# An Assessment of Oil and Gas Water Cycle Reporting in California

## Evaluation of Data Collected Pursuant to California Senate Bill 1281, Phase II Report

EXECUTIVE SUMMARY

A Commissioned Report prepared by the
California Council on Science and Technology

CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

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# An Assessment of Oil and Gas Water Cycle Reporting in California:

## Evaluation of Data Collected Pursuant to California Senate Bill 1281

An Independent Review of Scientific and Technical Information

## Executive Summary


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*August 2019*

**Acknowledgments**

This report has been prepared by the California Council on Science and Technology (CCST) with funding from the Division of Oil, Gas, and Geothermal Resources.


ISBN Number: 978-1-930117-62-4
An Assessment of Oil and Gas Water Cycle Reporting in California: Evaluation of Data Collected Pursuant to California Senate Bill 1281 (Executive Summary)

**Citation**

California Council on Science and Technology. 2019. An Assessment of Oil and Gas Water Cycle Reporting in California: Evaluation of Data Collected Pursuant to California Senate Bill 1281. Sacramento, CA. https://ccst.us/reports/oil-and-gas-water-cycle-reporting/.

**About CCST**

The California Council on Science and Technology is a nonpartisan, nonprofit organization established via the California State Legislature in 1988. CCST responds to the Governor, the Legislature, and other State entities who request independent assessment of public policy issues affecting the State of California relating to science and technology. CCST engages leading experts in science and technology to advise state policymakers—ensuring that California policy is strengthened and informed by scientific knowledge, research, and innovation.

**Note**



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# An Assessment of Oil and Gas Water Cycle Reporting in California:

## Evaluation of Data Collected Pursuant to California Senate Bill 1281

### Overview

California was the fourth largest producer of oil and gas in the U.S. in 2017. More than 70 percent of annual oil production in California takes place in Kern County, a region where high quality water sources are scarce. Water is an important byproduct of oil extraction, and because California oil fields are mature and many contain heavy oil, they produce a greater proportion of water per barrel than most other U.S. producing regions (18 barrels of water for each barrel of oil in 2017 and increasing annually; Figure ES.1). In 2017, the California oil and gas (O&G) industry reportedly extracted more than 400,000-acre feet (AF) of water (Jordan, 2019) (equivalent to 3.1 billion barrels or 130 billion gallons). Defined as “produced water” by the industry, this water is generally not suitable for direct domestic or agricultural use due to high levels of salt, boron, and other constituents that are toxic to plants and exceed some drinking water standards. The salt level (salinity, reported as total dissolved solids, or TDS) is generally higher than 10,000 milligrams per liter (mg/L), or almost a third of the salt content of seawater. The water quality characteristics of produced water are a consequence of oil and gas formation in sediments of marine origin millions of years ago (in most cases). More than 96 percent of this produced water is generated in five of the State’s ten geographically-defined oil basins. These five basins include the San Joaquin, Los Angeles, Santa Barbara-Ventura, Santa Maria, and Monterey basins, and contain almost all active oil wells (about 135,000) in California. While the annual volume of produced water generated is small compared to California’s annual water use for irrigation (e.g. about 1% of 34 million AF in 2015), this produced water currently satisfies a significant portion of water uses needed by oil and gas field operators, including enhanced oil recovery (EOR). Where TDS levels are low (< 1,000 mg/L), some produced water is of suitable quality (based on salinity and boron concentrations) to meet local demands for agricultural uses, including food crop irrigation. For oilfields extracting more saline produced water, reuse can be achieved through removal of dissolved solids using appropriate water treatment technologies (e.g., reverse osmosis).

*California Average Produced Water-to-Oil Ratio, 1982-2017*

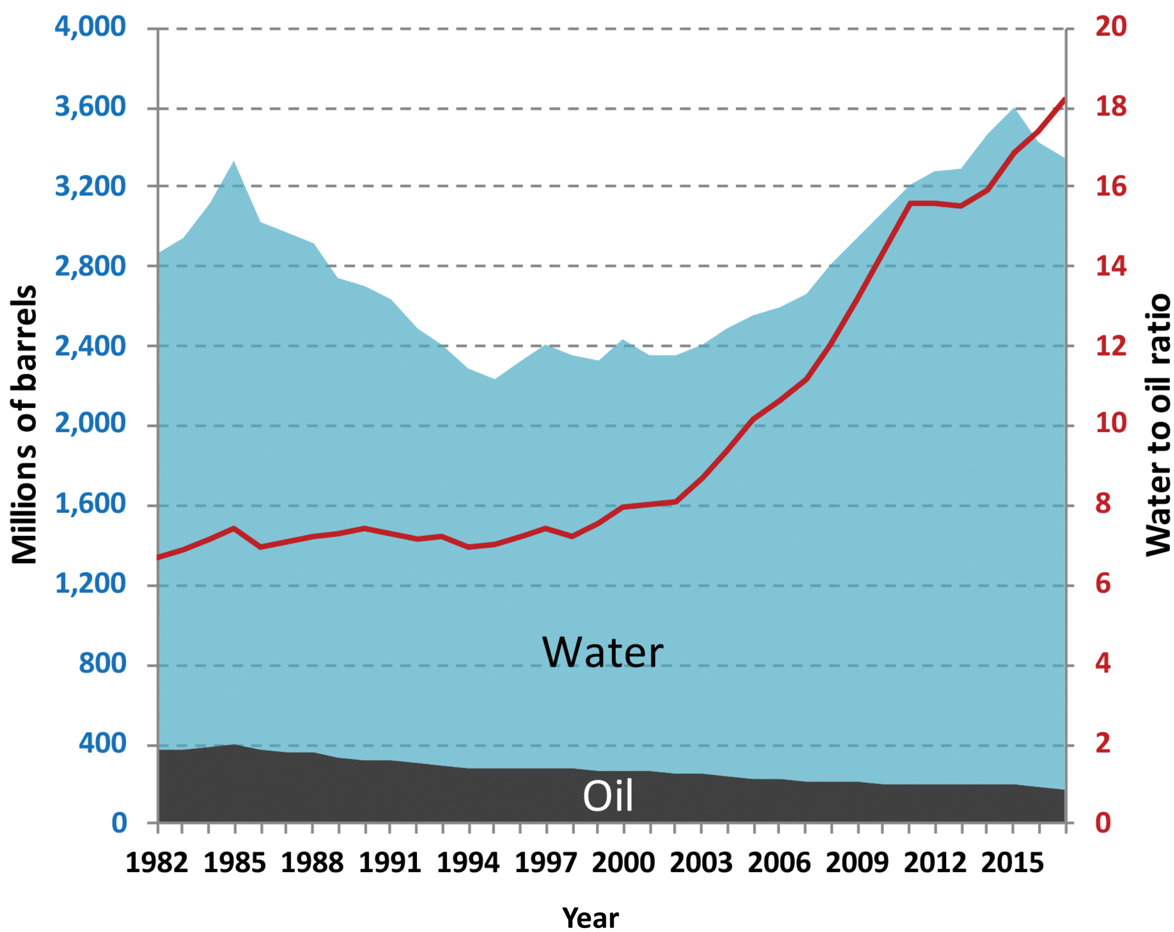


*Figure ES.1. California average produced water-to-oil ratio from 1982–2017. Produced water is primarily saline in quality. Oil production has been declining since about 1985. Water production began increasing in the early-mid 1990s. The water-to-oil ratio has increased steadily. Note: Black indicates the volume of oil produced; blue the volume of water produced; and red the proportion of water to oil. Source: Reproduced from Jordan (2019), original data from DOGGR (2018a, 2018b).*

In the context of recent severe drought conditions, California legislators raised concerns that the O&G industry may be using excessive amounts of high-quality water (i.e. water available for other beneficial uses) and that these uses could be satisfied by the produced water generated on-site. In addition, various organizations raised concerns over potential water quality impacts and possible human exposure from both off-site reuse and surface disposal of produced water, including disposal in unlined produced water ponds. To address these concerns, and consistent with other legislative mandates for increased reporting by the O&G industry, the California Legislature passed Senate Bill (SB) 1281 (Pavley, 2014) to expand reporting requirements for California oil and gas producers. The overall goal of this legislation was to enhance transparency concerning industry water management. Additional goals include ensuring appropriate data were available to assess the impact of O&G production on the water resources of the State; assessing reuse potential of produced water on-site and off-site; and addressing concerns over the risks to human health and the environment posed by surface disposal, reuse for irrigation, or surface water streamflow augmentation.

