Risk Posed to Groundwater Resources by the Disposal of Produced Water into Unlined Produced Water Ponds in California

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Outline of Presentation

• Background
• Tracking of Unlined Produced Water Ponds
• Groundwater Resources Underlying Produced Water Ponds in the Tulare Basin of San Joaquin Valley
• A case study
Background
Valleys and Basins

- The San Joaquin Valley occupies the southern two-thirds of the Central Valley.
- The San Joaquin Valley is separated into the San Joaquin Basin to the north and the Tulare Basin to the south.
- Nearly all unlined produced water ponds are in the Tulare Basin.

Figure from USGS 2019
An active produced water pond is currently receiving produced water (SWRCB 2019).

An inactive produced water pond has a physical connection to a produced water source, but not currently receiving produced water (SWRCB 2019).

In large complexes, produced water enters smaller unlined ponds that provide for floatation and skimming of remaining undissolved oil prior to flowing into larger unlined ponds for evaporation and percolation (Jordon et al. 2015). Disposal of produced water into unlined pits, sumps, or ponds has been ongoing in California since at least the early 1900s (Bean and Logan 1983).
Previous Work on Unlined Produced Water Ponds in the San Joaquin Valley

Grinberg 2014

Grinberg 2016

Jordon et al. (2015)
Stringfellow et al. (2015)

Heberger and Donnelly (2015)
Soon to be Released Report from the Division of Oil, Gas, and Geothermal Resources (DOGGR)

An Assessment of Oil and Gas Water Cycle Reporting in California:
Evaluation of Data Collected Pursuant to California Senate Bill 1281, Phase II Report

An Independent Review of Scientific and Technical Information

In 2014, the California Legislature passed SB 1281 in requiring field operators to report the volume and distribution of produced water in greater detail starting in Q1 2015.

Chapter 4 (DiGiulio and Shonkoff 2019)
Potential Impact to Groundwater Resources from Disposal of Produced Water into Unlined Produced Water Ponds in the San Joaquin Valley
Tracking of Unlined Produced Water Ponds
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Not Applicable</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Evaporation-Percolation</td>
<td>Sump (unlined) - Evaporation and Percolation (infiltration): Water is placed into an unlined sump, allowed to percolate into the ground and/or evaporate into the atmosphere.</td>
</tr>
<tr>
<td>2</td>
<td>Evaporation (lined sump)</td>
<td>Sump (lined) – Evaporation: Water is placed into a lined sump, open tank, or similar container for evaporation into the atmosphere.</td>
</tr>
<tr>
<td>3</td>
<td>Surface Water Body</td>
<td>Surface Water Discharge: Water is discharged into a surface body of water such as an ocean, lake, pond, river, creek, aqueduct, canal, stream, or watercourse.</td>
</tr>
<tr>
<td>4</td>
<td>Sewer System</td>
<td>Domestic Sewer System: Water is placed into a sewage disposal or treatment system, which is generally operated by a municipality or consortium for domestic waste.</td>
</tr>
<tr>
<td>5</td>
<td>Subsurface Injection</td>
<td>Subsurface Injection: Water is injected into the subsurface of the same oil field and operator, from which it was produced.</td>
</tr>
<tr>
<td>6</td>
<td>Other (i.e. turned over to commercial water disposal)</td>
<td>Other: Water is disposed of by another method, such as commercial disposal, industrial use, non-class II wells, etc…</td>
</tr>
<tr>
<td>7</td>
<td>Sale/Transfer – To other operator or oil field</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Surface Discharge: Water is used on oil field land or surface for dust control, landscaping, pasture augmentation, infiltration, evaporation, etc…</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Operator’s facilities within oil field</td>
<td>Operator’s facilities within oil field: Water is used for operator’s facilities within the oil field (i.e., tankage, equipment operation, onsite storage, equipment/facilities cleaning and testing, etc…)</td>
</tr>
<tr>
<td>10</td>
<td>Well Stimulation Treatment</td>
<td>Well Stimulation Treatment: Water is used in a well stimulation treatment operation (i.e., hydraulic fracturing, acid matrix, acid fracturing, etc…)</td>
</tr>
<tr>
<td>11</td>
<td>Sale/Transfer – Domestic Use</td>
<td>Sale/Transfer – Domestic Use: Water is used for agriculture, irrigation, water replenishment, water banking, livestock, etc.</td>
</tr>
<tr>
<td>12</td>
<td>Drilling, well work, and well abandonments</td>
<td>Drilling, well work, and well abandonments: Water is used to support well drilling, rework, and abandonment operations, for such things as well control fluid, drilling mud, cementing, etc…</td>
</tr>
</tbody>
</table>
SB 1281 also required DOGGR to provide the State Water Resources Control Board (SWRCB) with an annual inventory of all unlined oil and gas field produced water ponds or sumps.
### State Water Resources Control Board Geotracker

