OIL, FOOD, AND WATER: Challenges and Opportunities for California Agriculture

Matthew Heberger and Kristina Donnelly

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Pacific Institute
654 13th Street, Preservation Park
Oakland, California 94612
Phone: 510.251.1600 | Facsimile: 510.251.2203
www.pacinst.org

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Cover photo: Oil well surrounded by an almond orchard in Kern County in the southern San Joaquin Valley. In addition to being prime agricultural land, this area is also part of the Semitropic Oil Field.

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ABOUT THE AUTHORS

MATTHEW HEBERGER

Matthew Heberger is a senior research associate in the Pacific Institute's Water Program, where he conducts research on water resources policy, planning, and management. In the last 18 years he has worked on water issues as a hygiene and sanitation educator in West Africa, consulting engineer, and policy analyst in Washington, D.C., and in California. Matthew holds a B.S. in Agricultural and Biological Engineering from Cornell University and received a master's degree in Water Resources Engineering from Tufts University.

KRISTINA DONNELLY

Kristina Donnelly is a Research Associate with the Water Program. Kristina works primarily on U.S. water governance and policy. Prior to joining the Institute, Kristina worked for the Arava Institute for Environmental Studies, conducting transboundary water research and organizing educational programs for students and professionals. Before that, she was selected as the 2008/09 Sea Grant Fellow with the Great Lakes Commission in Ann Arbor, Michigan. Kristina received a B.S. in Mathematics from American University and a M.S. in Natural Resources and Environment from the University of Michigan.

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EXECUTIVE SUMMARY

California is a major producer of agricultural products consumed in the United States and around the world. At the same time, the state is one of the nation's largest producers of oil and gas. Both industrial sectors face growing competition and risks related to water availability and quality. Oil and gas production is concentrated in arid areas of the state, where it may compete for water with agricultural, municipal, or domestic water users. Further, pollution due to spills, leaks, or disposal of oil-field wastes can contaminate the soil and water resources used by agriculture. There is also growing interest among irrigators and water managers in reusing oil-field wastewater for agriculture and food production. However, there has been little review or analysis of the water-related interactions between oil and gas production and agriculture.

Oil and gas exploration and production have the potential to affect California's agricultural and food systems, from farmworkers to consumers of agricultural products. In this analysis, we describe some of the water-related challenges that arise when these industries operate alongside one another. We also explore concerns related to emerging issues such as hydraulic fracturing, known as fracking. Below, we present our main findings and provide recommendations to better protect the safety of California's agriculture and food supply.

FINDING 1:

The disposal of oil-field wastewater in unlined percolation pits poses a significant risk of contaminating groundwater resources that may, in turn, be used by agriculture. While this practice has been banned in several states, it is still widely used in California.

Evaporation and percolation of oil and gas wastewater in unlined pits is the second most common disposal method in California. In 2013, an estimated 18% of oil-field wastewater, or 24 billion gallons, was disposed of in unlined percolation pits. Some of this wastewater was from oil wells that had been hydraulically fractured, increasing the risk that fracking chemicals could contaminate soil and water. As of early 2015, an estimated 933 unlined percolation pits were thought to be in use in California. Most of these are in Kern County, although there are unlined pits in several other counties, including Monterey and Santa Barbara counties on the central coast, and San Benito, Tulare, Fresno, and Kings counties in the Central Valley. The use of unlined percolation pits is of particular concern when the wastewater seeps downward into groundwater near agricultural areas. Even old percolation pits that are no longer in use can contaminate soil and groundwater when rain or irrigation water seeps through surface layers and carries pollutants into shallow groundwater. Many states have banned the use of unlined percolation pits for the disposal of oil and gas wastes; among them were Texas in 1969, Ohio in 1985, and New Mexico in 2008.

Recommendation 1(a): California should follow several of the largest oil-producing states in phasing out the use of unlined percolation pits. Even old percolation pits that are no longer in use can contaminate soil and groundwater when rain or irrigation water seeps through surface layers and carries pollutants into shallow groundwater.

Recommendation 1(b): The state should require cleanup of existing sites, where necessary, and require long-term monitoring of pollution that may migrate in groundwater.

FINDING 2:
There are serious deficiencies in the way California regulates underground injection of oil and gas wastewater. In particular, wastewater has been injected in potential underground sources of drinking water, irrigation water, and water for livestock.

Underground injection is the most common disposal method for oil-field wastewater in California—with 80 billion gallons, or 60%, of the wastewater produced injected underground in 2013. With proper siting, construction, and maintenance, subsurface injection is thought to be less likely to result in groundwater contamination than disposal in unlined percolation pits. However, there are significant concerns about whether California's regulations, or the state's Underground Injection Control (UIC) Program, are adequately protective of groundwater aquifers that could be used as drinking water supplies or for agricultural irrigation. The extent of this threat to California's groundwater is not well understood because the state does not monitor groundwater to detect contamination from injection wells, nor does it require well operators to do so. California regulators are currently attempting to address shortcomings in the state's underground injection program, including closing inappropriately-sited injection wells and strengthening regulations to protect brackish groundwater. For the last 30 years, California has failed to enforce the federal law that restricts injection in aquifers where the concentration of total dissolved solids (TDS) is less than 10,000 milligrams per liter (mg/L).

Recommendation 2(a): The state should require oil companies to clean up contamination from injection wells that have failed.

Recommendation 2(b): Regulators should revisit old injection permits that were issued without an appropriate "area of review" calculation to determine the zone that would be affected by injection wells.

Recommendation 2(c): Given the potential to desalinate brackish groundwater to provide for agriculture and community water needs, policymakers should consider imposing more protective standards for brackish water above the federal requirement that requires protecting aquifers with total dissolved solids (TDS) of up to 10,000 parts per million.

FINDING 3:
Hundreds of chemicals are used in or produced from oil and gas exploration and production, many of which are harmful or have an unknown effect on livestock, crops, and farmworkers.

Oil and gas production generates several kinds of liquid waste, including drilling mud and produced water. Drilling mud is composed of drilling fluid, water, petroleum, and naturally-occurring constituents in the formation, as well as other chemicals and materials used in the drilling process. Produced water can contain elevated concentrations of minerals, metals, petroleum hydrocarbons, volatile organic compounds, radionuclides, and man-made chemicals used for hydraulic fracturing and other operations. If not properly treated or disposed of, chemicals in these wastes pose threats to agriculture, human health, and the environment.

Recommendation 3(a): Where exposure pathways to humans or sensitive environments exist, oil and gas companies should eliminate or seek to minimize the use of hazardous chemicals that do not biodegrade or otherwise become immobilized.

Recommendation 3(b): The state should require oil and gas operators to disclose all chemicals that are injected into wells, including during drilling, well cleanout and maintenance, hydraulic fracturing, acid stimulation, and enhanced oil recovery.

Recommendation 3(c): State regulators should limit or eliminate the use of chemicals with suspected but unknown health impacts pending further study.

Recommendation 3(d): The chemical and petroleum industries should fund independent scientific studies to increase understanding of the health and environmental impacts of those chemicals whose impacts are not known, especially those that remain in waters after hydraulic fracturing and other oil-field operations. Priority research should focus on a handful of chemicals in produced water with known or suspected health impacts and should study their uptake in food crops to determine whether there are pathways by which people are exposed to dangerous chemicals in the food they consume. Until the health and environmental impact of a chemical is understood, state oil and gas regulators should not allow its use.

FINDING 4:
Federal regulations for toxic chemicals and waste handling are outdated and inadequate to protect human health, the environment, and the safety of our food supply.

The oil and gas industry has a number of important exemptions under federal environmental laws that prevent tracking of wastes and controlling pollution. The main federal law regulating the use of chemicals is the Toxic Substances Control Act of 1976 (TSCA. Unlike European law, TSCA does not require companies to test chemicals for their toxicity or conduct a risk assessment when a new chemical is introduced. For years, environmentalists, public health activists, and the chemical industry itself have pointed out the shortcomings in the law and advocated for its reform. Reforming TSCA is a stated priority of the Obama administration, and in 2015, various bills were introduced in Congress to amend it, but none passed. Among other things, meaningful reforms would make more information available on the environmental and health effects of chemicals used by industry, including oil and gas exploration, and support the use of safer chemicals.

Recommendation 4(a): Congress should pass meaningful reform of the Toxic Substances Control Act of 1976, the main federal law regulating the use of chemicals. Meaningful reforms would make more information available on the environmental and health effects of chemicals used by industry, including oil and gas exploration, and support the use of safer chemicals.

Recommendation 4(b): Congress should amend the Resource Conservation and Recovery Act to end the exemptions for oil-field wastes from being regulated as toxic chemicals. Most oil-field wastes contain hazardous chemicals as defined in the Act and regulating them as such would help ensure their safe handling and disposal.

Recommendation 4(c): Congress should close the loophole in the Safe Drinking Water Act that exempts hydraulic fracturing chemicals from the regulation under the Act. This would allow state and federal governments to regulate these chemicals where they may affect drinking water sources.

Recommendation 4(d): Congress should pass federal legislation clarifying the ability of the Bureau of Land Management (BLM) to regulate hydraulic fracturing on federally-owned lands.

FINDING 5:
Idle, orphaned, and abandoned wells can allow oil, wastes, and chemicals to move into soil and groundwater, posing a largely hidden threat in agricultural regions near or overlapping with oil and gas production.

Across the state, there are more than 21,000 idle wells that have not been in use in more than six months and 110 "orphaned wells" whose owner is unknown. Further, there are an unknown number of abandoned water wells in and near oil- and gas-producing regions. Old wells that have not been properly sealed can allow contaminants to travel from deep underground into soils or freshwater aquifers. Even wells that have been properly plugged can become pathways for pollutants to contaminate soil and water due to degradation of cement or casings, for example, as a result of faults or compaction. This may be an even larger potential problem in California, because there are almost 116,000 old wells listed by the state as having been plugged and abandoned.

Recommendation 5(a): To prevent contamination of near-surface groundwater resources, the state should ensure that idle wells are closed down and sealed properly.