The California Division of Oil, Gas, and Geothermal Resources ("The Division") was assigned the lead for implementation and management of these new reporting requirements. Water quality impacts are generally under the jurisdiction of the State Water Resources Control Board (State Water Board, SWB) and the relevant regional water quality control boards.

Reporting under SB 1281 has been underway since 2015. A sufficient quantity of data are now available to assess the overall utility of the SB 1281 dataset relative to the goals of the legislation, and in the context of other reporting requirements established to increase transparency on water management by the O&G industry. Accordingly, The Division contracted with the California Council on Science and Technology (CCST) to conduct a study addressing the following overall question: "*What is the utility of the SB 1281 dataset to answer important questions on water resources, public health, and the environment; are there opportunities for improvement?*" In implementing the assessment, CCST considered that the overall utility of the SB 1281 dataset could be assessed by reviewing the datasets generated to date and determining whether the data provide answers to the following overarching questions:

- **Question ES.1.** What are the sources, volumes, and quality of water used for oil and gas development and production in California?

- **Question ES.2.** What are the characteristics/quality of produced water across the State, and how do these vary over time?

- **Question ES.3.** What are the potential reuse options for produced water both within and outside of the oilfields, taking into consideration treatment technologies?

- **Question ES.4.** What are the potential and actual hazards, risks, and impacts to environmental and human health from various dispositions of produced water reuse and discharges to land, water, and subsurface injection?

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**Study Process**

CCST organized and directed the study leading to this Report. Members of the CCST Steering Committee were appointed based on technical expertise and a balance of viewpoints. Appendix B in the full Report provides information about CCST's Steering Committee membership. All experts who contributed to the study were evaluated for potential conflicts of interest. Under the guidance of the Steering Committee, a team of experts (study team) assembled by CCST developed the findings based on original technical data analyses and a review of the relevant literature. Appendix C in the full Report provides information about the authors. The Steering Committee met regularly to guide the lead authors of the study team as they studied each of the issues identified in the scope of work. With regular interaction, the authors and the Steering Committee were able to collaborate to develop a series of findings, conclusions, and recommendations defined as follows:

> ***Finding.*** *Facts the study team has found that could be documented or referenced and that have importance to the study.*

> ***Conclusion.*** *A deduction the study team made based on findings.*

> ***Recommendation.*** *A statement that recommends an action to be considered as a result of the Report findings and conclusions.*

The committee process ensures conclusions are based on findings (facts), and recommendations are based on findings and conclusions. Both the authors and the Steering Committee members proposed draft conclusions and recommendations. These were modified based on peer review and discussion within the Steering Committee, along with continued consultation with the authors. Final responsibility for the conclusions and recommendations in this Executive Summary lies with the Steering Committee. All Steering Committee members have agreed with these conclusions and recommendations. The conclusions and recommendations expressed in this publication are those of the Steering Committee and authors, and do not necessarily reflect the views of their institutions or the agency that provided support for this project.

## Summary of Key Findings, Conclusions, and Recommendations

### Question ES.1. What are the sources, volumes, and quality of water used for oil and gas development and production in California?

> ***Conclusion ES.1.*** *The SB 1281 dataset provides an accounting of O&G industry water use, reuse, and disposal quantities on an annual basis beyond what was available prior to its collection, but improved reporting is required to increase accuracy, utility, ease of use, and assessment of both reuse opportunities and risks associated with disposal.*

The SB 1281 dataset has advanced a general understanding of the sources, volumes, and quality of water used for oil and gas development and production in California. Based on comparisons between the monthly produced water data provided to The Division since 1977, and the data reported in SB 1281, the SB 1281 dataset provides a fairly accurate estimate of the volume of water produced and volumes of water reinjected, reused, or disposed of by the industry for the period assessed, from the first quarter of 2015 through the last quarter of 2017. Table ES.1 provides a summary of the total volumes produced during this time period for the five major basins noted. Produced water from these five basins represents more than 96 percent of the total volumes produced in California.

*Table ES.1. Average annual volumes of total produced water and of fresh/brackish (≤10,000 mg/L TDS) produced water (not currently reused by agriculture) from 2015 Q4 to 2017 Q1 in the five major sedimentary basins.*

| Basin | Total Produced Water (AFY) | Fresh/Brackish Produced Water (AFY) | Percent Fresh/ Brackish |
|---|---|---|---|
| Los Angeles | 123,643 | 115 | < 0.01% |
| Salinas | 16,271 | 0 | - |
| San Joaquin | 255,590 | 5,445 | 2.1% |
| Santa Barbara-Ventura | 10,732 | 5,776 | 53.8% |
| Santa Maria | 7,104 | 0 | - |
| Total | 413,340 | 11,337 | 2.7% |

Of the volumes of produced water generated in these basins, approximately 82% was re-injected at the site where it was withdrawn, either for EOR or for disposal via permitted Class II disposal wells. The remainder was either reused or disposed of at an off-site location (Figure ES.2). The SB 1281 dataset provides an estimate of the volume injected in underground injection control (UIC) wells but does not differentiate between injection for EOR versus disposal.

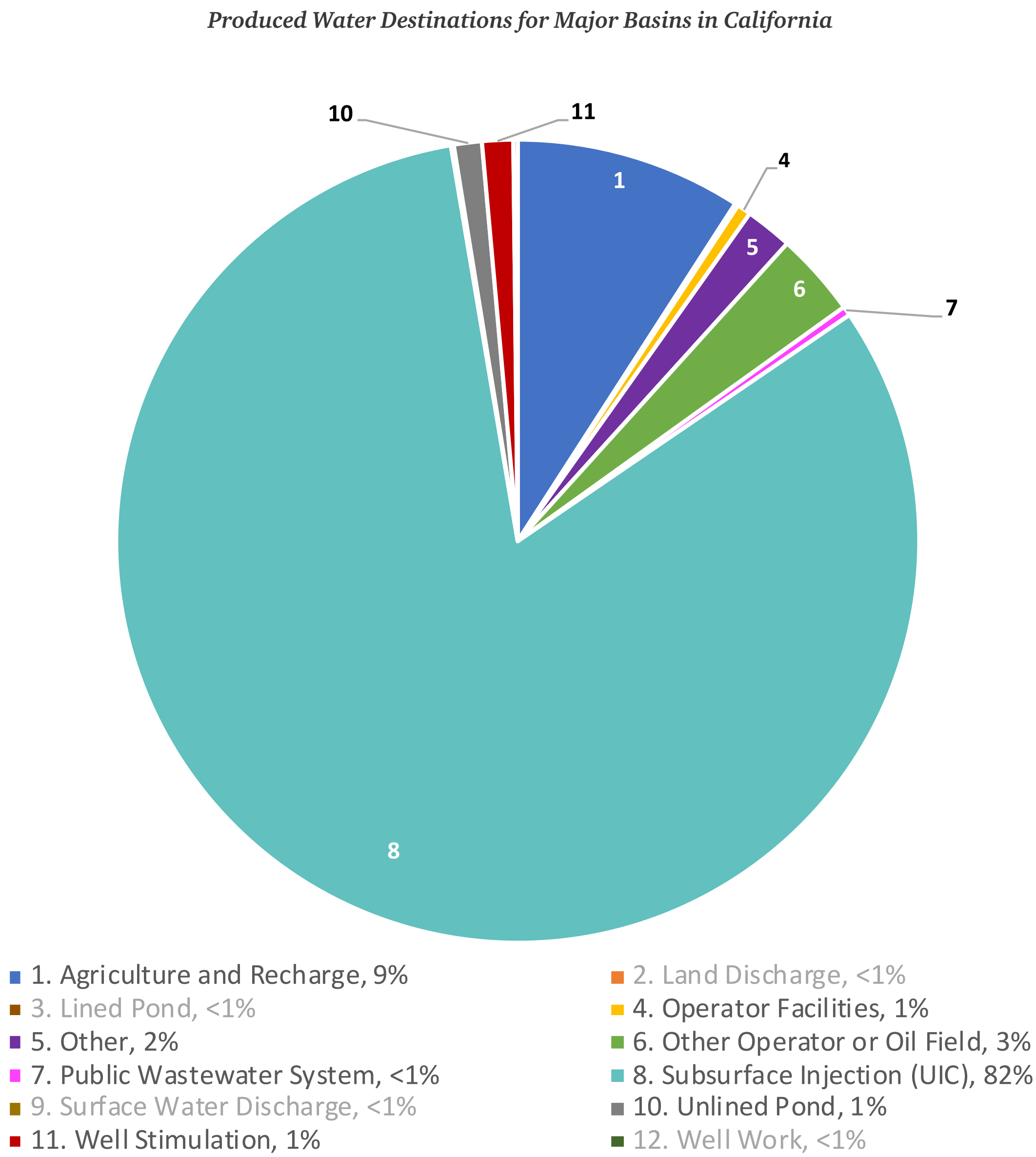


***Figure ES.2. Destinations of produced water for the five major basins in California, 2015 Q4–2017 Q1. Values are percentages of the total 103,335 acre-feet per quarter (AFQ). Unlabeled wedges are 1% or less of the total. Source: SB 1281 dataset.***

