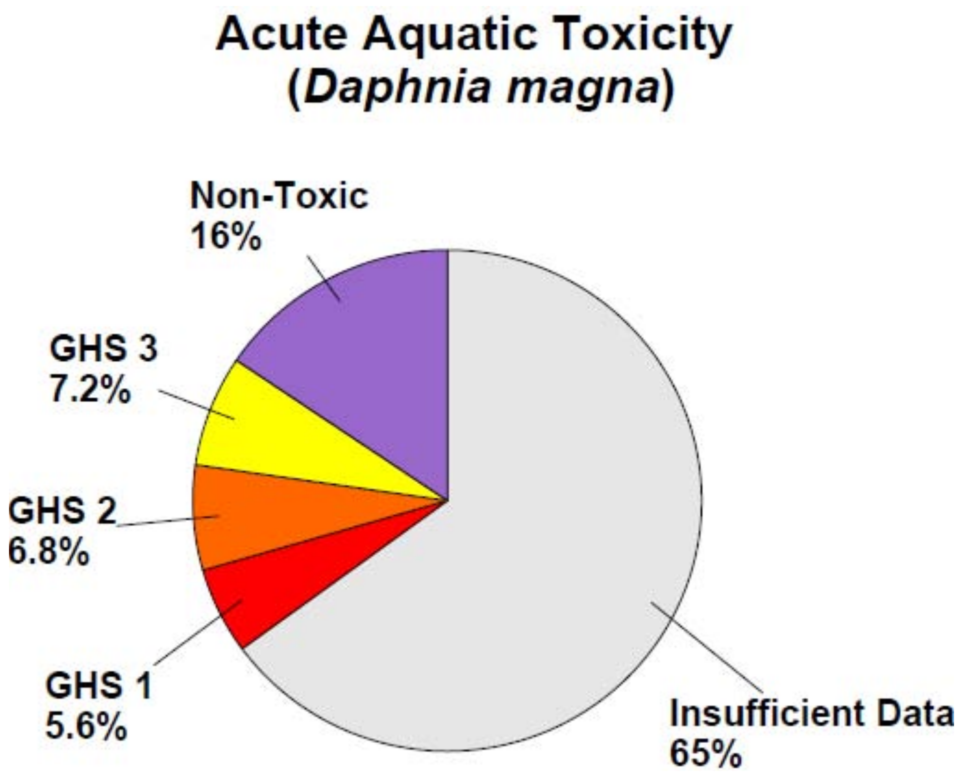
CCST CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

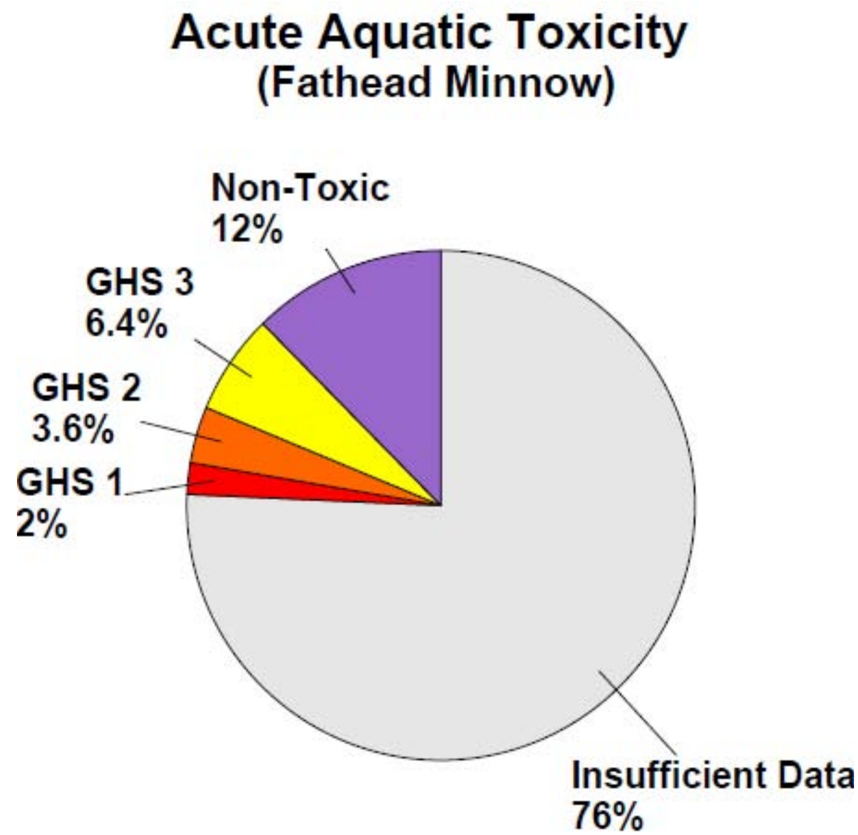
BERKELEY LAB

Availability of information for characterizing the hazard of stimulation chemicals used in hydraulic fracturing

Number of chemicals	Proportion of all chemicals	Identified by unique CASRN	Impact or toxicity	Quantity of use or emissions
172	55%	Available	Available	Available
17	5%	Available	Available	Unavailable
6	2%	Available	Unavailable	Available
121	38%	Unavailable	Unavailable	Available

How acutely toxic are constituents to aquatic environment?





The lower the Globally Harmonized System category number (GHS), the more acutely toxic the constituent. Some constituents had an acute aquatic toxicity of 1. Acute toxicity was not available for many constituents.

CCST
CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

BERKELEY LAB

Risk Ranking for Acute Health Effects

Chemical Name	Reported frequency of use	Reported median mass fraction per WST (mg/kg)	Acute Toxicity
Distillates, petroleum, hydrotreated light paraffinic	✔	✔	
Isotridecanol, ethoxylated	✔		✔
Hydrochloric acid		✔	✔
Polyethylene-polypropylene glycol	✔		✔
Sodium hydroxide			✔
Glyoxal		✔	✔
Potassium carbonate	✔	✔	
Glutaraldehyde			✔
Ammonium Persulfate	✔		✔
Hydrofluoric acid		✔	✔
Sodium tetraborate decahydrate	✔	✔	
5-Chloro-2-methyl-3(2H)-isothiazolone	✔		✔

Risk Ranking for Chronic Health Effects

Chemical Name	Reported frequency of use	Reported median conc. per WST (mg/kg)	Chronic Toxicity
Proppant material		✔	✔
Glutaraldehyde	✔	✔	✔
Zirconium oxychloride[2]	✔	✔	✔
Bromic acid, sodium salt (1:1)		✔	✔
Hydrochloric acid	✔	✔	✔
Boron sodium oxide	✔	✔	✔
Ethylbenzene		✔	✔
Naphthalene	✔		✔
Sodium tetraborate decahydrate	✔	✔	✔
Boric acid, dipotassium salt		✔	✔
Aluminum oxide		✔	✔
Diethanolamine		✔	✔

Principle 3. Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation

- ***Recommendation 3.2. Limit the use of hazardous and poorly understood chemicals.***
  - *Report the unique CASRN identification for all chemicals used*
  - *Disallow the use of chemicals with unknown environmental profiles*
  - *Reduce the overall number of different chemicals, and the use of more hazardous chemicals and chemicals with poor environmental profiles*
  - *Limit the chemicals to those on an approved list*
  - *Apply Green Chemistry principles*
  - *Engage in discussion of technical issues involved in restricting chemical use with a group representing environmental and health scientists and industry practitioners, either through existing roundtable discussions or independently.*

Principle 3. Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation

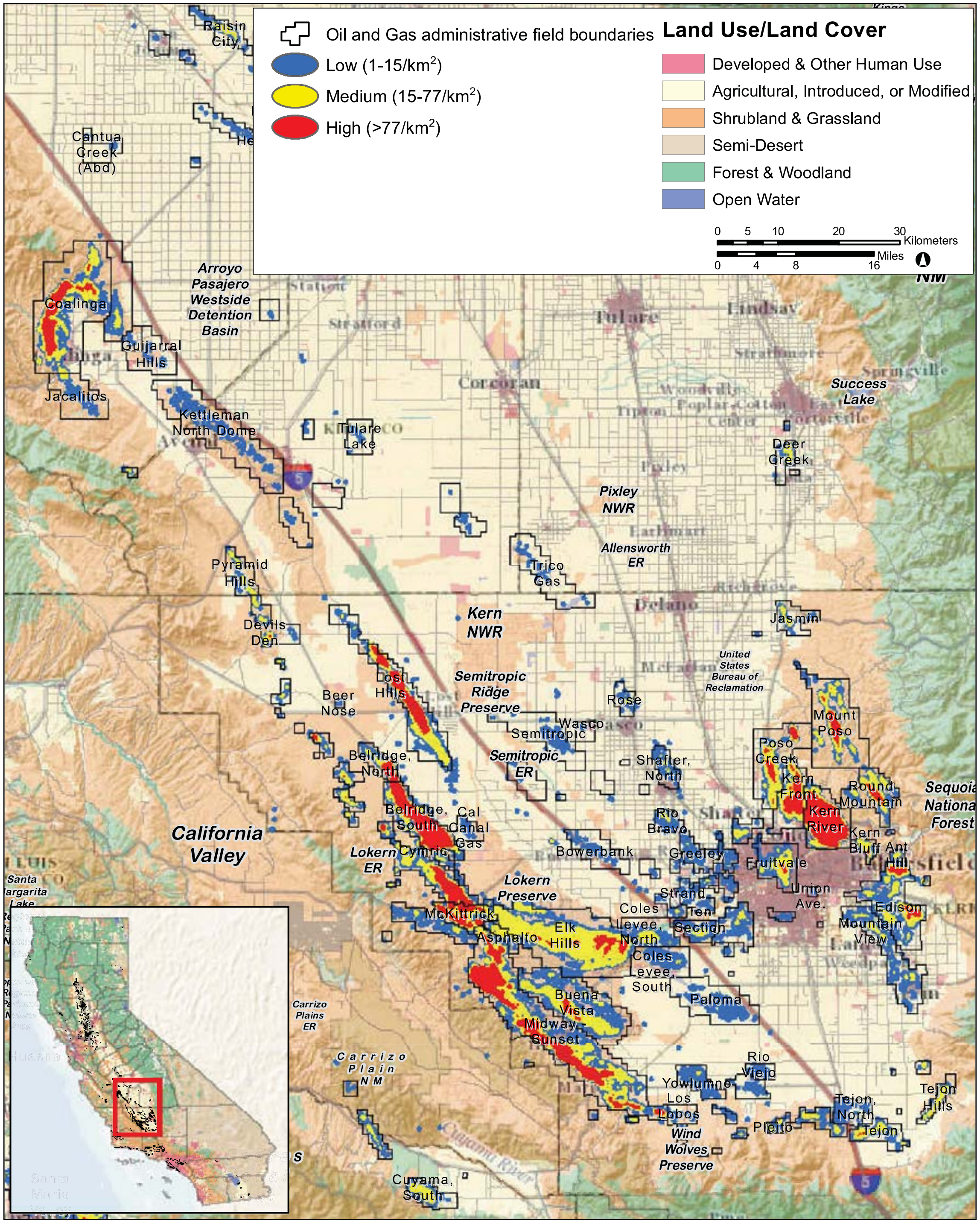
- **Conclusion 3.3. The majority of impacts associated with hydraulic fracturing are caused by the indirect impacts of oil and gas production enabled by the hydraulic fracturing.**
  - *Impacts caused by additional oil and gas development enabled by well stimulation (i.e. indirect impacts) account for the majority of environmental impacts associated with hydraulic fracturing.*
  - *All oil and gas development causes similar impacts whether the oil is produced with well stimulation or not.*
  - *If indirect cause concern, these concerns in most cases extend to any oil and gas development*
  - *As hydraulic fracturing enables only 20% of production in California, only about 20% of any given indirect impact is likely attributable to hydraulically fractured reservoirs.*

