Well Stimulation in California

Preston Jordan
State Water Resources Control Board

April 8, 2015

Team Performing the Independent Scientific Review of Well Stimulation

- **The California Council on Science and Technology**
  - Provided oversight, scientific guidance and input for the project
- **Lawrence Berkeley National Laboratory**
  - Performed the majority of the analyses
- **Subcontractors**:
  - The Pacific Institute
  - Physicians, Scientists and Engineers for Healthy Energy
  - Stanford University
  - Dan Gautier (USGS retired)
  - Scripps Institute of Oceanography
  - CSU Stanislaus Endangered Species Recovery Program
  - University of the Pacific

CCST
CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

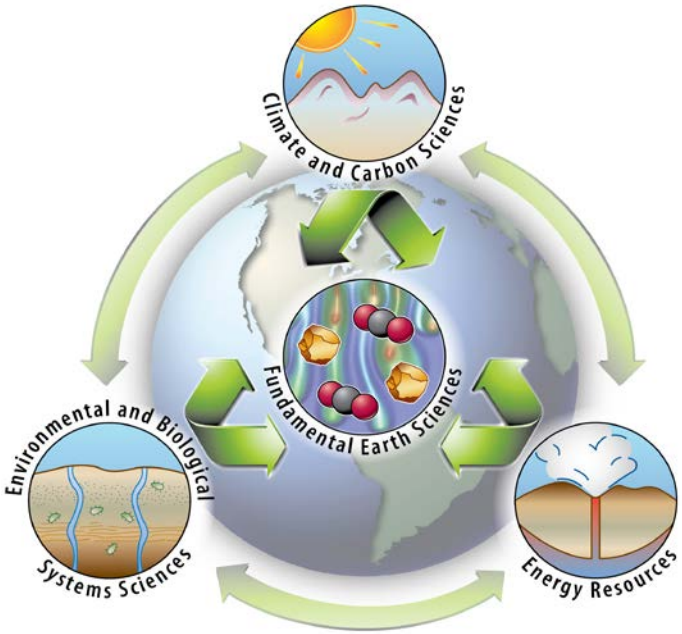
- CCST is a nonpartisan, impartial, not-for-profit 501(c)(3) corporation established via Assembly Concurrent Resolution (ACR 162) in 1988 by a unanimous vote of the California Legislature

- 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, and from the philanthropic community

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.**

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

Partial List of Researchers

- Jens Birkholzer[2]
- Heather Cooley[3]
- Kristina Donnelly[3]
- Jeremy Domen[1]
- Laura Feinstein[4]
- Jeremy Hanlon[1,2]
- Jane Long[4]
- Matthew Heberger[3]
- James Houseworth[2]
- Matthew Reagan[2]
- Whitney Sandelin[1]
- Will Stringfellow[1,2]
- Charuleka Varadharajan[2]

[1]University of the Pacific, [2]Lawrence Berkeley National Laboratory, [3]Pacific Institute, [4]California Council on Science & Technology

Outline

- Data utilized
- California versus elsewhere
- Water use per operation
- Number of operations
- Geographic distribution
- Water use by area
- Number of constituents
- Constituent properties
- Produced water disposal release mechanisms
- Subsurface release mechanisms

Data Sources Utilized

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)

Data Sources Utilized

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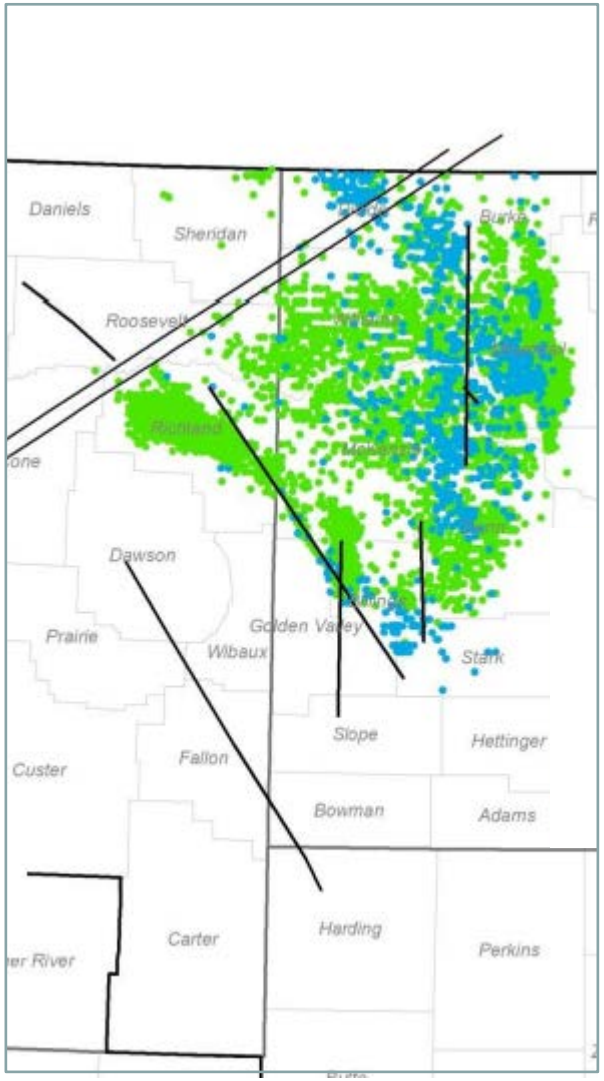
DOGGR notices	2014	x	x	x	x	x	x		x	x	x
SCAQMD	2013-2014	x	x	x	x	partial	x	x	x	x	
CVRWQCB	2012-2013	x	x	x	x	x	x	x	x		TVD
FracFocus	2011-2014	partial	p			x	x	x	x	partial	TVD
Well record search	2002-2013		p			x					
DOGGR GIS well table	all		p			x	x				MD-partial

Each has its own advantages and disadvantages, but together they provide an accurate, if not complete and precise, understanding.

Hydraulic Fracturing Distribution

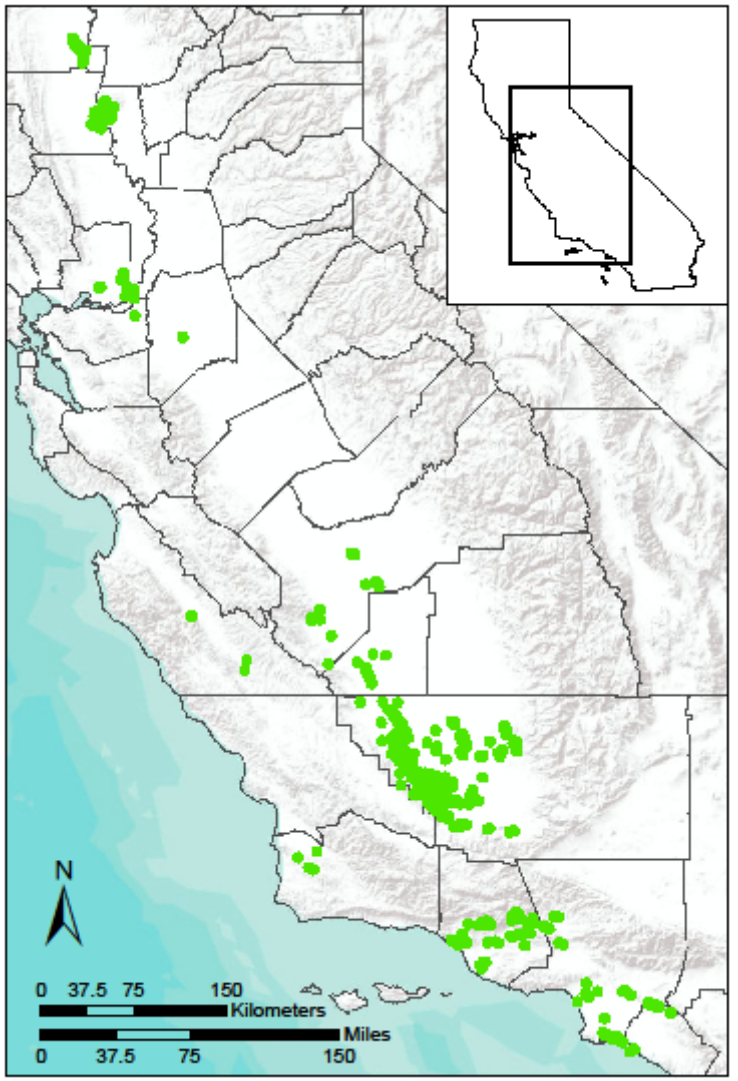
North Dakota and Montana: Bakken and Three Forks



http://energy.usgs.gov/Portals/0/Rooms/oil_and_gas/noga/multimedia/2013_Bakken_ThreeForks_Assessment.pdf

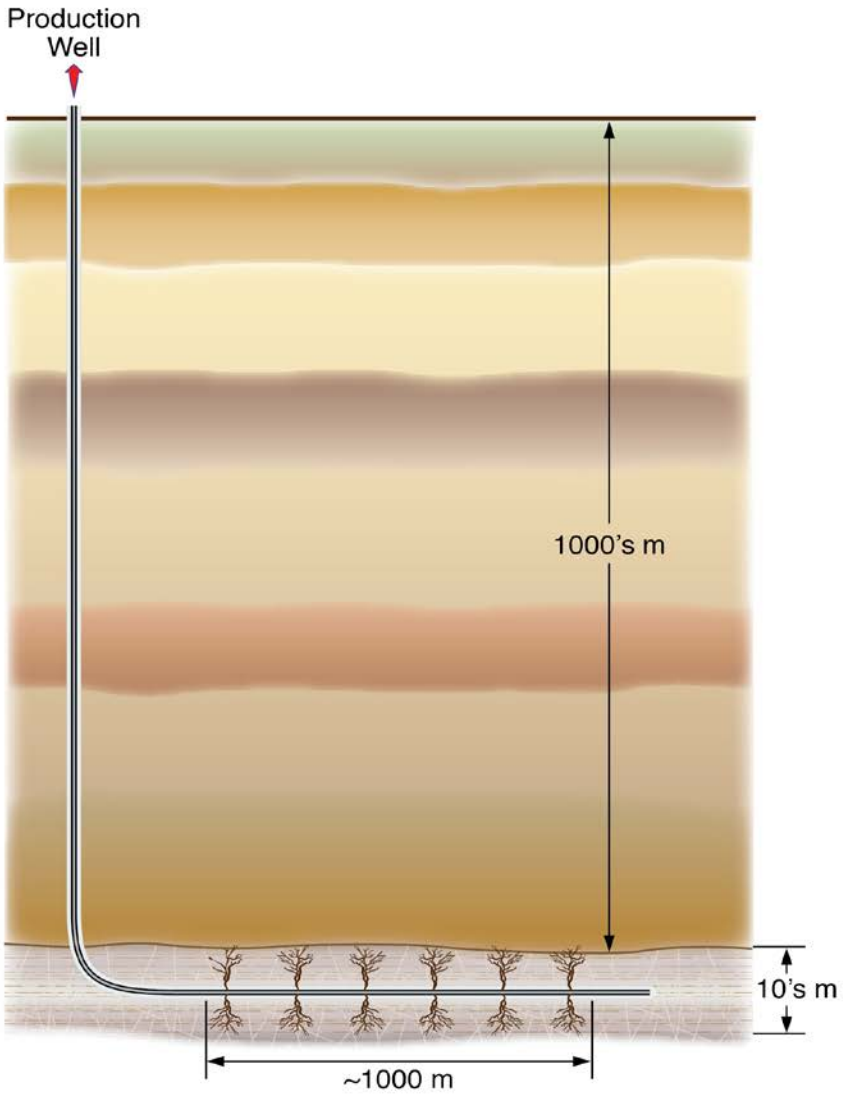
through 2013: 110 million m^3 oil (700 million bbl)

California: various geologic units

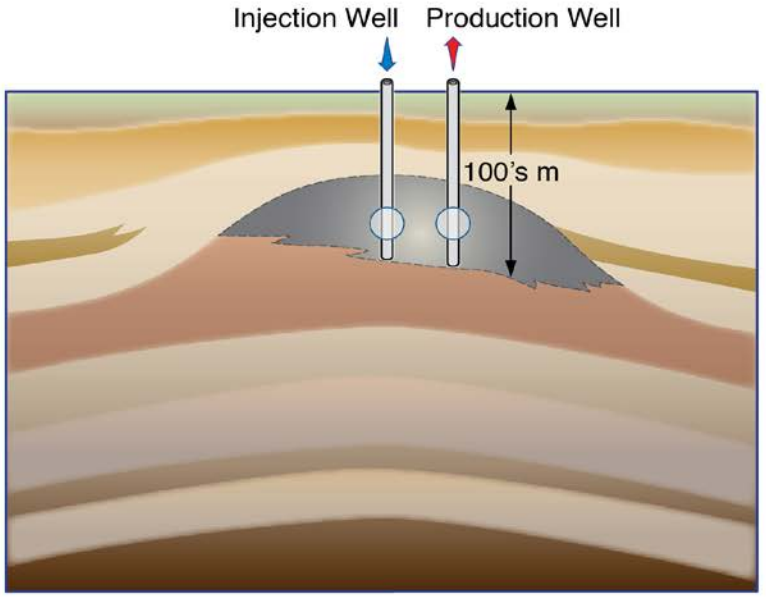


2002-2014: 100 million m^3 oil (600 million bbl)

Typical Source Rock Stimulation



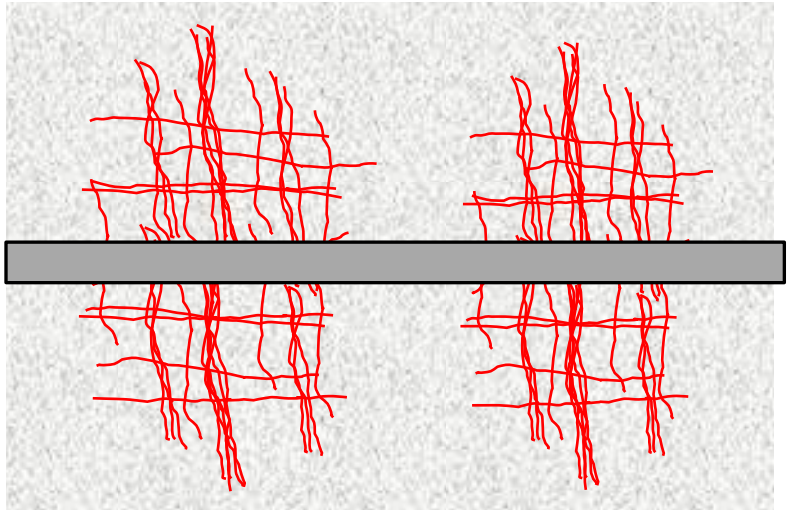
Typical California (Migrated Oil) Stimulation



ESD14-047

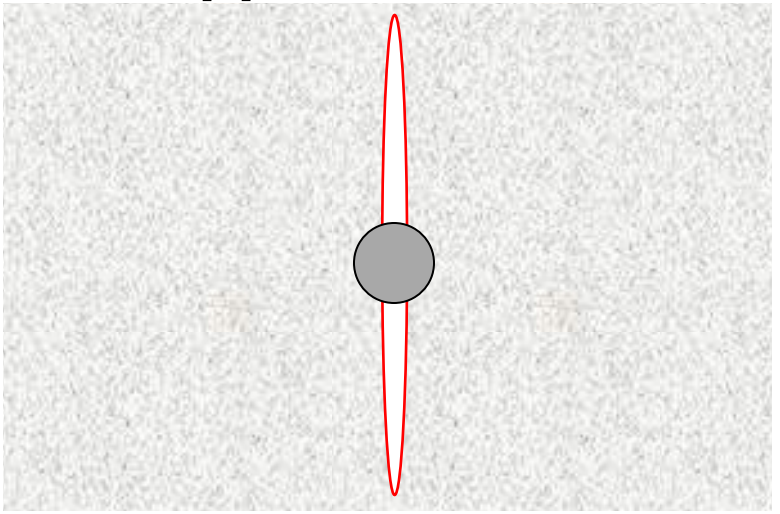
CA Hydraulic Fractures: Smaller and Simpler