Furthermore, the SB 1281 dataset, while imperfect, results in a fuller understanding of the O&G industry's role in regional water balances than was previously possible from water reporting collected by the Division, such as the monthly production and injection dataset ("monthly dataset"). Using the SB 1281 dataset in conjunction with the monthly dataset, this Report provides the first full assessment of all water inputs, applications, and outputs for California's O&G industry (Figure ES.3). While the O&G industry derives the vast majority of its saline water from produced water, more than a third of the industry's fresh/brackish water inputs were from external sources such as municipal water suppliers and water wells. The O&G industry is a net discharger of saline water (TDS > 10,000 mg/L), and net consumer of fresh/brackish water (TDS< 10,000 mg/L).

*Water Cycle: California's Oil and Gas Industry*

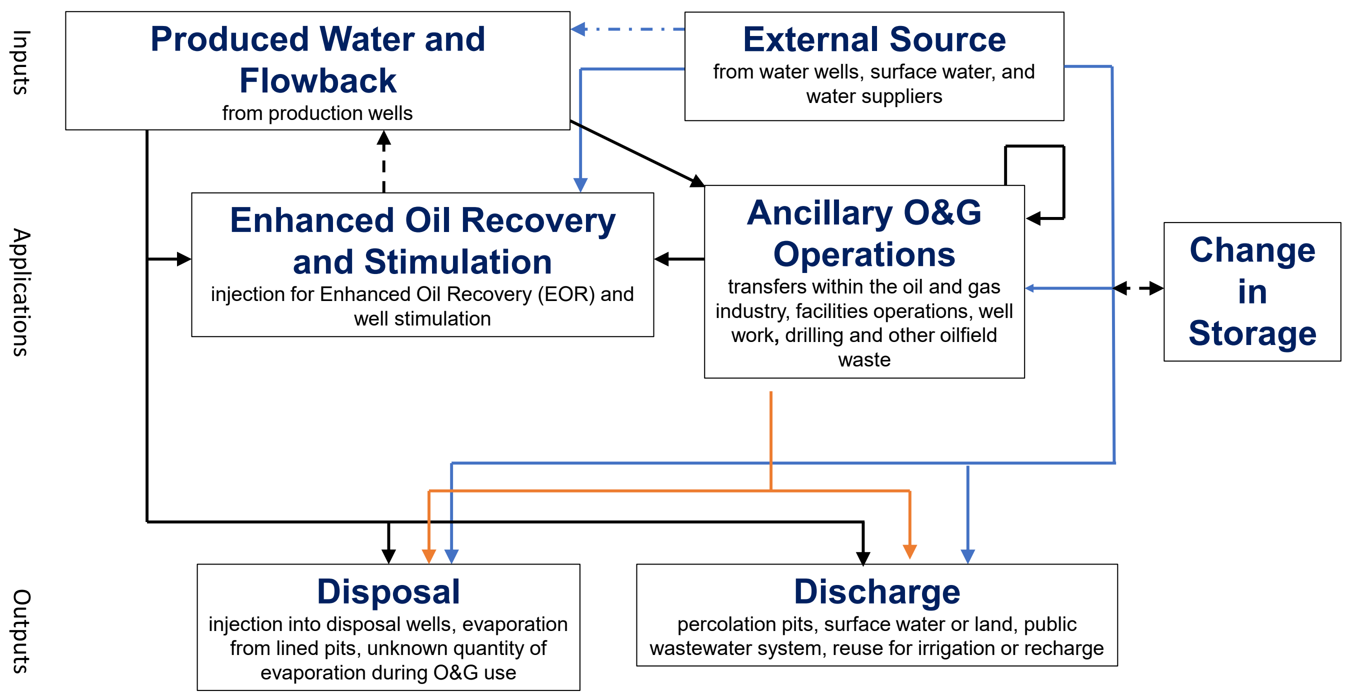


*Figure ES.3. Water cycle diagram for California's oil and gas industry.*

These results demonstrate the value of the SB 1281 dataset for understanding the full impact of the O&G industry to regional water resources. However, the SB 1281 dataset is difficult to use and lacks a number of attributes that could improve the value of the data for assessing water reuse opportunities or the risks of irrigation reuse and surface disposal, among other issues.

> ***Recommendation ES.1.*** *A number of modifications to the SB 1281 dataset should be made, including:*
>
> - *Reduce redundancies in reporting requirements between monthly and SB 1281 datasets. The monthly dataset currently captures well-by-well water production which is then repeated in SB 1281 dataset, resulting in duplicate data and no increased value of the dataset.*

> - *Report field-wide produced water by aggregation of data on a field or regional water management basis rather than on a well-by-well basis.*
> - *Provide a usable dataset for analysis by reducing the number of reports from three to one report, based on accounting for all important water flow streams.*
> - *Include spatial identification for all off-site disposal options.*
> - *Modify treatment categories reported, as outlined in specific recommendations.*

More detailed recommendations designed to enhance the future utility of the dataset are provided in each chapter of the Report.

**Question ES.2. What are the characteristics/quality of produced water across the state, and how do these vary over time?**

> ***Conclusion ES.2.*** *The SB 1281 dataset only contains one water quality parameter, TDS, which is reported as a binary value (less than or equal to 10,000 mg/L, or more than 10,000 mg/L). The lack of more extensive water quality data severely limits the value of the SB 1281 dataset to assess further reuse opportunities, as well as to identify the potential hazards associated with surface disposal.*

The SB 1281 dataset is insufficient to assess the extent of reuse opportunities for produced water because multiple water quality characteristics are needed to determine suitability for beneficial uses. For example, reuse for agricultural irrigation requires, at a minimum, data on boron, chloride, and other inorganic constituents (sodium, calcium, magnesium) beyond TDS. The data are also insufficient to address the broader question of the spatial and temporal variability in produced water quality across the State, and other data sources had to be evaluated as documented in this Report.

> ***Recommendation ES.2.*** *Actual TDS or electrical conductivity data should be included in the SB 1281 dataset for all produced water. A select number of additional water quality parameters should be reported for those fields in which produced water quality indicates strong potential for irrigation reuse, based on criteria established in Chapter 2.*

The quantification of TDS (or its estimation through electrical conductivity measurements) in all produced water, measured at oil-water separators or other points of produced water aggregation, will lead to the identification of potential reuse opportunities. While TDS is a useful screening parameter to determine the likelihood of reuse, increasing reuse of produced water for irrigation will require much more intensive characterization of the chemical and toxicological characteristics of produced water, particularly in situations in which off-site reuse or disposal occurs consistent with regulatory requirements established by the agencies with jurisdiction.

**Question ES.3. What are the potential reuse options for produced water both within and outside of the oilfields, taking into consideration treatment technologies?**

> ***Conclusion ES.3.*** *The opportunities for expanded off-site reuse of produced water with a modest level of treatment are limited and occur mostly at the local level in proximity to active fields producing low salinity produced water. Currently, over 38,000 acre-feet per year (AFY) (approximately 10% of the annual volume of produced water) is being reused for irrigation, primarily in the eastern San Joaquin Valley.*

Assessing the potential for water reuse options using the SB 1281 dataset is restricted by the lack of water quality data. Based on review of water quality characteristics of produced water across California and over extended time periods provided in publicly-available produced water databases (see Chapter 3), the 50th percentile or median TDS level is about 26,000 mg/L and only 5% of the TDS values are lower than 2,200 mg/L. Thus, the bulk of this water is generally unsuitable for municipal or irrigation beneficial uses without extensive treatment, and the substantial cost of treatment and transportation may pose a significant barrier to expanded reuse opportunities. However, in reviewing these databases, the study team estimates that up to an additional 64,000 AFY could potentially be available for irrigation reuse, though additional treatment beyond oil removal may be required.