Recommendation 5(b): Regulators should examine whether current bonding requirements are sufficient to cover the costs of well closure and any cleanup of contamination caused by abandoned or orphaned wells.

Recommendation 5(c): The legislature should ensure that impact fees on oil and gas production are sufficient to fund the closure of orphaned wells and cover other costs of programs to mitigate air and water pollution caused by the industry.

Recommendation 5(d): The state should conduct an assessment of the over 116,000 plugged and abandoned oil and gas wells to determine which of these, if any, pose a risk to freshwater aquifers, and take appropriate steps to alleviate the threat of contamination.

FINDING 6:
There is growing potential for competition for water between oil and gas companies and farming communities, and concern that the use of this water by the oil industry will drive up the price that farmers pay for irrigation water.

Water is used throughout the oil and gas exploration, drilling, and production process. One of the largest uses of water in petroleum production is for enhanced oil recovery (EOR), which includes techniques, such as water flooding and steam flooding, in which water is injected into oil-bearing formations to increase the flow of oil toward a well. Water is also used as the base fluid for hydraulic fracturing, acid stimulation, and other well stimulation techniques. We estimate that oil companies use between 12,000 and 49,000 acre-feet of freshwater annually for enhanced oil recovery. Water use for well stimulation in California is considerably lower, at 700 to 900 acre-feet per year, with 90% of this being freshwater. Much of this water use is occurring in water-scarce regions of the state and competes directly with agricultural water users.

Recommendation 6(a): Oil and gas companies should reduce or eliminate their use of freshwater that could otherwise be put to agricultural or municipal uses. Companies can do this by increasing the amount of water that they treat and recycle onsite, or by using recycled wastewater from cities or other industries.

Recommendation 6(b): The legislature can support this by declaring that freshwater use for oil and gas production does not constitute a "reasonable use" where recycled water use is available. Similar legislation was passed in 2010, declaring the use of potable water for landscape irrigation as a waste or unreasonable use of water if recycled water is available.[1]

FINDING 7:
There is an opportunity to expand the recycling of oil-field wastewater for "beneficial uses," such as for crop irrigation or livestock watering. However, the health and food safety impacts of this practice are poorly understood.

In drought-prone California, irrigators and water managers are increasingly looking at wastewater from oil fields as a potential resource. In California, wastewater from five oil fields—Deer Creek, Jasmin, Kern River, Kern Front, and Mount Poso—is treated and reused for irrigation. Scientists should conduct a study to determine what level, if any, of chemicals in oil-field wastes is safe for farmworkers, animals, and consumers. Such a study should be performed by an independent science panel, and would help to reduce the uncertainties around the safety of this practice.

Recommendation 7(a): The state should develop a uniform set of guidelines for the reuse of oil and gas wastewater, similar to the Title 22 regulations for the reuse of treated sewage. This should include commissioning an independent scientific study to determine what level, if any, of chemicals in oil-field wastes are safe for farmworkers, animals, and consumers. This study could help identify any health or environmental issues associated with this practice, establish clear guidelines for water treatment and testing, and help reduce the fear, uncertainty, and doubt that currently surround the practice.

Recommendation 7(b): An independent scientific assessment of the safety of oil-field wastewater should include an assessment of whether contaminants can bioaccumulate in meat, eggs, or dairy products, and what the possible health impacts of this are. A useful parallel can be seen in the methods used by the FDA and NOAA to test seafood following oil spills, for example the 2010 Deepwater Horizon accident in the Gulf of Mexico. This risk-based approach is based on limiting consumption to levels that avoid cancers and chronic health effects.

Recommendation 7(c): The state should establish uniform and science-based water quality criteria and monitoring requirements. Regional water boards should not issue new permits for the reuse of oil-field wastewater for irrigation until the risks have been comprehensively assessed and appropriate monitoring and reporting requirements put in place. Water quality criteria and monitoring requirements should be designed to protect farmworkers as well as consumers.

1 California Water Code, Section 13550-13557.

Recommendation 7(d): Oil companies that provide water for irrigation should be required to provide a list of all chemicals used in the drilling, stimulation (if applicable), maintenance, and production process in oil fields to their Regional Board and the water utility. This step that should be implemented immediately to help inform concerned growers and consumers about potential hazards, and discourage the use of dangerous chemicals in areas where water will be reused to irrigate food crops.

Recommendation 7(e): U.S. EPA should conduct a scientific analysis to re-examine whether the requirement that oil-field wastewaters for wildlife and agricultural uses must not have more than 35 mg/L of oil is sufficiently protective of the food supply, farmworkers, and the environment.

FINDING 8:
Pollution from past oil and gas exploration and production and waste disposal exist in the soil and groundwater throughout the state, often very near or upstream from agriculture. The full extent of "legacy pollution" is poorly understood.

Until 2013, oil companies in the Central Valley could legally dump drilling mud containing chemicals on land without reporting and without a permit. In 2013, the Central Valley water board allowed the waiver to expire under pressure from advocacy groups that raised concerns about the health and environmental risks of this practice. While the practice has been disallowed, there are a number of locations where drilling mud has been dumped on farm fields through 2013 and where farmers have planted crops above buried pits.

Recommendation 8(a): Oil and gas companies should be required to conduct testing and remediation of soil in areas where drilling mud disposal has occurred.

Recommendation 8(b): Industry and water quality regulators should catalog and map the locations of drilling mud disposal areas and make this information publicly available, so that farmers are aware of the potential risk when deciding to farm that land or utilize local groundwater.

FINDING 9:
Missing and inaccurate data prevent better understanding the fate of oil-field wastes.

In their submissions to DOGGR, oil and gas companies reported the disposal method for 18% of oil and gas wastewater (over 25 million gallons) as *other, missing,* or *unknown*. Incomplete and inaccurate reporting prevents the public and regulators from understanding the fate and transport of oilfield wastes and their potential impact on the environment and public health.

Recommendation 9(a): DOGGR should better verify the data submitted by oil and gas companies on wastewater handling and its disposition to ensure that it is complete and accurate. These data should be expanded to include details on water recycling and beneficial reuse.

FINDING 10:
In areas where agriculture and oil production overlap, farmworkers are among the most vulnerable to the health effects of air and water pollution.

Those who live and work in rural communities where oil and gas extraction take place bear the most direct burden from air, water, and soil contamination. In areas where oil and gas wastewater is used to irrigate crops, farmworkers may be exposed to harmful chemicals through direct contact with irrigation water or through volatilization of chemicals from water. Additionally, in some rare cases, farmworkers may be exposed to chemicals if they drink irrigation water, which may be necessary if growers or labor companies fail to provide clean drinking water. Contaminants from oil and gas production also contribute to air pollution, another health threat facing farmworkers and local residents.

Recommendation 10(a): In areas where farmworkers may be exposed to oil-field wastes in air, soil, or water, regulators should analyze the associated health risks and, if important exposure pathways are found, identify how to avoid or lessen workplace exposures. In particular, regulators should do more to measure and enforce air quality limits on volatile compounds that can contribute to asthma and respiratory problems.

Recommendation 10(b): The Division of Occupational Safety and Health (Cal/OSHA) should require employers to analyze potential chemical hazards and communicate these hazards to employees. Such an analysis could reassure farmworkers if it revealed there were no health or safety concerns or lead to new regulatory protections if hazards are identified.

INTRODUCTION

Both oil and agriculture play central roles in the history, culture, and economy of California. The state is among the most productive agricultural regions in the world, producing nearly 400 different agricultural commodities. California growers supply about half of the fresh fruits, vegetables, and nuts eaten by Americans, including some crops which are not grown commercially elsewhere in the United States, such as almonds, artichokes, dates, figs, raisins, kiwis, and olives (California Department of Food and Agriculture 2014). Additionally, California provides products for the international market, accounting for 15% of the nation's total value of agricultural exports.

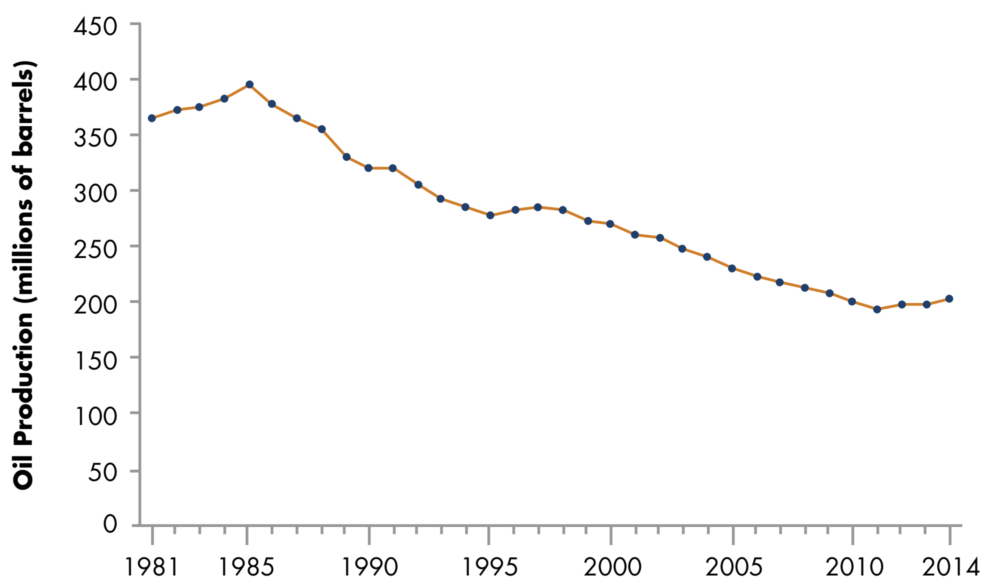
California is also a major producer of crude oil. Oil production in California peaked in the mid-1980s at nearly 400 million barrels per year and has steadily declined to its current level of 200 million barrels per year (Figure 1). Despite this decline, California accounts for 6.4% of the crude oil produced in the United States and is the third-largest oil producer among the states (behind Texas and North Dakota) (U.S. EIA 2015a; U.S. EIA 2015b). Although it is a major oil producer, the state produces a more modest amount of natural gas, accounting for less than 1% of U.S. natural gas production. Throughout the report, we frequently use the short phrase "oil production" to refer to the entire oil and gas production cycle from exploration, drilling, and production through well closure and abandonment.