High Volume – Horizontal Well Application



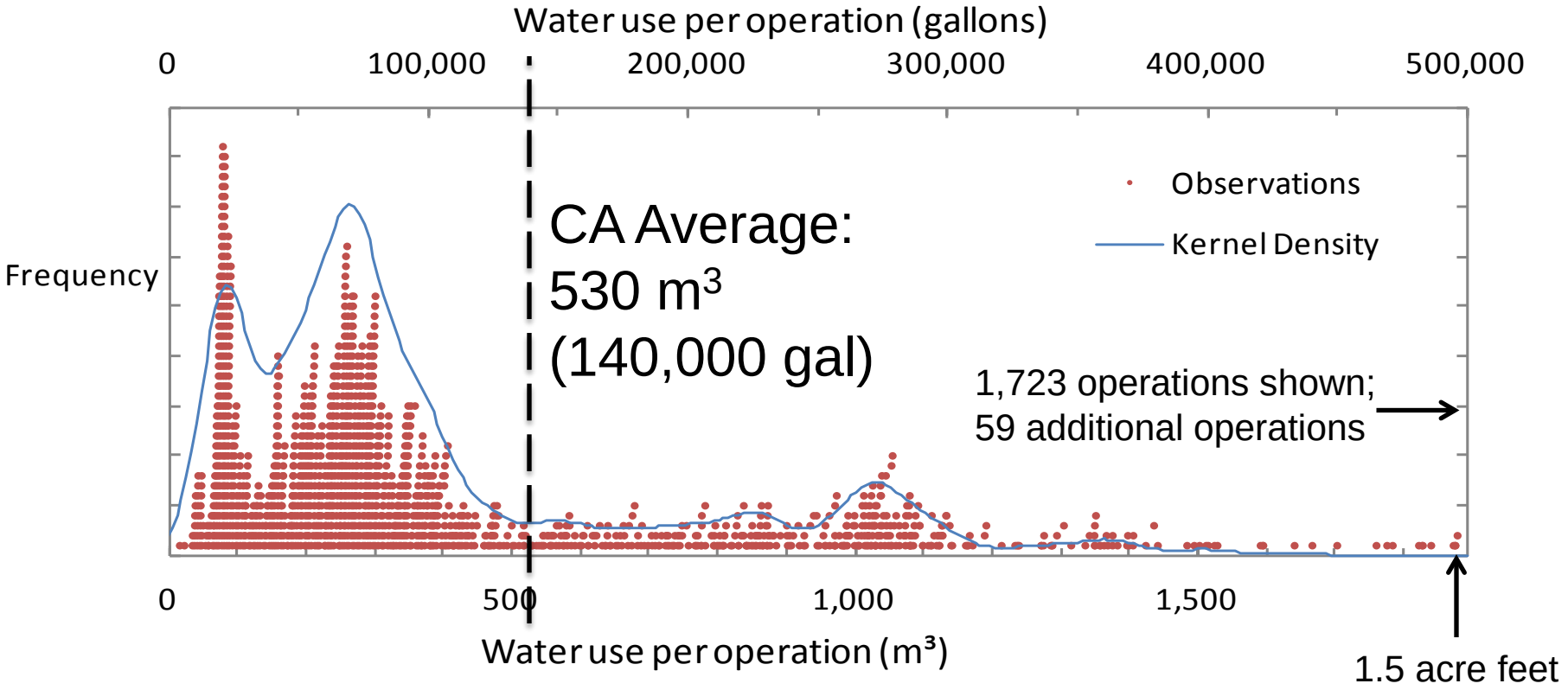
- Larger volumes of water
- Slick-water (detergents) additives
- Complex fracture networks
- (Banned in New York)

Typical California Vertical Well Application



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

Distribution of water use per hydraulic fracturing operation in California?



Much less than the >4,000 m³ (3 acre feet) per operation typical elsewhere (e.g., Eagle Ford, Bakken)

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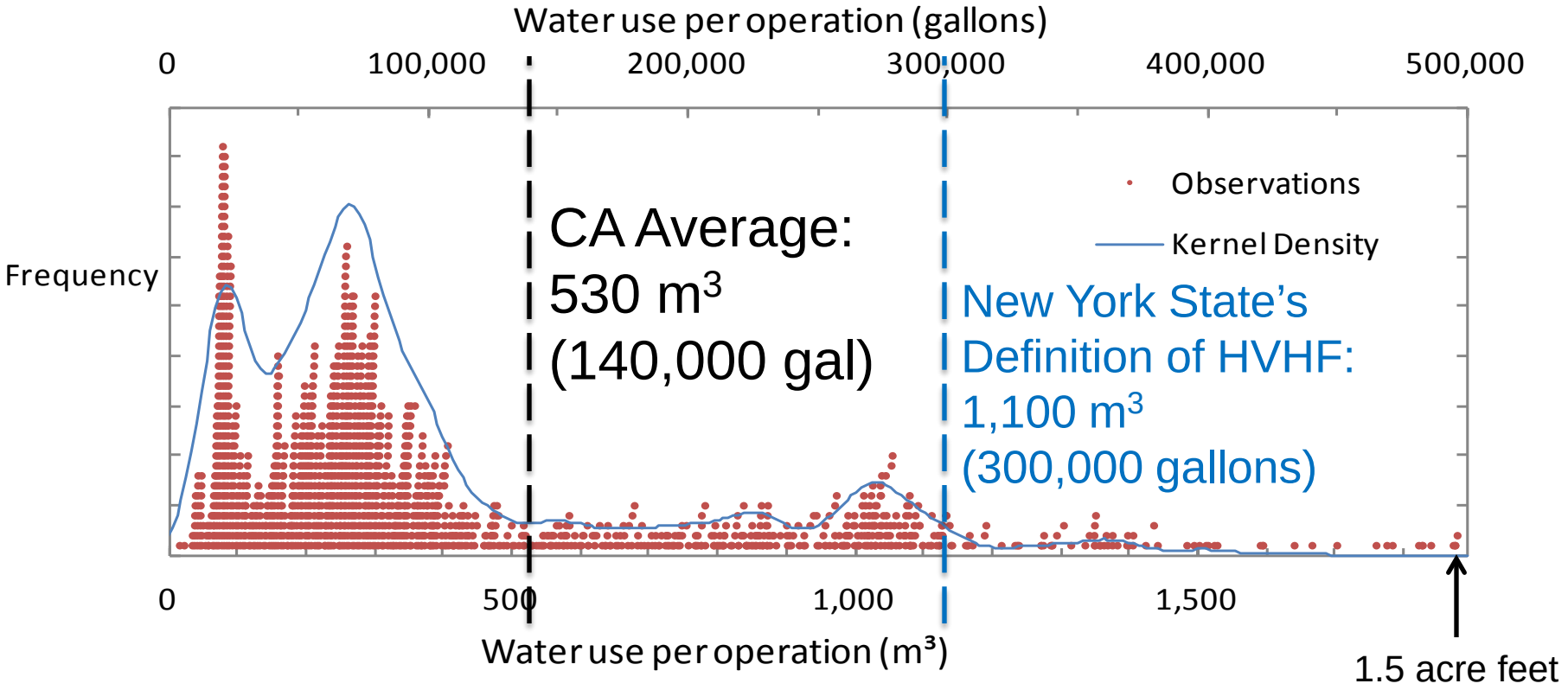

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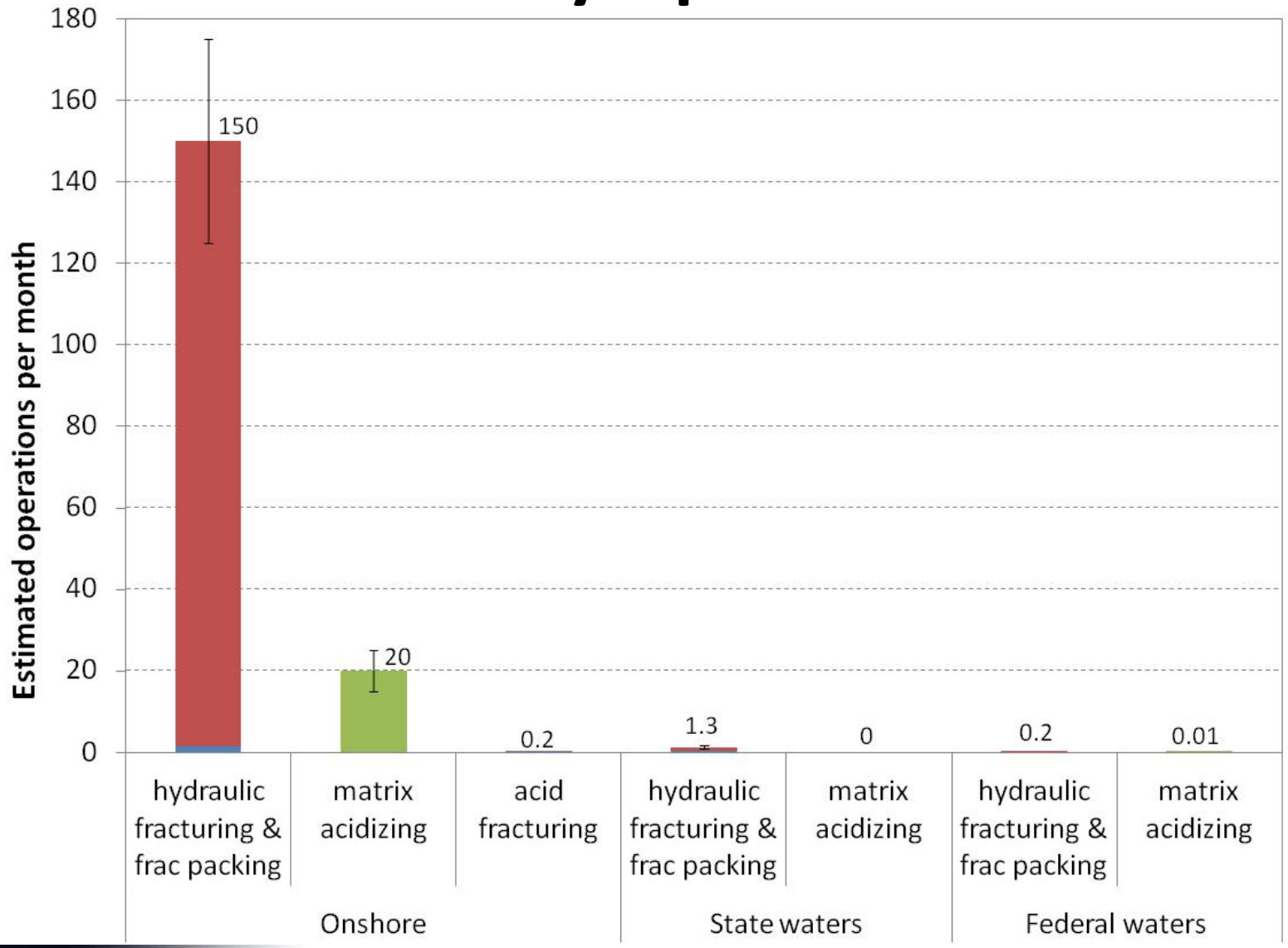
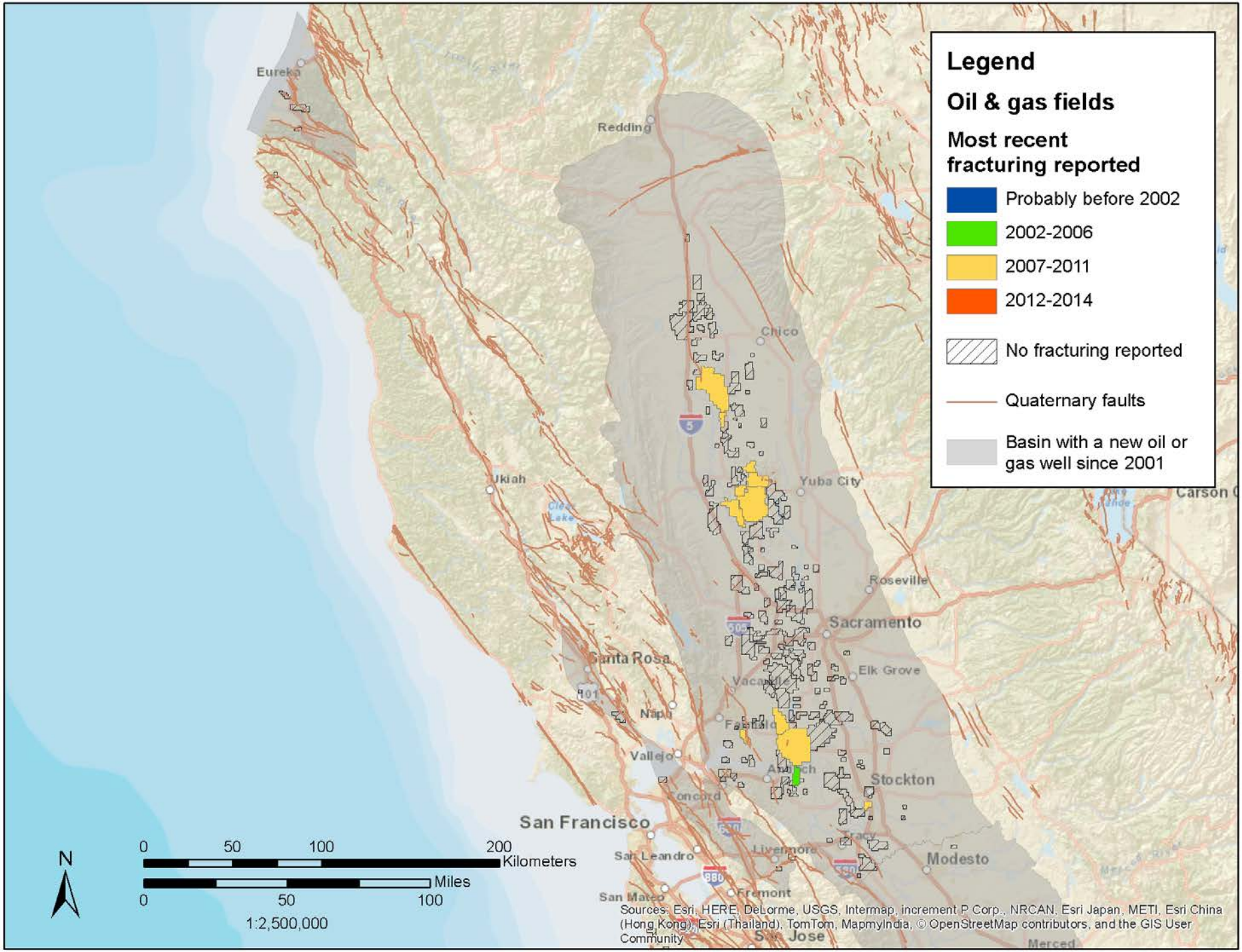
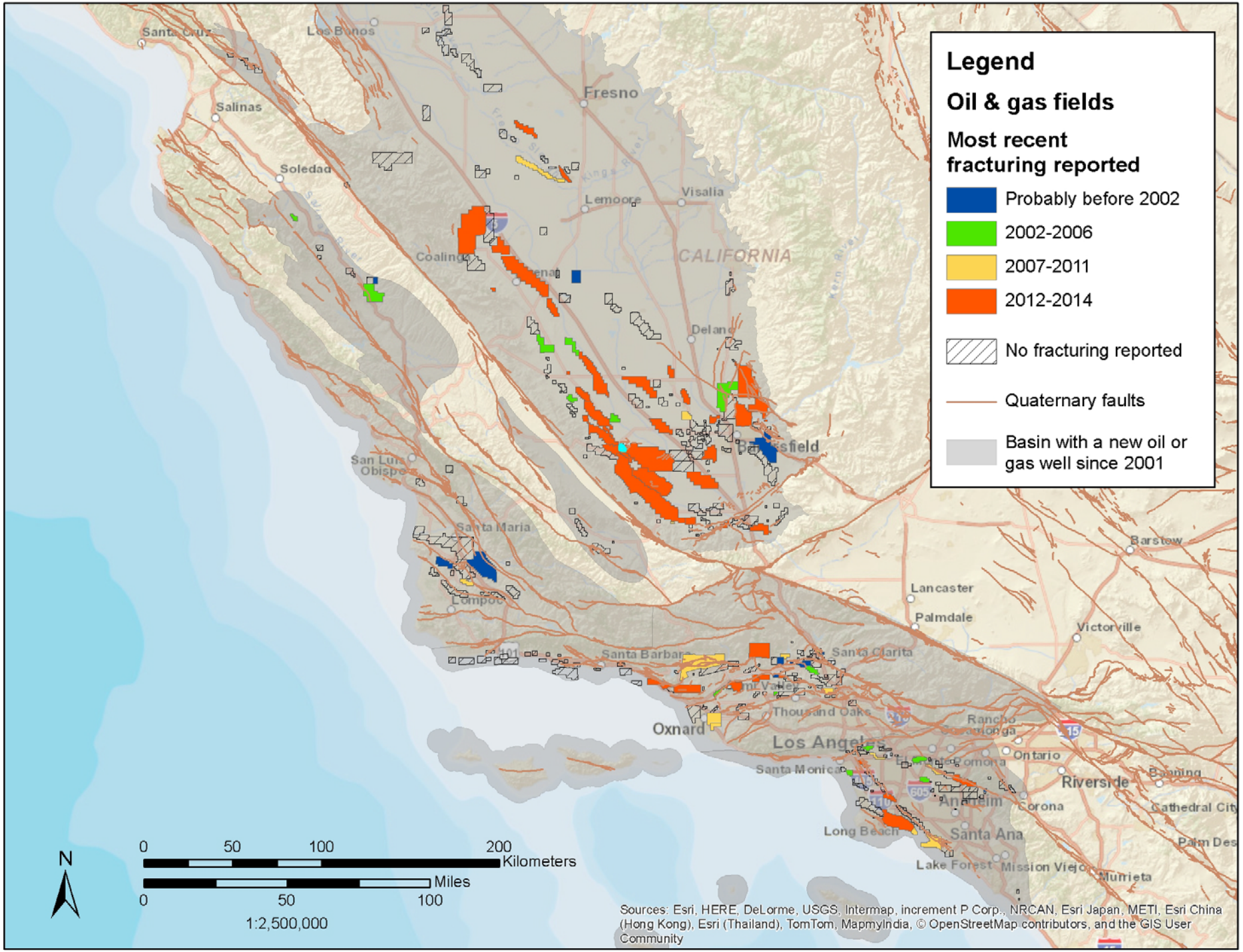
How Many Operations?