Across the five major basins evaluated, the O&G industry meets 68% of their saline water demand through reuse, and up to 41% of their fresh/brackish water demand is satisfied by reuse. Fields that may have excess produced water available for reuse with minimal treatment are concentrated in the southeastern San Joaquin Valley (Figure ES.4).

> ***Recommendation ES.3.*** *In the context of assessing reuse opportunities, the SB 1281 dataset should distinguish between injection for purposes of onsite enhanced oil recovery and offsite injection for permanent disposal of produced water in injection wells.*

*Oil and Gas Fields in California: Reuse Quality of Produced Water*

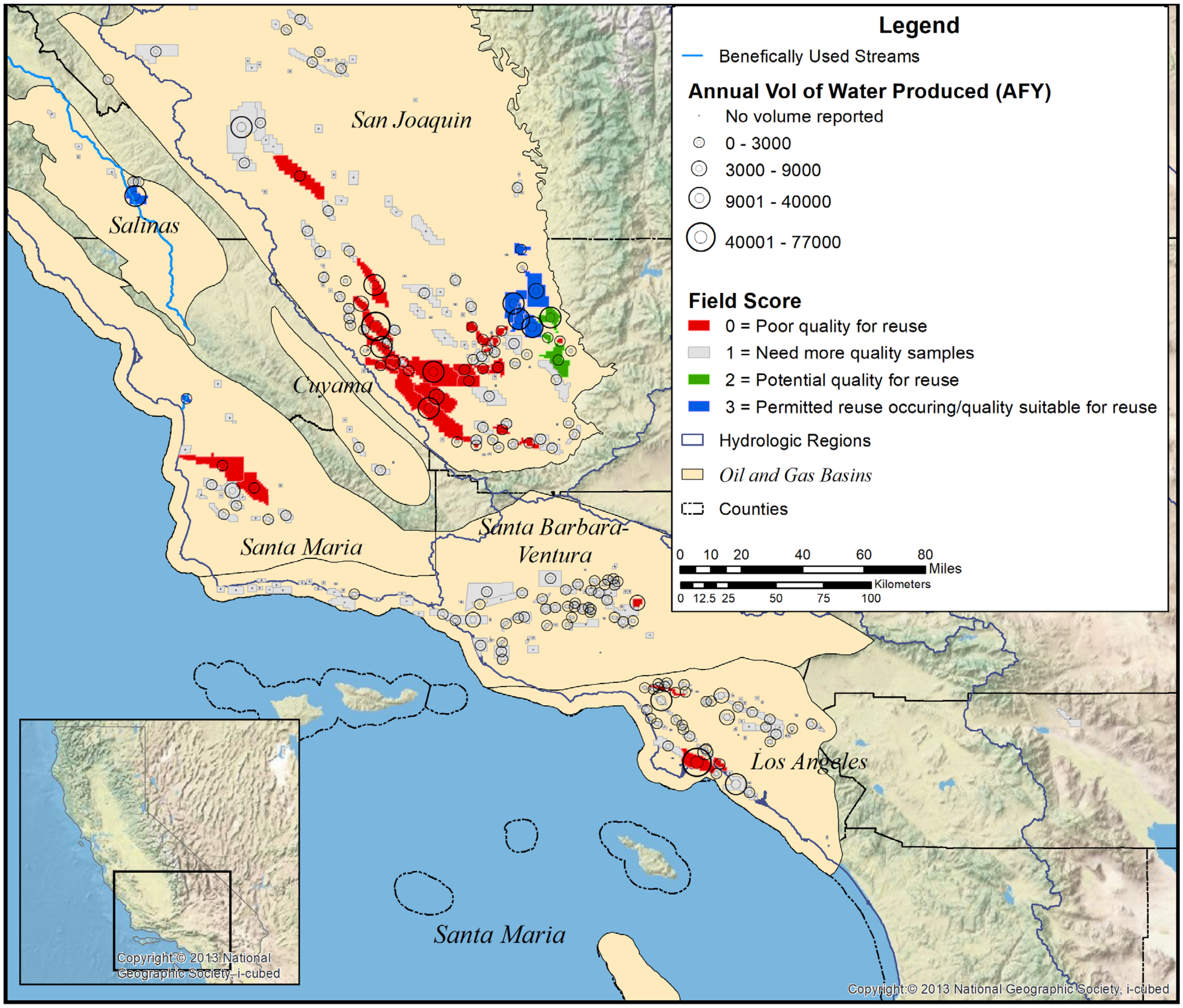


*Figure ES.4. Map of oil and gas fields in California color-coded by field score to indicate potential for reuse of produced water for agriculture and average annual volume of water (AFY) produced. Red indicates water is of poor quality for reuse; grey indicates there is a need for more water quality samples before potential for reuse can be assessed; green indicates water quality is potentially suitable for reuse for agriculture; and blue indicates permitted reuse of water for agriculture is already occurring. Fields in the remaining portion of California did not have data on produced water quality.*

**Question ES.4. What are the potential and actual hazards, risks and impacts to environmental and human health from various dispositions of produced water reuse and discharges to land, water, and subsurface injection?**

The SB 1281 dataset does not provide the data needed to address the issue of the potential or actual hazards and risks associated with subsurface injection, surface disposal, or irrigation reuse of produced water. However, this Report provides a detailed evaluation of the potential hazards associated with the various surface dispositions of produced water in California, with a focus on irrigation reuse and surface disposal of produced water. Produced water quality is highly heterogeneous throughout the State. An assessment of the risks from produced water reuse will require thorough water quality assessments on a case-by-case basis and an assessment of potential exposure pathways resulting from surface disposition of produced water. Currently more than 90% of the surface destinations for produced water occur in the southeastern portions of San Joaquin Valley. While all surface disposal options are subject to appropriate permit conditions, significant data gaps exist on the relevant characteristics of the chemicals found in some produced waters. Such data are needed to complete risk analyses where there is a potential for exposure at unacceptable levels.

> ***Conclusion ES.4.*** *Because of widespread use of chemical additives in routine O&G operations, including various forms of well stimulation, more detailed assessment is needed to evaluate the reuse potential for produced water. In addition, human health and environmental risk characterization of produced water that is discharged to the surface and reused outside of the oilfield is hindered by the lack of necessary water quality data for this waste stream.*

California has a clear set of chemical and toxicological measurement requirements for other reuse applications, such as recycling of municipal wastewater for irrigation use and indirect and direct potable reuse.

> ***Recommendation ES.4.*** *More widespread use of produced water for irrigation will require consideration of protocols currently being applied for other water recycling activities in California, including indirect and direct potable reuse of treated wastewater in those cases considered to pose high risk of human or ecological exposure.*

> ***Conclusion ES.5.*** *Wastewater disposal by the O&G industry in unlined produced water ponds presents a known but poorly quantified risk to groundwater quality. The exact volume of produced water disposed of in these unlined produced water ponds at the surface is uncertain.*

Currently, approximately 1 billion gallons a year (3,100 AFY) of wastewater from O&G extraction (a combination of produced water and on-site wastewater generation) are discharged to 540 unlined produced water ponds located primarily in Kern County (Figure ES.5). Review of the SB 1281 dataset could not confirm the total volume of produced water discharged to unlined ponds. These ponds are designed to dispose of water through percolation into the subsurface. Even though this destination for produced water represents less than 1% of the annual produced water volume, certain constituents in this water (e.g., TDS, soluble hydrocarbons) can reach groundwater in some cases. Therefore, this practice represents a direct discharge of produced water and other oilfield wastewaters to the surface and indirectly to groundwater that is in communication with the surface.