Principle 3. Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation

- ***Recommendation 3.3: Evaluate impacts of production for all oil and gas development, rather than just the portion of production enabled by well stimulation.***
  - Concern about indirect impacts should lead to study of all types of oil and gas production, not just production enabled by hydraulic fracturing.
  - Agencies with jurisdiction should evaluate impacts of concern for all oil and gas development, rather than just the portion of development enabled by well stimulation.
  - As appropriate, many of the rules and regulations aimed at mitigating indirect impacts of hydraulic fracturing and acid stimulation should also be applied to all oil and gas wells

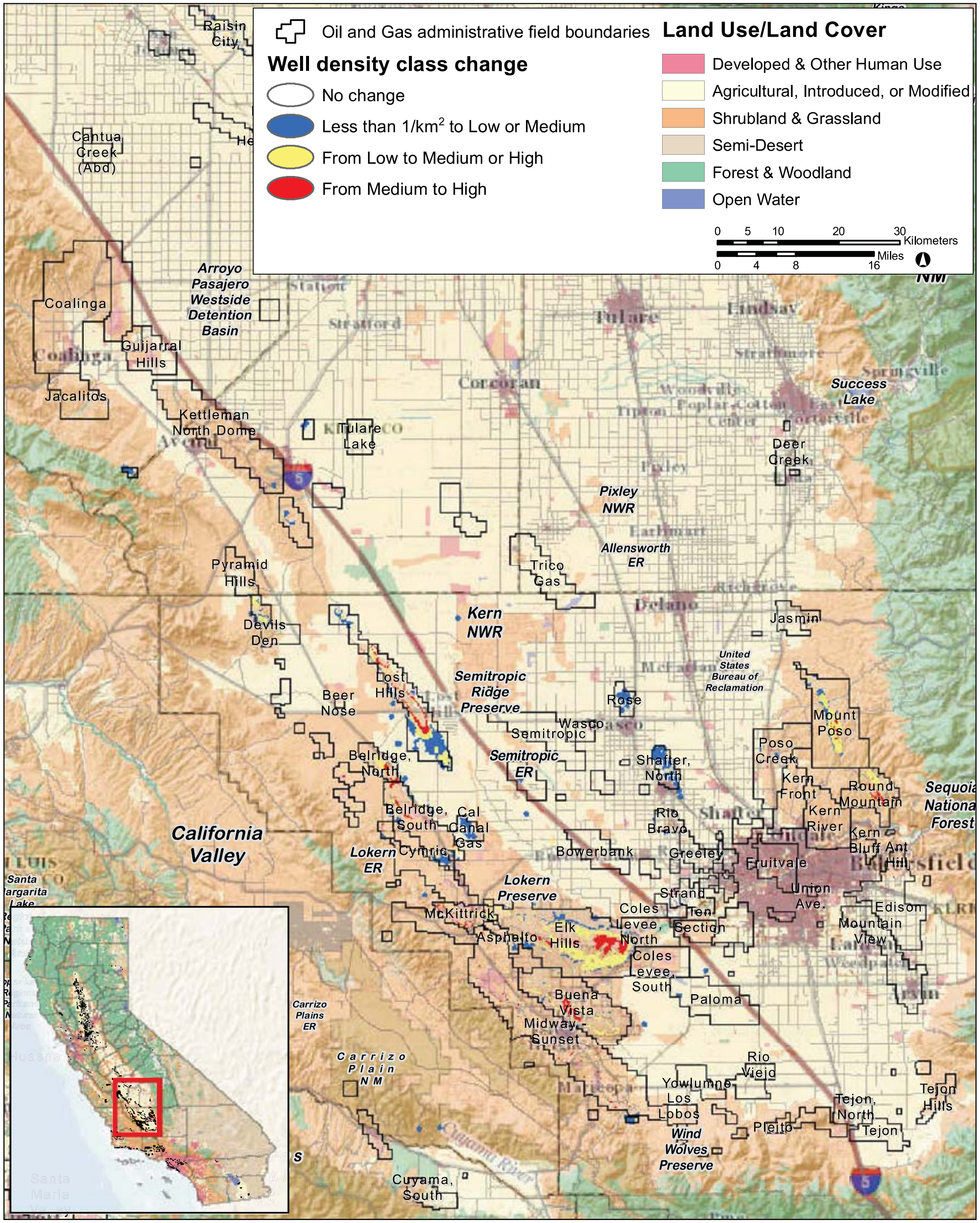
Principle 3. Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation

- **Conclusion 3.4. Oil and gas development causes habitat loss and fragmentation.**
  - *Any oil and gas development, including that enabled by hydraulic fracturing, can cause habitat loss and fragmentation.*
  - *The location of hydraulic fracturing-enabled development coincides with ecologically sensitive areas in Kern and Ventura Counties.*



CCST CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

BERKELEY LAB



CCST CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

BERKELEY LAB

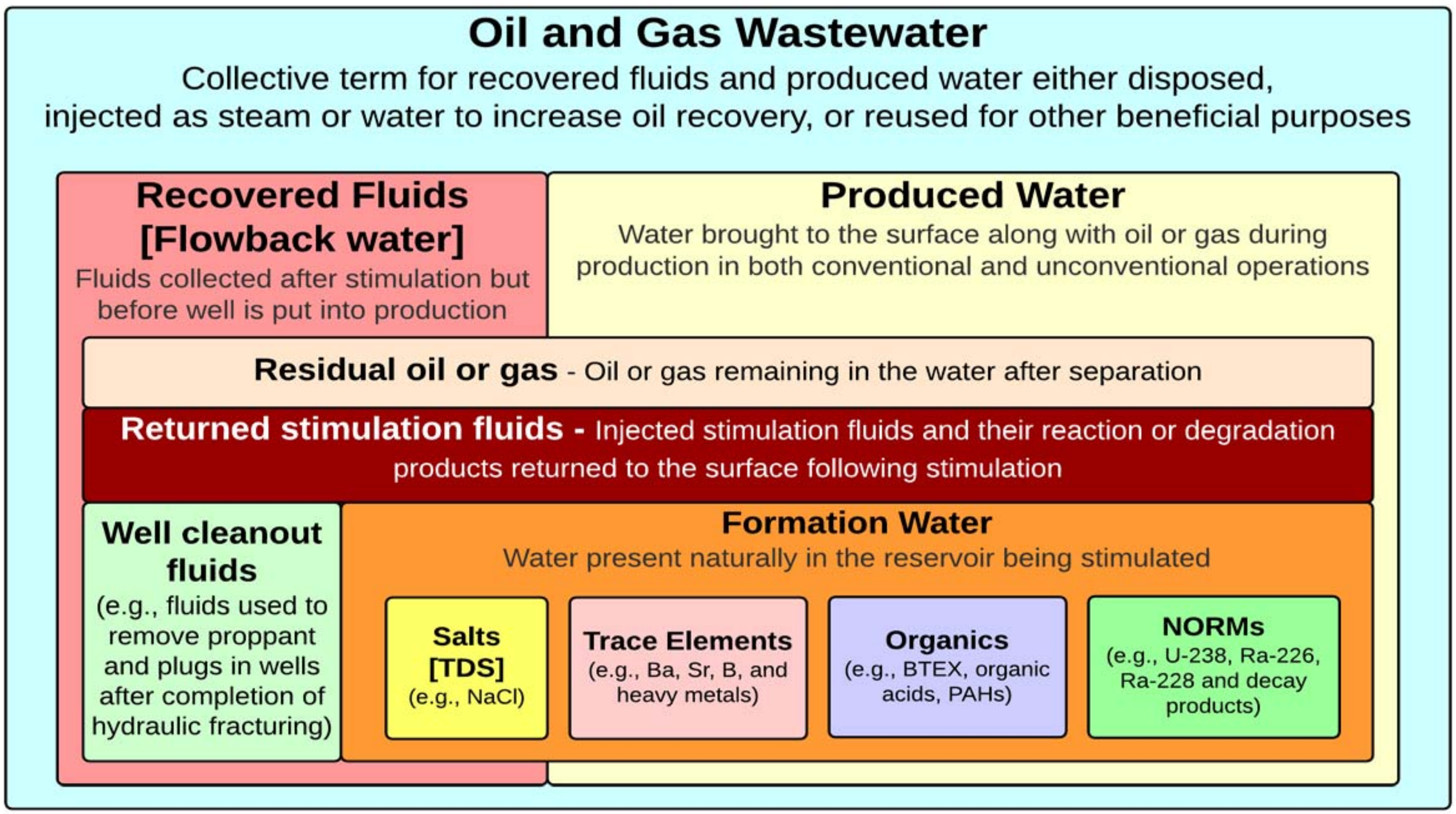
Principle 3. Account for and manage both direct and indirect impacts of hydraulic fracturing and acid stimulation