#### PROJECT SEARCH RESULTS

**SEARCH CRITERIA:** WATERPONDS

706 RECORDS FOUND

<table>
<thead>
<tr>
<th>REPORT</th>
<th>MAP</th>
<th>SITE / FACILITY NAME</th>
<th>SITE / FACILITY TYPE</th>
<th>CLEANUP STATUS</th>
<th>OIL FIELD</th>
<th>OIL FIELD OPERATOR</th>
<th>ADDRESS (OR PARTIAL ADDRESS)</th>
<th>CITY</th>
<th>ZIP</th>
<th>COUNTY</th>
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<td>SULPHUR CANYON RD</td>
<td>VENTURA</td>
<td>93001</td>
<td>VENTURA</td>
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<td>AERIAL ENERGY, NORTH BELRIDGE DISPOSAL PONDS</td>
<td>PRODUCED WATER PONDS</td>
<td>INACTIVE - PERMITTED</td>
<td>BELRIDGE, NORTH</td>
<td>AERIAL ENERGY LLC</td>
<td>HIGHWAY 33</td>
<td>SOUTH OF LOST HILLS</td>
<td>KERN</td>
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<td>ALISO CANYON OIL FIELD SUMP, POND, AND PIT ORDERS</td>
<td>PRODUCED WATER PONDS</td>
<td>OPEN - INACTIVE</td>
<td>ALISO CANYON</td>
<td>TERMO/CIRMIUN/ISO CAL GAS</td>
<td>0 PETER ROE FOOTHILLS, UNNAMED ROAD</td>
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<td>91326</td>
<td>LOS ANGELES</td>
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<td>ANDERSON TF #1</td>
<td>PRODUCED WATER PONDS</td>
<td>HISTORIC</td>
<td>RUSSELL RANCH</td>
<td>E &amp; B NATURAL RESOURCES MANAGEMENT CORPORATION</td>
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<td>ANTELOPE HILLS OIL FIELD, HOPPINS A LEASE (E.A. EVAPORATION PONDS)</td>
<td>PRODUCED WATER PONDS</td>
<td>ACTIVE - PERMITTED</td>
<td>ANTELOPE HILLS</td>
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<td>ANTELOPE HILLS OIL FIELD, HOPPINS A SOUTH LEASE</td>
<td>PRODUCED WATER PONDS</td>
<td>ACTIVE - PERMITTED</td>
<td>ANTELOPE HILLS</td>
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<td>[ ]</td>
<td>ANTELOPE HILLS OIL FIELD, PPEN LEASE</td>
<td>PRODUCED WATER PONDS</td>
<td>ACTIVE - PERMITTED</td>
<td>ANTELOPE HILLS</td>
<td>E&amp;G NATURAL RESOURCES MANAGEMENT CORPORATION</td>
<td>ANTELOPE HILLS OIL FIELD</td>
<td>NORTH BELRIDGE</td>
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<td>ANTELOPE HILLS OIL FIELD</td>
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<td>ACTIVE - PERMITTED</td>
<td>ANTELOPE HILLS</td>
<td>E&amp;G NATURAL RESOURCES MANAGEMENT CORPORATION</td>
<td>ANTELOPE HILLS OIL FIELD</td>
<td>NORTH BELRIDGE</td>
<td>KERN</td>
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</tr>
</tbody>
</table>

**Screenshot of Geotracker Database**
Locations of Produced Water Ponds in California

<table>
<thead>
<tr>
<th>Regional Water Board</th>
<th>Active Ponds</th>
<th>Inactive Ponds</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lined</td>
<td>Unlined</td>
</tr>
<tr>
<td>Central Coast</td>
<td>32</td>
<td>9</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>76</td>
<td>0</td>
</tr>
<tr>
<td>Central Valley</td>
<td>31</td>
<td>530</td>
</tr>
<tr>
<td>Santa Ana</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>139</td>
<td>541</td>
</tr>
</tbody>
</table>

Data Source: SWRCB January 2019 Produced Water Pond Status Report (SWRCB 2019)

1,229 produced water ponds in California

1,050 of 1,229 produced water ponds (85%) are unlined

1037 of 1050 (99%) of unlined produced water ponds are in the Central Valley jurisdiction