***Locations of Unlined Produced Water Pond Facilities in California***

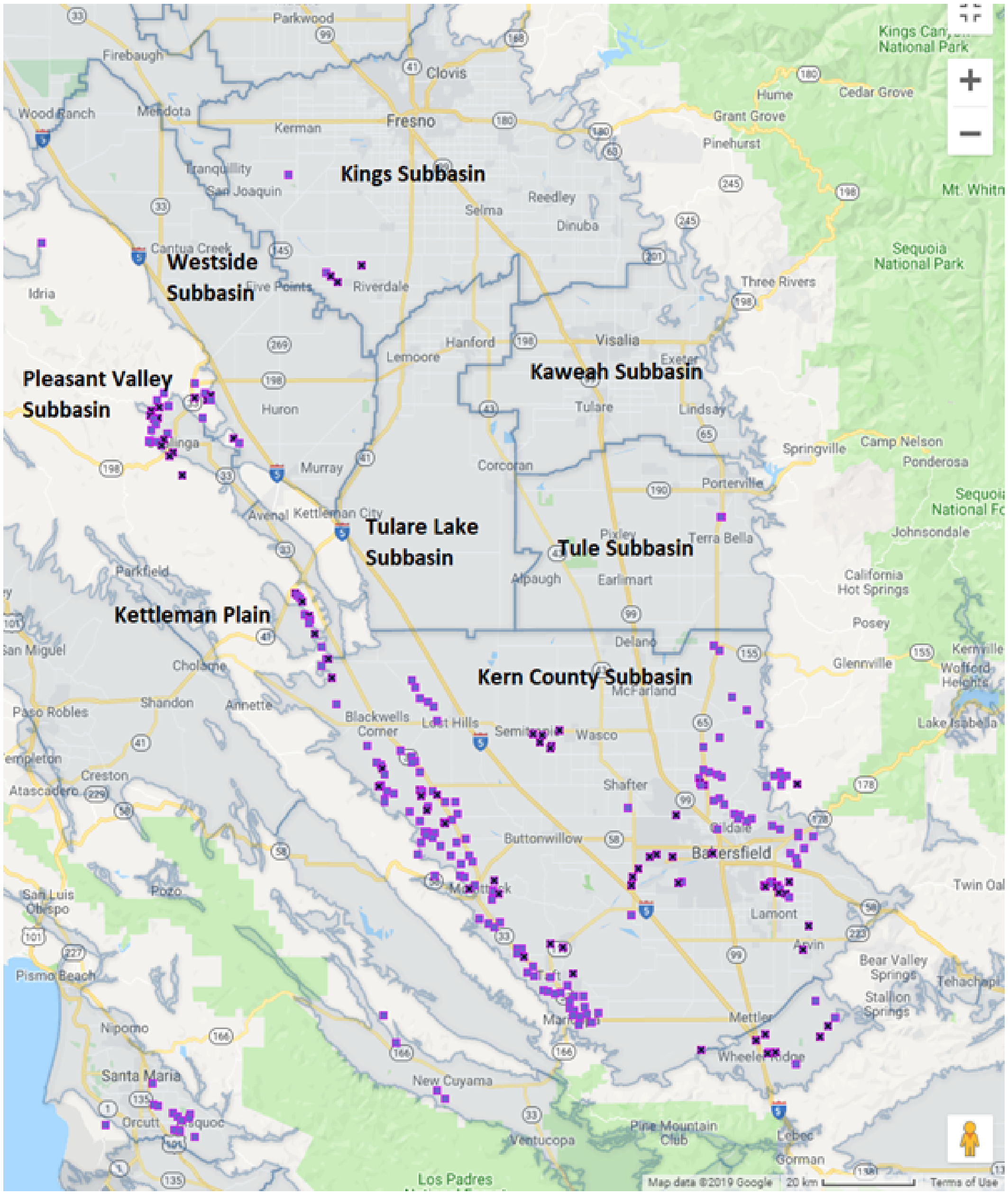


*Figure ES.5. Location of primarily unlined produced water pond facilities and groundwater subbasins in the Tulare Lake Hydrologic Basin. Source: Reproduced from SWRCB Geotracker website (SWRCB, 2018b).*

Discharges to these produced water ponds are subject to regulatory oversight consistent with permit requirements for such discharges or are facing regulatory actions due to failure to meet permit requirements. However, uncertainties persist on the potential impact to groundwater resource quality. The absence of more detailed chemical characterizations limits the ability to assess the long-term risks of this disposal practice.

An analysis of available physical, chemical, and toxicological properties of identified chemicals used in O&G operations in California shows that many are poorly characterized and lack important data required to assess health hazards, treatment potential, and environmental fate and behavior. Such analyses are most needed where degradation and contamination risks to groundwater may be present from past or continued disposal of produced water. For example, discharge of produced water since the 1960s at the McKittrick 1 & 1-3 Facility—unlined produced water ponds in Kern County—has degraded groundwater quality, resulting in regulatory responses by the Central Valley Regional Water Quality Control Board (CVRWQCB). This example illustrates the consequences of exceeding the site subsurface capacity to tolerate waste disposal. In some basins, unlined produced water ponds are located in areas with groundwater resources that are or could be used for municipal and agricultural use, and where contamination from produced water ponds may have occurred or has the potential to occur. It should be noted that the CVRWQCB is actively working to address these issues through the implementation of regulatory responses to non-compliance, with permit requirements established for surface disposal of produced water.

> ***Recommendation ES.5.*** *Agencies with jurisdiction should develop an unlined disposal site risk prioritization system to evaluate which sites are most in need of investigations to determine the nature and extent of current or potential future impacts. Given these uncertainties, reduction or elimination of this disposal practice should be the subject of thorough review by the appropriate agencies where these agencies find that produced water disposal poses unacceptable risks of groundwater quality degradation.*

### Supporting Findings, Conclusions and Recommendations from the Report

The report includes a number of additional findings, conclusions, and recommendations (FCRs). The above summary rests upon the following key subset of FCRs.

**FCR 1.1. Value of the SB 1281 dataset** *(Chapter 1, Sections 1.1, 1.2.1)*

***Finding 1.1.1.*** Prior attempts to collect data on water use by the O&G industry, such as the monthly and SB 4 datasets, captured only a subset of water handled by the industry.

***Finding 1.1.2.*** The SB 1281 dataset provides unique value by encompassing all water handled by the O&G industry in its three reports, including previously unreported uses, such as for dust suppression, equipment cleaning, drilling muds, and domestic water.

***Finding 1.1.3.*** Much of the new information gained from the SB 1281 dataset is found in the Other Allocation report, which is the sole source of state information on water used by the industry that is neither produced nor injected.

***Conclusion 1.1.1.*** The SB 1281 dataset, while imperfect, allows a fuller understanding of the O&G industry's role in regional water balances than was previously possible. By capturing all inputs, outputs, and applications of water, the dataset enables calculations of metrics such as demand, reuse, and net impact to the surface water cycle, which were previously impossible to calculate.

***Conclusion 1.1.2.*** Any revisions to the SB 1281 dataset should preserve and enhance its unique capacity to provide insight into the oil and gas water cycle and the impact of the industry to regional water balances.

**FCR 1.2. Redundancy between the 1281 and monthly datasets** *(Chapter 1, Sections 1.2.1, 1.2.2)*

***Finding 1.2.1.*** The SB 1281 dataset includes three reports: Injection, Production, and Other Allocation, which have non-parallel sets of columns.

***Finding 1.2.2.*** The monthly dataset includes three reports: Injection, Production, and California oil and gas wells. The Injection and Production reports give information on volumes of water (in addition to oil and gas where appropriate), and source/disposition and quality of water that are similar to information found in the SB 1281 dataset.

***Conclusion 1.2.1.*** The Well-to-Well Allocation report seeks to itemize the movement of water from every production well to every injection well. In practice, however, water moves from production wells to centralized treatment facilities (e.g. oil-water separators) and back to injection wells, and these volumes cannot be accurately tracked in the way intended by this report.

***Conclusion 1.2.2.*** Per-well reporting of produced and injected water in the SB 1281 dataset was largely redundant with existing reporting in the monthly dataset. At the same time, the Well-to-Well Allocation report was excessively complex and failed to accurately represent how water moves through an oil field.

***Conclusion 1.2.3.*** The SB 1281 dataset provides better information on source, destination, and quality of water than the monthly dataset.

***Conclusion 1.2.4.*** Redundancy between the SB 1281 dataset and the monthly dataset can be reduced by appropriately augmenting the monthly dataset to take over well-by-well reporting on production and injection from the SB 1281 dataset.

***Conclusion 1.2.5.*** The SB 1281 dataset can be used to gather information at the lease scale or larger.

***Conclusion 1.2.6.*** The monthly dataset appears to have more reliable information on volumes of produced and injected water than the SB 1281 dataset.

***Recommendation 1.2.1.*** Make the monthly dataset the repository for volumes of water produced and injected; focus the SB 1281 dataset instead on flows of water into and out of the O&G industry.

***Recommendation 1.2.2.*** The monthly dataset should adopt similar variables for source, destination, and quality as the SB 1281 dataset to eliminate the per-well reporting in the SB 1281 dataset; operators can be required to simply report on a per-lease basis to the SB 1281 dataset.