- ***Recommendation 3.4: Minimize habitat loss and fragmentation in oil and gas producing regions.***
  - *Enact regional plans to conserve essential habitat and dispersal corridors for native species in Kern and Ventura Counties.*
  - *A program to set aside compensatory habitat in reserve areas when oil and gas development causes habitat loss and fragmentation should be developed and implemented*

Principle 4.
Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

Wastewater, Recovered Water and Produced Water

- California Reservoirs produce 10 times as much water as they produce oil
- Recovered fluids are only a small fraction of total injected stimulation fluids
- Produced water may contain stimulation fluids at unknown concentrations
- Produced water from fractured and unfractured wells is often comingled

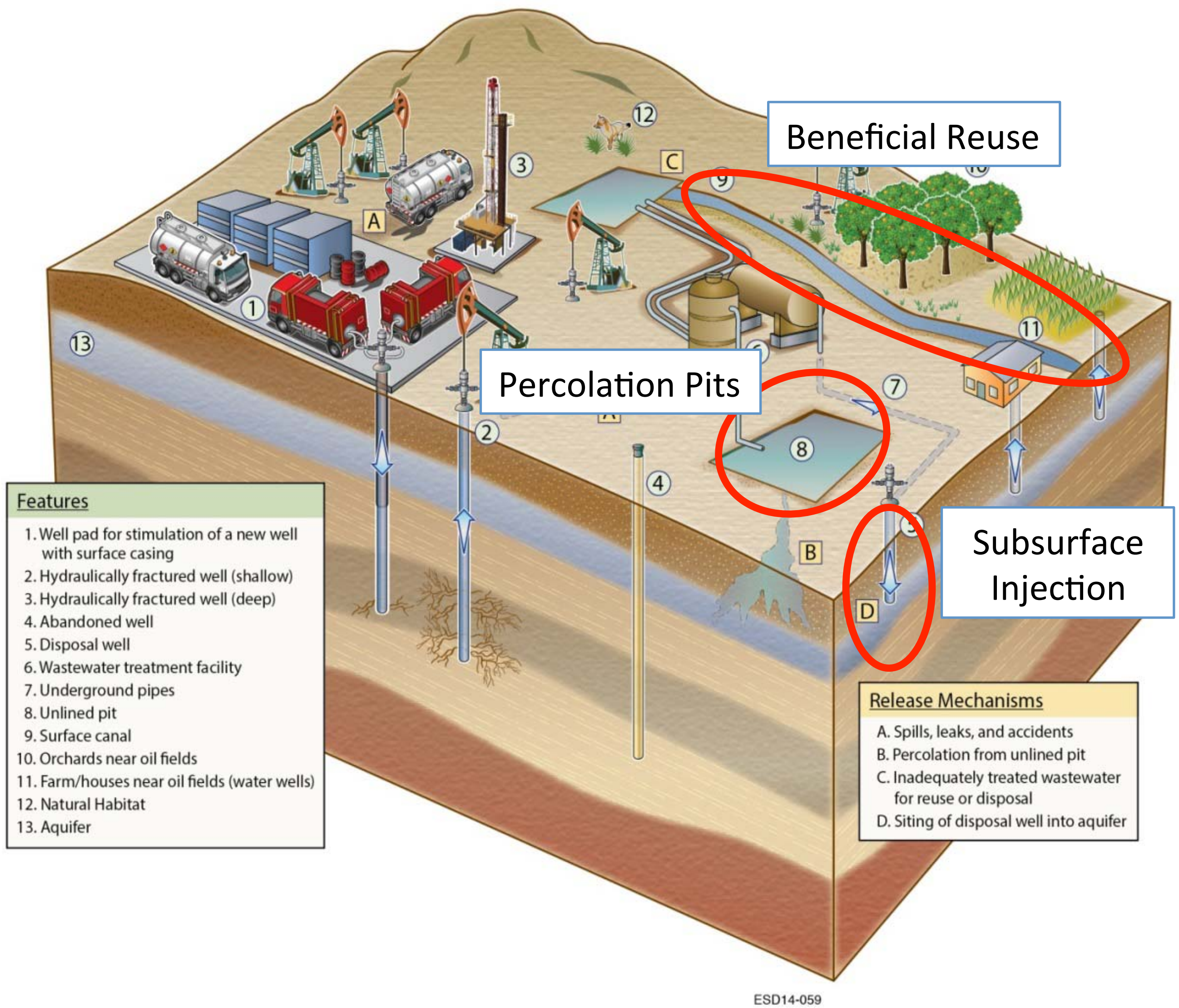


* Boxes are not drawn to scale and are separated for visual clarity.

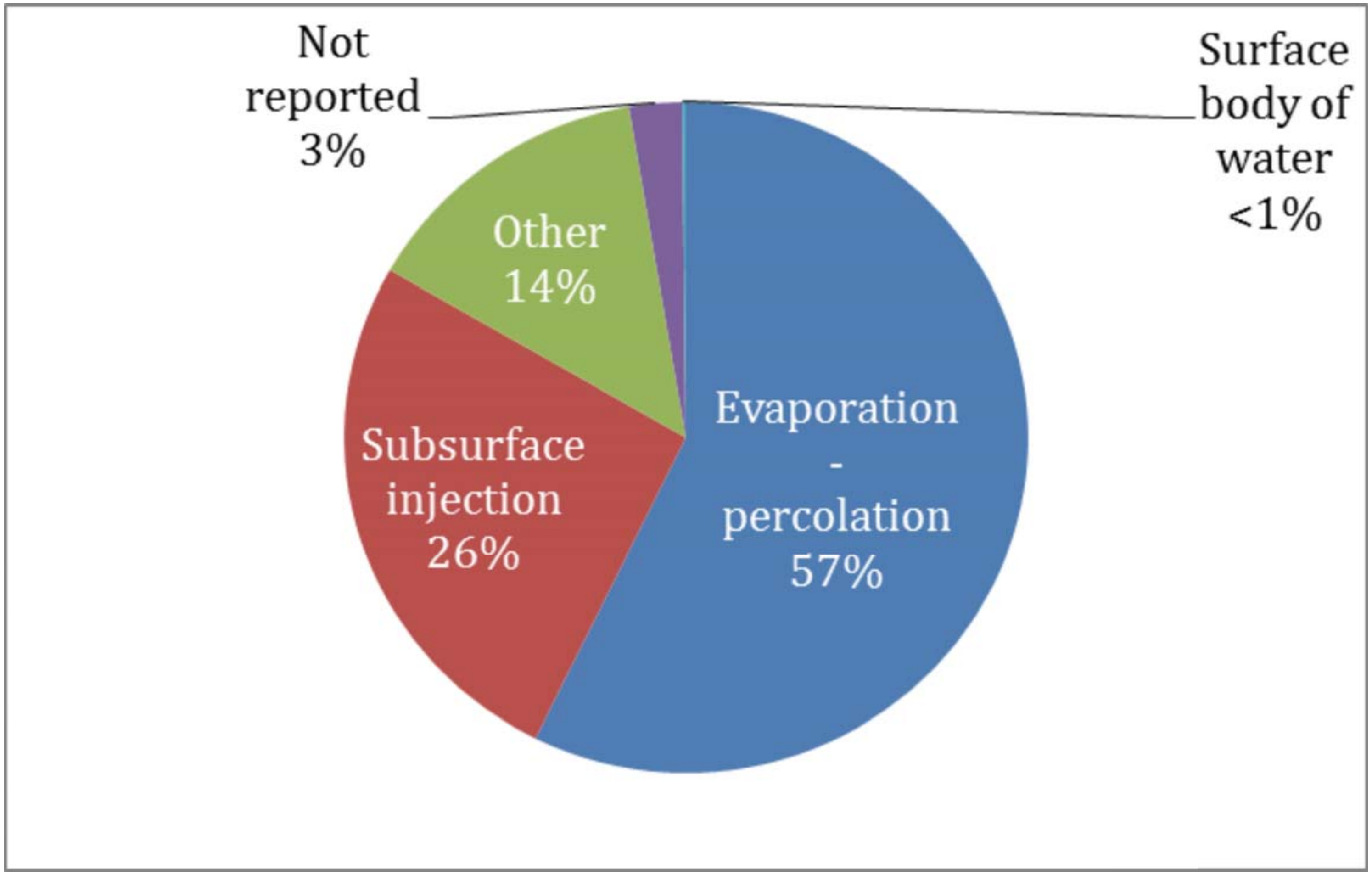
"An Independent Scientific Assessment of Well Stimulation in California," July 2015

Produced Water

- California Reservoirs produce more than ten times as much water as they produce oil
- Produced water from fractured wells may contain stimulation chemicals
- Produced water from fractured and unfractured wells is often comingled
- Produced water can be a resource



Produced water disposal as reported during the first full month after stimulation



Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

- **Conclusion 4.2. The chemistry of produced water from hydraulically fractured or acid stimulated wells has not been measured.**
  - Chemicals used in each hydraulic fracturing operation can react with each other and react with the rocks and fluids of the oil and gas reservoirs
  - Acid can dissolve and mobilize naturally occurring heavy metals and other contaminants
  - These contaminants may be present in recovered and produced water but have not been measured systematically in California

Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

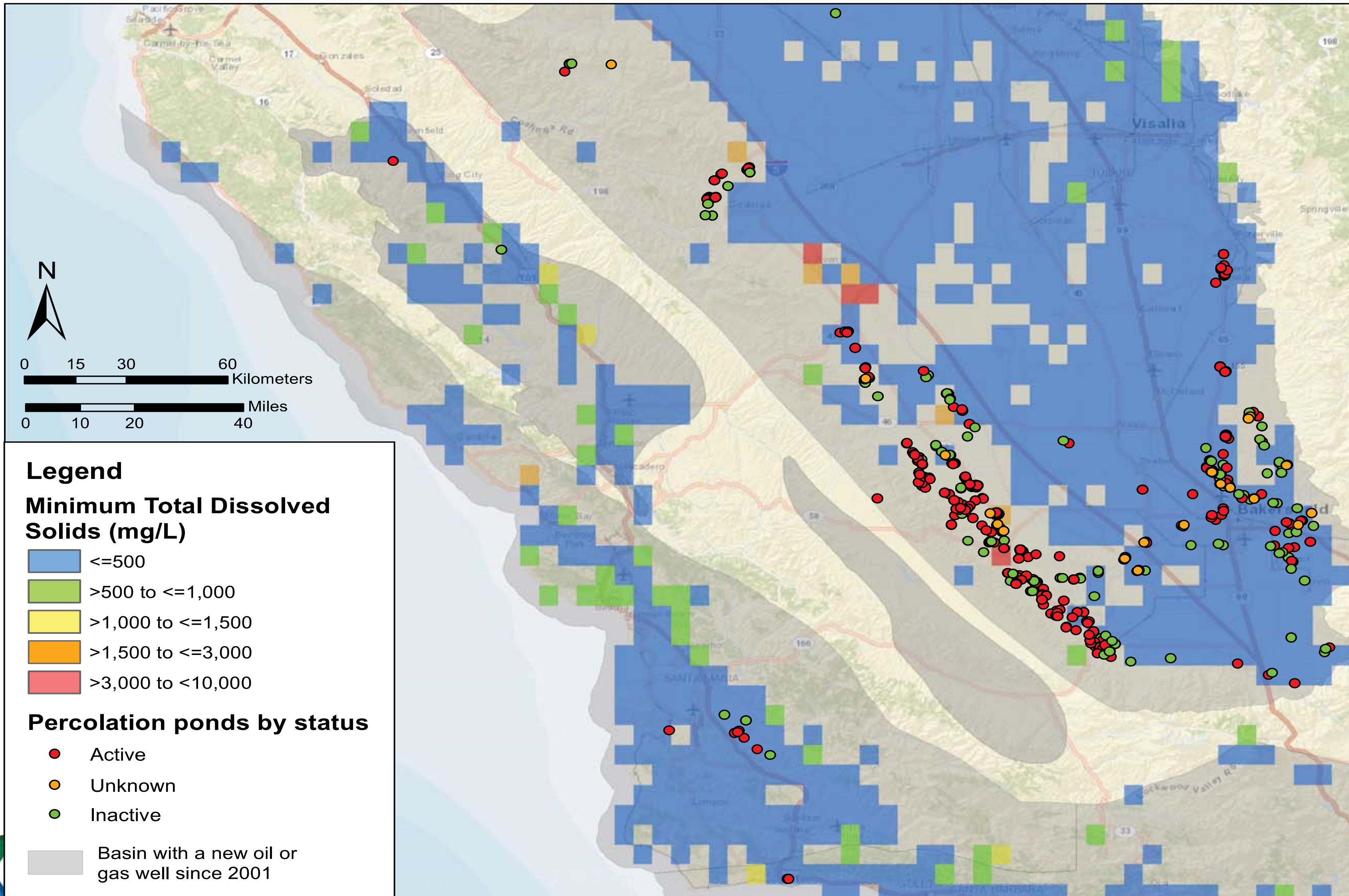
- ***Recommendation 4.2: Evaluate and report produced water chemistry from hydraulically fractured or acid stimulated wells.***
  - *Evaluate the chemistry of produced water from hydraulically fractured and acid stimulated wells.*
  - *Determine how this chemistry changes over time.*

Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

- **Conclusion 4.1. Produced water disposed of in percolation pits could contain hydraulic fracturing chemicals.**
  - Based on publicly available data, operators disposed of more than half of the produced water from stimulated wells in Kern County in percolation pits.
  - An estimated 36% of the active percolation pits in the Central Valley operate without necessary permits from the Central Valley Regional Water Quality Control Board (CVRWQB) and the CVRWQB has a plan to bring unpermitted sumps into compliance.
  - Unregulated percolation pits present an unjustified risk to water supply, wildlife, vegetation, and human health.

Location of percolation pits used for produced water disposal and the location of groundwater of varying quality

Data from Central Valley Regional Water Quality Board



Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

- ***Recommendation 4.1: Ensure safe disposal of produced water in percolation pits with appropriate testing and treatment or phase out this practice.***
  - *Promptly ensure through appropriate testing that the water discharged into percolation pits or sumps does not contain hazardous chemicals, including chemicals used in hydraulic fracturing if the produced water comes from stimulated reservoirs.*
  - *If the presence of hazardous chemicals cannot be ruled out, or the water successfully treated to reduce their concentration to acceptable levels, then phase out the practice of discharging produced water into percolation pits.*
  - *Investigate any legacy effects of discharging produced waters into percolation pits including the potential effects of stimulation fluids.*
  - *Operation of percolation pits without necessary permits should be halted. (Volume II, Chapter 2; Volume III Chapter 4 and 5)*

Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

- **Conclusion 4.3. Required testing and treatment of produced water destined for reuse may not detect or remove chemicals associated with hydraulic fracturing and acid stimulation.**
  - Produced water from oil and gas production has potential for beneficial reuse, such as for irrigation or for groundwater recharge.
  - However, stimulation chemicals may persist in produced water from fields that have applied well stimulation technologies.
  - Some produced water from one oil field in California with occasional hydraulic fracturing operations has been used for irrigation purposes.
  - Such water **may** contain well stimulation chemicals.

Produced water used for irrigation in the Cawelo water district

Photo credit: Lauren Sommer/KQED

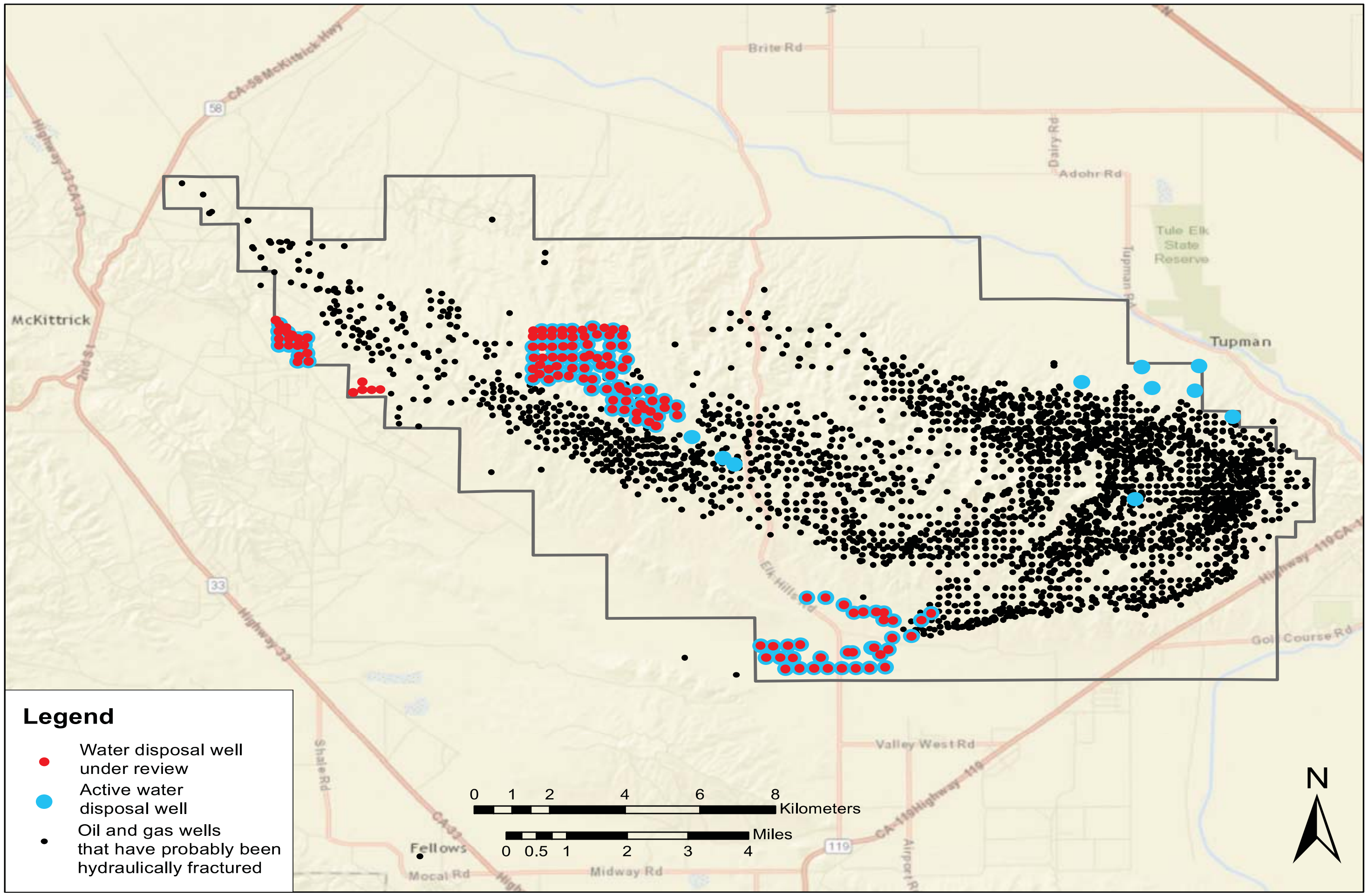
Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

- ***Recommendation 4.3: Protect water designated for beneficial reuse from contamination by hydraulic fracturing chemicals and stimulation reaction products.***
  - *Opportunities should be pursued to increase the beneficial use of produced water from oil and gas operations, such as for irrigation or for groundwater recharge*
  - *However, produced water from hydraulically fractured wells cannot be reused for such purposes until or unless testing shows non-hazardous concentrations, or required water treatment reduces concentrations to non-hazardous levels*

Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

- **Conclusion 4.4 Injection wells currently under review for inappropriate disposal into protected aquifers may have received water containing stimulation chemicals.**
  - DOGGR is currently reviewing injection wells for possible inappropriate disposal of oil and gas wastewaters into protected groundwater.
  - The wastewaters disposed in some of these wells likely included stimulation chemicals.