Figure 1.

California crude oil production (million barrels).

Note: An oil barrel is equivalent to 42 gallons.

Source: U.S. EIA (2015a)



Over its long history, California's oil and gas industry has gone through and continues to undergo changes. Today, the San Joaquin Valley is considered a "mature" oil producing region unlikely to return to the peak production levels of the 1980s (Gautier and Takahashi 2007). However, in 2011, crude oil production began increasing slightly for the first time in decades. Around the same time, a report from the U.S. Energy Information Administration (U.S. EIA) claimed that the Monterey Shale Basin contained 15.4 billion barrels of technically-recoverable crude (Baker 2013)—or two-thirds of the country's proven oil reserves—and could theoretically sustain today's production level for more than 75 years (INTEK Inc. 2011; Sahagun 2014). This report, if true, could have meant a major increase in the footprint of oil production in California, and as such, it caused great concern among environmental groups. However, the potential of the Monterey Shale has since been dramatically downgraded more than once. Most recently, in October 2015, the U.S. Geological Survey estimated that the Monterey Shale contains only 21 million barrels of recoverable oil, a reduction of 99.9% from the 2011 estimate (Tennyson et al. 2015).

Recently, there have been a number of signs that the relationship between oil and agriculture has become increasingly strained. One recent legal complaint declares that "farmers and oil companies existed harmoniously in the Valley for over one hundred years" but that "the relationship between farmers and oil companies changed a few years ago in the wake of changes in oil production activities" (Parris 2015, 3). One of the major concerns about oil and gas activities in and around agricultural land is the potential threat of air, soil, and water contamination and resulting impacts on the food supply, soil quality, and farmworkers. Additionally, oil drilling in California occurs mostly in arid areas, where all water uses are in competition for water resources. Against the backdrop of California's recent drought, water use for oil and gas production—particularly for hydraulic fracturing—has attracted a great deal of attention from some activists and the media (Sommer 2014b; Valentine 2015). On the other hand, oil and gas production poses an opportunity to agriculture as a new source of irrigation water.

This paper represents the first comprehensive assessment of the interaction between food production and oil and gas development in California. Our focus is on water resources, although we briefly touch on other relevant issues throughout the report. In the following pages, we provide background on oil and gas production in California and discuss how water is used in oil and gas development. We present some of the challenges and opportunities when these industries operate alongside one another. We conclude with a set of recommendations for making oil and gas exploration and production safer for California's food and agricultural systems.

OIL AND GAS PRODUCTION ON AND NEAR CALIFORNIA'S AGRICULTURAL LANDS

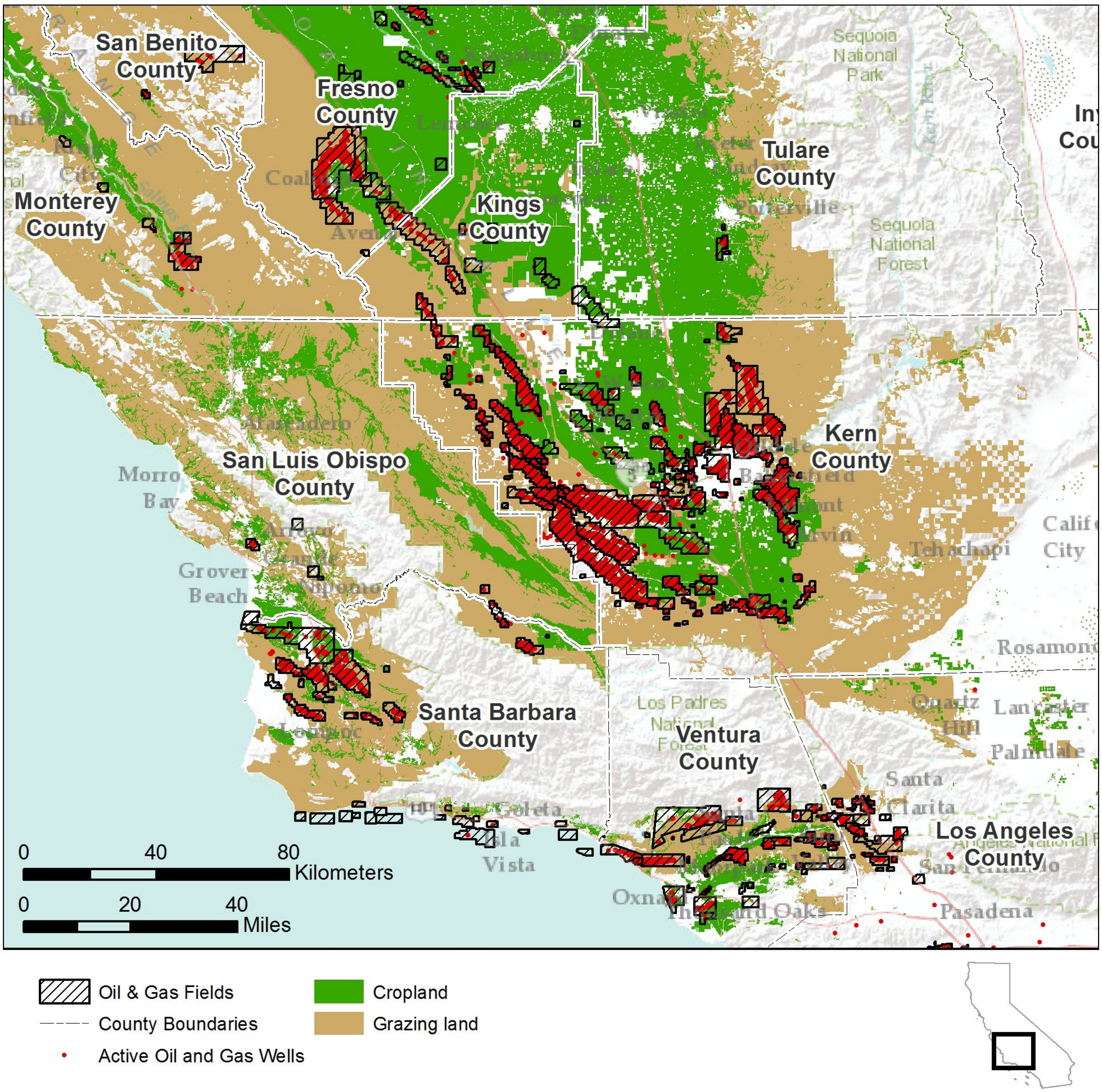
California has about 76,000 active oil and gas production wells, more than half of which are in Kern County, the top oil-producing county in America (California Council on Science & Technology and Lawrence Berkeley National Laboratory 2015b).[2] There are also significant

2 We determined that there are 76,137 wells that produced oil or gas in California in 2014 based on data in the Division of Oil, Gas, and Geothermal Resources' (DOGGR's) Production and Injection Database. However, it is difficult to confirm this estimate. According to geographic data files published by DOGGR in 2015, there are currently 67,350 active oil and gas wells in the state. According to the California Department of Conservation web page "Oil and Gas Facts for 2005" (the most recent available), there were 49,773 oil and gas wells actively producing in 2005.

oil fields in the Los Angeles and Ventura coastal plains and the nearby offshore area, as well as in Monterey County's Salinas Valley. In addition, there are natural gas fields in the Sacramento River Valley and the Sacramento-San Joaquin Delta. Each of these areas, with the exception of urban parts of Los Angeles, overlaps with or is immediately adjacent to agricultural and grazing lands, as shown in Figure 2 and Figure 3. Recently, expansion of oil production often has led

Figure 2.

Active oil and gas wells in California.



Source: DOGGR GIS data (DOGGR 2015a) and the Department of Conservation's Farmland Mapping and Monitoring Program (DLRP 2012).

Figure 3.

Oil production facility and unlined percolation pit in Kern County with orchards downhill a short distance away.

Note: This facility is in the Racetrack Area of the Edison Oil Field about one mile northeast of the town of Edison, near Comanche Drive and Breckenridge Road, and is operated by Valley Water Management. Facilities in this area use unlined percolation pits to dispose of oil-field wastewater from a number of independent oil companies, including Vaquero Energy, Naftex Operating Company, Sequoia Exploration, and Tri-Valley Corp.

Photo: ©2015 courtesy of Pistachio Production Ltd.

to the conversion of agricultural land, either by increased drilling in areas with a low well density or expansion of drilling outside areas that are already developed.

In order to better understand the relationship between oil and gas wells and farmland in California, we conducted a geospatial analysis using Geographic Information System (GIS) software and data from the Department of Conservation's Farmland Mapping and Monitoring Program. We found that, in the San Joaquin Valley and Southern California, there are 1,942 active oil and gas wells located on farmland. Among these wells, the majority, or 1,672 wells, are on high-quality lands the department refers to as prime farmland. This is defined as land with "the soil quality, growing season, and moisture supply needed to produce sustained long-term production of agricultural crops" (DLRP 2012).

In addition to the wells directly on farmland, there are many wells that are near cropland. Nearly a quarter of all active oil and gas wells (13,926 wells) are within one mile of cropland (Table 1). Further, more than half of active production wells (31,168) are within three miles of cropland, and 93% of wells (55,475) are within five miles of cropland.

Table 1.

Proximity of active oil and gas wells to cropland in the San Joaquin Valley and Southern California.

Minimum distance from cropland	Cumulative number of active oil and gas wells	Percent of active oil and gas wells
On cropland	1,942	3%
1 mile	13,926	23%
3 miles	31,168	52%
5 miles	55,745	93%
8 miles	59,840	100%

Note: We analyzed the area south of the Sacramento-San Joaquin Delta due to computing limits, thus our analysis excludes some oil and gas wells in the Sacramento Valley north of the Delta.

