Oil, Gas, and Groundwater Quality in California—a discussion of issues relevant to monitoring the effects of well stimulation at regional scales

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Mission is to collect, analyze and disseminate the impartial hydrologic data and information needed to wisely manage water resources for the people of the United States and the State of California

http://ca.water.usgs.gov/index.html
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Framing the Problem

Where is the water and what does it already have in it?

Where is well stimulation occurring?

What mechanisms link well stimulation to the water?

How can we monitor those mechanisms?
Where is fresh water?

- No systematic delineation of aquifer zones containing less than 3,000 mg/l total dissolved solids
- Virtually no information on zones where salinities are between 3,000 and 10,000 mg/l total dissolved solids
- Current and future beneficial uses may not fit either category
Comparison of locations of beneficial use water wells (based on DWR logs) and oil, gas, and UIC wells, and hydraulically fractured wells

Oil, Gas, and UIC Wells

- Active, idle, and new
- Hydraulically fractured

DOGGR All_Wells_11-19-14

Beneficial-Use Wells

- number of domestic wells per 1 sq.mi. section
- 0
- < 3
- 3 - 10
- 10 - 100
- > 100 (Johnson and Belitz, 2015, J.Hydrol.Region.Stud.)
Kern County: Oil, gas, and UIC wells, and hydraulically fractured wells are located in areas with beneficial use water wells.
Well Stimulation and Overall Risk to Groundwater Quality
Well stimulation is taking place in the context of a long history of oil and gas development.
Volume of fluid used in well stimulation a very small fraction of fluid flows in oil and gas fields

Well stimulation < 1 TAF/yr
Well Stimulation Risks to Groundwater Quality Small in Comparison to Other Risks Associated with Oil and Gas Development
Pathway of Concern #1: Zonal Isolation ??

Zones where fluids—for enhanced recovery, well stimulation, and/or waste produced water—are injected into formations that are not isolated from useable groundwaters.
Waste Disposal Well Injection Volumes

The yellow circles indicate locations and volumes of the study area Waste Injection Wells. These include 47 Active, Idle, and Plugged Wells.

Map by: Ed Tedesco 2/25/2015

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Pathway of Concern #2: Surface Activities
Pathway of Concern #3: Well Integrity
Wells in Kern River Oil Field with resistivity logs (Beeson and others, 2014)

Of the 168 currently active oil fields greater than 2 mi$^2$ in size, 31 contain more than 100 known wellbores per square mile
Suggested Regional Monitoring Program Components

- **Zonal Isolation**: characterizing the location and extent of risk that any fluid related to oil and gas development is transported outside of isolated zones and towards protected resources and setting up monitoring networks to provide early warning of transport (not distinguishing between WST, EOR or UIC mechanisms).

- **Surface Activity Effects**: describing how oil and gas activities on the surface have affected shallow groundwater quality in focused areas such as southern Kern County (not duplicating RB site characterization work); and

- **Well Integrity**: evaluating the potential risk of well integrity failures and inadequate seals to groundwater quality statewide as the infrastructure ages (need the other two done first).
Exploratory Work

- Reconnaissance-level vulnerability assessment
- Detailed characterization of two oil fields
- Exploratory chemical sampling and analysis
Proximity of oil and gas zones to groundwater as reconnaissance-level categorization of vulnerability
Proximity Example: Kern River and Rose Oil Fields
Proximity Example: Kern River and Rose Oil Fields
Statewide Proximity Mapping
Mapping of Salinity

- Identify 3D extent of groundwater salinity classes, (TDS: > 10,000, 3,000-10,000, < 3,000 mg/L)
- Identify data gaps
- Proposals for filling gaps

Wilmington (LA)  
Santa Maria Valley
Salinity from E-logs to Fill Data Gaps

- Pilot analysis of borehole geophysical log data to estimate gw salinity in selected areas of the LA basin with extensive supporting data (water chemistry, geology, geophysical data) for calibrating estimates.
Detailed Field Characterization Pilot

- Purpose was to work through process of using existing data and develop water quality sampling strategies
- Two fields (Santa Fe Springs, Montebello) located in the Los Angeles basin: many oil fields, large gw pumping, and extensive data
- Characterization includes proximity to useable groundwater, number and age of boreholes, geologic structures, well stimulation techniques used, and injection history
Visualizing the system

- Existing 3d geologic model
- Will be added:
  - Wells (oil, injection, water)
  - Fresh & saline groundwater distribution from:
    - Water chemistry
    - Geophysical logs
  - Exempted aquifers

Ponti et al. (2014)
Result--where to monitor
Analytical Constituents

- Hydrocarbon gas concentrations and isotopes
- Noble and atmospheric gases
- Volatile and semi-volatile organic constituents
- Inorganics (tracers of salts)
- Nutrients
- Naturally occurring radioactive material
- Water and solute isotopes
- Groundwater age dating tracers
Geochemical end-member mixing model
Exploratory Groundwater Sampling

- Determine if we could see geochemical differences in California groundwaters indicative of oil and gas influence

- CAUTION – this was a test of geochemical methods; we don’t know if signals were diffusion or other pathways
Exploratory Sampling Outcome

Kern exploratory data

- Biogenic methane
- Buttonwillow RS contains C3
- Aera 3113-4 contains C3, C4, C5
- 353600119430001 contains C3, C4, C5
- USGS EnergyDB, Kern County
- 352400119050001 contains C3, C4
- 352200119040001 contains C3, C4
- ROGGMP produced water
- Thermogenic methane
An Approach for Monitoring Groundwater in High Vulnerability Oil Fields

- Monitoring Framework – Zonal Isolation
  - Quasi-vertical boundary at down gradient Administrative boundary of oil field separating O&G activities from down gradient useable gw
  - Quasi-horizontal boundary within oil field separating useable gw from deeper saline/exempted gw

- Monitoring Questions
  - Where are the boundaries located?
  - Are contaminants crossing boundaries? (rates, directions, timing of transport, risk factors)
Well-Network Design

- Shallow, mid-depth, and deep wells along multiple flow paths in an oil field

Well types
- Existing wells preferred
- Depth-dependent sampling in existing wells
- Converted O&G wells?
- Drill new wells
Summary

- Three-component regional monitoring program
- Start with zonal isolation component
- Use same analytical suite everywhere; develop library of source characteristics
- Products will support long-term UIC program in addition to SB4 program
- Site-specific approach required
- Availability of wells for sampling and existing but confidential subsurface information major time factors
<table>
<thead>
<tr>
<th>Zone</th>
<th>Data Availability</th>
</tr>
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<tbody>
<tr>
<td>near-surface</td>
<td>mixed: data associated with specific contamination &amp; waste disposal sites, shallow public supply wells, some broader assessments in some places</td>
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<tr>
<td>zones</td>
<td>extensive baseline data from GAMA and DDWR: raw data available but not synthesized and pathways not identified</td>
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<tr>
<td>currently used for public water supply</td>
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<tr>
<td>lowest quality irrigation source water/</td>
<td>3,000 mg/l TDS</td>
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<td>supply for brackish desalination projects</td>
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<tr>
<td>characteristics of zones between</td>
<td>extremely limited information including lack of location and extent of resources, boundaries of zones defined by TDS levels</td>
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<td>groundwater resources and oil and gas</td>
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<tr>
<td>activities</td>
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<tr>
<td>hydrocarbon producing zones</td>
<td>extensive information held by oil and gas operators</td>
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USGS Discussion Paper