Legend
Oil & gas fields
Most recent fracturing reported
Probably before 2002
2002-2006
2007-2011
2012-2014
No fracturing reported
Quaternary faults
Basin with a new oil or gas well since 2001
Eureka
Redding
Chico
Ukiah
Yuba City
Roseville
Sacramento
Santa Rosa
Elk Grove
Napa
Vallejo
Stockton
San Francisco
San Leandro
Livermore
Modesto
Fremont
San Mateo
San Jose
Merced
Carson
N
0 50 100 200 Kilometers
0 50 100 Miles
1:2,500,000
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community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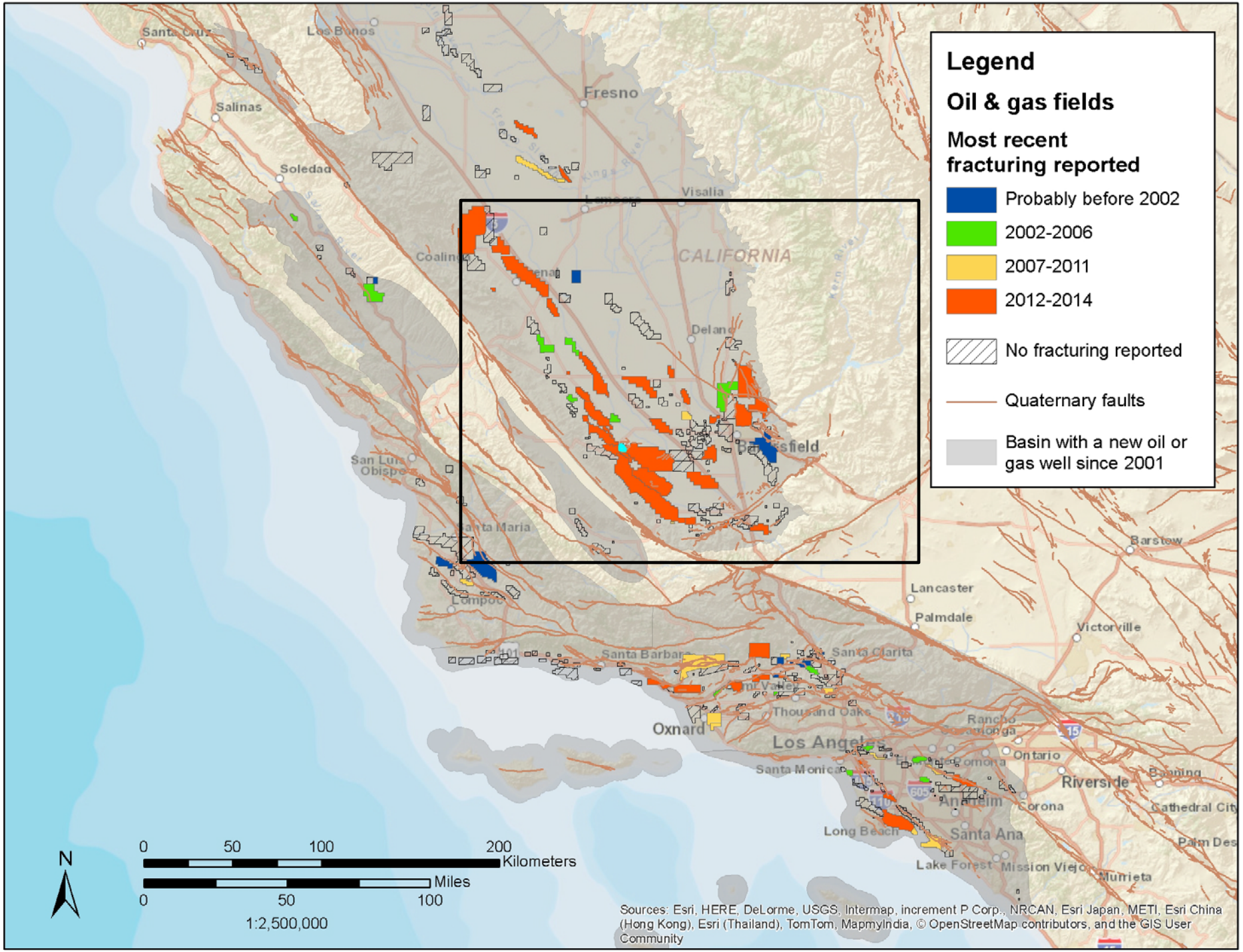
Los Banos
Fresno
Salinas
Soledad
Lemoore
Visalia
Coalinga
CALIFORNIA
Delano
San Luis Obispo
Santa Maria
Lompoc
Santa Barbara
Oxnard
Thousand Oaks
Santa Clarita
Los Angeles
Santa Monica
Lancaster
Palmdale
Victorville
Barstow
Ontario
Riverside
Anaheim
Corona
Long Beach
Santa Ana
Lake Forest
Mission Viejo
Murrieta
Cathedral City
Palm Des
N
0 50 100 200 Kilometers
0 50 100 Miles
1:2,500,000
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community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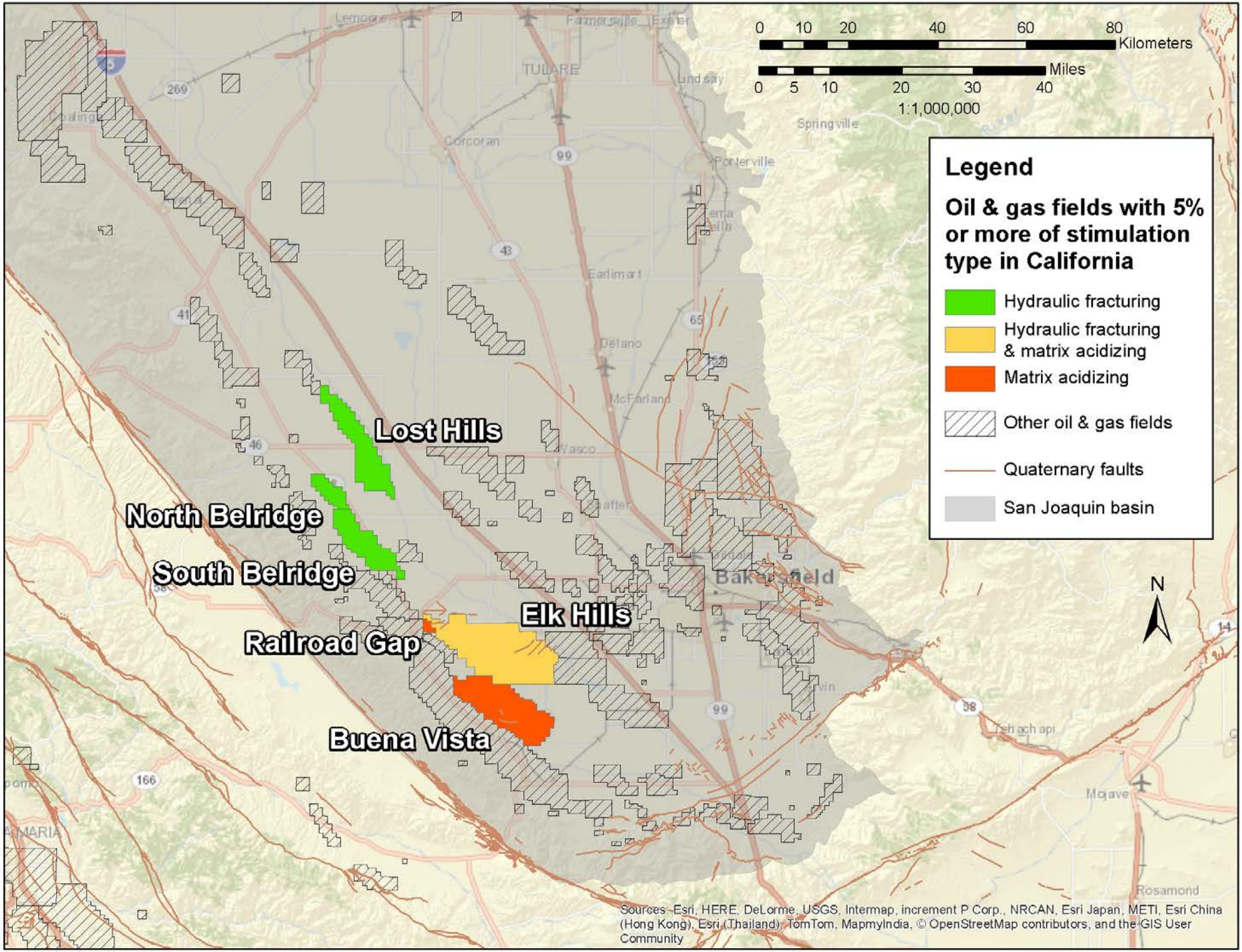
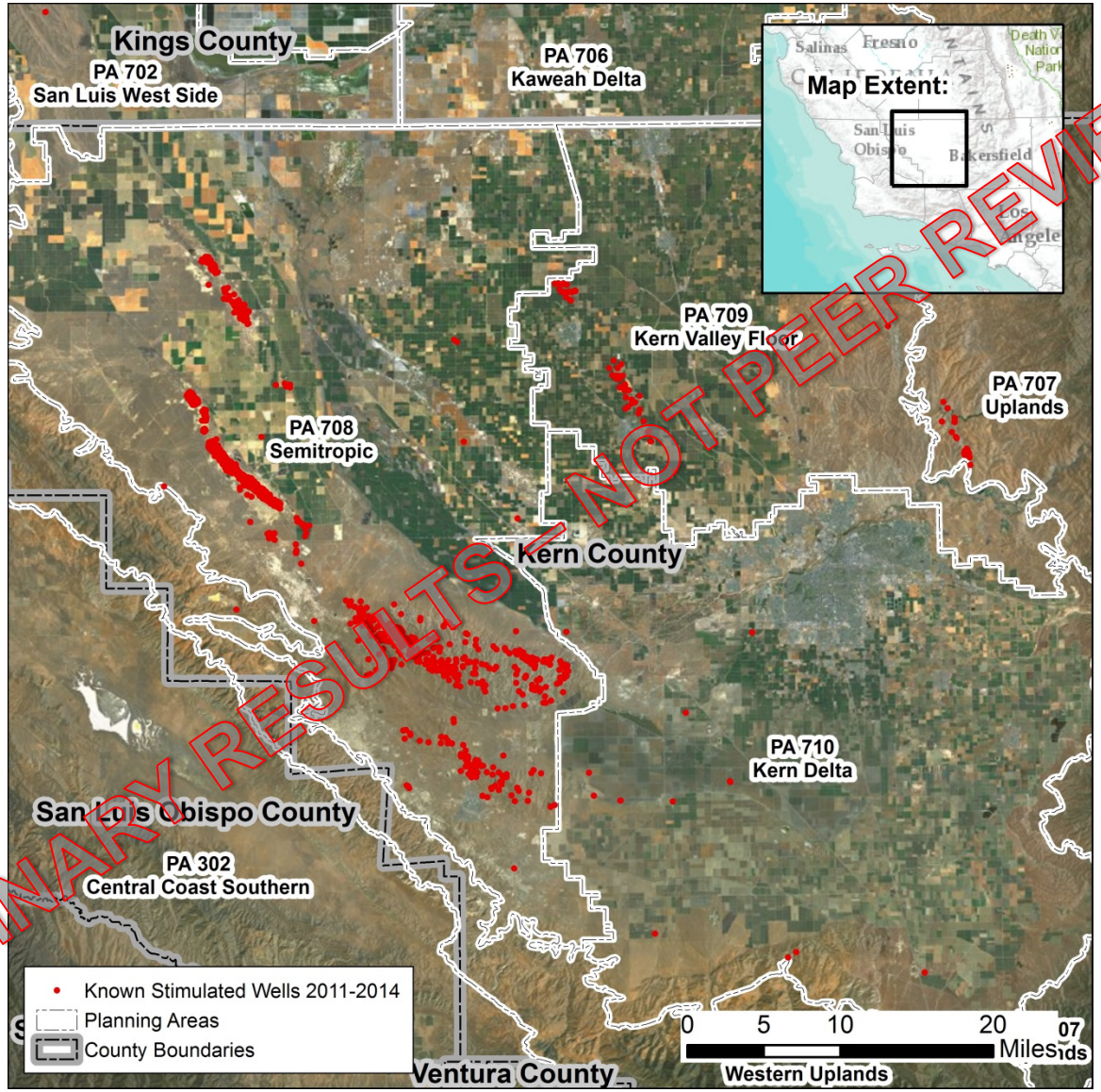
Cathedral City
Palm Des
N
0 50 100 200 Kilometers
0 50 100 Miles
1:2,500,000
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