In addition to wells on or near cropland, 4,871 active oil and gas wells are located on grazing land.[3] The proximity of oil wells to cropland and grazing land underscores the potential threat to agriculture and the need to monitor and regulate the release of pollution by the oil industry.

Recently, the number of wells drilled has grown. Since 2011, the number of new wells in California has averaged 2,330 per year, compared to an average of 700 per year from 2005 to 2010, and some of these wells were drilled on prime agricultural land. In addition, the number of exploratory wells drilled outside existing oil and gas fields (also referred to as "wildcat" wells) has also been growing. Since 2011, oil companies have drilled an average of 13 wildcat wells (defined here as wells drilled outside of existing oil fields) per year, up from an average of less than 2 per year (Figure 4). New oil wells can take agricultural land out of production and disrupt farming operations (Box 1). Wildcat wells can be particularly disruptive, because they are, by definition, in areas that do not already have oil development activities.

3 The Department of Conservation defined grazing land as "land on which the existing vegetation is suited to the grazing of livestock. This category is used only in California and was developed in cooperation with the California Cattlemen's Association, University of California Cooperative Extension, and other groups interested in the extent of grazing activities." (DLRP 2012).

WATER USE FOR OIL AND GAS PRODUCTION

Water is used throughout the oil and gas exploration, drilling, and production process. One of the largest uses of water in petroleum production is for "enhanced oil recovery (EOR)," which includes techniques referred to as water flooding and steam flooding. These techniques, developed in the 1960s by Royal Dutch Shell, work by injecting large volumes of hot water and steam underground to increase the pressure in oil-bearing formations and to soften thick oil deposits so that the oil more easily flows to the well. EOR is also used to control land subsidence, which plagued some California oil fields in the early 1900s. These techniques are widespread in California and are especially useful on the thick, molasses-like oil in Kern County.

According to data from the state's oil and gas regulator—the California Division of Oil, Gas, and Geothermal Resources (DOGGR)—California oil and gas companies injected 320 million gallons per day (360,000 acre-feet per year) for EOR in 2013 (DOGGR 2015b).[4] Two-thirds of the water

4 In this report, we frequently report water volumes in acre-feet, a unit commonly used by California water managers. An acre-foot of water is equivalent to 325,851 gallons, enough to supply the annual water needs for two to four households.

Box 1.

Competition for Land

In the United States, individuals or corporations can own underground minerals, including oil and gas, without owning the land above. Under the "split estate" system of property rights, landowners must allow land access to drillers who hold underground mineral rights. As a result, farmers can often do little to stop an oil and gas company from drilling wells and setting up operations on their land. Under California law, mineral rights owners have "dominance" and are permitted "reasonable access," even on private property (Cox 2015c).

The footprint of a well pad necessary to extract oil and gas resources is not negligible. Well pads can take valuable land out of production. Roads, pipelines, and tanks can disrupt farming operations. Further, truck traffic and gas flaring have led to complaints about visual blight, loud noises, bright lights, vibration, traffic, dust, and odors (Cox 2011). Further, more farmers are becoming concerned about issues of soil and water contamination caused by spills or unsafe waste disposal.

Oil companies that want to drill typically negotiate with landowners individually and often enter into contracts to provide monthly payments to compensate farmers for lost production. Nevertheless, there are no mechanisms under California law for dealing with disputes between landowners and subsurface rights holder, other than for the landowner to file a civil lawsuit. The Bakersfield Californian noted in 2011 that "sharply increased oil production on prime farmland outside Shafter is straining the uneasy relationship between two pillars of Kern County's economy" (Cox 2011). One large Kern County grower, Pacific Ag Management Inc., told reporters in 2015 that no oil production should be allowed on its property without first obtaining its permission (Cox 2015c). The company has sought a change in the law that would require oil companies to obtain a conditional use permit for instances of conflict with surface property owners.

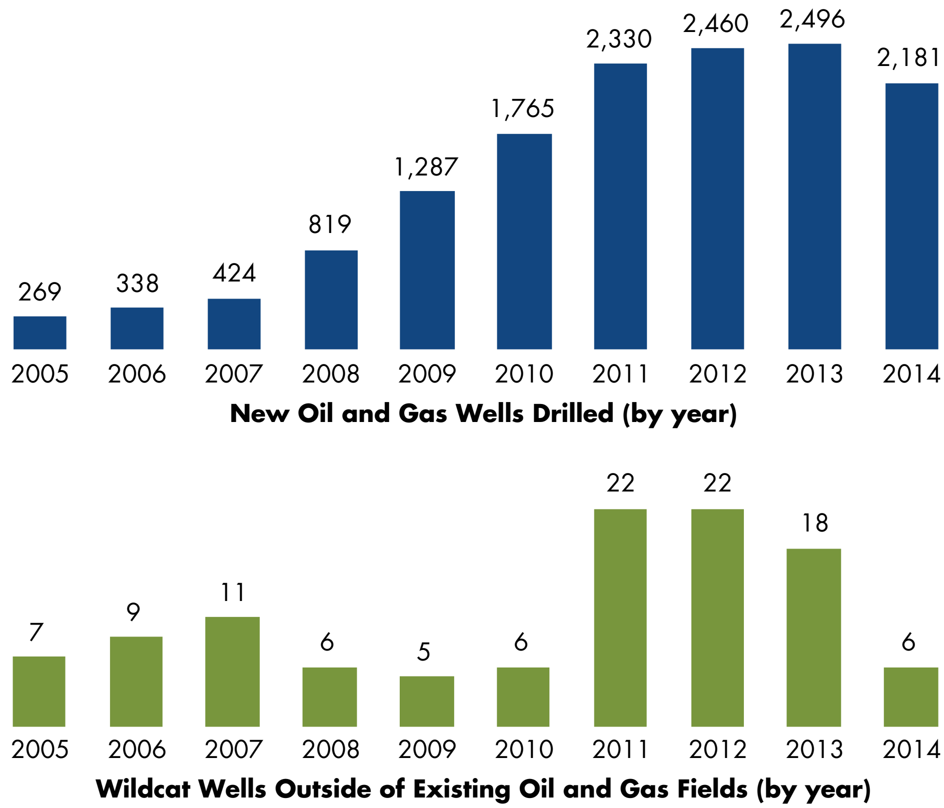
This problem of split estates is not limited to California. A 2013 report by Reuters showed how homeowners across the country have found themselves vulnerable when owners of the mineral rights beneath their property decide to drill and frack oil and gas wells in their backyard (Conlan and Grow 2013). The Natural Resources Defense Council (NRDC) has stated that federal and state laws do not do enough to protect split-estate landowners and has called on Congress to make is easier for surface owners to purchase the minerals beneath their land so that landowners can control what happens on their own property (Mall 2014).

injected for EOR was produced water, or water that is pumped to the surface along with oil and gas. Therefore, oil and gas companies are reusing water that would otherwise be a waste stream in need of disposal. In addition to using produced water, however, oil and gas companies obtained water from outside of the oil field for EOR, including between 12,000 and 49,000 acre-feet

Figure 4.

More oil and gas wells are being drilled outside of established fields (administrative field boundaries).

Source: DOGGR All Wells data file (DOGGR 2015a).



of freshwater (CCST and LBNL 2015b, II:111).[5] Freshwater for EOR was obtained from a number of sources, including domestic water systems (72%), groundwater wells (25%), and wastewater from an industrial facility (1.6%). In some cases, the source was not reported (1.4%) or reported as "another source or combination of the above sources" (0.1%).

Water is also used as the base fluid for hydraulic fracturing, acid stimulation, and other well stimulation techniques. Hydraulic fracturing, or "fracking," is a process where water, sand, and chemicals are injected into an underground formation in order to increase the flow of gas or oil to a well. A recent analysis by the California Council on Science and Technology (CCST) and the Lawrence Berkeley National Laboratory (LBNL) found that 40% to 60% of new oil wells completed in the last decade were hydraulically fractured and that about 20% of oil production in the state is from fractured wells (CCST and LBNL 2015a, I:iv). Matrix acidizing and acid stimulation are much less frequently practiced in California, although both use water, mixed with acid, to dissolve some of the rock and increase permeability. Finally, another form of low-volume fracturing referred to as "frack-packing" is performed to allow oil to flow more freely in the zone immediately around the well. This process typically uses about 1/10th the volume of fluid and sand as a regular hydraulic fracturing operation.

Water use for well stimulation by California oil producers is less on average compared to producers in other states. The average water volume used for

5 The estimated range of freshwater use for enhanced oil recovery is so large because of ambiguity in the reporting categories in DOGGR's database, which includes categories that may be composed partly or entirely of freshwater, including "water combined with chemicals such as polymers," "another kind of water," and "not reported."

each hydraulic fracturing operation in California was 140,000 gallons, far less than the volumes of water that are typically used for fracking in some other regions experiencing a shale gas boom; for example, each fracking operation in the Eagle Ford Shale formation in Texas uses an average of 4.25 million gallons of water (CCST and LBNL 2015a, I:121). Annually, water use for well stimulation in California over the last five years likely averaged 230 to 290 million gallons per year, or 700 to 900 acre-feet per year—equivalent to the amount of water a California farm would use to irrigate perhaps 150 to 300 acres, depending on the crop and growing conditions. Oil producers used some recycled water from other oil-field operations for well stimulation (about 10%). Most water for stimulation was freshwater (>90%) and was mostly used for hydraulic fracturing but also included some for matrix acidizing.

Freshwater use for hydraulic fracturing is currently much lower than freshwater use by the oil industry for other purposes. Freshwater use for enhanced oil recovery (EOR) in 2013 was 10 to 50 times larger than the amount used for hydraulic fracturing and other well stimulation techniques (CCST and LBNL 2015b). These data suggest that the recent focus by some activists solely on the water demands of hydraulic fracturing ignores the larger issue of water use by the oil and gas industry for other purposes, such as EOR.