***Recommendation 1.2.3.*** Add a column to the monthly production and injection dataset for operators to report the water treatment facility to which each production and injection well connects.

***Recommendation 1.2.4.*** Instead of attempting to apportion flows of water between individual wells as is currently done in the Well-to-Well Allocation report, operators should simply include the water treatment facility or facilities connected to each production and injection well in the monthly dataset.

**FCR 1.3. Using the SB 1281 dataset for insight into the water cycle** *(Chapter 1, Section 1.3.2)*

***Finding 1.3.1.*** Calculating water inputs, outputs, and applications by the O&G industry required extensive parsing, reorganizing, and compiling of data from three reports: Production, Injection, and Other Allocation.

***Finding 1.3.2.*** The three reports contained similar variables but had slightly different structures, making it challenging to sum quantities across reports. For example, produced water used for well stimulation was reported in the Production report, whereas water from external sources used for well stimulation was found in the Other Allocations report.

***Finding 1.3.3.*** The three reports also allowed for duplicate reporting of some flows of water. For example, produced water that was injected into a UIC well was reported in all three reports: once in the Production report with a destination of underground injection, once in the Injection report with a source of produced water, and once (erroneously) in the Other Allocations report with a source of produced water and destination of underground injection.

***Conclusion 1.3.*** The SB 1281 dataset is not structured to facilitate straightforward calculations of water inputs, outputs, and applications by the O&G industry, key variables for understanding the impact of the O&G industry on regional water resources.

***Recommendation 1.3.1.*** Collapse the three SB 1281 datasets (Injection, Production, Other Allocation) into one master All Flows report, as described in Recommendations 1.4.2 and 1.4.3.

***Recommendation 1.3.2.*** Denote source and destination for every flow. Produced water should be a source, rather than a separate report. Likewise, water injected into a UIC well should be a destination, rather than a standalone report. Make Storage a source and a destination, rather than a separate variable.

***Recommendation 1.3.3.*** Eliminate duplicate reporting across the three reports. In theory, collapsing the three reports into one should reduce the likelihood of duplicate reporting. Definitions of sources and destinations should also be revised as necessary to prevent ambiguity. For example, Destination 9, "Operator's Facilities," should not include onsite storage if the stored water is reported elsewhere.

***Recommendation 1.3.4.*** The Division quarterly summary reports should give use, reuse, percentage reused, sources, and destinations per hydrologic region. This additional information would not replace sources and destinations, but would facilitate calculating larger, more integrative categories such as demand, reuse, total inputs from external sources, and total discharges to the surface.

**FCR 1.4. Water reuse by the O&G industry** *(Chapter 1, Section 1.3.3)*

***Finding 1.4.*** The O&G industry meets much of its demand for saline water by reusing produced water.

***Conclusion 1.4.*** Although the O&G industry reuses much of the saline water it produces, in certain basins, a substantial amount is either disposed of underground or discharged at the surface. A smaller proportion of industry fresh water demand is met by recycled water, because the majority of fresh/brackish water used by the O&G industry is water obtained from external sources rather than produced water.

**FCR 1.5. Water use and discharges by the O&G industry** *(Chapter 1, Section 1.3.3)*

***Finding 1.5.1.*** For saline water, volumes discharged at the surface exceeded water diverted from external sources. For fresh/brackish water, volumes diverted from external sources exceeded what was discharged at the surface.

***Finding 1.5.2.*** Net withdrawal of fresh/brackish water for the O&G industry is less than 0.1% of all water applied for human use in a hydrologic region.

***Conclusion 1.5.*** The O&G industry is a net generator of saline water and a net consumer of fresh/brackish water.

**FCR 1.6. Facilitating assessment of regional water impacts** *(Chapter 1, Section 1.3.1)*

***Finding 1.6.*** Hydrologic region can serve as a reasonable framework for assessing water budgets, but hydrologic region is not reported as a variable in the SB 1281 dataset.

***Conclusion 1.6.*** Without hydrologic region reported, the SB 1281 dataset structure and data quality do not facilitate assessment of regional water availability and quality.

***Recommendation 1.6.1.*** The SB 1281 dataset should be expanded to denote hydrologic region of each lease.

***Recommendation 1.6.2.*** To enable the assessment of regional water availability, The Division quarterly summary reports should be expanded to provide use, reuse, sources, and destinations of water as a function of hydrologic region.

**FCR 1.7. Data quality, organization, and reporting requirements in the SB 1281 dataset** *(Chapter 1, Section 1.4)*

***Finding 1.7.*** There were a large number of data quality problems in the SB 1281 dataset. Examples include:

- Much of the water quality reporting did not appear credible when considering the source or destination of the water, such as saline water from a municipal water supplier, or saline water discharged for agriculture and recharge.
- Blank fields could signify zeroes, not applicable, or failure to report.
- Multiple source and destination categories were vaguely defined or aggregated in groupings that are very different.
- Text fields with slight variants or misspellings (i.e. Smith Corp., smith corp., Smith corporation, and Smith corpration) created unintentional mismatches in the dataset.
- Invalid data entries, such as data of the wrong value type or outside the range of possible values, caused loss of information.

***Conclusion 1.7.1.*** Data quality problems made accurate analysis challenging. In particular, water quality reporting that seems illogical undermines the ability to accurately assess impacts to water resources. Simple data validation fixes could make accurate analysis easier and faster.

***Recommendation 1.7.1.*** Zero values should always be actively reported (not left blank) to enable accurate calculations of means.

***Recommendation 1.7.2.*** Source and destination categories should be better defined to better elucidate the industry's impact on water resources.

***Conclusion 1.7.2.*** The SB 1281 dataset could be improved with certain changes in data quality assurance to reduce the errors in the final dataset. Specific recommendations follow:

***Recommendation 1.7.3.*** Update the terms and definitions for sources and destinations to better describe and distinguish the categories as described in Appendix 1.1. Key points to consider in renaming sources and destinations: a) "Domestic Use" should not be used to refer to reuse for agriculture or recharge; b) Oceans and surface water should be distinguished in sources and destinations, given the large quality differences; c) Constrain the definition of the "Other" category such that it explicitly excludes reporting water that could be reported in another, better-defined category; d) Create separate categories for injection in disposal wells versus injection in EOR wells; and e) Treat storage as a source and a destination, not a separate variable.

***Recommendation 1.7.4.*** Reducing the number of sources and destinations reported by field would simplify reporting without functional loss of important information. For instance, Source 10, "Other Class II Recycled fluid source," along with Source 11, "Recycled Class II fluids from operator's drilling," and Source 5, "Industrial Waste – Class II fluid treated by 3rd party" could become one source defined simply as "Class II Fluids (other than produced water)."

***Recommendation 1.7.5.*** Add columns to the reports to allow more detailed reporting on the identity and location of the source and destination. For example, external sources (such as municipal suppliers and municipal wastewater) should provide names of public water systems and their associated Public Water System Identification Number (PWSID), the tracking identification number used by the State Water Board. Discharges should identify the relevant permit, if applicable. Discharges to municipal wastewater systems should include PWSID.

***Recommendation 1.7.6.*** Limit invalid data entry by requiring operators to choose from a drop-down list where appropriate and restrict the ability to leave fields blank. There should be pre-defined options for every field. Most text entry fields, such as operator and field names, should be selected from a drop-down menu to prevent alternative spellings.

***Recommendation 1.7.7.*** Enact mechanisms to distinguish between zero, not applicable, and failure to report. All fields should require the reporter to select an option before submitting the report. If an operator fails to report information, that should be noted as "failure to report" in the master dataset, rather than blanks.

***Recommendation 1.7.8.*** Beta test the form to observe how operators interpret the form. This would enable The Division to find opportunities to clarify the form.

***Recommendation 1.7.9.*** Perform selective ground-truthing on the information reported in the dataset. Reports of large volumes of saline water from a water well, municipal water supplier, or municipal wastewater, as well as substantial discharges of saline water, should be flagged for closer inspection to verify that the reporting is accurate. Independent datasets on groundwater quality, such as GeoTracker GAMA, could be used to validate the SB 1281 dataset.

***Recommendation 1.7.10.*** Perform further, in-depth data validation between information reported in the SB 1281 dataset and in the monthly dataset, and compare volumes reported for well stimulation with those reported in SB 4.

**FCR 2.2. SB 1281 Destination Codes** *(Chapter 2, Section 2.4)*

***Finding 2.2.1.*** The current destination code of Agriculture and Recharge does not distinguish between direct and indirect reuse for agriculture.