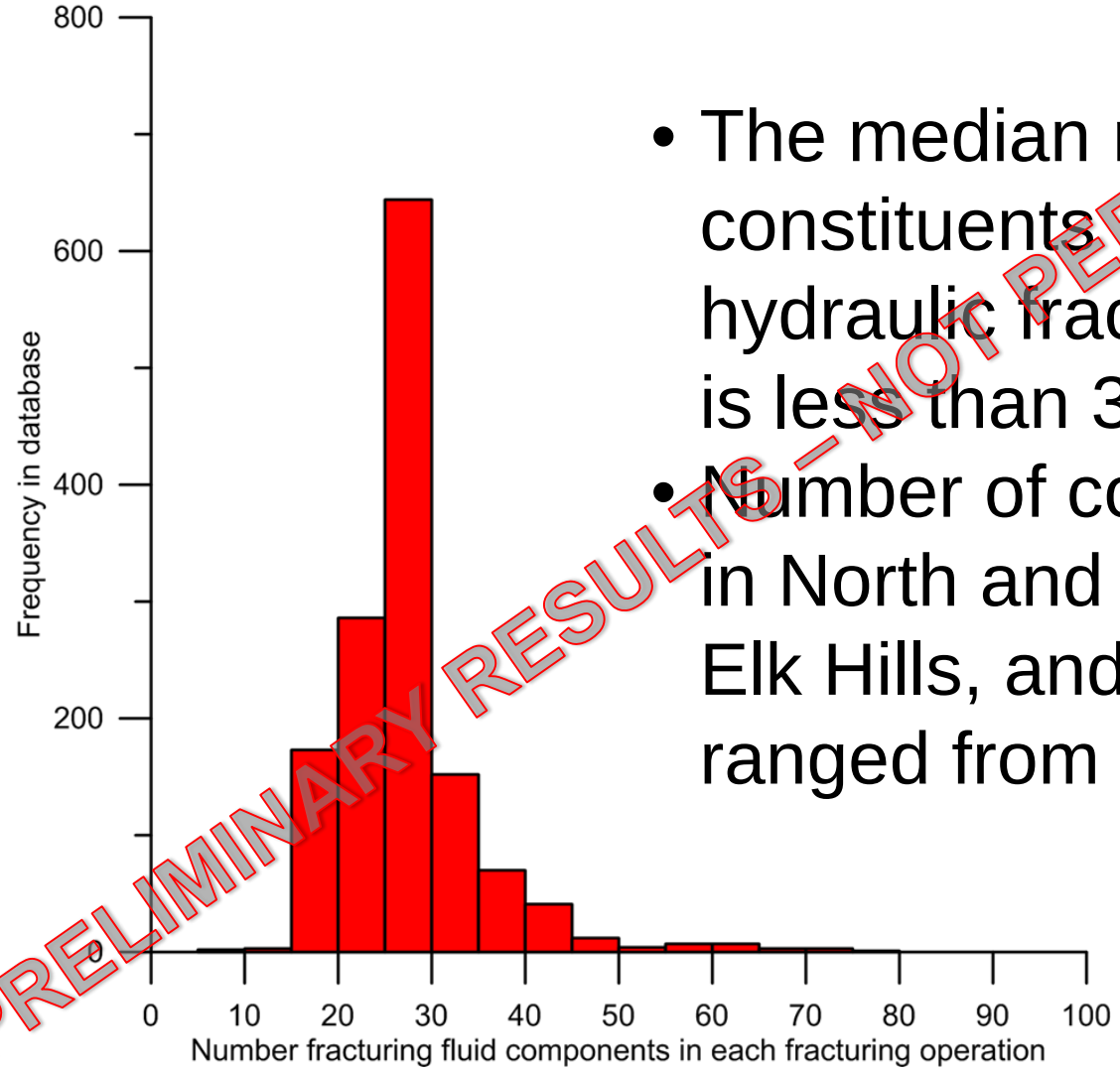

0 10 20 40 60 80
Kilometers
0 5 10 20 30 40
Miles
1:1,000,000
Legend
Oil & gas fields with 5% or more of stimulation type in California
Hydraulic fracturing
Hydraulic fracturing & matrix acidizing
Matrix acidizing
Other oil & gas fields
Quaternary faults
San Joaquin basin
Lost Hills
North Belridge
South Belridge
Elk Hills
Railroad Gap
Buena Vista
N
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community


Kings County
PA 702
San Luis West Side
PA 706
Kaweah Delta
Map Extent:
PA 709
Kern Valley Floor
PA 707
Uplands
PA 708
Semitropic
Kern County
PA 710
Kern Delta
San Luis Obispo County
PA 302
Central Coast Southern
Known Stimulated Wells 2011-2014
Planning Areas
County Boundaries
Ventura County
0 5 10 20
Miles
Western Uplands
PRELIMINARY RESULTS - NOT PEER REVIEWED

Water Demand by Planning Area

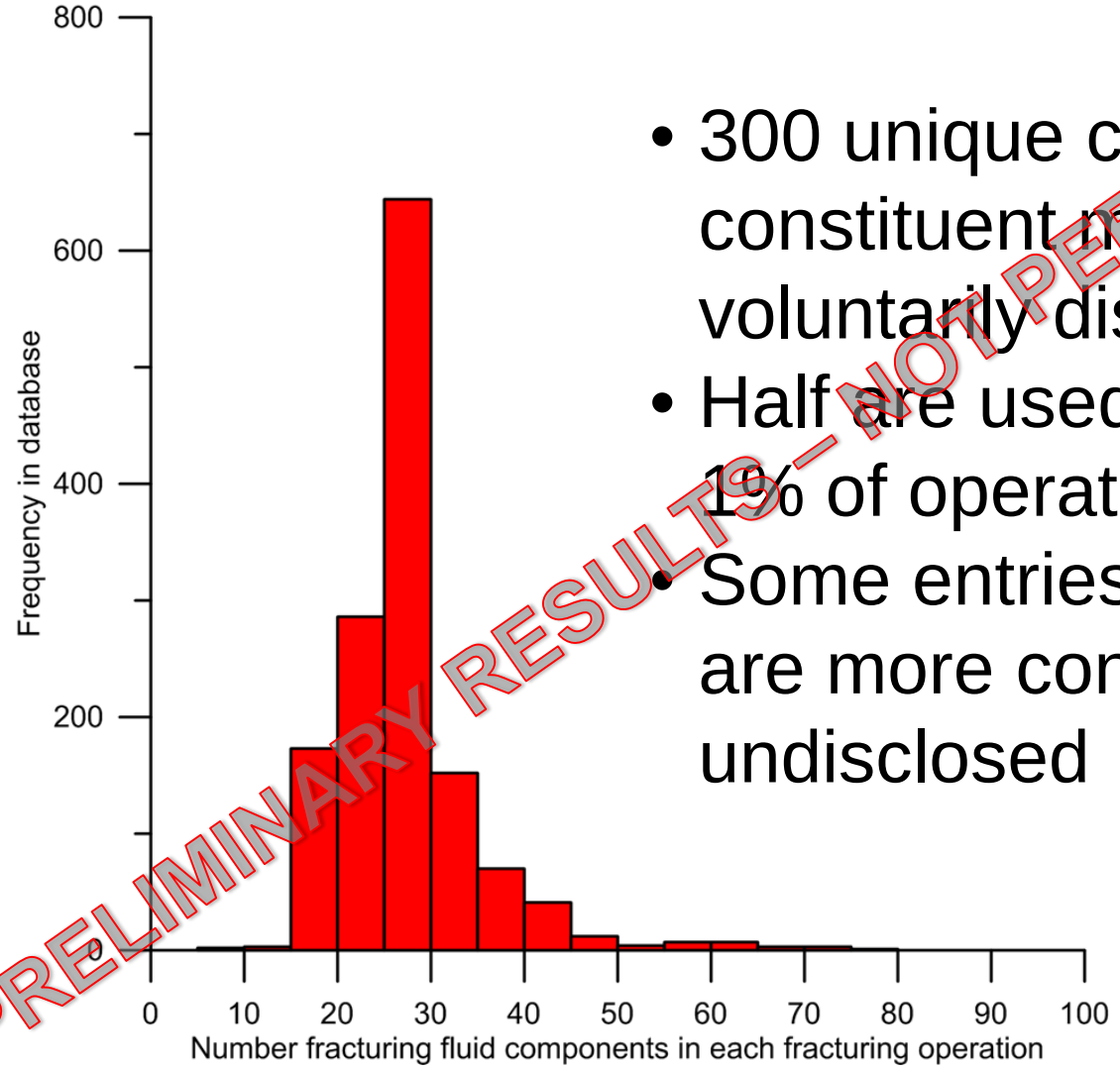
Planning Area	Estimated annual hydraulic fracturing		Annual supply for enabled EOR (m^3)	Estimated annual water use		Water use in Planning Area
	Operations	Water demand		(m^3)	(acre-feet)	
Semitropic (Kern)	1,600	850,000	1,800,000	2,700,000	2,200	0.17%
Kern Delta (Kern)	4	2,100		2,100	1.7	0.00011%
Kern Valley Floor (Kern, Tulare)	34	18,000		18,000	15	0.0017%
Uplands (Fresno, Tulare, Kern)	18	9,500		9,500	7.7	0.015%
Western Uplands (San Benito, Fresno, Kings, Kern)	6	2,900		2,900	2.4	0.1%
San Luis West Side (Fresno, Kings)	1	270		270	0.22	0.000017%

How Many Stimulation Constituents?



- The median number of constituents used in each hydraulic fracturing operation is less than 30
- Number of constituents each in North and South Belridge, Elk Hills, and Lost Hills fields ranged from 70 to 196

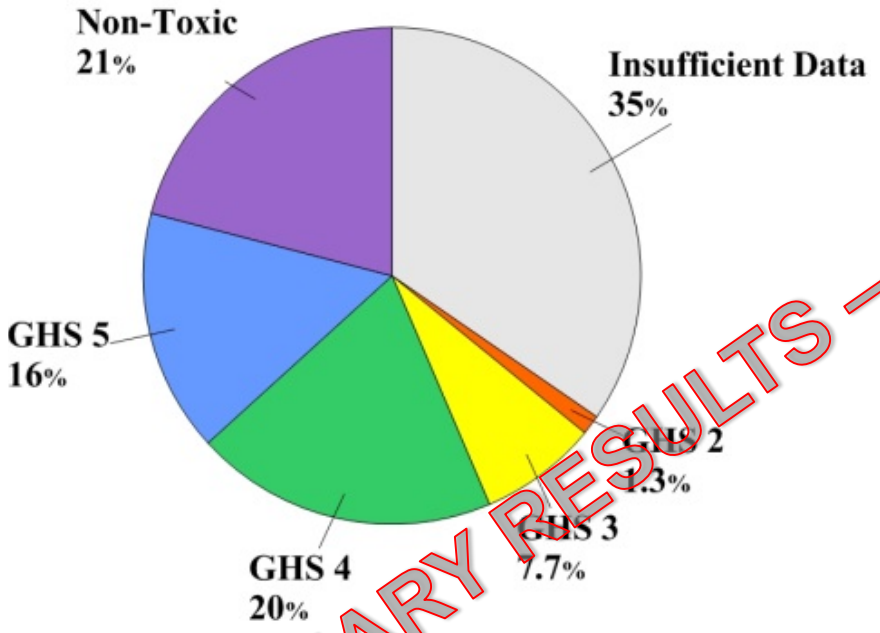
How Many Stimulation Constituents?



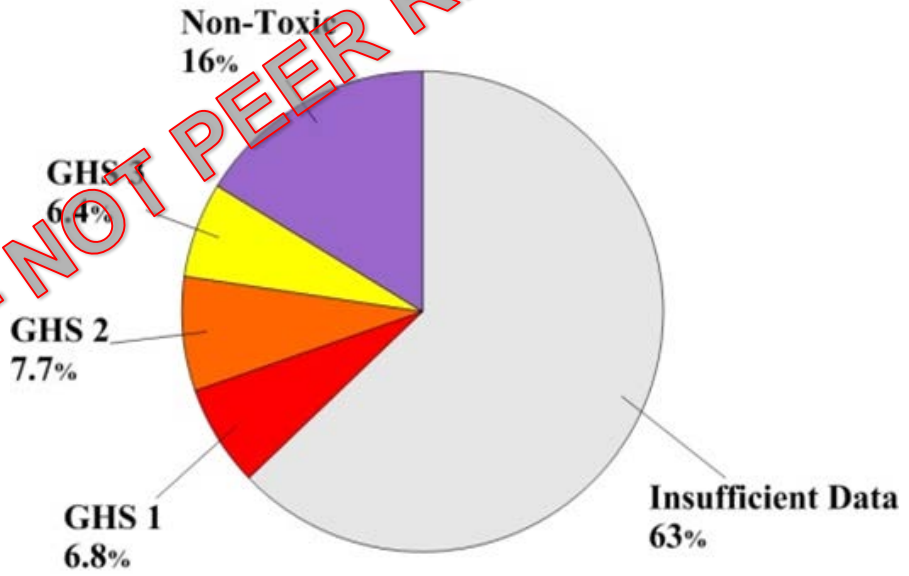
- 300 unique constituents and constituent mixtures voluntarily disclosed
- Half are used in less than 1% of operations
- Some entries indicate there are more constituents undisclosed

How Acutely Toxic Are Constituents?

Acute Oral Toxicity
(*g. Rattus*)



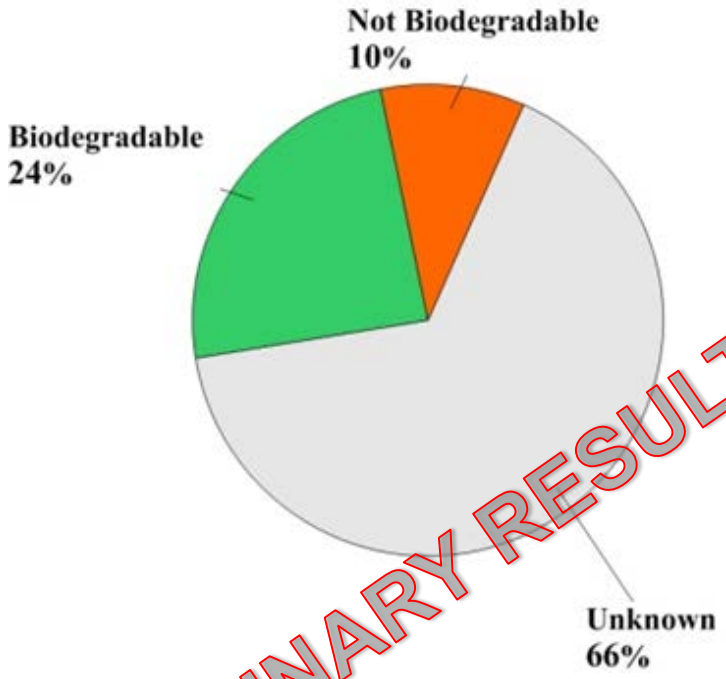
Acute Aquatic Toxicity
(*Daphnia Magna*)



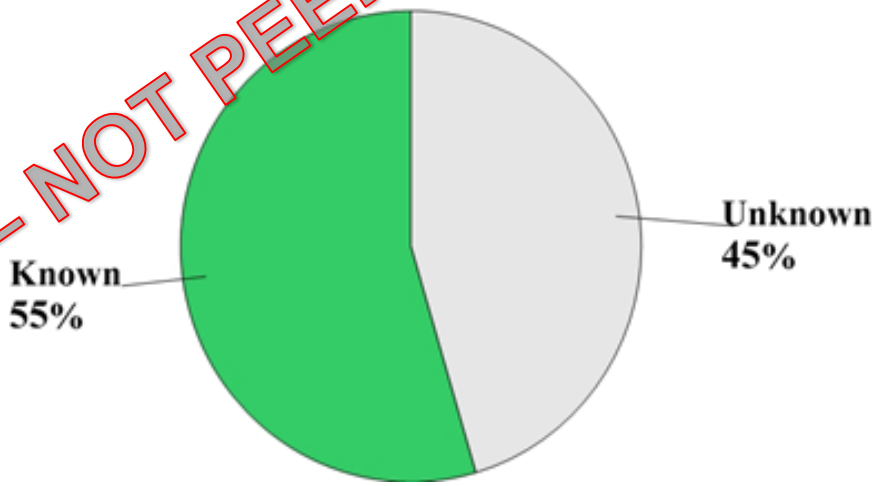
The lower the Globally Harmonized System category number (GHS), the more acutely toxic the constituent. No constituents were identified that had an acute oral toxicity of 1, which is the most toxic, and few GHS 2. Some constituents had an acute aquatic toxicity of 1. Acute toxicity was not available for many constituents.