COMPETITION WITH AGRICULTURE FOR WATER

As oil and gas development in the United States has expanded and moved into new areas, there has been growing concern that oil and gas operations would use water that would have otherwise been used by farms, or that it would drive up the price that farmers pay for water, harming livelihoods and rural communities. Competition for water would be most acute during droughts or interruptions in water supply. This is of particular concern in states like California and Texas, which are prone to multiyear droughts and have extensive oil and gas activities. In Texas, for example, new water wells have been drilled in high water-stress areas to provide water for oil and gas operations (Nicot et al. 2011). A recent report suggested that natural gas companies' fracking of the Eagle Ford Shale contributed to the precipitous decline of the Carrizo-Wilcox Aquifer during the 2012 drought, finding that oil companies continued to pump from the aquifer while some farmers in the area were fallowing their crops (Galbraith 2013).

The oil industry can also negatively impact neighboring groundwater users. As discussed on page 14, about 25% of the water injected for enhanced oil recovery (the major water use in oil and gas production) comes from the operators' own groundwater wells (Belridge Water Storage District 2012; CCST and LBNL 2015b). When surface water is unavailable, such as during a drought, water users increasingly pump from groundwater aquifers, putting them into direct competition with nearby agricultural, municipal, and domestic groundwater users. In particular, overpumping can reduce the amount of water available for other users, increase energy pumping costs by lowering the water table in the area, and reduce the area's groundwater quality. Many of the most productive oil fields are located in the Kern County sub-basin, which the state Department of Water Resources considers to be in critical overdraft (DWR 2015). To date, there have not been any confirmed reports of agricultural wells going dry because of increased pumping from oil production; however, the impacts of pumping are poorly understood in California due to a lack of available groundwater data (including data on baseline conditions) that would clearly show before-and-after effects.

To date, we are not aware of any water transfers from agriculture to oil production that have caused controversy in California. Competition over water was a major concern to the state legislature in 2013, when it included several provisions into SB4 in order to gather more information about water use by the oil industry. However, this concern seems to have lessened since the projections for recoverable oil in the Monterey Shale have been downgraded and it no longer appears that the state is on the verge of an oil boom.

WASTEWATER MANAGEMENT AND DISPOSAL

Oil and gas production generates several kinds of liquid waste. The first of these is drilling mud. Drilling fluid is circulated through the wellbore during drilling and well-maintenance operations to lubricate and cool the drill bit, control pressure, and carry the underground material (known as cuttings) back up to the surface. Drilling mud is the waste that results; it is composed of drilling fluid, water, petroleum, cuttings, and naturally-occurring chemicals in the formation, as well as other chemicals and materials used in the drilling process. This mud is typically brought to the surface and collected into a pit, where the solid and liquid material are separated and disposed of separately. However, California law does not require temporary storage pits to be lined, unlike in states like New Mexico, which require liners.[6] While the U.S. Environmental Protection Agency (U.S. EPA) exempts drilling muds from many federal regulations, California prohibits permanent disposal in open pits.[7] According to the most recent data available, in 1995, the vast majority of the solid waste from drilling in California is buried onsite. Of the liquid waste, more than half (56%) is spread on the land, while 24% is disposed of through evaporation, and 18% is handled through onsite remediation (ICF Consulting 2000).

Other liquid wastes are created during oil and gas production. Oil wells in California generate on average 15 barrels of water—called "produced water—for every barrel of oil (DOGGR 2015d, 3). This is somewhat higher than the national average of about 9 barrels of water per barrel of oil but lower than in some other western states; for example, in Wyoming, the ratio of water to oil is 36:1 (J. Veil 2015, 113). This produced water comes from deep underground and is typically salty, containing other dissolved or suspended chemical constituents that occur naturally in the formation. Produced water is sometimes referred to as oil-field brine, connate water, or formation water. According to the state water board, oil-field produced water can contain elevated concentrations of:

- General minerals (salts)
- Metals (e.g., arsenic)
- Trace elements (e.g., boron, strontium, thallium, lithium),
- Petroleum hydrocarbons
- Polynuclear aromatic hydrocarbons (PAHs)
- Volatile organic compounds (VOCs)
- Benzene, toluene, ethylbenzene, and xylene (BTEX)
- Radionuclides

For stimulated wells, wastewater also contains stimulation chemicals and their byproducts. Of the approximately 300 chemicals used for well stimulation in California, 28% were unknown because companies maintain that they are "trade secrets, confidential business information, or proprietary information" (CCST and LBNL 2015b, II:81). For a third of the chemicals reportedly used in California, the acute toxicity (or short-term health impact) is unknown, and for 80% of the chemicals,

6 New Mexico Administrative Code, 19.15.17.11, Subsection F.
7 California Code of Regulation, Title 26, Section 14-1775, Oilfield Wastes and Refuse.

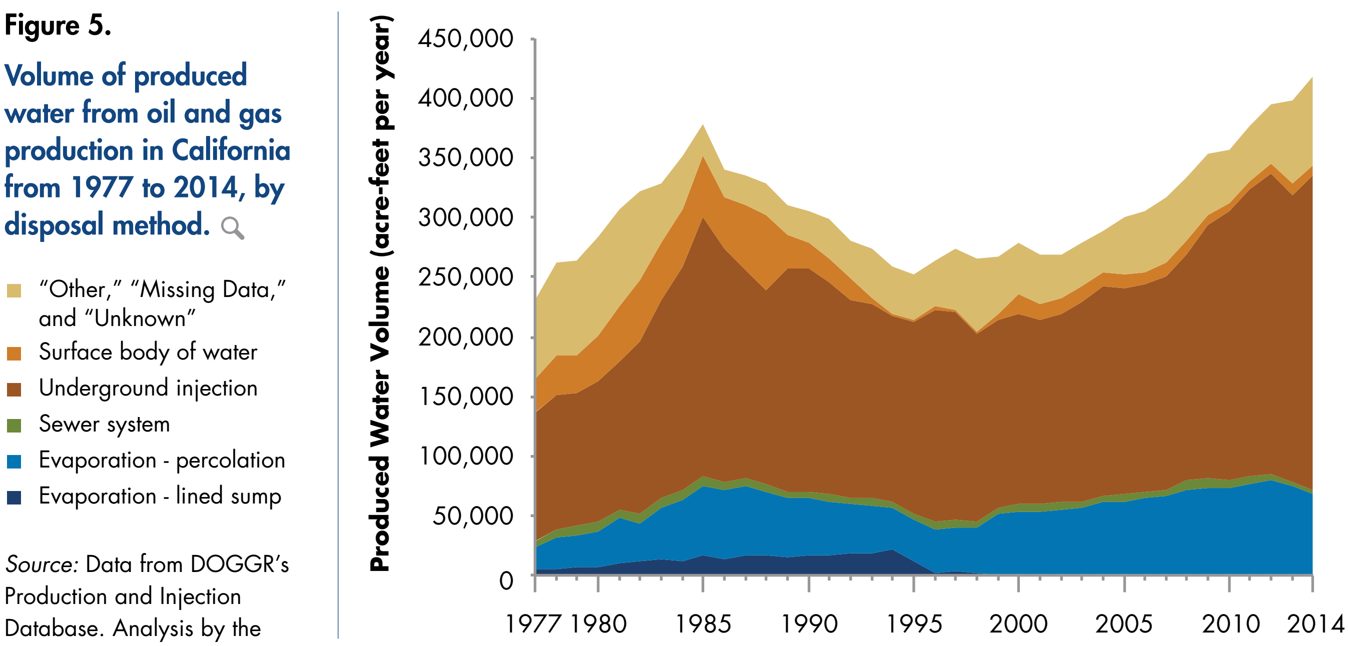
the chronic toxicity (or long-term health impact) is unknown. Researchers concluded that many of the unreported chemicals in well stimulation fluids are likely surfactants or quaternary ammonium compounds (QACs), a class of compounds whose environmental hazard is highly variable and which may persist in the environment for a long time (CCST and LBNL 2015b, II:80–82). When oil drillers inject stimulation fluids into a well, they recover only a small percentage of this fluid before the well begins producing oil and gas (CCST and LBNL 2015b). The remainder stays underground or returns to the surface mixed with produced water, creating concerns that fracking chemicals could contaminate soil and water if this waste stream is not carefully managed.

The volume of produced water is steadily growing and, along with it, issues related to its handling and disposal. In general, the longer oil extraction has taken place in a formation, the higher the proportion of water produced. Figure 5 shows the volume of produced water from oil and gas production in California from 1977 to 2014. After peaking in the mid-1980s, produced water volume declined for a decade, along with declining oil production. Around the year 2000, the trend reversed, with water production increasing despite a continued decline in oil production.

Table 2 shows the methods used by California oil and gas companies to dispose of wastewater in 2013. In total, oil and gas production generated 134 billion gallons (410,000 acre-feet) of wastewater. The most common method of disposal was subsurface injection, which accounted for 60% of the total. The second most common disposal method is in "evaporation-percolation" pits. Percolation pits are one of the oldest methods for disposing of produced water, by which much of the water percolates into the ground and the remainder is lost to evaporation. Eighteen percent of oil-field wastewater, or 24 billion gallons (75,000 acre-feet), was disposed of in these unlined percolation pits. This includes some wastewater from oil and gas wells that have been hydraulically fractured (CCST and LBNL 2015b, II:99). This disposal method has been banned or phased out in several other states (Grinberg 2014).

Figure 5.

Volume of produced water from oil and gas production in California from 1977 to 2014, by disposal method.



Source: Data from DOGGR's Production and Injection Database. Analysis by the authors.

Table 2.

Oil and gas wastewater disposal in California in 2013.

Disposal method	Billion gallons	Acre-feet	Percentage of total
Subsurface injection	80	250,000	60%
Unknown	25	76,000	18%
Evaporation-percolation	24	75,000	18%
Surface body of water	3.3	10,000	2%
Sewer system	1.0	3,200	0.8%
Evaporation, lined sump	0.07	200	0.1%
Total	**134**	**410,000**	**100%**

Source: Data from DOGGR's Production and Injection Database. Analysis by the authors. Figures may not sum due to rounding.