530 of 1050 (50%) of unlined produced water ponds in the Central Valley jurisdiction are active.
Produced Water Disposition Between 1977 to 2017

Data from DOGGR Well Production and Injection Summary Reports
In 2007, disposal of produced water into evaporation-percolation ponds was at least 25.6 billion gallons. In 2017, disposal into evaporation percolation ponds was at least 1.9 billion gallons.
In 2003, disposal of produced water into evaporation-percolation ponds was at least 24.5% of produced water generated. In 2017, only 1.4% of produced water was reported as disposed in evaporation-percolation ponds.
In May 2014, the Central Valley Regional Water Quality Control Board (CVRWQCB) located 326 facilities with 1100 produced water ponds and evaluated Waste Discharge Requirements (WDRs).
Cumulative Disposal Volumes

Data Source: DOGGR Well Production and Injection Summary Reports
Groundwater Resources Underlying Produced Water Ponds in the Tulare Basin of the San Joaquin Valley
Groundwater Resources in the Tulare Basin of the San Joaquin Valley

The Tulare Basin has 7 groundwater subbasins (locations of nearly all unlined ponds)

Salinity of Groundwater Determined in Part by:

- Origin of sediments (marine versus continental)
- Sources (stream, irrigation) and salinity of recharge water
- Evaporation and transpiration
- Geochemical processes such as ion exchange, mineral dissolution, and precipitation and associated depth and residence time
- Biological reactions that affect the oxidation/reduction state of groundwater

Figure from DiGiulio and Shonkoff (2019)
Hydrogeology of the Kern River Subbasin Area

- Nonmarine Kern River and Tulare Formations are the primary formations used for water supply.
- The Kern River Formation in the eastern portion contains sediment from the Sierra Nevada Mountains.
- Groundwater in the eastern portion of the Kern subbasin is primarily calcium bicarbonate waters in the shallow zones, increasing in sodium with depth.
- The Tulare Formation in the central and western portion contains sediments from Coast Range sources.
- Bicarbonate is replaced by sulfate and to a lesser degree by chloride in an east to west trend across the subbasin. West-side waters are primarily sodium sulfate to calcium-sodium sulfate type.
- TDS increases from east to west.

Figure from Gautier and Hosford Scheirer (2003)
Locations of Produced Water Ponds and Concentrations of TDS in Water Wells

Data from Stanton et al. 2017, Qi and Harris 2017, Metzger et al. 2018, Metzger and Landon (2018a, b), GAMA Geotracker System, DOGGR (2019)
Salinity Profiles in USGS Study Areas

Data from Metzger et al 2018, Metzger and Landon (2018a, b)

Figure from Metzger and Landon (2018a)
Salinity of Groundwater in Water Wells in Kern County

Data from Metzger et al 2018, Metzger and Landon (2018a, b)
Salinity of Groundwater in Water and Production Wells in Kern County

Data from Metzger et al 2018, Metzger and Landon (2018a, b)
## Beneficial Use: Maximum Allowable TDS Levels for Protection of Groundwater Resources for Oil and Gas Development and Disposal of Produced Water in California

<table>
<thead>
<tr>
<th>Maximum TDS (mg/L)</th>
<th>Applicability to O&amp;G Industry</th>
<th>Enforceability</th>
<th>Overseeing Agencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>3,000 mg/L or EC &lt; 5,000 µS/cm for municipal water supply (MUN)</td>
<td>Land disposal, produced water ponds</td>
<td>States Sources of Drinking Water Policy (SWRCB Res No. 88-63 (SWRCB 2006). <strong>TDS and EC not defined for other beneficial use such as that used for agriculture (AGR).</strong></td>
<td>SWRCB</td>
</tr>
<tr>
<td>“Freshwater” Undefined</td>
<td>Conventional O&amp;G Development</td>
<td>PRC § 1722.22 for casing requirements</td>
<td>DOGGR</td>
</tr>
<tr>
<td>10,000</td>
<td>Well stimulation</td>
<td>USDW, CA Water Code § 10783(k)(2)</td>
<td>DOGGR, SWRCB</td>
</tr>
<tr>
<td>10,000</td>
<td>UIC Program</td>
<td>UDSW, protected unless exempted, 40 C.F.R. 144.3</td>
<td>EPA, DOGGR</td>
</tr>
<tr>
<td>10,000</td>
<td>O&amp;G development on federal or tribal land</td>
<td>Onshore Oil &amp; Gas Order No. 2, 53 Federal Register 46798</td>
<td>BLM, DOGGR, SWRCB</td>
</tr>
</tbody>
</table>
### Effluent Limits