Other Relevant Properties?

Biodegradability of Organic Chemicals



Availability of Log K_{ow}

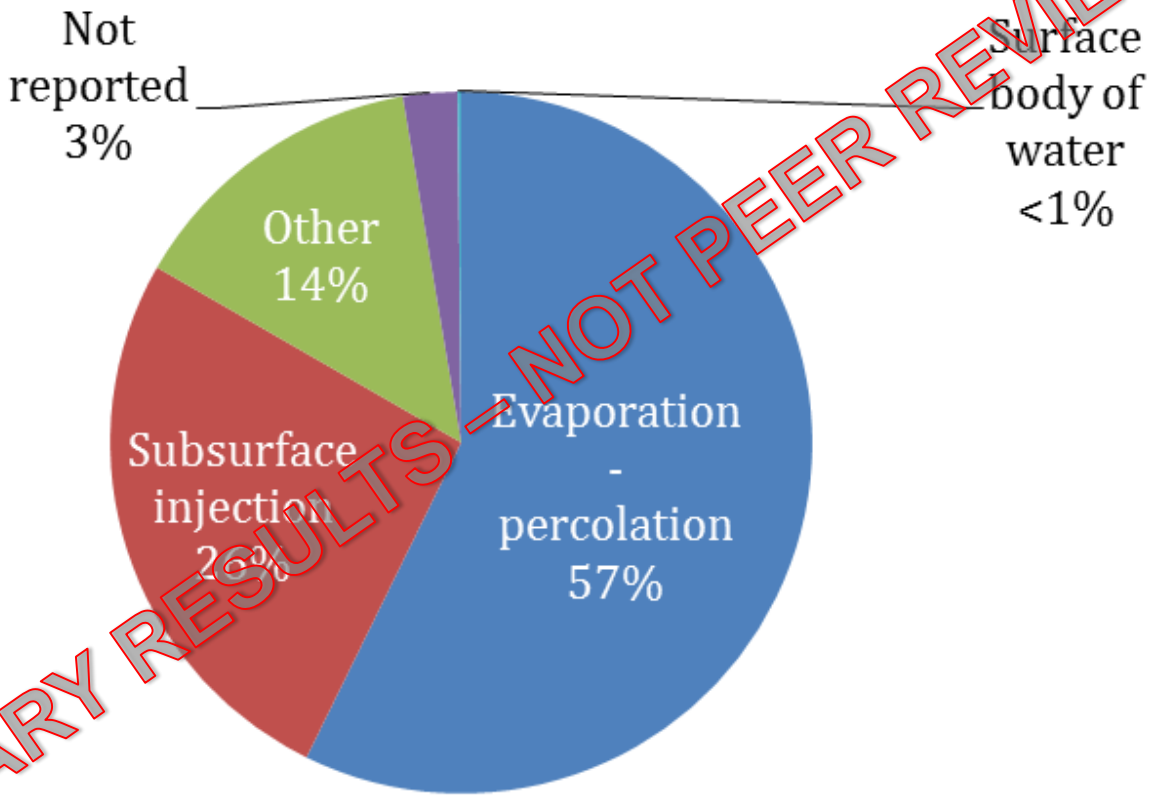


Biodegradability is relevant to a constituents persistence in the environment.
Log K_{ow} is relevant to the bioaccumulation potential of a constituent.

Wastewater Characteristics

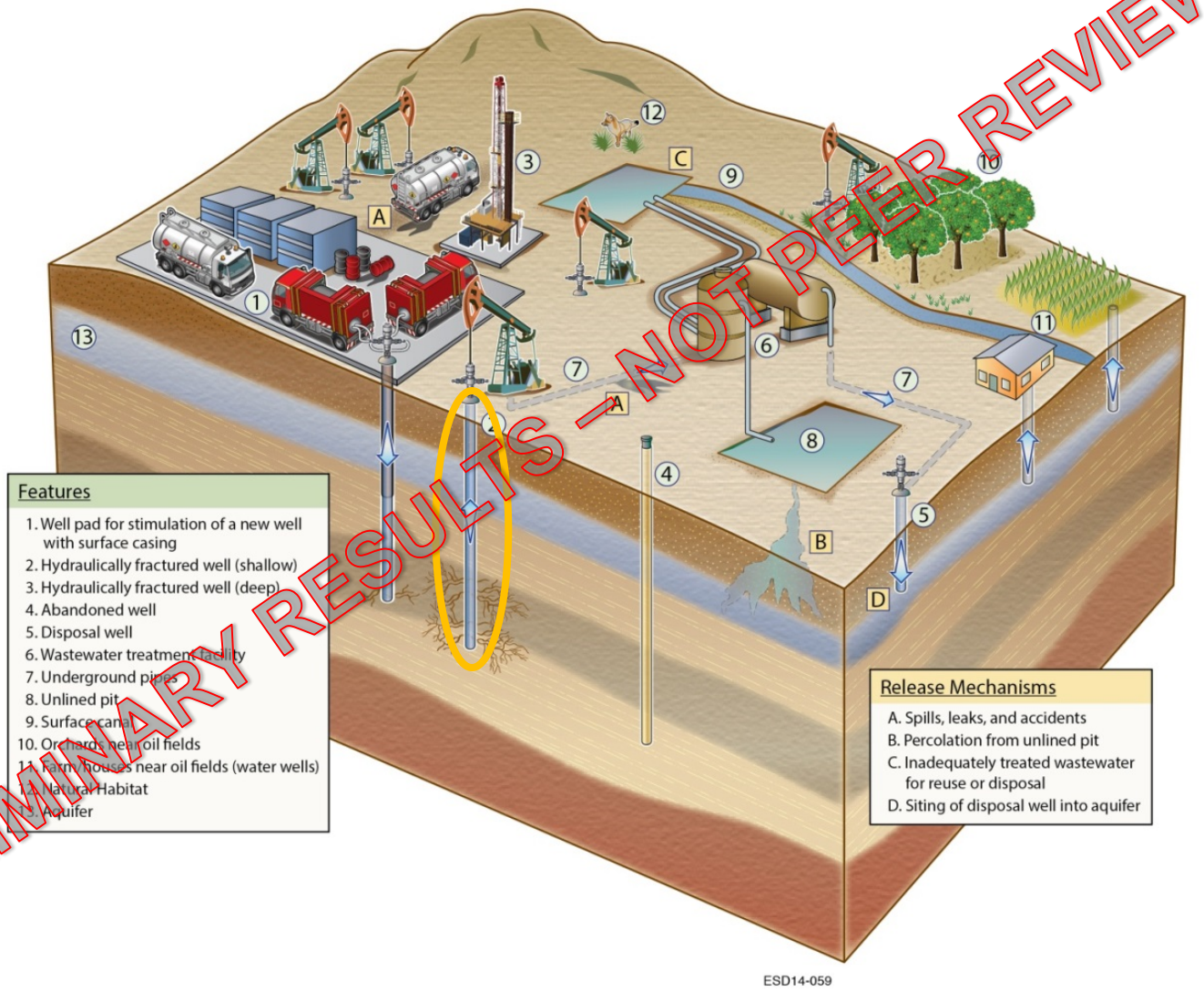
- "Recovered fluid" (water captured prior to production, also defined as "flowback") characteristics in stimulation completion reports
  - Fluids can represent a mixture of formation water, returned stimulation fluids and well cleanout fluids
  - Volumes are small relative to stimulation fluid volume
  - Chemical analysis of some samples show high levels of total carbohydrates (guar gum), TDS, trace elements, NORMs and organics.
- Most stimulation fluid returns are commingled and co-managed with other "produced water"

How Is Produced Water from Hydraulically Fractured Wells Disposed?

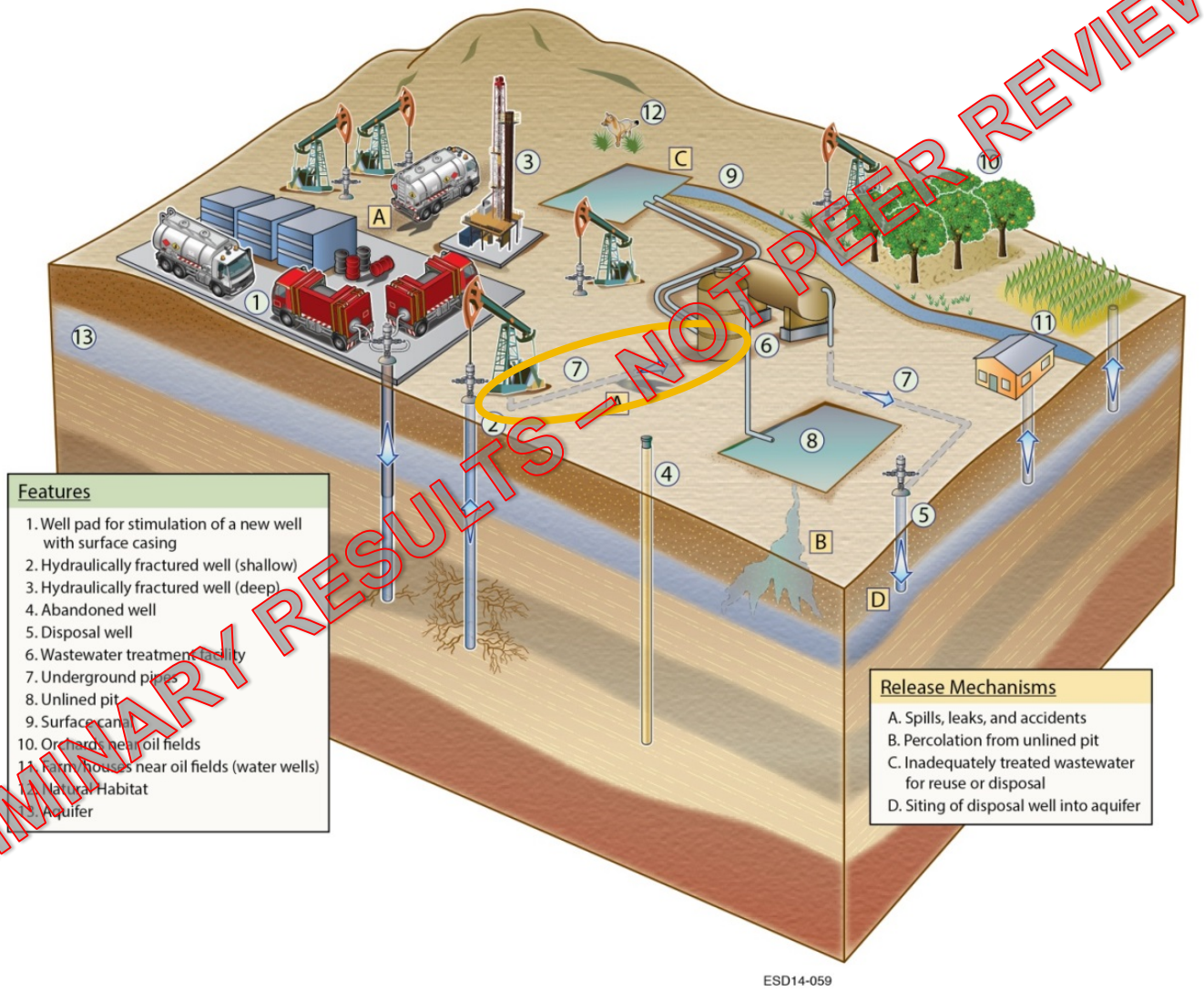


First month after hydraulic fracturing from 2011 to late 2014, however some operators have indicated they submitted data indicating disposal in ponds that is actually by injection