It is also worth noting that the disposal method for 18% of oil and gas wastewater (over 25 million gallons) is listed as other, missing, or unknown. Better data are needed to fully understand the fate of oil-field wastes. Although new regulations (specifically, SB 1281) require oil companies to report to DOGGR more detailed information regarding the source and disposition of produced water, DOGGR should better verify reported data and ensure that oil and gas companies submit complete and accurate data on wastewater handling and its disposition, including details about its disposal or beneficial reuse.

Given the growing volume of produced water and related environmental and health concerns, California oil and gas companies should prioritize the use of management and technology to ensure its safe handling and disposal. A useful model is provided by the Department of Energy's Argonne National Laboratory, which has developed a three-tier framework for produced water management and pollution prevention (J. A. Veil et al. 2004, 42). The first tier is "waste minimization" and stresses the use of technology and processes that reduce the amount of wastewater generated in the first place, for example through technologies such as the downhole oil/water separator. While this technology has been in use since 1999 and has been shown to be feasible, few oil producers have adopted it, most likely due to its cost and complexity (J. A. Veil et al. 2004, 47). The second tier of the DOE produced water management framework is to reuse or recycle produced water wherever practical. Finally, the third tier of the framework is disposal of water that cannot be recycled or reused, most frequently by underground injection.

SOIL AND WATER CONTAMINATION

The threat of environmental contamination from oil and gas production waste is not new. In 1910, a well in Kern County blew out during drilling, creating what became known as the Lakeview Gusher, the largest oil spill in history. Soon after the blow out, a river of oil flowed toward Buena Vista Lake, the source of irrigation water for local communities (Gautier and Takahashi 2007). The oil companies' managers realized this would be a calamity and rushed to stop the stream by building earthen dams and storage pits. While there has not been a new gusher in California in decades, there are a number of other ways that oil and gas extraction can and still do pollute the air, soil, and water, affecting farms and the food supply. In this section, we discuss the ways in which contaminants can enter the environment, as well as the risks these releases pose to agriculture, including farmworkers and consumers. We also discuss the possible impact of "legacy pollution" from past disposal of wastes.

RISKS FROM SOIL AND WATER CONTAMINATION

Contaminant releases from oil and gas production can pollute soil, harm ecosystems and wildlife, and threaten water supplies. As discussed previously, produced water from oil and gas operations contains salt, boron, heavy metals, and radioactive elements. While oil releases tend to get more attention, wastewater from oil and gas operations can be particularly damaging, as it can release contaminants (such as salts and heavy metals) that do not degrade naturally in the environment. Wastewater may also contain chemicals, such as surfactants and biocides, injected by oil companies during different stages of exploration and production. These chemicals are often associated with hydraulic fracturing, but many of the same chemicals are used for other purposes during oil and gas operations, such as well cleanout and maintenance or enhanced oil recovery. These chemicals are thought to be in widespread use even in California oil fields that use conventional production methods, where fracking does not take place (Taylor et al. 2014, 8–9).

Many of the concerns outlined in this section relate to groundwater. This is a resource that is hidden from view but of vital importance to California's cities, farms, and ecosystems. In a normal year, groundwater makes up about 40% of the state's water supply, and the share goes up even higher during a drought (DWR 2003; Freeman 2010). Groundwater is often connected to surface water resources, so contamination could subsequently intercept rivers, streams, and surface water resources. Additionally, contaminated water may be used by plants that naturally draw from shallow groundwater.

In addition to being an important water source for California, groundwater can be extremely slow and expensive, or even impossible, to clean up. Moreover, groundwater moves slowly, and it can often take decades for contaminants to migrate underground or appear in wells. This is the case with a number of pollutants that are found in groundwater aquifers today, including nitrates resulting from the use of fertilizers and manure applied to the land for decades (Harter et al. 2012), or pesticides like 1,2,3-Trichloropropane, which has not been used since the 1970s but which continues to be detected in drinking water (Sarathy et al. 2009; SWRCB 2015).

Potential Impacts on Crops

Environmental releases of wastewater and other materials used for oil and gas development pose a potential threat to soil and crop health because of the mix of chemical compounds present. Salts, boron, arsenic, and other compounds in produced water can damage crops directly by slowing their growth or reducing their yield. Different crops have varying degrees of salt tolerance, and some may not even grow in soils that are too saline. Research on tomato plants showed that diluted produced water from natural gas drilling significantly affected plant growth as well as the absorption of essential minerals (Martel-Valles et al. 2013).

Chemical constituents that modify soil characteristics have the potential to negatively affect soil fertility. Soil fertility depends on several factors, including nutrient and mineral content, organic matter content, pH, structure, the diversity of microorganism communities, and the amount of topsoil available. Too much salt in soil can also reduce permeability, cause surface crusting, and reduce infiltration and water flow (J.A. Veil et al. 2004). Another concern is related to biocides, which are used in fracking fluid, and which may be present in produced water. If present, there is a potential for biocides to impact microbial communities that play a vital role in soil fertility and naturally break down toxins (Shariq 2015).

Potential Impacts on Livestock

In California, there are many grazing lands on or near oil and gas fields. Figure 6 is a photo of cattle in Kern County drinking from a seep (where water oozes up out of the ground) approximately 300 feet downhill from percolation ponds where oil-field-produced water is disposed. The small seep is the only surface water or patch of green for miles in this hilly and arid area, and is likely a direct outflow of produced water that has seeped through the soil back to the surface.

Petroleum hydrocarbons and other constituents found in oil-field waste are harmful to exposed livestock. Livestock may be exposed through several pathways, including inhalation; ingestion of contaminated feed, plant matter, soil, and water; and direct contact with contaminated water and soil. As far back as 1979, following several incidents in Oklahoma where livestock near drilling sites became ill or died, veterinarians published research on animal toxicoses, or poisonings, of cattle near oil and gas well drilling sites (Edwards, Coppock, and Zinn 1979). The investigators found "diagnostically significant" levels of petroleum hydrocarbons, toxic chemicals, and heavy metals in the intestinal contents and tissues of cows. The authors recommended excluding cattle from the areas around well pads to limit their exposure to toxic chemicals.

More recently, there has been a flurry of interest in how hydraulic fracturing wastes affect animals, after several widely-publicized cases in which farm animals and pets near gas-drilling areas became sick or died. In 2009, 17 cows in Caddo Parish, Louisiana, died after drinking hydraulic fracturing fluid. A year later, a Pennsylvania cattle herd was quarantined after being exposed to drilling wastewater, and the animals later experienced

Figure 6.

Cattle in Kern County drinking from a seep approximately 300 feet downhill from percolation ponds where oil-field-produced water is disposed.

Notes: These unlined pits are in the Mount Poso Oil Field and are operated by Griffin Resources. Surrounding land is privately-owned farm land, according to county assessor's office data, and is predominantly used for grazing cattle.

Photo by the authors.

an "abnormally high level of reproductive failure"(Bamberger and Oswald 2014). In Louisiana, the cows were not sent for slaughter, but in the Pennsylvania case, some animals were slaughtered, "and the meat products derived from these cattle became an indistinguishable part of the food chain" (Bamberger and Oswald 2014).

Livestock that have been exposed to pollutants in oil-field wastes exhibit a range of symptoms, depending on the contaminant and level of exposure. Consumption of petroleum hydrocarbons by livestock has been shown to cause neurotoxicity; fetal toxicity; damage to the gastrointestinal tract, respiratory system, kidney, and liver; anorexia; lethargy; and death (Pattanayek and DeShields 2004). Livestock that have consumed excessive salts, which are typically present in produced water from oil-field operations, can exhibit weakness, dehydration, tremors, aimless wandering, ataxia (loss of control of body movements), seizure-like activity, partial paralysis, and death (Meehan, Stokka, and Mostrom 2015).

When oil-field wastes cause animals to become sick or die, it is often difficult to trace the result back to its cause. Veterinarians or ranchers are not always able to correctly diagnose an illness or identify the cause of death. Oil-field operators are not required to disclose all of the chemicals used in the drilling and production process, making it difficult to evaluate the possible causes or risk factors of animal morbidity or mortality.

Some guidance for the quality of produced water has been created in order to protect livestock. A report from the National Academies Press states that water with a TDS level of less than 1,000 mg/L is considered suitable for livestock, although water with TDS greater than 5,000 mg/L will often cause intestinal distress (National Research Council 2010). The American Petroleum Institute (API) has created screening levels for the protection of livestock exposed to hydrocarbons (Pattanayek and DeShields 2004). The chemicals for which the API set screening limits include: oil; benzene, toluene, ethylbenzene, and xylene (BTEX); and polycyclic aromatic hydrocarbons (PAHs). It is important to note, however, that both the API guidelines and the National Academies research are designed to prevent livestock from getting sick or dying; they are not designed to protect consumers and the public.

We know far less about how chemicals from oil and gas production may enter the food supply through animal products, for example, meat, eggs, or dairy products (Drouin 2014). The Food and Drug Administration (FDA) has not set standards for chemicals in food that are known to be present in crude oil. The agency typically comes up with new standards after an emergency. For example, they set "levels of concern" for PAH concentrations in Gulf of Mexico seafood following the 2010 Deepwater Horizon Spill, and officials compared samples to these levels when deciding whether to reopen an area for commercial fishing.

PATHWAYS OF CONTAMINATION

There are several pathways by which oil and gas production may contaminate soil and water. The most important ways contaminants can reach the environment and potentially harm agriculture include: unlined disposal or percolation pits; subsurface releases from underground injection or through idle or orphaned wells; surface spills and leaks, and illicit discharges; and legacy pollution from drilling mud disposal. Contaminants may also enter the environment through beneficial reuse for irrigation if water is not properly treated, which we discuss more detail starting on page 35. For a longer list describing many of the pathways by which oil and gas wastes can contaminate air, water, and soil, we refer the reader to pages 103 to 152 in An Independent Scientific Assessment of Well Stimulation in California, Volume II (CCST and LBNL 2015b). In the following pages, we describe those pathways which are the greatest threat, and conclude with recommendations for how to minimize these threats in order to protect California's land and water resources.