The location of wells in the Elk Hills field in the SJV that have probably been hydraulically fractured and the location of disposal wells under review for possibly injecting into protected groundwater



"An Independent Scientific Assessment of Well Stimulation in California," July 2015

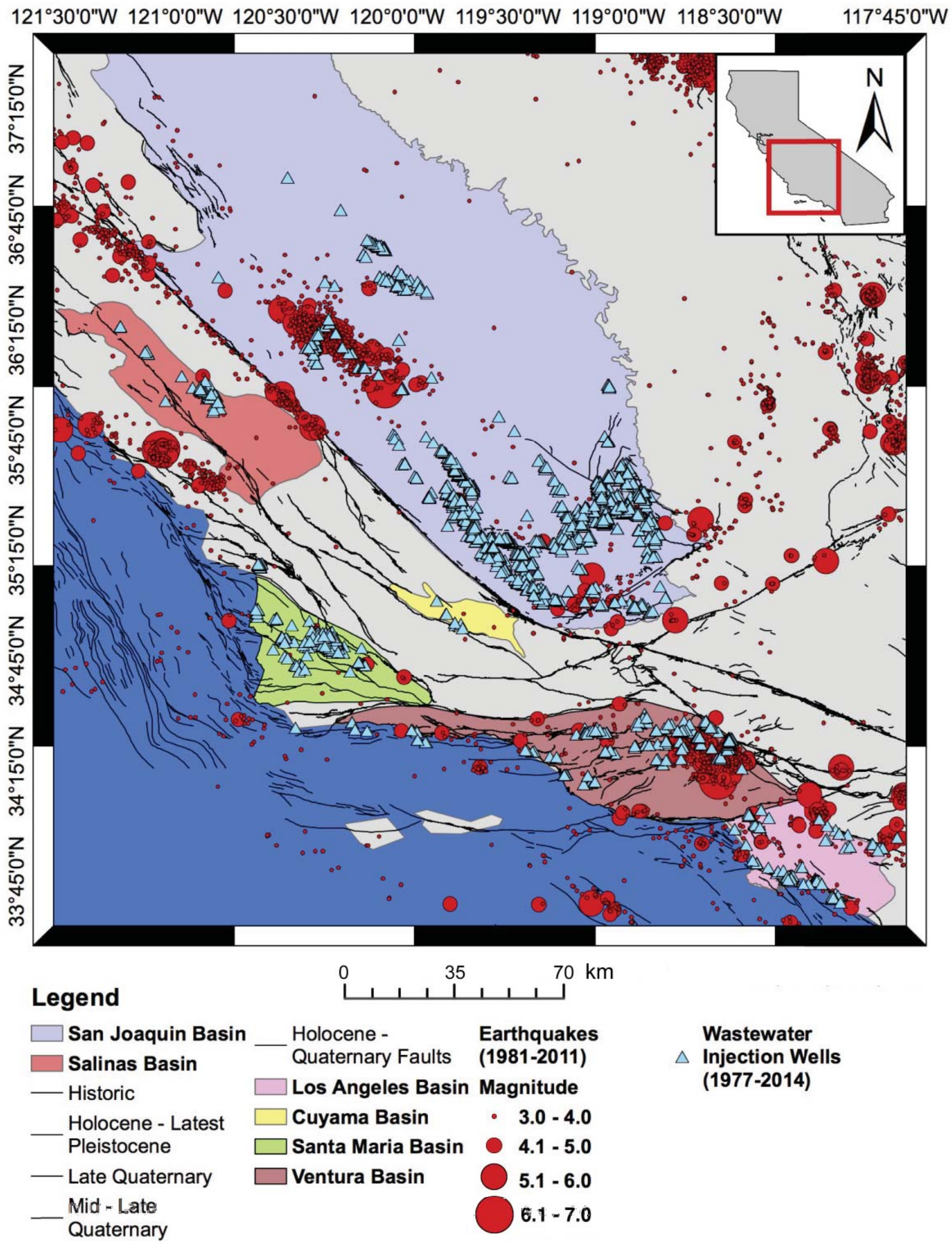
Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

- ***Recommendation 4.4: In the ongoing investigation of inappropriate disposal of wastewater into protected aquifers, recognize that hydraulic fracturing chemicals may have been present in the wastewater.***

Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately

- **Conclusion 4.5. Disposal of wastewater by underground injection has caused earthquakes elsewhere.**
  - Fluid injection to create a hydraulic fracture is not likely to cause earthquakes of concern.
  - However, disposal of wastewater by underground injection could cause felt or perhaps damaging earthquakes.
  - To date, there have been no reported California cases of induced seismicity associated with wastewater disposal
  - Since California has so much natural seismicity, seismologists have a hard time determining if any earthquakes may have been induced by fluid injection

California Seismicity and Wastewater Disposal Wells



CCST
CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

BERKELEY LAB

Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately

- ***Recommendation 4.5: Determine if there is a relationship between wastewater injection and earthquakes in California.***
  - *Initiate study to determine if there is a relationship between oil and gas-related fluid injection and any of California's numerous earthquakes.*
  - *Develop and apply protocols and best practices for monitoring, analyzing, and managing produced water injection operations to mitigate the risk of induced seismicity.*
  - *Investigate whether future changes in disposal volumes or injection depth could affect potential for induced seismicity.*

Principle 4. Manage water produced from hydraulically fractured or acid stimulated wells appropriately.

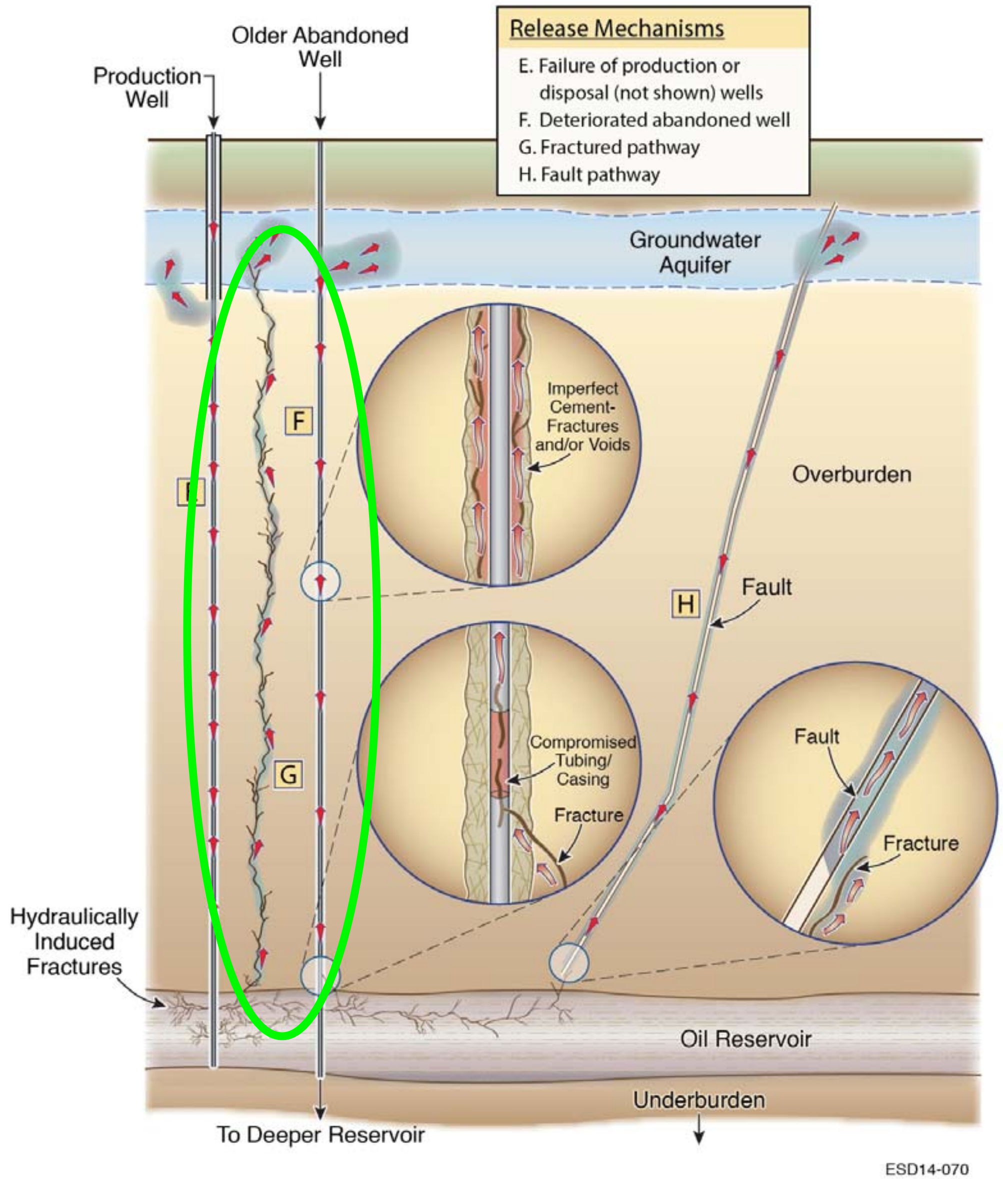
- **Conclusion 4.6. Changing the method of wastewater disposal will incur tradeoffs in potential impacts.**
- ***Recommendation 4.6: Evaluate tradeoffs in wastewater disposal practices***
  - *As California moves to change disposal practices, for example by phasing out percolation pits or stopping injection into protected aquifers, agencies with jurisdiction should assess the consequences of modifying or increasing disposal via other methods.*

Principle 5.
Add protections to avoid groundwater contamination by hydraulic fracturing.