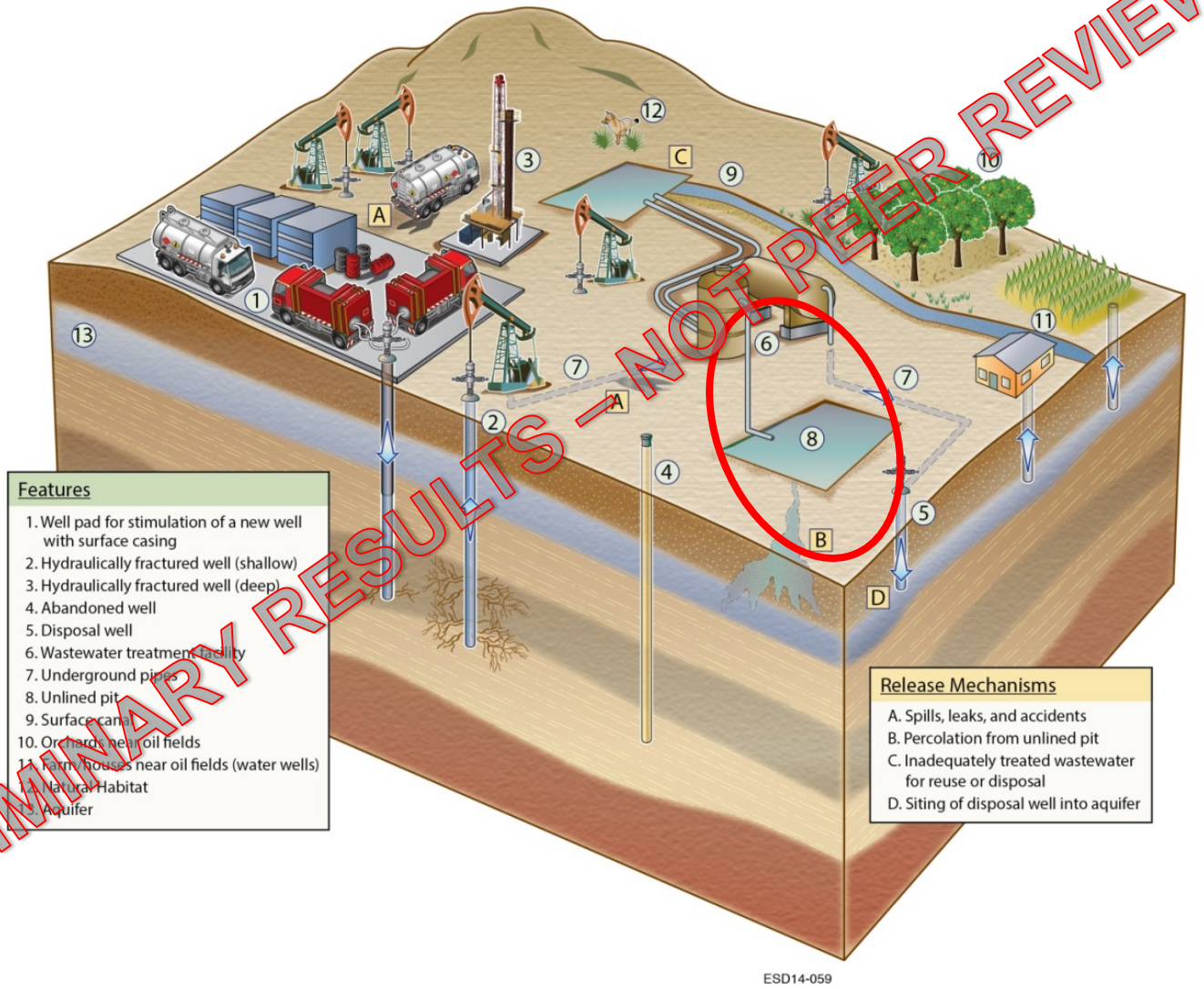
Produced Water Release Mechanisms



Produced Water Release Mechanisms

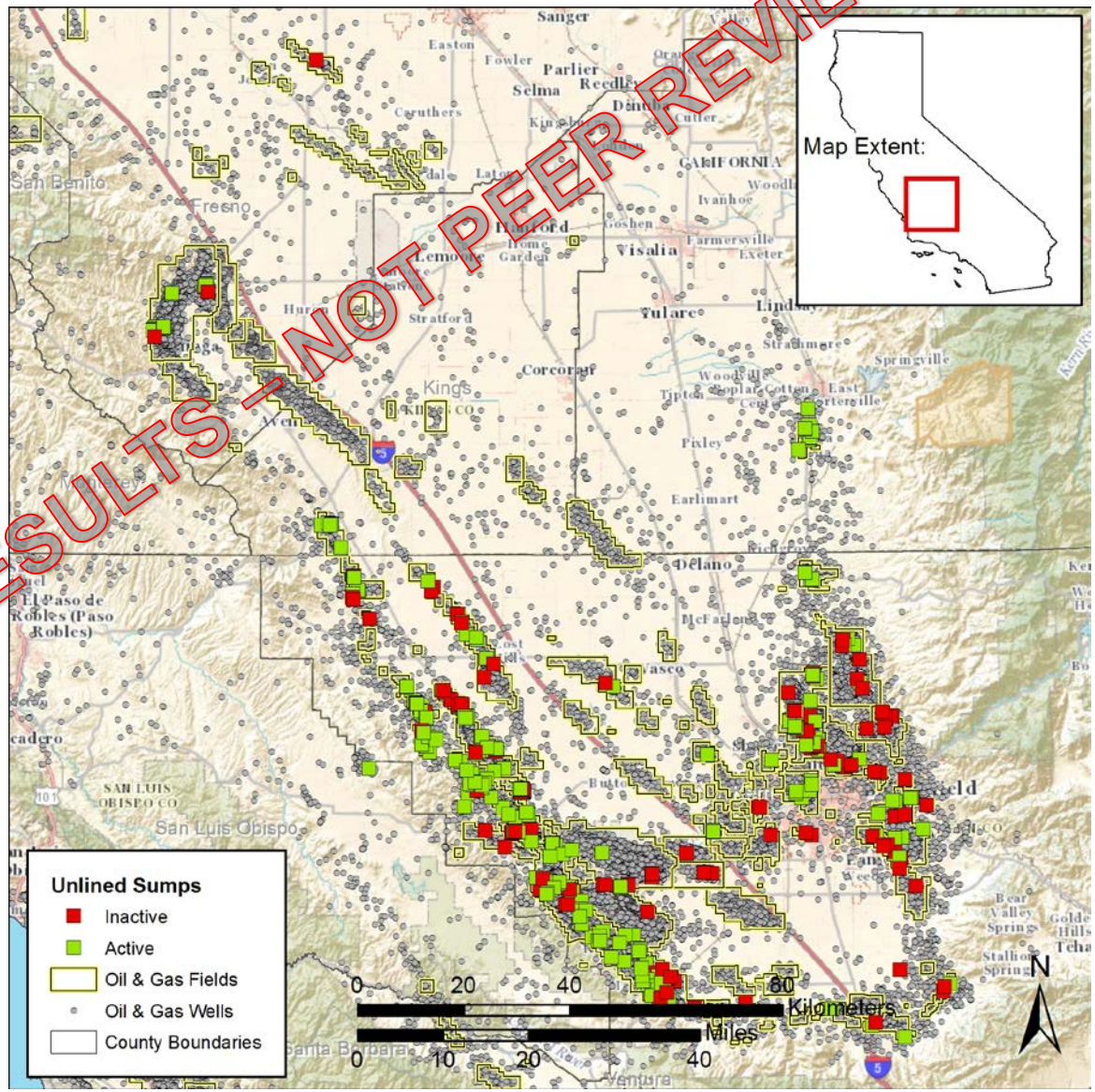


Produced Water Release Mechanisms



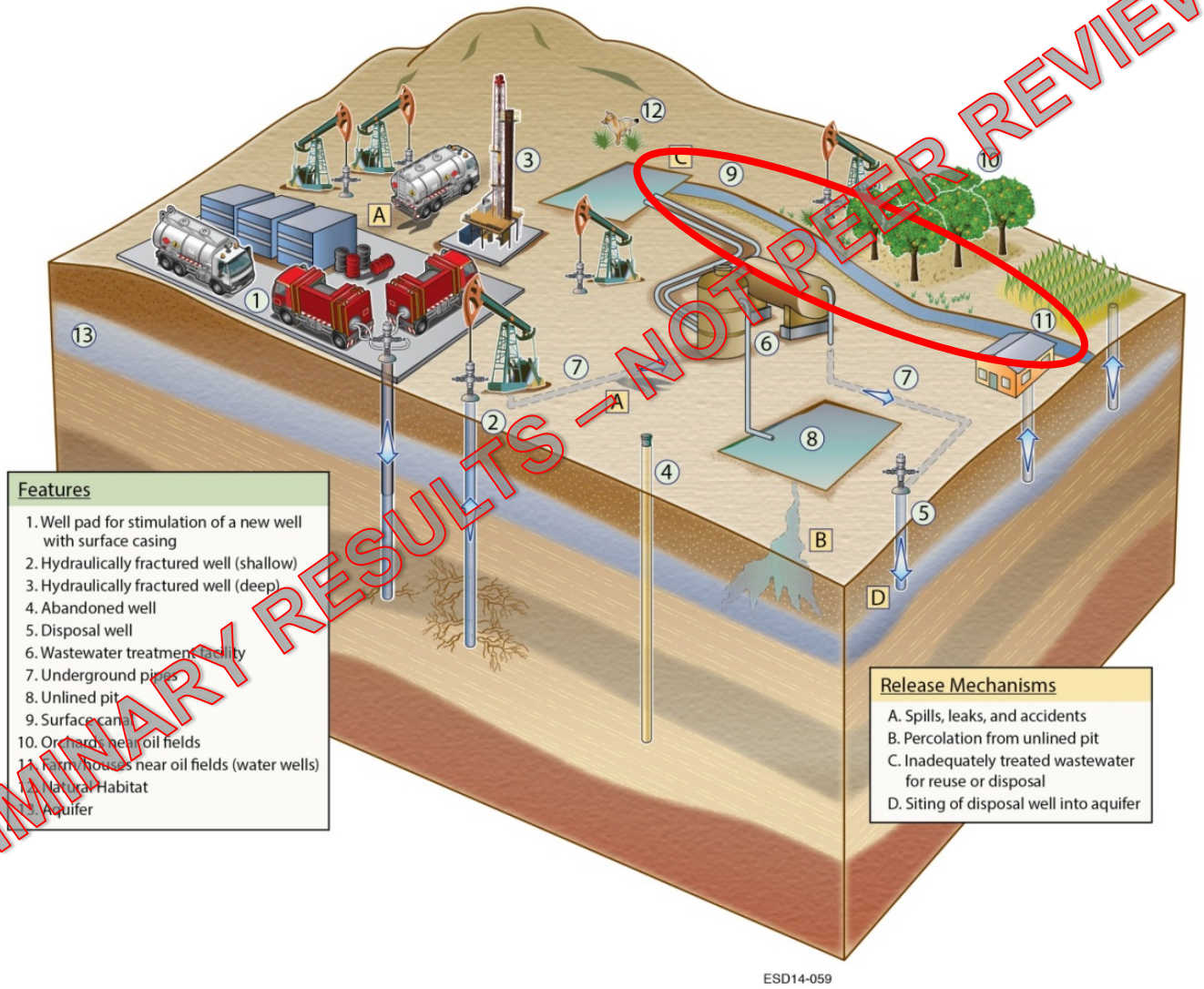
Unlined sumps in San Joaquin Valley

- 933 sumps as of April 2015
  - 62% active
  - 38% inactive
- 36% of active sumps are not permitted
- Spot checking indicates some sumps are not included



Data from Central Valley Regional Water Quality Board

Produced Water Release Mechanisms

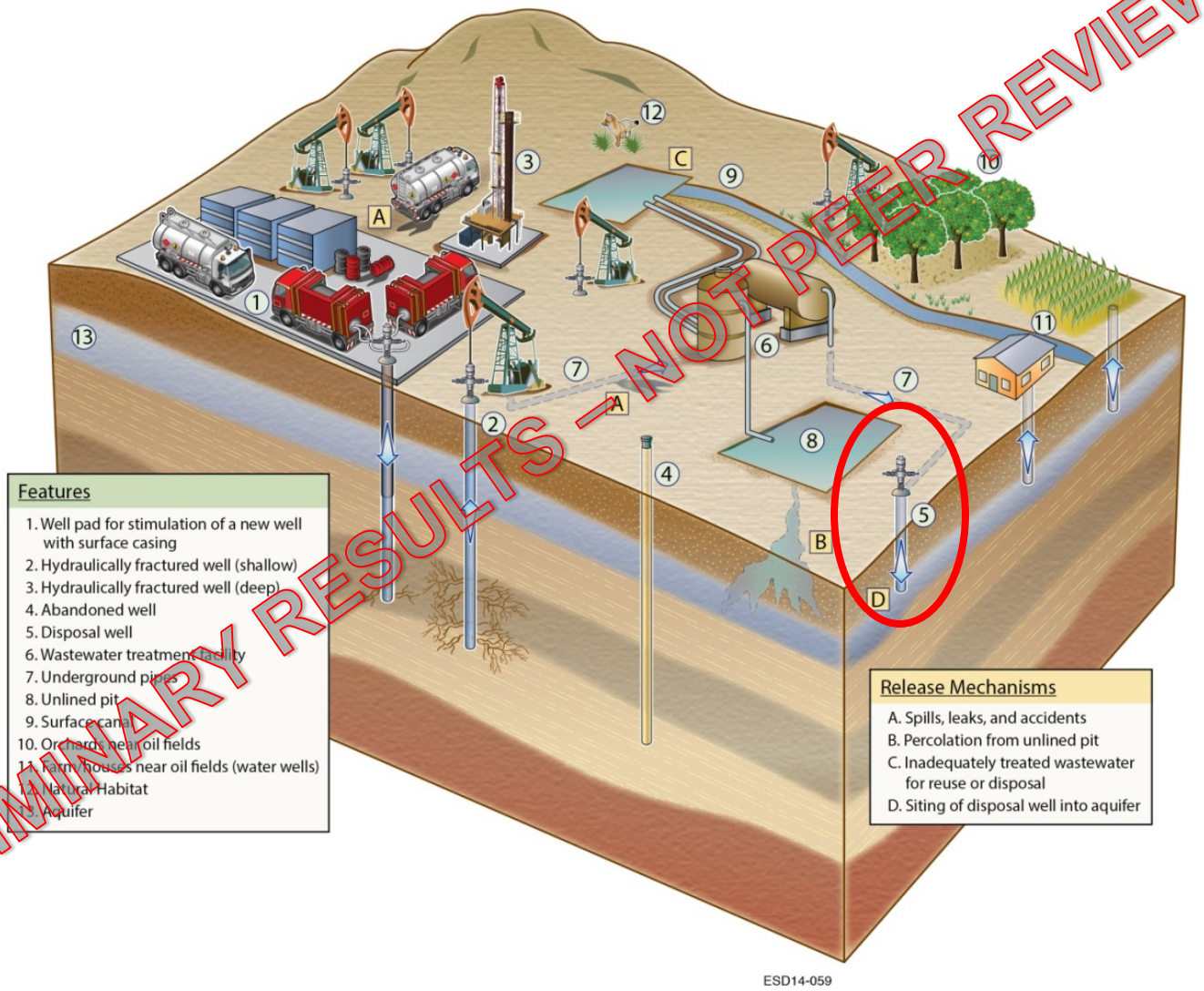


Produced Water Release Mechanisms

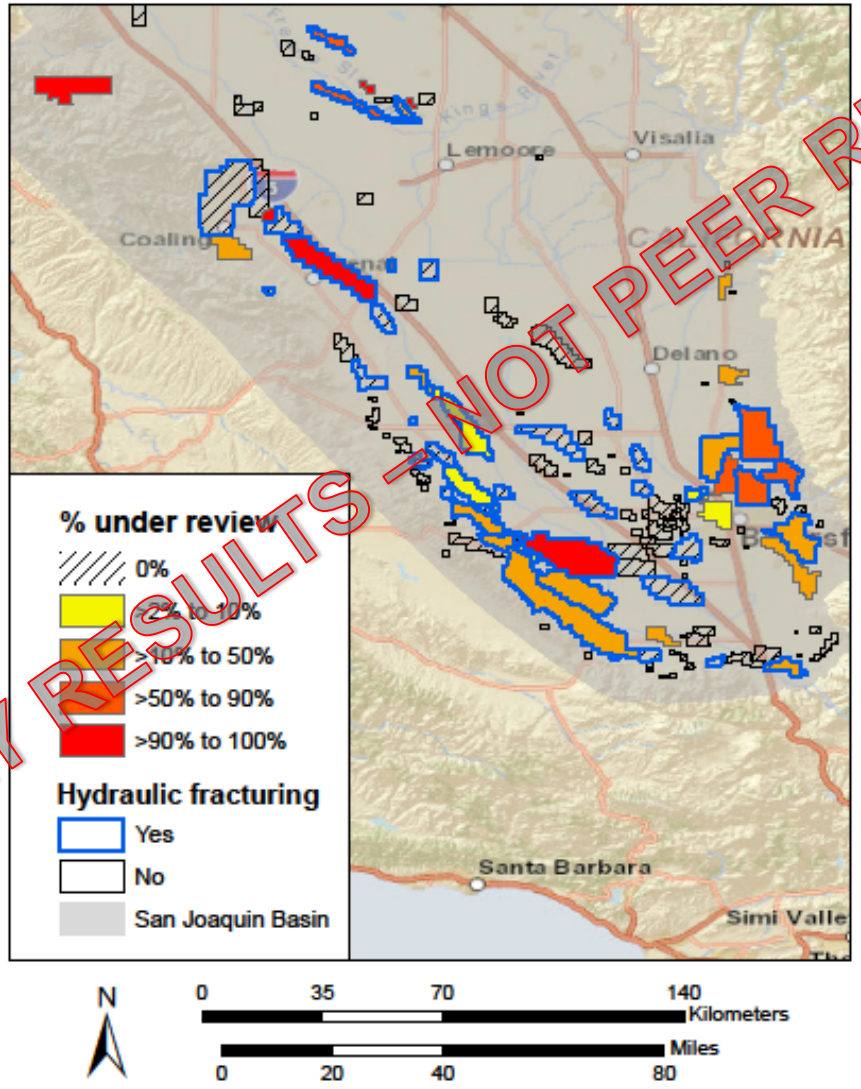
http://blogs.kqed.org/science/audio/california-farmers-look-to-oil-industry-for-water/