Unlined Percolation Pits

Evaporation and percolation in unlined pits is the second most common disposal method in California. As of early 2015, there were an estimated 933 percolation pits thought to be in use in California (CCST and LBNL 2015b). Most of these are in Kern County, but there are unlined pits in several other counties, including Monterey and Santa Barbara counties on the coast, and San Benito, Tulare, Fresno, and Kings Counties in the Central Valley (Figure 7). According to Clay Rodgers, an officer at the Central Valley Regional Water Quality Control Board (CVRWQCB), "the number of evaporation ponds is down from thousands in the mid-1980s" (Miller 2010a). There are also hundreds of old, inactive percolation pits on or near oil fields around the state. Many of these have been buried, and there is little indication at the surface that the site was once used to dispose of oil-field wastes.

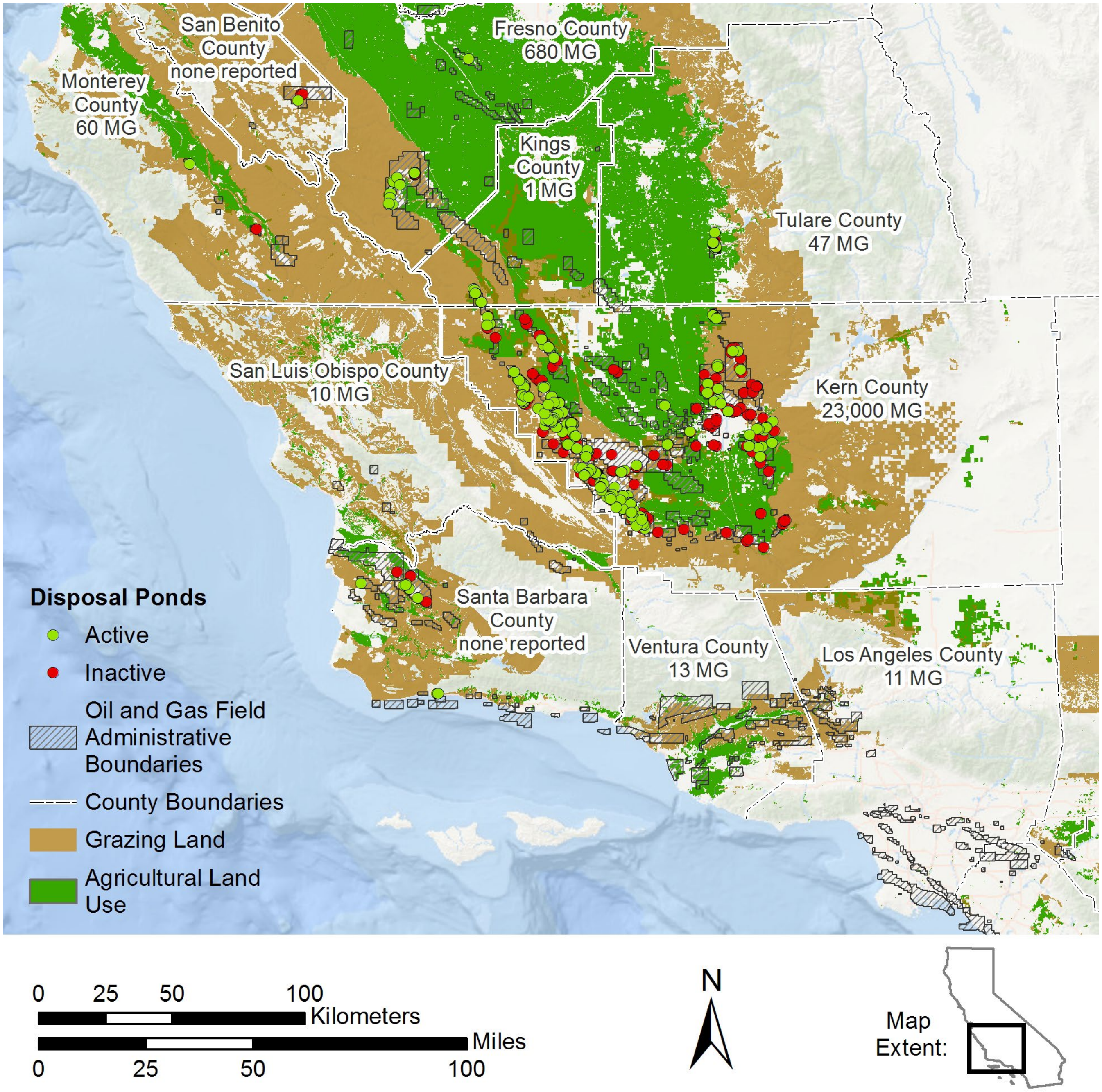
Unlined percolation pits are allowed in California with a permit from the regional water board. According to the CVRWQCB, a permit will be issued "if the discharger successfully demonstrates to the Regional Water Board in a public hearing that the proposed discharge will not substantially affect water quality nor cause a violation of water quality objectives" (CCST and LBNL 2015b, II:110). A third of the pits currently in use in the Central Valley are operating without a permit (Holcomb 2015). In other cases, a permit exists, but it is very old. For example, the permit for produced water disposal at the Fee 34 and Race Track Hill Facilities (shown in Figure 3) dates back to 1958, before the landmark environmental protection laws such as the Clean Water Act were passed (CVRWQCB 2015c). According to officials at the Central Valley water board, it is unlikely that a similar permit would be issued today (Rodgers 2015).

Unlined percolation pits provide a direct pathway for groundwater contamination. Even old percolation pits that are no longer in use can contaminate soil and groundwater when rain or irrigation water seeps through surface layers and carries pollutants into shallow groundwater. Nationwide, there is abundant evidence that groundwater contamination occurs when percolation pits are used to dispose of wastewater from oil and gas fields (EWG 2009; Earthworks 2008). In California, the CVRWQCB recently determined that disposal pits in Kern County north of Bakersfield polluted groundwater, and it ordered oil companies to close them (CVRWQCB 2015a). In a separate incident in 1999, when Kern County farmer Fred Starrh drilled wells to supplement his surface water deliveries, the groundwater caused his cotton plants to wilt, and he was ultimately forced to remove 6,000 acres from production (Flesher 2015). Subsequent testing showed high levels of chloride and boron, and noticeable amounts of radioactive compounds, all of which are found in oil-field wastewater. A court found that, from the 1970s until the early 2000s, Aera Energy had disposed of over 2.4 billion barrels (100 billion gallons or 310,000 acre-feet) of produced water into percolation pits next to his farm. In 2009, a federal judge ordered Aera to pay Starrh $8.5 million in damages (Miller 2010b).

Several states have banned the use of unlined percolation pits for the disposal of oil and gas wastes; for example, Texas in 1969 and Ohio in 1985 (Kell 2011, 2 and 48). In 2008, New Mexico banned unlined percolation pits after finding over

Figure 7.

Locations of oil and gas wastewater "evaporation-percolation pits" in California.



Notes: County labels indicate volume of wastewater sent to evaporation-percolation pits in the county in 2013, based on data from DOGGR. Data on the location and status of percolation pits is from the State Water Resources Control Board and the Central Valley Regional Water Quality Control Board.

400 cases of groundwater contamination from oil and gas waste pits.[8] In a 2007 study, New Mexico's Oil Conservation Division (OCD) concluded that liners in many pits had rips and tears, which could lead to groundwater contamination. This is a concern because testing of produced water from 37 pits found that concentrations of 17 chemicals (including arsenic, benzene, mercury, and cadmium) exceeded water quality standards (OCD 2007). As a result, New Mexico regulators banned new unlined pits, required old ones to be closed, created stricter requirements for the lining and construction of lined pits, and required stricter measures for the handling of fluids when groundwater is within 50 feet of the surface.

Underground Injection of Wastewater

Oil and gas companies dispose of some wastewater by injecting it into underground formations below freshwater aquifers. As of 2012, California had 49,783 such injection wells for oil and gas wastes (Gómez 2014, 60). The majority of these wells are used for enhanced oil recovery, that is, water is injected into oil or gas bearing formations in order to facilitate production. A smaller number of these wells are disposal wells, where water is injected into zones either without hydrocarbons or where hydrocarbons have already been depleted. Figure 8 shows a schematic of underground injection wells for disposal of oil and gas wastes and for enhanced oil recovery. This illustration shows a common situation, where underground injection wells puncture or pass through shallow freshwater aquifers, some of which are or may be used for water supply or irrigation.

Underground injection is considered safe when there are impervious "confining layers" that keep the wastes in place and prevent fluids from moving into drinking water aquifers. However, wastes can migrate out of the injection zone in several ways, including through: (1) idle or abandoned wells; (2) pathways created by failed well casings; and (3) natural or induced pathways, such as faults, fractures created by fracking, or other unknown and unseen natural cracks in the subsurface strata. Contamination can also occur when operators make mistakes or violate rules, or where regulators allow injection in the wrong areas.