Potential Subsurface Migration Pathways

Key Issues in California

- Shallow fracturing near groundwater
- Integrity of existing wells

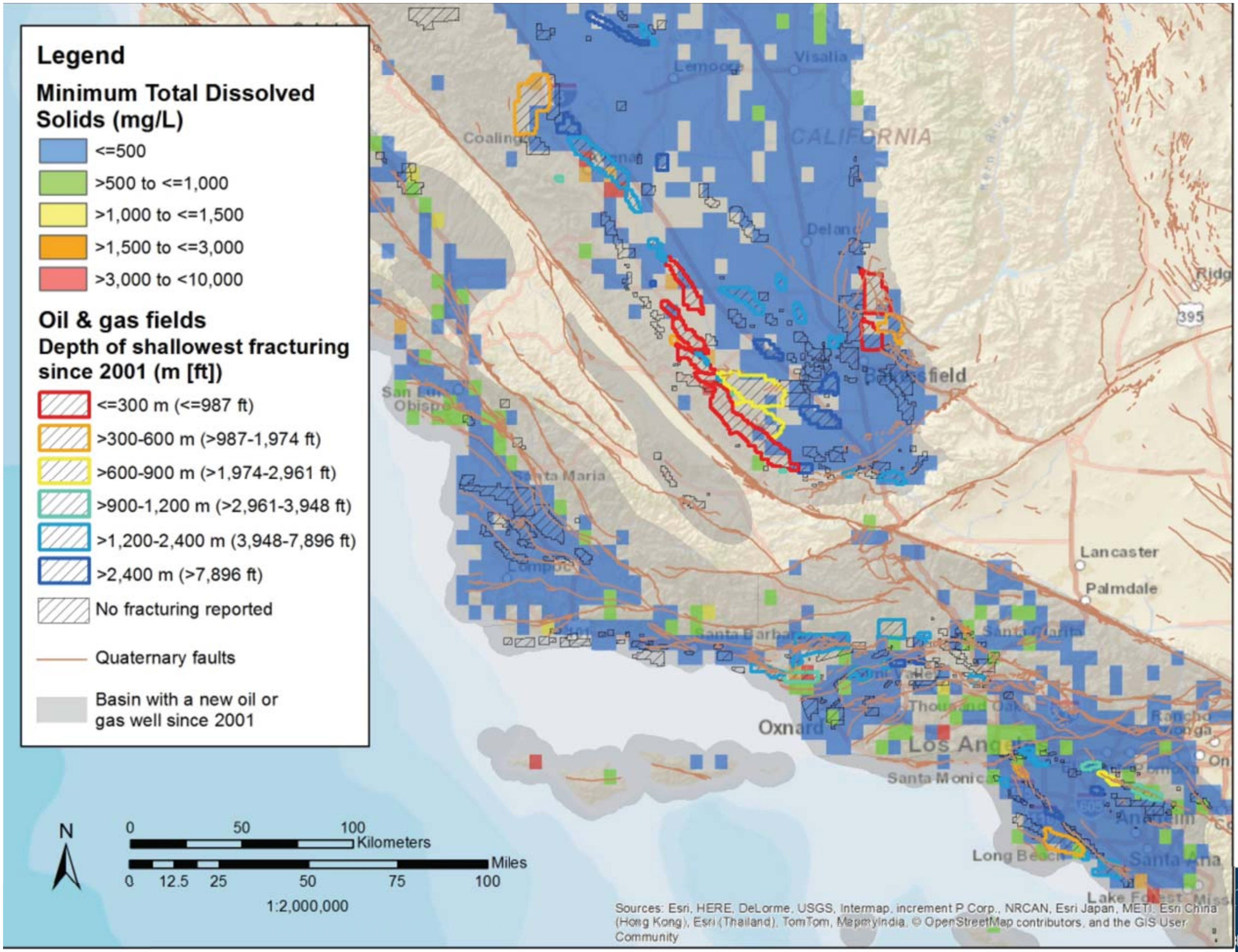


“An Independent Scientific Assessment of Well Stimulation in California,” July 2015

Principle 5. Add protections to avoid groundwater contamination by hydraulic fracturing.

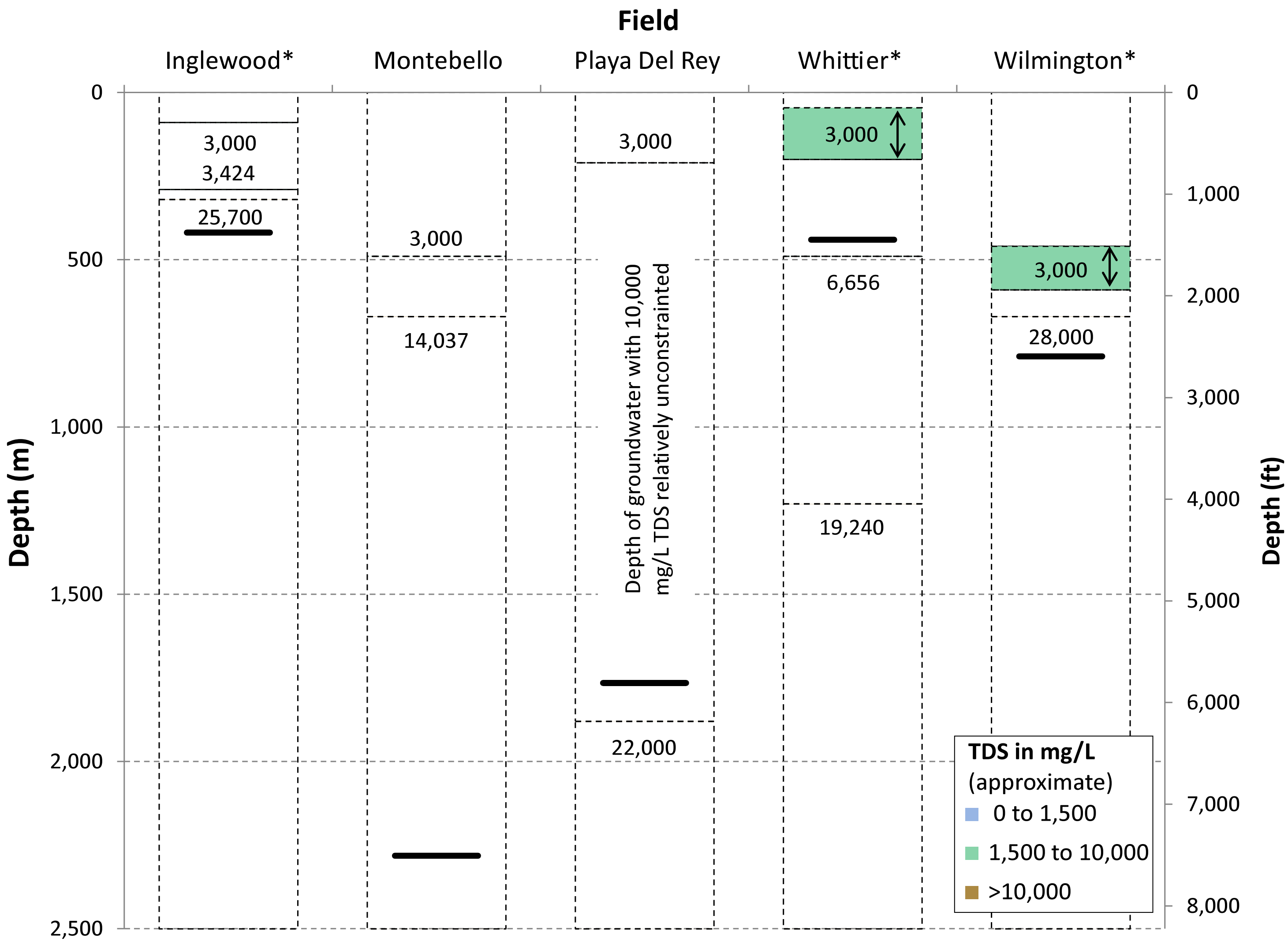
- **Conclusion 5.1. Shallow fracturing raises concerns about potential groundwater contamination.**
  - *About three quarters of all hydraulic fracturing operations take place in shallow wells less than 2,000 ft (600 m) deep*
  - *In a few places, protected aquifers exist above such shallow fracturing*
  - *Groundwater monitoring alone may not necessarily detect groundwater contamination from hydraulic fractures*
  - *Shallow hydraulic fracturing conducted near protected groundwater resources warrants special requirements for design, control, reporting, and corrective action*

Shallow fracturing locations and groundwater quality



BERKELEY LAB

Depths of groundwater total dissolved solids in five oil fields in the Los Angeles Basin



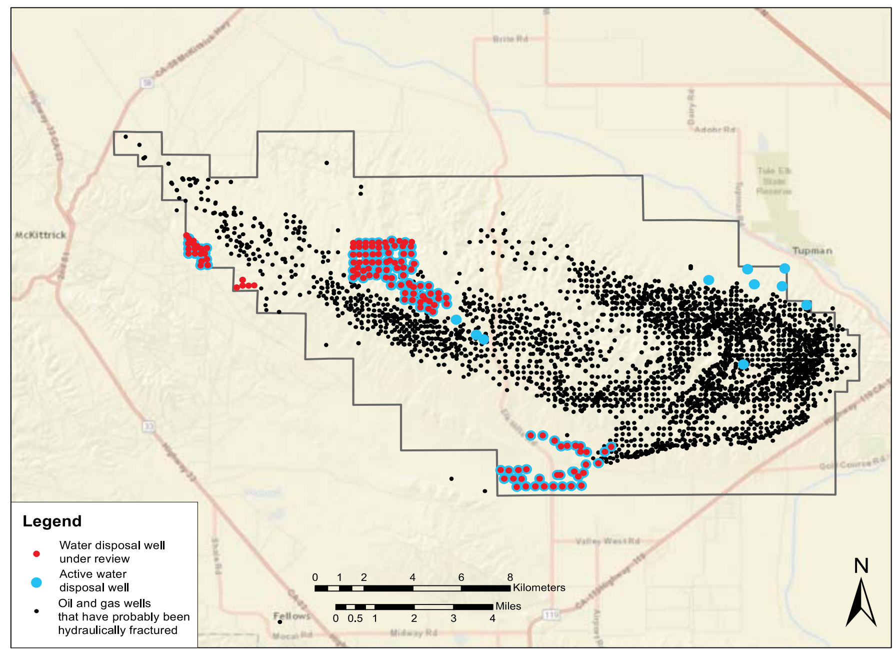
Principle 5. Add protections to avoid groundwater contamination by hydraulic fracturing.