Produced water used for irrigation in the Cawelo Water District

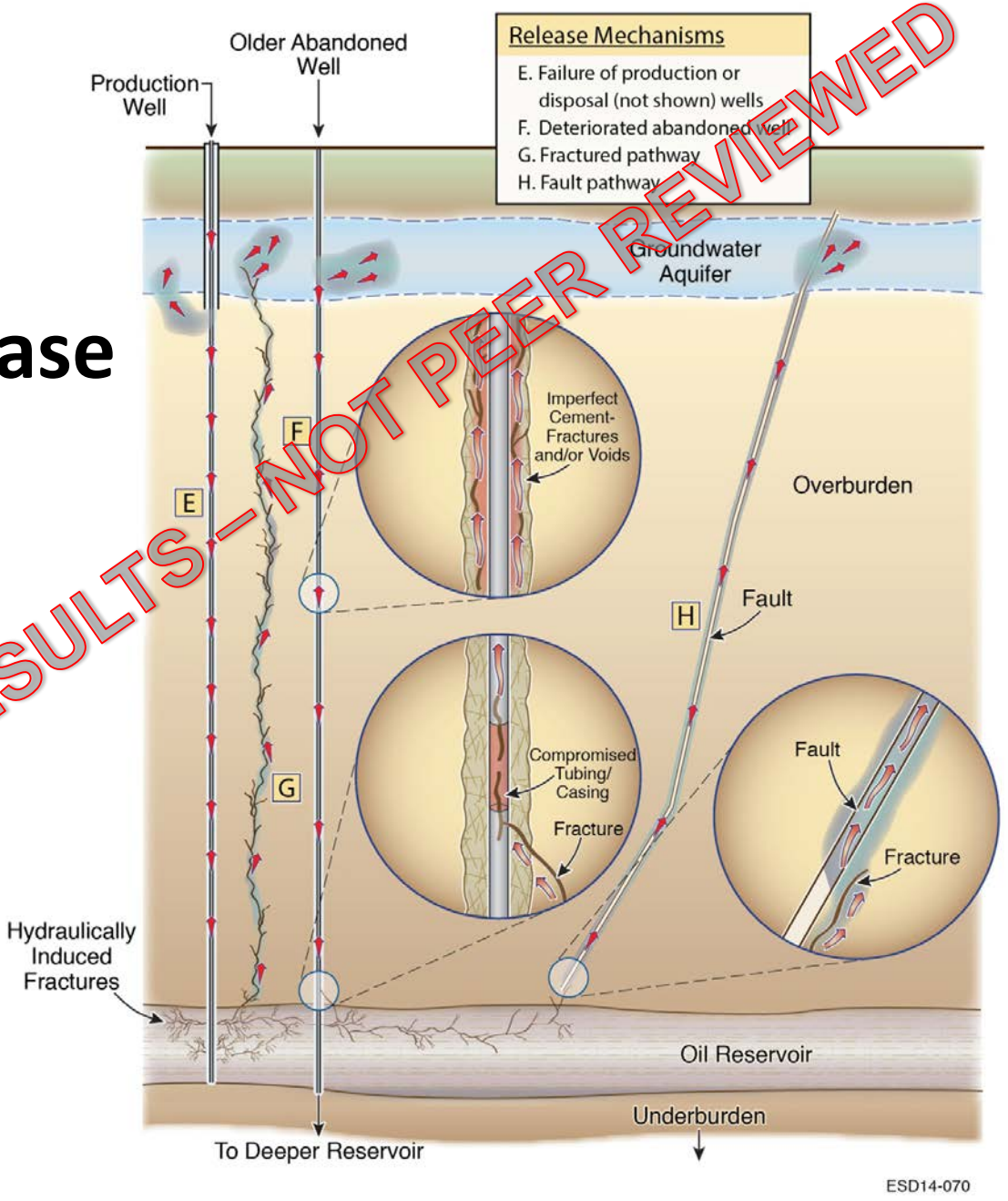
Produced Water Release Mechanisms



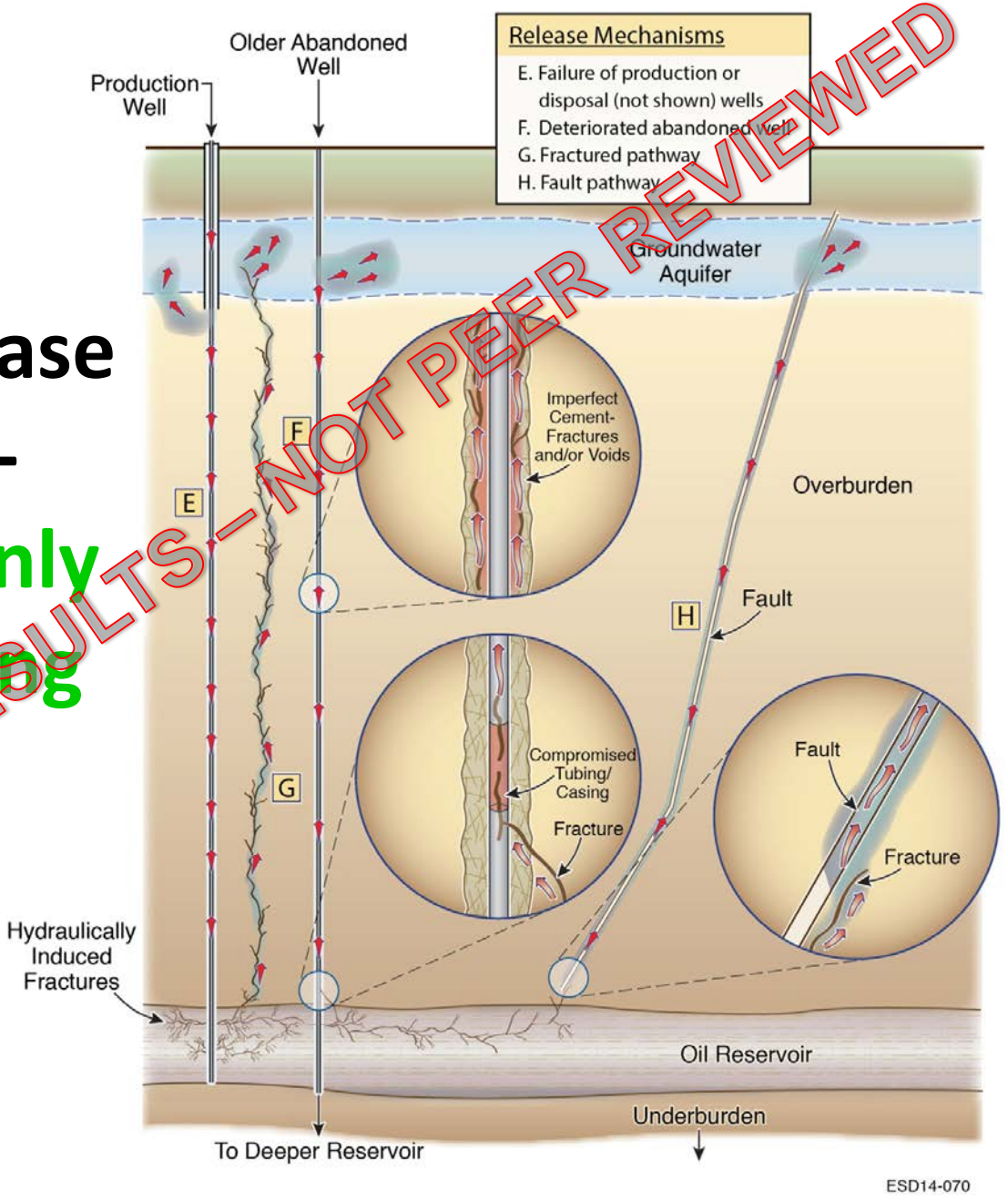
Water Disposal Well Review by DOGGR



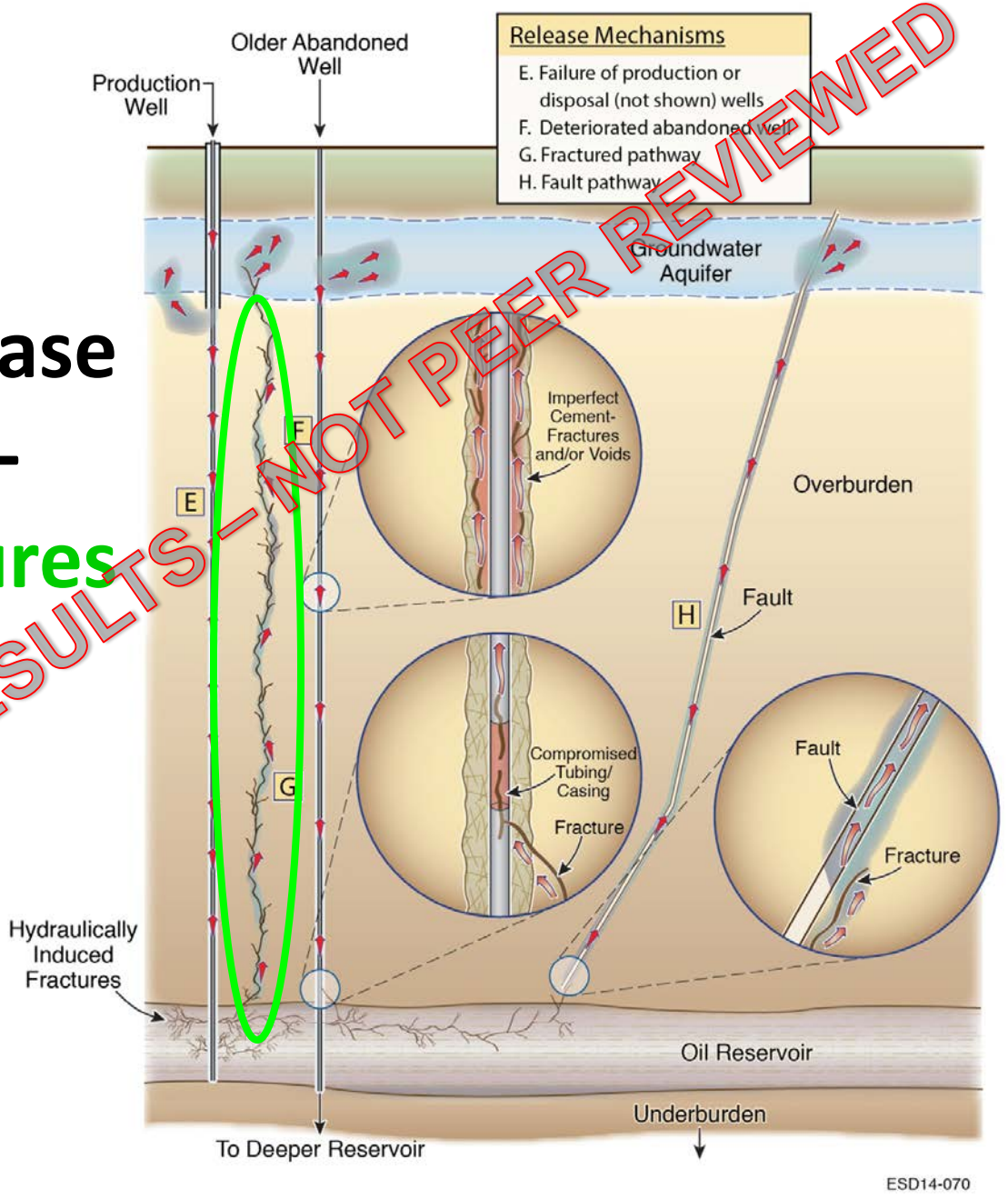
Potential Subsurface Release Mechanisms



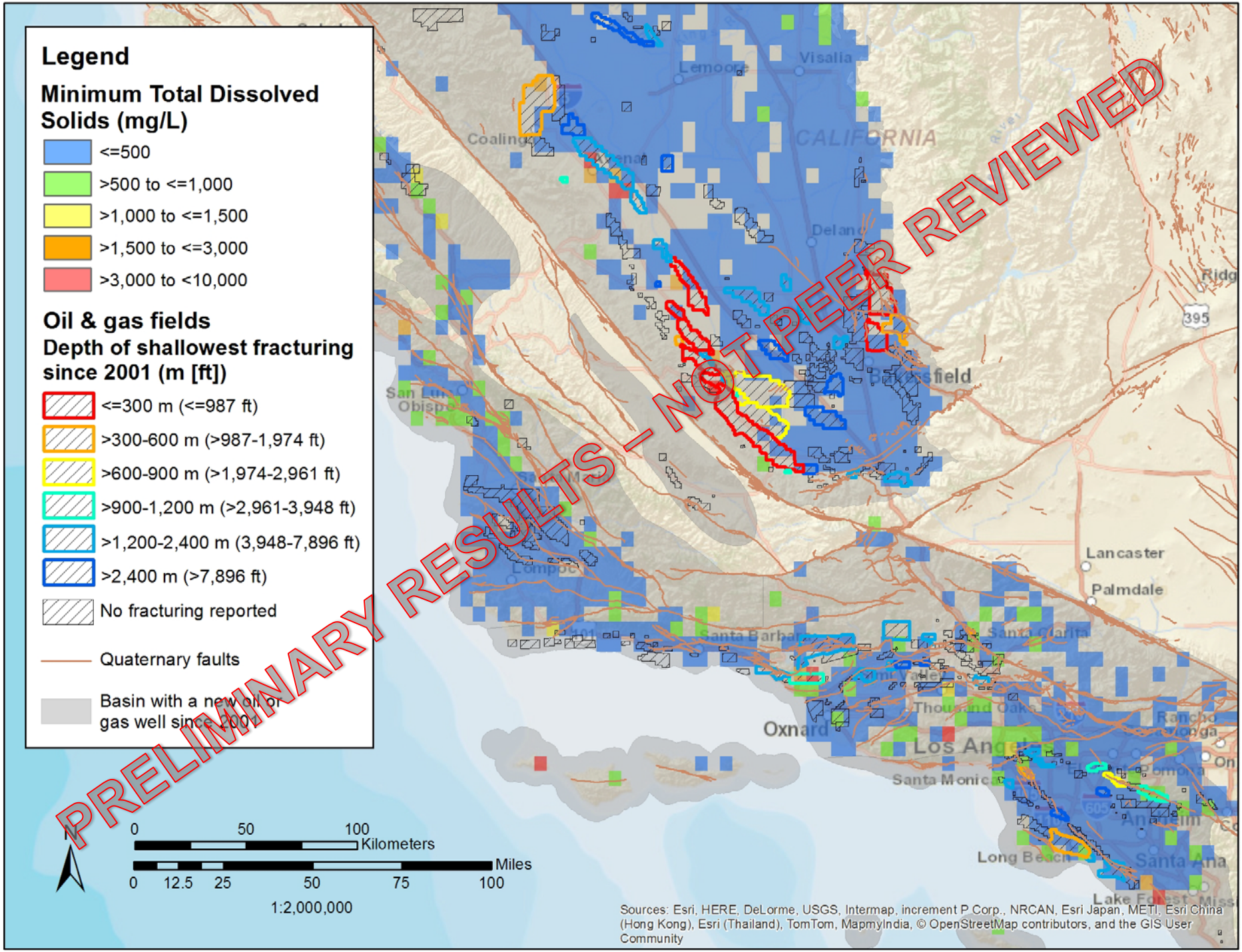
Potential Subsurface Release Mechanisms - Driving Force Only During Fracturing