***Finding 2.2.2.*** From our inspection of WDRs/NPDES permits, we observed that this destination code was used for a wide variety of discharges. A few operators appear to be reporting what happens to the water one or more steps downstream, rather than simply reporting what happens to the water at the moment it leaves their custody.

***Finding 2.2.3.*** Direct reuse for irrigation provides a more direct pathway of exposure for soil, crops, and human health than indirect reuse.

***Conclusion 2.2.1.*** It is important to differentiate between direct and indirect reuse of produced water. Direct and indirect reuse are not mutually exclusive, making it difficult to distinguish them with a single reporting code.

***Recommendation 2.2.1.*** To distinguish between direct and indirect produced water reuse applications SB 1281 should eliminate the Agriculture and Recharge code and replace it with three codes: “Water Supplier,” “Agriculture,” and “Groundwater Recharge.” If a discharge requires a permit, the operator should report such in a separate field associated with that discharge.

***Recommendation 2.2.2.*** Operators should be responsible only for reporting what happens to the water at the moment it leaves their custody. The eventual fate of produced water after it leaves the hands of the operator should be traced via the permit, not the SB 1281 dataset.

**FCR 2.3. Potential for expanded reuse of produced water for irrigation** *(Chapter 2, Sections 2.5.1, 2.5.2)*

***Finding 2.3.1.*** According to the SB 1281 dataset, 11,337 AFY of fresh/brackish water (≤ 10,000 mg/L TDS) not currently reused by agriculture was produced in the five major basins between 2015 Q4 and 2017 Q1.

***Conclusion 2.3.1.*** Based solely on the criterion of having a TDS of < 10,000 mg/L, there may be as much as 11,337 AFY of fresh/brackish water available for reuse outside of the O&G industry.

***Conclusion 2.3.2.*** The water quality information in the SB 1281 dataset is inadequate for a complete assessment of water suitability for agricultural reuse intended by the SB 1281 legislation. Additional water quality data are needed to better characterize the potential for expanded reuse of produced water for irrigation.

***Recommendation 2.3.1.*** The Division should carry out the intent of SB 1281 to track water “suitable for domestic or irrigation purposes” by more accurately capturing relevant water quality parameters; at a minimum, quantitative TDS concentrations should be reported. Boron and SAR concentrations are also important for determining irrigation suitability.

***Finding 2.3.2.*** Information to assess the potential for expansion of produced water for reuse was limited.

***Finding 2.3.3.*** Based on available water quality data beyond the SB 1281 dataset, we estimate that there is approximately 64,000 AFY of additional produced water available for expanded reuse with minimal treatment. This potential resource originates from eight fields, all within the San Joaquin basin.

***Finding 2.3.4.*** Where data were available, we found modest potential for expansion outside of the O&G industry for reuse by the agricultural industry. Of the eight fields where data supported a potential for reuse of produced water for agriculture, five currently have known permitted operations for agricultural reuse.

***Recommendation 2.3.2.*** Where there are indications of substantial volumes of produced water with TDS values feasible for reuse, from fields that are in proximity to agricultural regions, the Division should commission a study to conduct a detailed assessment of reuse potential. Such an assessment would evaluate the quality of water produced from each pool in a field for, at a minimum, boron and SAR concentrations; and potentially might consider other analytes of concern for soil and crop health identified in the United Nations Food and Agriculture Organization guidelines (Table 2.3).

***Finding 2.3.5.*** Produced water for reuse is typically obtained from centralized water-handling facilities.

***Conclusion 2.3.3.*** Sampling and reporting requirements for SB 1281 could be simplified by allowing operators to report water quality at centralized water handling facilities when commingled water shows little variation in parameters of interest.

***Recommendation 2.3.3.*** Water samples for assessing quality for agricultural reuse should be obtained from centralized water-handling facilities; in cases where there is significant variability in TDS (or EC), boron, and the SAR between wells, these samples should be taken from single wells.

***Recommendation 2.3.4.*** Research should be undertaken that provides a greater understanding of the technical and economic reuse potential for produced water in California. The study should assess the quality of produced water in alignment with accepted guidelines for irrigation water, as well as the economic cost-benefit analysis of treating and transporting produced water, taking into consideration local conditions.

**FCR 3.1. Produced water quality in California** *(Chapter 3, Section 3.2)*

***Finding 3.1.1.*** Salinity is reported in SB 1281 as above or below 10,000 mg/L TDS. With the exception of salinity, produced water quality parameters are not reported to SB 1281.

***Finding 3.1.2.*** Chemical constituents that are or may be in produced water (e.g., residual petroleum hydrocarbons, chemical additives, geogenic compounds, daughter products, and degradation byproducts of chemical transformations) are not required to be reported to SB 1281.

***Conclusion 3.1.1.*** SB 1281 is inadequate in reporting water quality parameters.
An understanding of produced water quality is essential to assess the potential for environmental and human health hazards, risks and impacts associated with produced water, to inform produced water management, and to identify opportunities for reuse outside of the oilfield.

***Recommendation 3.1.1.*** Require the SB 1281 dataset to include reporting of actual TDS measurements for all produced water at the level of the oil-water separator or similar point of aggregation.

***Recommendation 3.1.2.*** Priority water quality parameters and other approaches to water quality monitoring should be identified by a convened group of human and environmental health scientists with expertise in produced water quality and human and environmental health.

***Recommendation 3.1.3.*** SB 1281 should require reporting of all priority health- and environmentally-relevant water quality parameters for produced water discharged to the surface (e.g., to agricultural irrigation and unlined produced water ponds).

**FCR 3.2. Spatial tracking of produced water from production to disposal and reuse** *(Chapter 3, Section 3.2)*

***Finding 3.2.*** The SB 1281 dataset includes water disposition categories that are informative, but produced water disposition reporting lacks adequate spatial resolution. For instance, it may be reported that produced water from a given well in a particular oilfield and production zone was sent to an unlined produced water pond facility, but which pond facility is not clear.

***Conclusion 3.2.*** The lack of spatially-explicit tracking of produced water in the SB 1281 dataset makes it difficult to assess and manage potential environmental, ecological, and human health hazards risks and impacts, at spatial scales relevant to human and environ***mental exposures.***

***Recommendation 3.2.*** Update the SB 1281 dataset requirements to enable regulators to trace the geographic and geological source and fate of produced water to support assessments of environmental and exposure pathways, particularly for produced water discharged to the surface. For example, the use of unique spatial identifiers should be considered: these could include latitude and longitude coordinates for specific produced water pond facilities or water recipient facility locations where water is intended for reuse (e.g. agricultural irrigation).

**FCR 3.4. Chemical use in oil and gas operations** *(Chapter 3, Section 3.4)*

***Finding 3.4.1.*** The SB 1281 dataset lacks the water quality information necessary to conduct quantitative risk assessments. However, other publicly available datasets can be used in concert with the SB 1281 dataset to assess produced water quality, including chemical additives disclosed as used in O&G operations.

***Finding 3.4.2.*** Chemical additives reported to be used in O&G operations cannot always be identified, and when they can be, they may not be well-described. In datasets supplemental to the SB 1281 dataset, 630 unique chemical additives were identified as used in oil and gas wells and associated operations in California from 2011 – 2018. Nearly half of the disclosed chemical additives could not be definitively identified due to lack of a unique Chemical Abstract Service Registry Numbers (CASRNs). An analysis of available physical, chemical, and toxicological properties of identified chemicals used in O&G operations in California shows that many are poorly characterized and lack important data required to assess health hazards, treatment potential, and environmental fate and behavior.

***Conclusion 3.4.1.*** Available chemical data suggest there are aquatic, air pollution, and carcinogenic chemical hazards associated with produced water in California.

***Conclusion 3.4.2.*** Chemical additives that are not disclosed using CASRN cannot be definitively identified and cannot be evaluated in terms of their potential human health and environmental hazards, risks, and impacts. Available chemical data suggest that there are potential human and ecological health risks associated with produced water where exposure pathways exist.

***Recommendation 3.4.*** All chemical additives used in any type of O&G operation—not just for well stimulation—in California should be required to be disclosed to a publicly available, digitized database. Agencies with jurisdiction could consider phasing out the use of chemicals or chemical mixtures whose identities cannot be verified or disclosed. Submitted data including chemical names, CASRN, and usage data (frequency, mass, or concentration) should be validated and verified. Environmental and toxicological profiles should be developed for chemical additives and, to the extent possible, chemical additive mixtures used in O&G operations that lack any publicly available information.