- ***Recommendation 5.1: Protect groundwater from shallow hydraulic fracturing operations.***
  - Agencies with jurisdiction should act promptly to locate and catalog the quality of groundwater throughout the oil-producing regions.
  - Hydraulic fracturing near protected groundwater resources should be required to provide adequate assurance that the expected fractures will not extend into these aquifers and cause contamination.
  - If the operator cannot demonstrate the safety of the operation with reasonable assurance, deny the permit, or develop protocols for increased monitoring, operational control, reporting, and preparedness.

Principle 5. Add protections to avoid groundwater contamination by hydraulic fracturing.

- **Conclusion 5.2: Leakage of hydraulic fracturing chemicals could occur through existing wells.**
  - California reservoirs have a high density of existing wells that could form leakage paths away from the fracture zone to protected groundwater or the ground surface.
  - The pending SB 4 regulations going into effect July 2015 do address concerns about existing wells in the vicinity of well stimulation operations; however, it remains to demonstrate the effectiveness of these regulations in protecting groundwater.

Elk Hills Field



Principle 5. Add protections to avoid groundwater contamination by hydraulic fracturing.

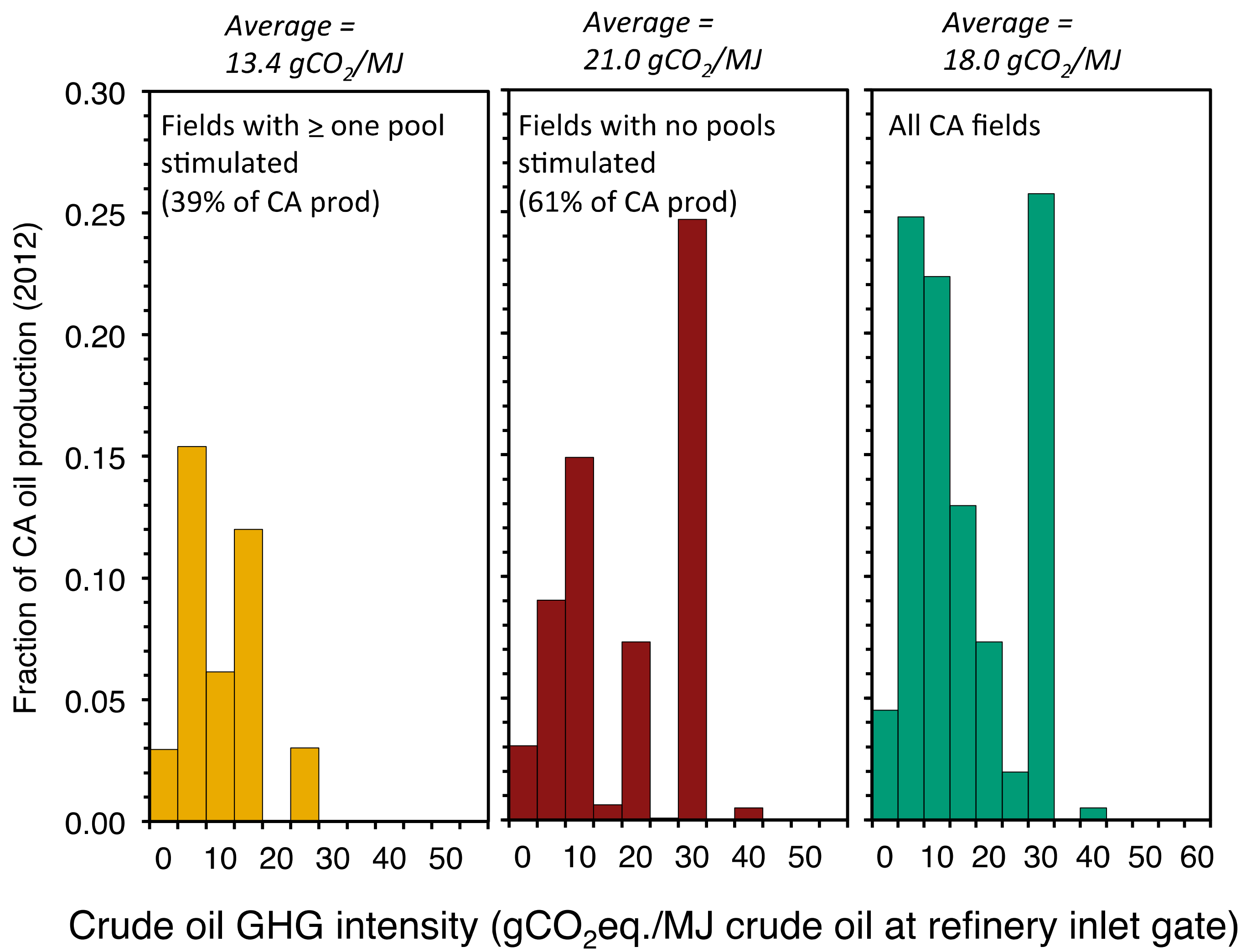
- ***Recommendation 5.2: Evaluate the effectiveness of hydraulic fracturing regulations designed to protect groundwater from leakage along existing wells.***
  - Within a few years of the new regulations going into effect, DOGGR should conduct or commission an assessment of the regulatory requirements for existing wells near stimulation operations and their effectiveness in protecting groundwater with less than 10,000 TDS from well leakage
  - This assessment should include comparisons of field observations from hydraulic fracturing sites with the theoretical calculations for stimulation area or well pressure required in the regulations

Principle 6.
Understand and control emissions and their impact on environmental and human health.

Principle 6. Understand and control emissions and their impact on environmental and human health.

- **Conclusion 6.1. Oil and gas production from hydraulically fractured reservoirs emits less greenhouse gas per barrel of oil than other forms of oil production in California.**
  - All oil and gas production operations in the State contribute to about 4% of California total greenhouse gas emissions, about 20% of which is related to well stimulation.
  - Oil and gas production from hydraulically fractured reservoirs emits less greenhouse gas per barrel of oil than production using steam injection or the average barrel imported to California.
  - If the oil and gas derived from stimulated reservoirs was no longer available, and demand for oil remained constant, the replacement fuel could have larger greenhouse emissions.

Distribution of Crude Oil Greenhouse Gas Intensity



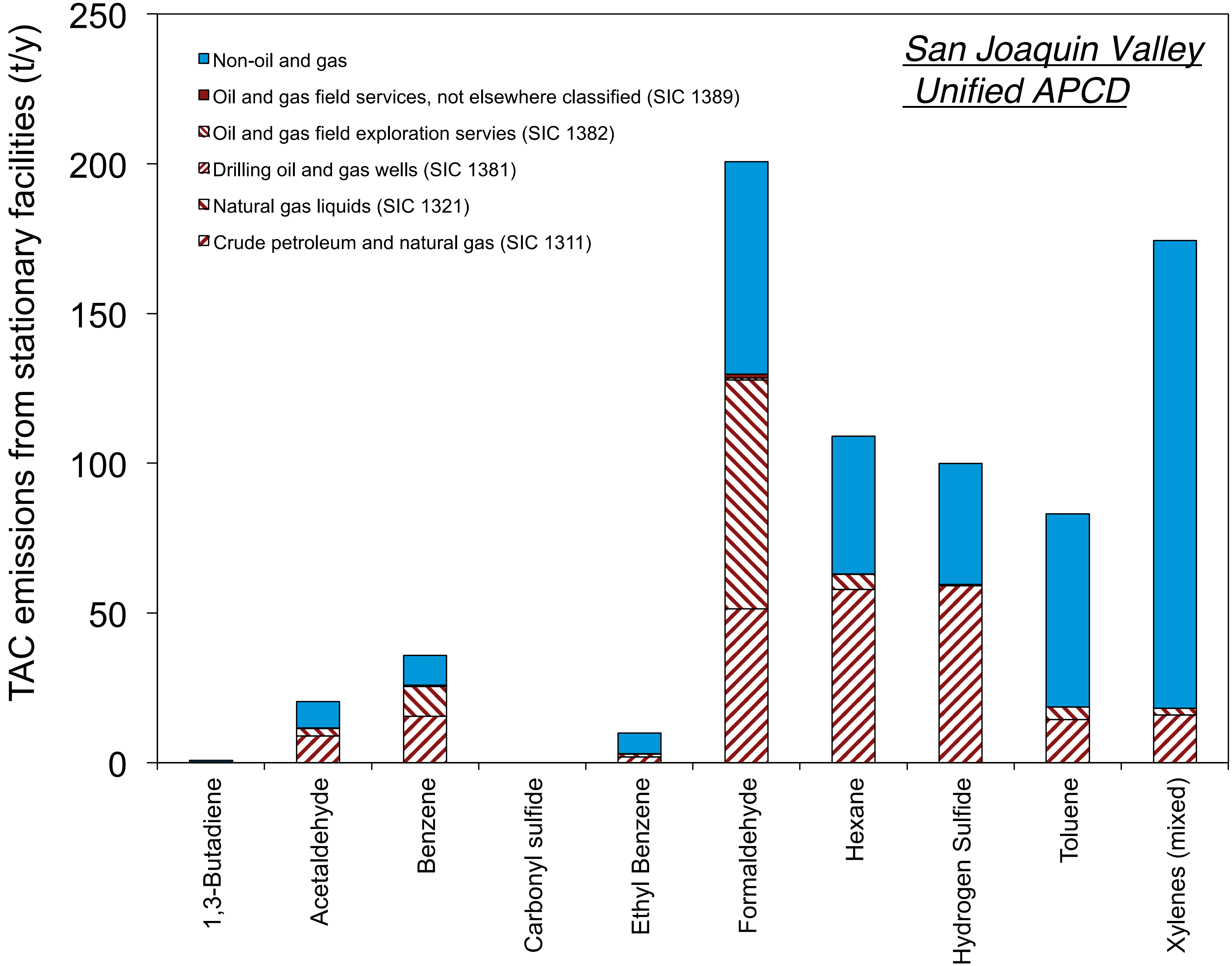
“An Independent Scientific Assessment of Well Stimulation in California,” July 2015

Principle 6. Understand and control emissions and their impact on environmental and human health.