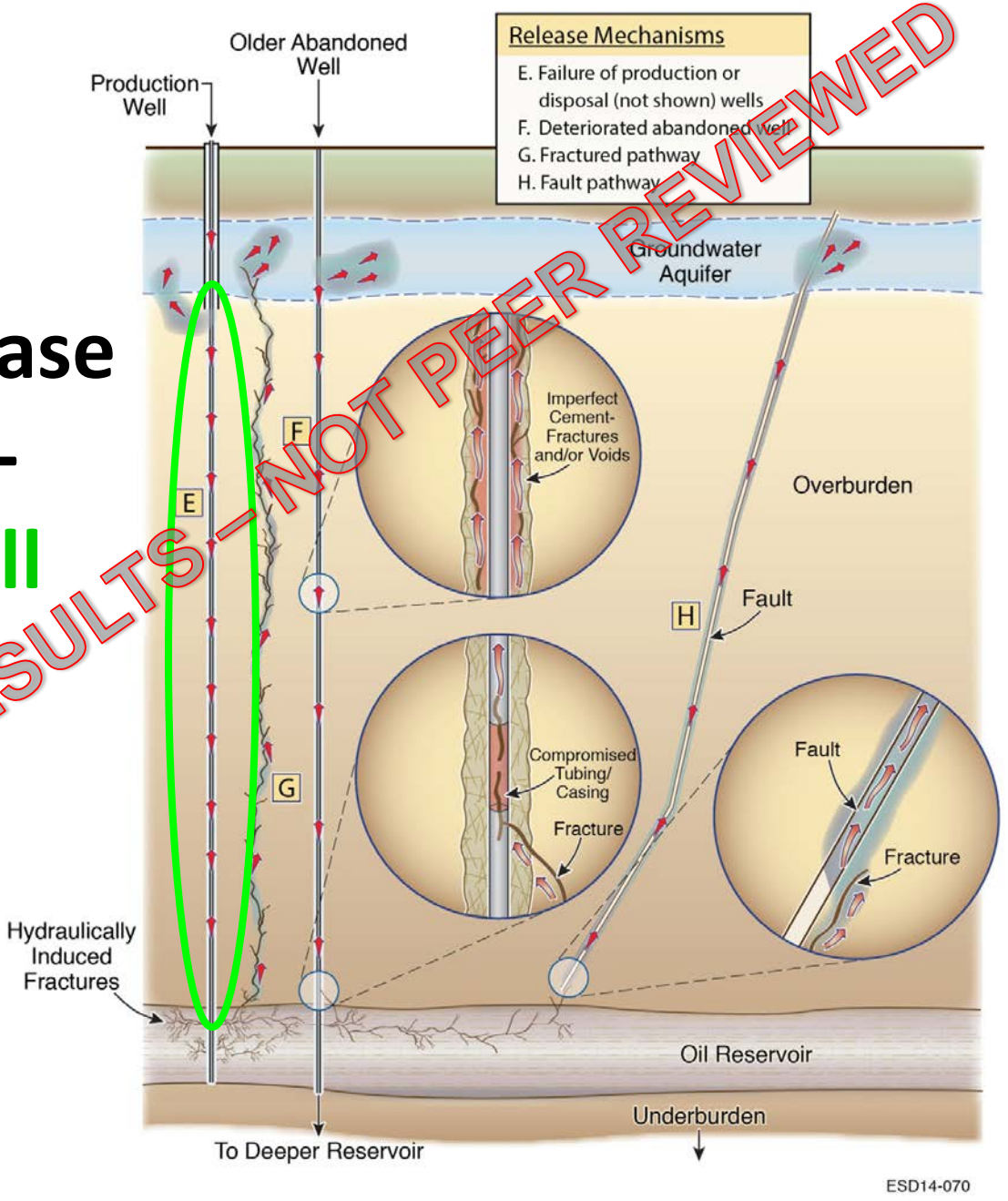
Potential Subsurface Release Mechanisms - Hydraulic Fractures



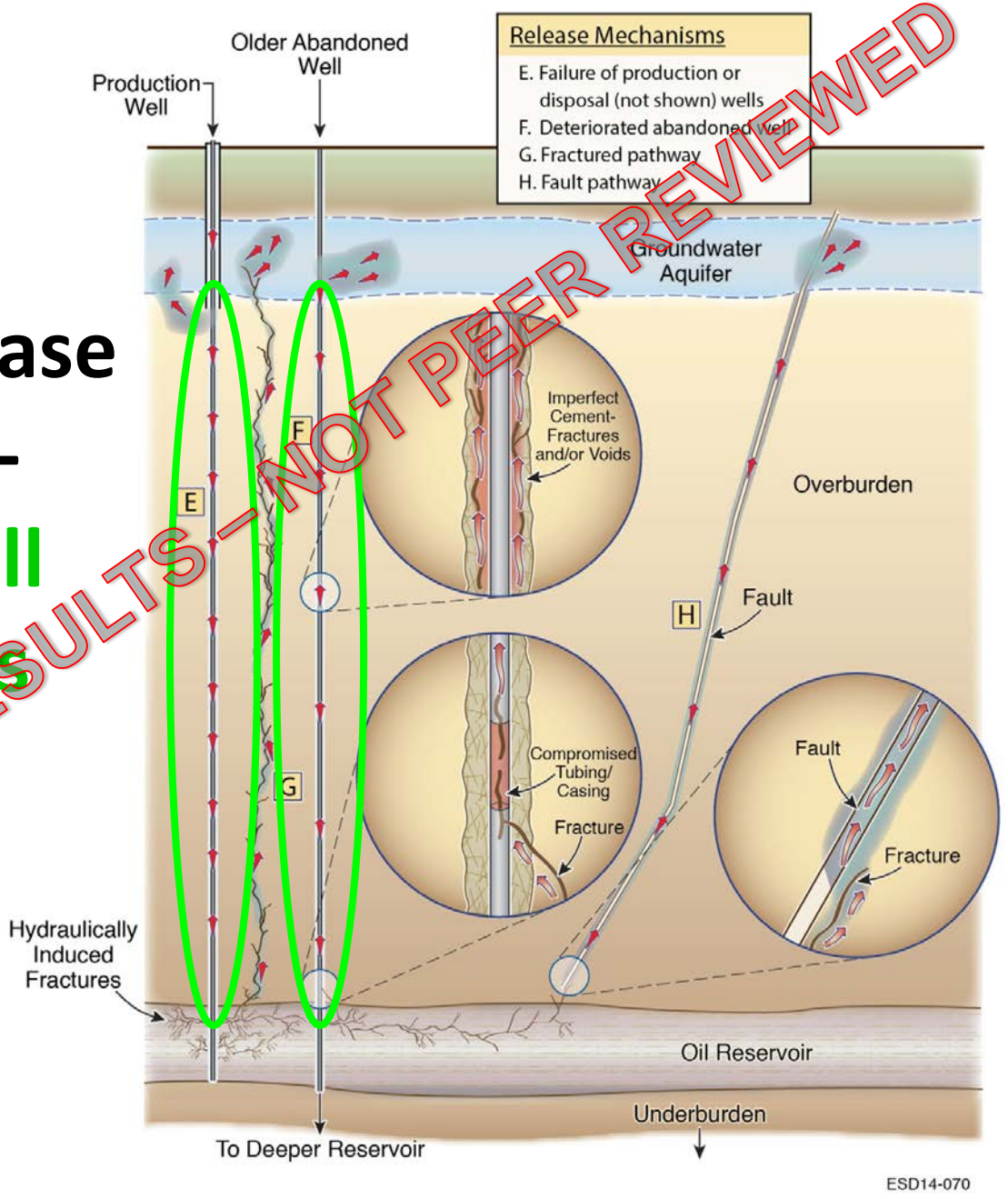
Depth to Top of Fractured Interval


Legend
Minimum Total Dissolved Solids (mg/L)
<=500
>500 to <=1,000
>1,000 to <=1,500
>1,500 to <=3,000
>3,000 to <10,000
Oil & gas fields
Depth of shallowest fracturing since 2001 (m [ft])
<=300 m (<=987 ft)
>300-600 m (>987-1,974 ft)
>600-900 m (>1,974-2,961 ft)
>900-1,200 m (>2,961-3,948 ft)
>1,200-2,400 m (3,948-7,896 ft)
>2,400 m (>7,896 ft)
No fracturing reported
Quaternary faults
Basin with a new oil or gas well since 2001
PRELIMINARY RESULTS – NOT PEER REVIEWED
Visalia
Lemoore
Coalinga
CALIFORNIA
Delano
Bakersfield
Lancaster
Palmdale
Santa Barbara
Oxnard
Los Angeles
Santa Monica
Long Beach
Santa Ana
0 50 100 Kilometers
0 12.5 25 50 75 100 Miles
1:2,000,000
Sources: Esri, HERE, DeLorme, USGS, Intermap, increment P Corp., NRCAN, Esri Japan, METI, Esri China (Hong Kong), Esri (Thailand), TomTom, MapmyIndia, © OpenStreetMap contributors, and the GIS User Community

Potential Subsurface Release Mechanisms - Fracturing Well



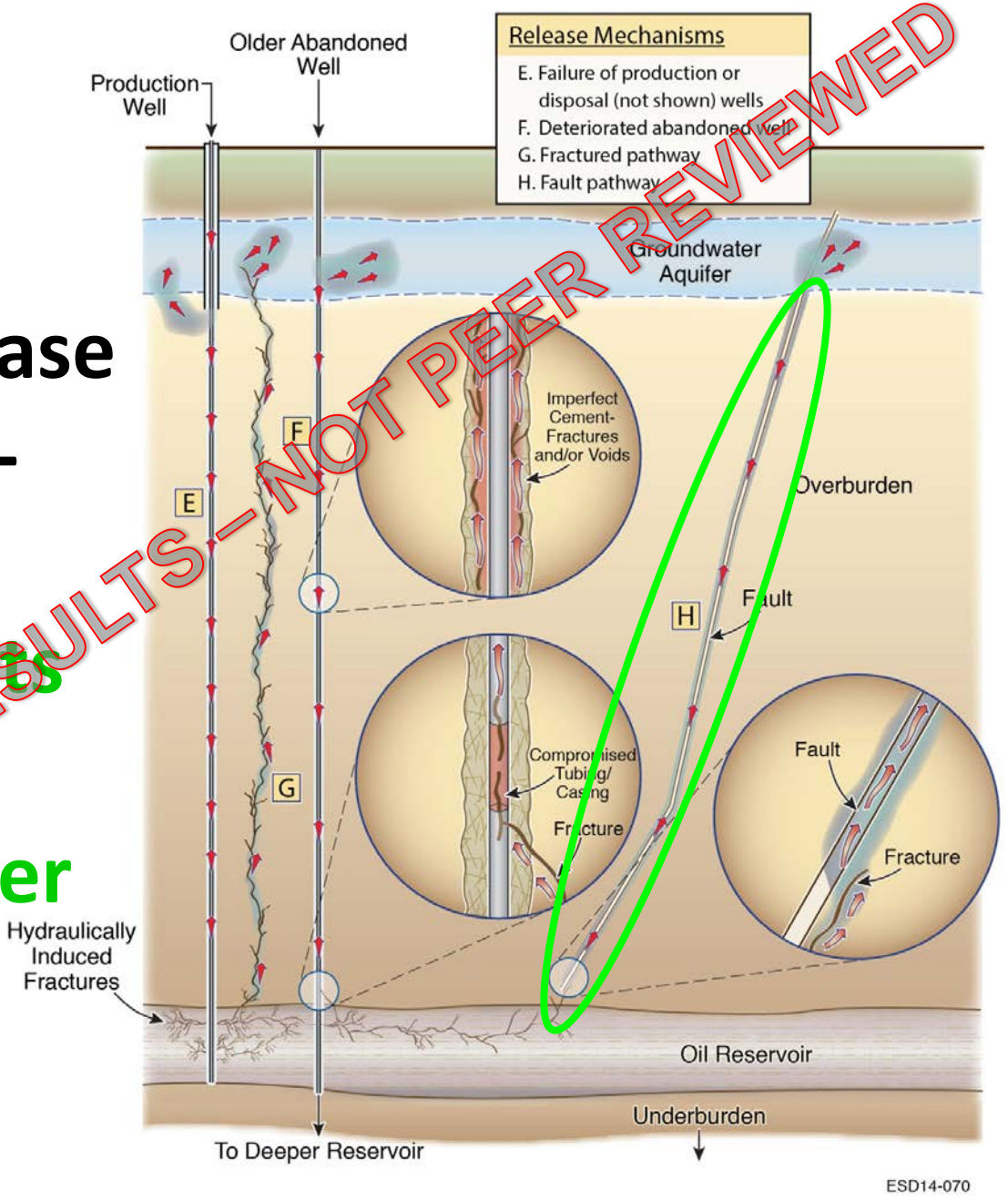
Potential Subsurface Release Mechanisms - Fracturing Well & Offset Wells



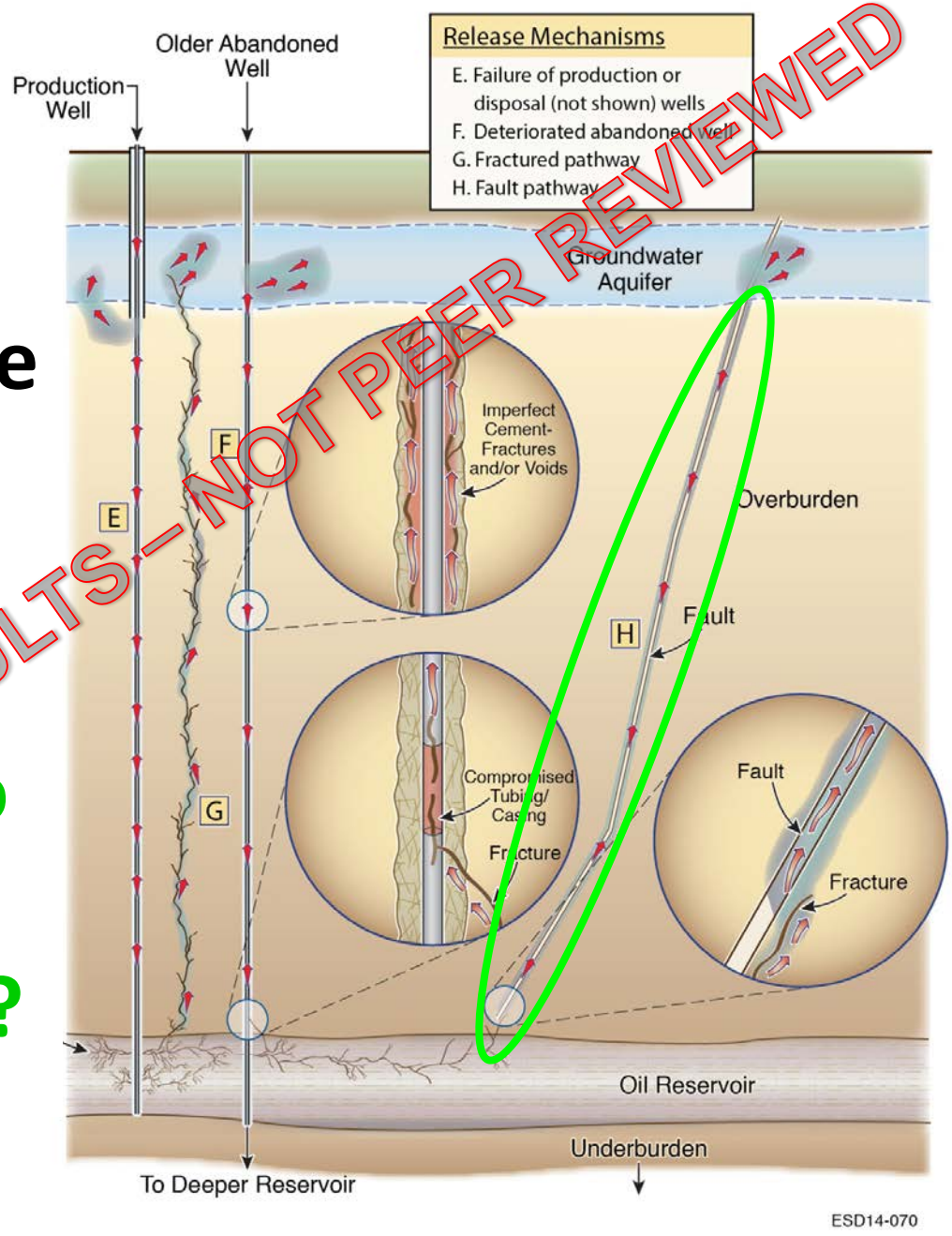
Potential Leakage Via Wells

- Well records indicate about an hour to fracture one stage at an average flow rate of about 1,000 gallons/minute
- On the order of 1 out of 20 wells would likely have a detectable gas leak if gas were present (Watson and Bachu, 2009), but the volume of stimulation fluid that might be released would be practically undetectable
- On the order of 1 out of 20,000 steam injection wells blows out upon commencement of injection

Potential Subsurface Release Mechanisms - Fault density suggests tens of intersections per year



Potential Subsurface Release Mechanisms - Fault sealing in natural state, but how do they respond to being intersected?



Conclusions and Needs

- Little water use
- Tens of constituents per operation, a couple hundred in regular use statewide
- Basic, environmentally relevant parameters needed for many constituents
- Produced water is the main concern currently, both what it contains and how it is disposed
- Research is needed regarding propagation of shallow fractures and fault response to fracture intersection (dedicated field site?)

Acknowledgments

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- Lawrence Livermore National Laboratory and you for involving us in developing groundwater monitoring guideline recommendations regarding well stimulation