#### Tulare Basin Effluent Limits (CVRWQCB 2018)

- 1,000 µS/cm electrical conductivity
- 200 mg/L chloride
- 1 mg/L boron

<table>
<thead>
<tr>
<th>TDS (mg/L)</th>
<th>SJV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;10,000</td>
<td>96.28</td>
</tr>
<tr>
<td>&lt;10,000</td>
<td>3.70</td>
</tr>
<tr>
<td>Unknown</td>
<td>0.02</td>
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</table>

Data from DOGGR SB 1281 reporting

SJV – San Joaquin Valley

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Data from USGS Produced Water Database
## Treatment

<table>
<thead>
<tr>
<th>Treatment</th>
<th>SJV (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deoiling</td>
<td>94.87</td>
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<tr>
<td>Deoiling + Other Treatment</td>
<td>0.25</td>
</tr>
<tr>
<td>No Method</td>
<td>2.06</td>
</tr>
<tr>
<td>Membrane Treatment</td>
<td>0.00003</td>
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<tr>
<td>Desalination</td>
<td>0</td>
</tr>
<tr>
<td>Untreated</td>
<td>2.82</td>
</tr>
</tbody>
</table>

Data reported to DOGGR under SB 1281

SJV – San Joaquin Valley

Only 0.25% of produced water discharged to unlined ponds is treated beyond deoiling.

Photo credit - Clean Water Action
A Case Study
Evaluation of Groundwater Contamination at the McKittrick 1 & 1-3 Facility

- The public record is extensive and easily accessible.
- The first Waste Discharge Requirement permit was issued in 1961 - an example of the long-term practice of disposal of saline (> 10,000 mg/L TDS) produced water into unlined produced water ponds.
- Discharge rates average 67,000 bbd (~ 1 billion gallons per year). Disposal volume over a 60-year operating period is estimated > 60 billion gallons.
- Complex hydrogeological and geochemical conditions that underlie and are in proximity to the facility are likely typical of numerous produced water ponds throughout the Tulare basin.
- Land utilized for agriculture with irrigation water supplied by water wells is located 457 m north of the McKittrick 1 & 1-3 Facility.
Location on Monitoring Wells at the McKittrick 1 & 1-3 Facility

Figure from CVRWQCB (2019)
Perched and Regional Aquifer Conditions at the McKittrick 1 & 1-3 Facility

Figure from CVRWQCB (2019)
Levels of TDS, Chloride, and Boron in CYM-21D1 at the McKittrick 1 & 1-3 Facility

Figure from CVRWQCB (2019)
Water Isotope Values in Monitoring Well and Pond Samples at the McKittrick 1 & 1-3 Facility

$\delta^{18}O_{sample} (\text{‰}) = \left( \frac{^{18}O/^{16}O}{^{18}O/^{16}O}_{VSMOW} \right)_{sample} - 1 \times 1000$

$\delta^2H_{sample} (\text{‰}) = \left( \frac{^{2}H/^{1}H}{^{2}H/^{1}H}_{VSMOW} \right)_{sample} - 1 \times 1000$

Vienna Standard Mean Ocean Water (VSMOW)

Figure from CVRWQCB (2019)
Conclusions

As stated by the California Council on Science & Technology and the Lawrence Berkeley National Laboratory in 2015:

- Unlined produced water ponds poses a risk to groundwater resources in California.

- If concentrations of salinity and constituents of concern cannot be reduced to levels protective of groundwater resources, this practice should be phased out.

- Groundwater investigations should be expanded to determine the extent of groundwater impact from past disposal.

Jordon et al. (2015)
Stringfellow et al. (2015)
References

Bean, R.T., Logan, J. 1983. Lower Westside water quality investigation, Kern County: California State Water Resources Control Board

https://geotracker.waterboards.ca.gov/regulators/deliverable_documents/6581008017/vwmc_mck113_noph_all.pdf

https://www.conservation.ca.gov/dog/SB%201281/Pages/SB_1281DataAndReports.aspx


http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201320140SB1281


https://www.cleanwateraction.org/sites/default/files/docs/publications/In%20the%20Pits.pdf


Metzger, L.F., & Landon, M.K. (2018b). Water and petroleum well data used for preliminary regional groundwater salinity mapping near selected oil fields in central and southern California. https://www.sciencebase.gov/catalog/item/5a735aaee4b0a9a2e9e1429d


Thank You!

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