- ***Recommendation 6.1: Assess and compare greenhouse gas signatures of different types of oil and gas production in California.***
  - Conduct rigorous market-informed life-cycle analyses of emissions impacts of different oil and gas production to better understand GHG impacts of well stimulation.

Principle 6. Understand and control emissions and their impact on environmental and human health.

- **Conclusion 6.2. Air pollutants and toxic air emissions from hydraulic fracturing are mostly a small part of total emissions, but pollutants can be concentrated near production wells.**
  - Emissions of all constituents from oil and gas are a small part of total emissions in LA
  - Oil and gas production enabled by stimulation in the San Joaquin Valley likely accounts for significant emissions of sulfur oxides (SO_x), volatile organic compounds (VOC) and some air toxics, notably hydrogen sulfide (H_2S)
  - Atmospheric concentrations of pollutants near production sites can be much larger than regional averages and could potentially cause health impacts due to enhanced exposure near the source of emissions.



"An Independent Scientific Assessment of Well Stimulation in California," July 2015

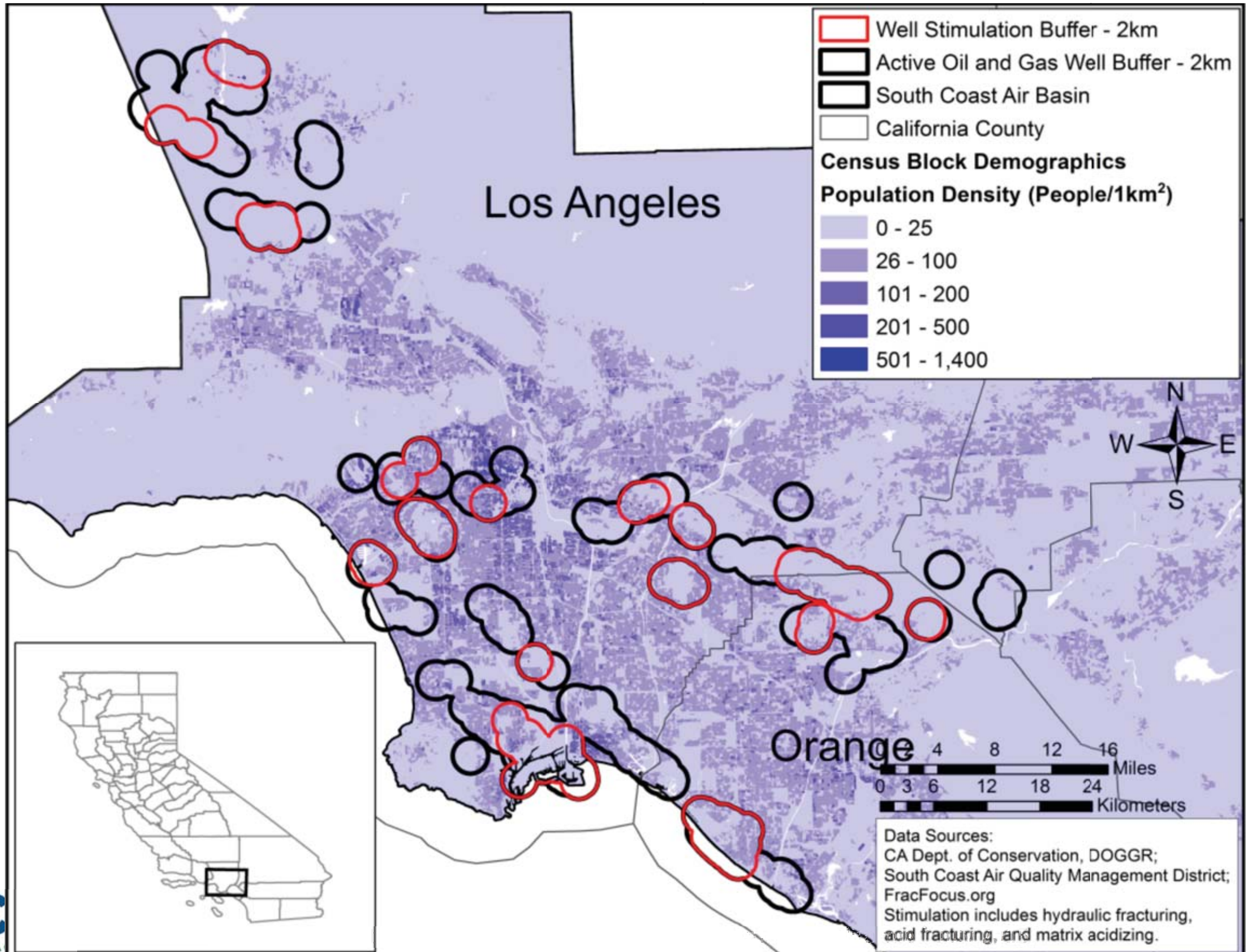
Principle 6. Understand and control emissions and their impact on environmental and human health.

- **Recommendation 6.2: Control toxic air emissions from oil and gas production wells and measure their concentrations near productions wells**
  - Apply reduced-air-emission completion technologies to all production wells
  - Reassess opportunities for emission controls in general oil and gas operations to limit emissions.
  - Improve specificity of inventories to allow better understanding of oil and gas emissions sources.
  - Improve understanding of toxics concentrations near stimulated and un-stimulated wells

Principle 6. Understand and control emissions and their impact on environmental and human health.

- **Conclusion 6.3. Emissions concentrated near all oil and gas production could present health hazards to nearby communities in California.**
  - Many of the constituents used in and emitted by oil and gas development are known to be damaging to health, and place disproportionate risks on sensitive populations
  - Oil and gas development poses more elevated health risks when conducted in areas of high population density, such as the Los Angeles Basin
  - Health risks near oil and gas wells may be independent of whether wells in production have undergone hydraulic fracturing or not

Population density within 2,000 m of currently active oil production wells



Principle 6. Understand and control emissions and their impact on environmental and human health.

- **Recommendation 6.3: Assess public health near oil and gas production.**
  - Initiate studies in California to assess public health as a function of proximity to all oil and gas development, not just stimulated wells, and
  - Develop policies, for example science-based surface setbacks, to limit exposures.

Principle 6. Understand and control emissions and their impact on environmental and human health.

- **Conclusion 6.4. Hydraulic fracturing and acid stimulation operations add some occupational hazards to an already hazardous industry.**
  - Studies done outside of California found workers in hydraulic fracturing were exposed to respirable silica and VOCs, especially benzene, above recommended occupational levels.
  - No similar studies have been done in California.

Principle 6. Understand and control emissions and their impact on environmental and human health.

- **Recommendation 6.4: Assess occupational health hazards from proppant use and emission of volatile organic compounds.**
  - Design and execute California-based studies focused on silica and volatile organic compounds exposures to workers engaged in hydraulic fracturing-enabled oil and gas development based on the NIOSH occupational health findings and protocols.

Principle 7.
Take an informed path forward.

Principle 7. Take an informed path forward.

- **Conclusion 7.1. Data reporting gaps and quality issues exist.**
  - Significant gaps and inconsistencies specific to California exist in available data from mandatory and voluntary reporting, in terms of duration, accuracy, and completeness of data.
  - Mandatory reporting under SB 4 has clearly improved previous reporting practices; however, additional quality control, reporting and data handling requirements may be warranted

Principle 7. Take an informed path forward.

- **Recommendation 7.1: Improve and modernize record keeping for oil and gas production.**
  - DOGGR should digitize paper records and provide them in databases that facilitate searches and quantitative analysis.
  - DOGGR should also institute and publish data quality assurance practices, and institute enforcement measures to ensure accuracy of reporting.
  - After a few years of mandated reporting, a study should assess the value, completeness and consistency of reported data and, as necessary, revise or expand reporting requirements

The quality, completeness and availability of the data collected by the South Coast Air Quality Management District provides a good example the State should seek to emulate.

Principle 7. Take an informed path forward.

- **Conclusion 7.2. Future research would fill knowledge gaps**
  - Questions remain that can only be answered by new research and data collection.
  - The Summary Report and Volumes II and III of this study provide many detailed recommendations for filling data gaps with additional research.
  - An important element of future research are dedicated field pilot studies of hydraulic fracturing operations where data collection and interpretative analysis can be much more intense and ubiquitous than is possible in general
  - Another important element are regional-scale evaluations with advanced analysis of existing and new data

Principle 7. Take an informed path forward.

- **Additional Research Needs**
  - Has any protected groundwater been contaminated with stimulation chemicals in the past, and what would protect against this occurrence in the future?
  - What environmental risks do stimulation chemicals pose, and are there practices that would limit these risks?
  - Can water being produced from hydraulically fractured wells become a resource for California?
  - How does oil and gas production as a whole (including that enabled by hydraulic fracturing) affect California's water system?
  - Does California's current or future practice of underground injection of wastewater present a significant risk of inducing earthquakes?
  - How can the public best be protected from air pollution associated with oil and gas production?

Principle 7. Take an informed path forward.

- **Recommendation 7.3: Conduct integrated research to close knowledge gaps.**
  - Conduct integrated research in California to answer key questions about the environmental, health, and seismic impacts of oil and gas production enabled by well stimulation.
  - Integrated research should include regional hydrologic characterization as well as dedicated hydraulic fracturing field studies related to surface and groundwater protection, induced seismicity, ecological conditions, as well as air and health effects.

Principle 7. Take an informed path forward.

- **Conclusion 7.4. Ongoing scientific advice could inform policy.**
  - As the State digests this scientific assessment and as more data become available, continued interpretation of the impacts of well stimulation and the potential meaning of new scientific data and analysis would inform the policy framework for this complex topic.
- **Recommendation 7.4: Establish an advisory committee.**
  - The State of California should establish a standing scientific advisory committee to support decisions on the regulation of oil and gas development.

Questions?

Please ask questions by typing them in the "Questions" window in your Control Panel.

We will answer as many questions as possible at the end.