**FCR 3.5. The SB 1281 dataset on produced water treatment categories** *(Chapter 3, Section 3.5)*

***Finding 3.5.1.*** The treatment categories used in the SB 1281 dataset are not sufficiently specific; they do not provide the detail necessary to determine which treatment process is being applied. Thus, treatment level cannot be accurately assessed in the context of responsible produced water beneficial reuse potential.

***Conclusion 3.5.1.*** More detailed and specific reporting regarding treatment technologies and treatment trains is required for risk management of produced water, in particular produced water that is discharged to the surface and reused outside of the oilfield.

***Recommendation 3.5.1.*** The SB 1281 dataset on treatment should be modified to require detailed information on the specific treatment process or processes used. The current categories are overly broad and should be abandoned and replaced by detailed descriptions of the actual treatment technology applied (e.g., three-phase separator, WEMCO, ion exchange, walnut-shell filters). The sequence of technologies used to treat produced water should be identified, especially for produced water that is discharged to the surface or reused outside of the oilfield.

***Finding 3.5.2.*** No one treatment technology can be expected to adequately remove all potential chemicals of concern that can exist in produced water, but treatment trains can be developed for functionally complete treatment. Of the screened technologies, reverse osmosis and biological treatment have the greatest potential to treat chemical additives of concern that may be found in produced water intended for reuse outside of the oilfield.

***Conclusion 3.5.2.1.*** Certain chemical constituents are well-proven to be removed by state-of-the-art physical, chemical, and biological treatment approaches. However, some chemical additives reported as used in O&G development operations in California are not expected to be effectively removed by commonly-used physical, chemical, and biological treatment technologies.

***Conclusion 3.5.2.2.*** Further research and applied investigations are warranted to assess the efficacy of removal of chemical additives and other chemical constituents, particularly for applications of produced water discharged and reused at the surface.

**FCR 3.6. Evolving chemical landscapes and produced water reuse** *(Chapter 3, Section 3.6)*

***Finding 3.6.1.*** Produced water quality is highly heterogeneous across geographic and geological space and operators use a wide variety of chemical additives in their operations. While disclosure of chemicals is expected to result in significantly more information about chemical use, questions remain as to how these chemicals may transform under high temperature and pressure and in the presence of other chemical constituents in oilfield reservoirs and associated processes.

***Finding 3.6.2.*** Produced water can meet traditional water quality standards and still pose toxicological, mutagenic, and carcinogenic risks when there is a human or ecological exposure pathway. These mechanisms are difficult to ascertain without non-targeted or bioanalytical testing.

***Conclusion 3.6.*** Answering questions of produced water quality and associated public health and ecological risks is aided, but not satisfied by, chemical disclosure. While pollutant-by-pollutant chemical disclosure and monitoring is important, produced water reuse outside of the oilfield with human and ecological exposure potential could benefit from more holistic approaches to water quality testing (e.g., non-targeted chemistry and cell line assays) that are not directly focused on understanding all of the chemicals in the mixture. Existing water reuse frameworks that address evolving chemical landscapes (e.g., municipal wastewater) may inform produced water treatment, monitoring, and management.

***Recommendation 3.6.1.*** Agencies with jurisdiction should ensure that the best available research informs their regulations. To this end, they should convene water quality and public health experts to conduct non-targeted water quality research on produced water that is currently or is being considered to be reused outside of oilfields with potential human and ecological exposure pathways (e.g., agricultural irrigation).

***Recommendation 3.6.2.*** More holistic approaches to water quality testing (e.g., non-targeted chemistry and cell line assays) could be integrated into produced water discharge permit requirements as is being considered for municipal wastewater recycling for potable reuse.

**FCR 4.1. Reporting of disposal volumes into unlined produced water ponds pursuant to SB 1281** *(Chapter 4, Section 4.2)*

***Finding 4.1.1.*** Reporting pursuant to SB 1281 indicates that 3,182 AFY of produced water is currently disposed into unlined produced water ponds in the San Joaquin Valley.

***Finding 4.1.2.*** A review of discharge records at the McKittrick 1 & 1-3 Facility (a single facility) indicates that on average 3,152 AFY is disposed into unlined produced water ponds at this facility.

***Conclusion 4.1.*** Because there are numerous active facilities of comparable size to the McKittrick 1 & 1-3 Facility in the San Joaquin Valley, including the McKittrick 1-1 Facility where 1,059 AFY of produced water is currently disposed into unlined produced water ponds, the accuracy of reported volumes pursuant to SB 1281 is in question.

***Recommendation 4.1.*** All facility records should be reviewed to verify that reporting under SB 1281 accurately reflects volumes of disposal of produced water into unlined produced water ponds in the San Joaquin Valley.

**FCR 4.3. Spatially-explicit information for produced water ponds: risk assessments** *(Chapter 4, Section 4.2)*

***Finding 4.3.1.*** The overall volume and categorical disposition (e.g., reuse, disposal) of produced water is currently reported under SB 1281, but not the spatially-explicit destination.

***Conclusion 4.3.1.*** Without spatially-explicit destination information, it is not possible to trace produced water from a particular oil field or formation to a particular produced water pond, and volumes of produced water discharged to a particular unlined produced water pond cannot be ascertained.

***Recommendation 4.3.1.*** Data reported under SB 1281 should include spatially-explicit destination information (e.g., facility name and latitude/longitude) in addition to disposition of produced water to improve the ability to assess the risk posed to groundwater resources from disposal of produced water into unlined produced water ponds.

***Finding 4.3.2.*** Potential impact to groundwater resources from disposal of produced water into unlined produced water ponds is, in part, a function of annual and cumulative discharge volumes and the quality of discharged produced water.

***Conclusion 4.3.2.*** Though this information is necessary to assess potential impacts of discharging to unlined ponds, data reported to SB 1281 is currently not useful to determine annual or cumulative discharge volumes to individual produced water pond facilities.

***Recommendation 4.3.2.*** Annual and cumulative discharge volumes should be assessed at active produced water pond facilities.

**FCR 4.4. Produced water ponds are in areas that have groundwater that is or could be fit for agricultural, municipal, or domestic use** *(Chapter 4, Section 4.3)*

***Finding 4.4.1.*** Reporting pursuant to SB 1281 provides information on the locations of produced water ponds and the volumes of produced water disposed in unlined produced water ponds in general.

***Finding 4.4.2.*** Groundwater resources that are or could be used for agricultural, municipal, or domestic use exist in areas of unlined produced water ponds in the central, northwestern, and eastern portion of the Tulare basin. Groundwater resources that could be treated for these uses exist in the western portion of the Kern County subbasin of the Tulare basin. With the exception of the eastern portion of the Tulare basin, where deep groundwater resources are present, groundwater resources having beneficial use appear to be limited to surficial (less than 300 m in depth) deposits.

***Conclusion 4.4.1.*** Due to their shallow depth, many groundwater resources in the Tulare basin with potential for beneficial use may be particularly vulnerable to contamination from unlined produced water ponds.

***Conclusion 4.4.2.*** Discharge of produced water into unlined produced water ponds poses risks to groundwater resources that are currently used or could be used in the future for beneficial purposes.

***Recommendation 4.4.1.*** Agencies with jurisdiction should continue to investigate the use of produced water ponds and require appropriate testing and treatment of any water discharged into produced water ponds.

***Recommendation 4.4.2.*** These agencies should develop a risk prioritization system to designate which unlined produced water ponds require in-depth, site investigations to determine the nature and extent of historical, current, and future impacts from the discharge of produced water. Such a risk prioritization should start with produced water ponds having the greatest present or past cumulative discharge volumes and should also include criteria such as the presence of groundwater resources having agricultural, municipal or domestic uses or potential for use with treatment.

***Recommendation 4.4.3.*** For high-priority produced water ponds, a facility-by-facility assessment should be undertaken to determine where impacts to groundwater resources have already occurred or are likely to occur if the practice continues.

***Recommendation 4.4.4.*** Agencies with jurisdiction should promptly ensure through appropriate testing and treatment that any water discharged into produced water ponds does not contain concentrations of chemicals related to oil and gas development that could impact groundwater resources. Given the potential for impact to groundwater resources, it may be advantageous for these volumes to decrease over time and the agencies with jurisdiction should thoroughly consider alternatives to this practice in the future.

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AN ASSESSMENT OF OIL AND GAS
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California Senate Bill 1281
(Executive Summary)
California Council on Science and Technology • August 2019