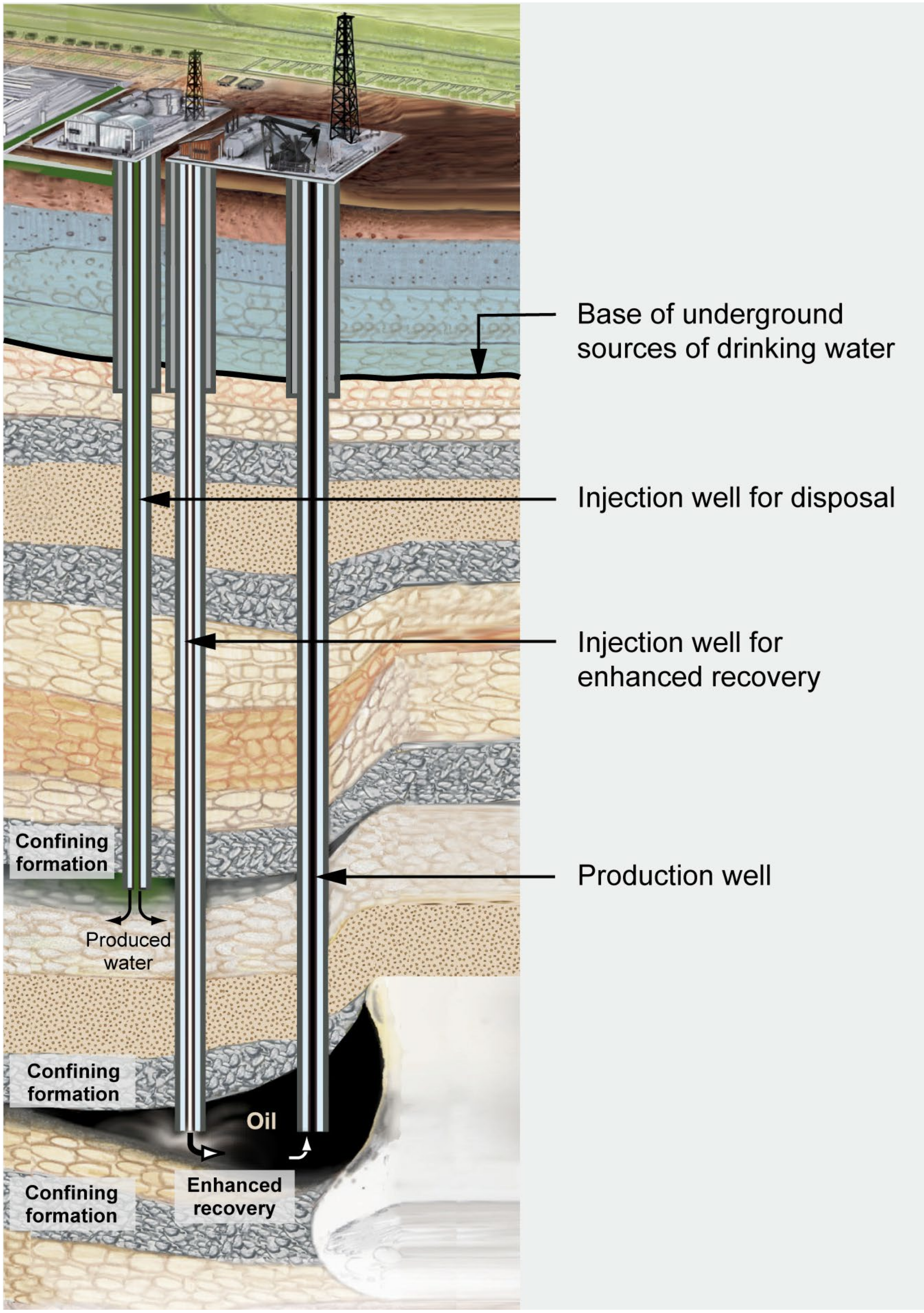
Underground injection wells are regulated by the U.S. EPA and the state of California through the Underground Injection Control (UIC) program. The Safe Drinking Water Act of 1972 (SDWA) authorizes the U.S. EPA to regulate underground injection of different classes of waste (hazardous industrial wastes, sewage, etc.) and classifies oil and gas waste injection wells as "Class II wells." Since 1983, the U.S. EPA has delegated primary authority, or primacy, for regulating Class II wells to California's Division of Oil, Gas, and Geothermal Resources (DOGGR).

State and federal agencies largely rely on industry to implement safeguards to protect drinking water; for example, by requiring well operators to meet technical standards for constructing, operating, testing, and monitoring injection wells (Gómez 2014). California regulators require operators to conduct mechanical integrity testing to show that fluids are less likely to be injected outside of the intended zone through faulty joints or cracks in the well casing, possibly contaminating drinking water aquifers. This is a particular concern when former production are re-purposed as injection wells, a common practice in California oil fields. The SDWA also requires state regulators to conduct an "area of review evaluation" before approving new underground injection projects, to ensure that the "zone of endangering influence"

8 Mexico Administrative Code, 19.15.17.8(A): "After June 16, 2008, an unlined pit is prohibited and the division shall not issue a permit for an unlined pit."

Figure 8.

Schematic of underground injection wells for disposal of oil and gas wastes and for enhanced oil recovery.



Source: Reprinted from the U.S. EPA (Gómez 2014) does not intersect with drinking water aquifers. State regulators have two options: they may use geological data and a simple equation to estimate zone into which wastes are likely to move, or they may assume a fixed one-quarter mile radius around the point of injection. With few exceptions, California regulators have relied on the simple quarter-mile assumption (Walker 2011, p. 37).

Despite the general safety of this disposal practice, there have been some instances of contamination related to underground injection of oil and gas wastes. There are confirmed cases from across the United States in which wastes have migrated from the formation where they were injected and have contaminated soil and groundwater, threatening the environment, farms, and public health (Lustgarten 2012; Government Accountability Office (GAO) 1989; Gómez 2014). For example, Texas recently confirmed six contamination incidents directly caused by Class II injection operations (Kell 2011). There have also been a number of alleged or suspected instances of contamination associated with injection wells in California. From 2009 to 2010, there were 21 cases of alleged contamination reported in California (Gómez 2014). A 2014 lawsuit alleged that oil companies that injected wastewater near agricultural fields used "aging and sometimes faulty injection wells" and claimed that oil companies neglected to determine whether this injection would impact nearby water wells (Cox 2014). However, there is insufficient data to identify the scope of this problem in California. The state does not monitor groundwater to detect contamination from injection wells; nor does it require well operators to do so. Investigations are typically conducted only in response to citizen complaints.

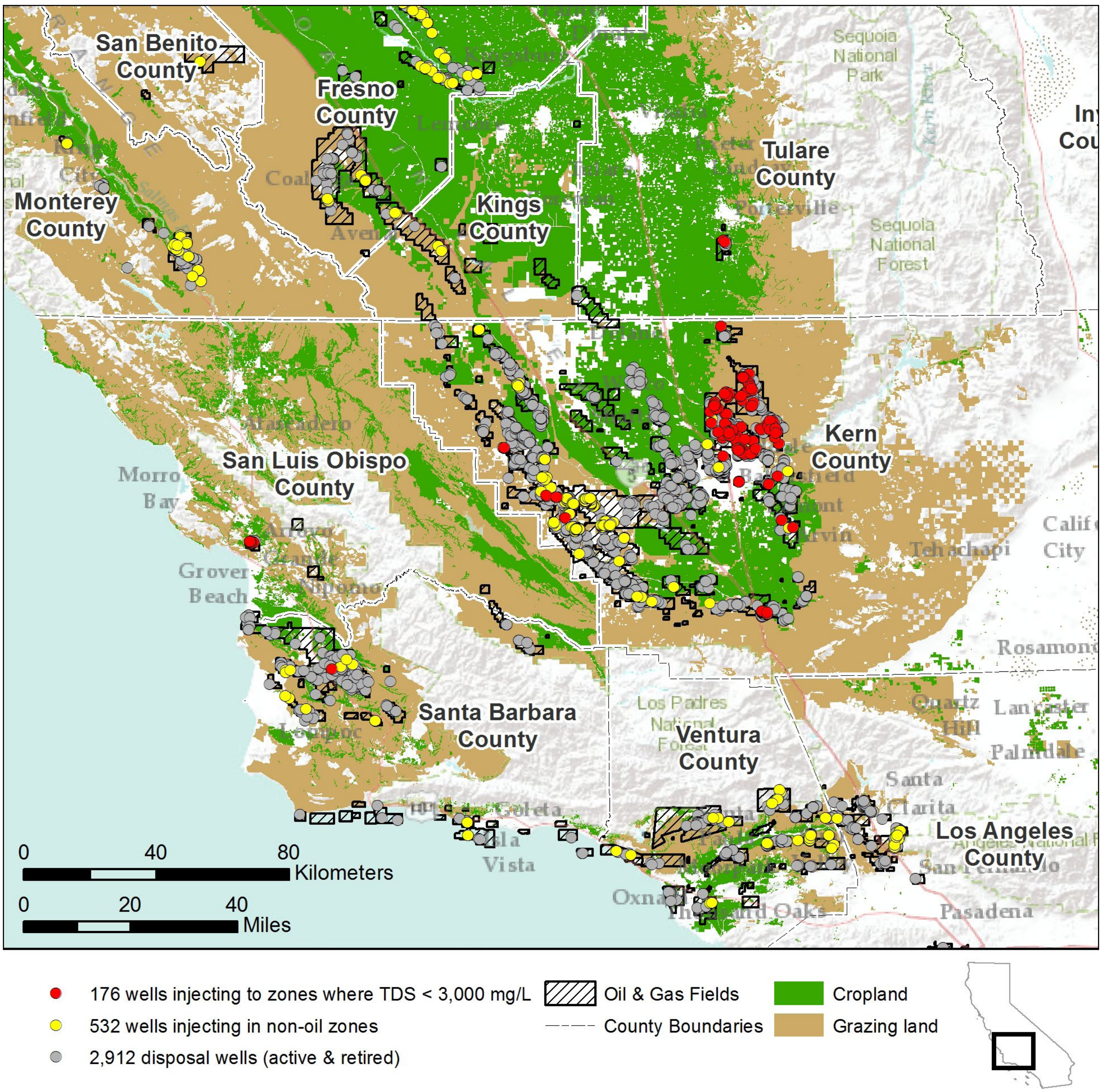
It was recently discovered that California has allowed oil companies to inject wastes into waters that are considered potential water supplies. In 2011, the U.S. EPA brought in outside experts to assess California's management of oil-field wastewater that is disposed of underground via deep injection wells (Walker 2011). The consultants' report revealed deficiencies in the way California has been managing underground injection through the state's UIC program, including allowing oil companies to inject wastes into freshwater aquifers. Under federal law, injection is not permitted into "underground sources of drinking water" (USDWs), defined as groundwater aquifers with 10,000 milligrams per liter (mg/L) or less of total dissolved solids (TDS). These aquifers could theoretically supply water for human consumption, if treated. California's regulations defined freshwater as groundwater containing less than 3,000 mg/L TDS. Therefore, the state failed to protect groundwater containing between 3,000 and 10,000 mg/L TDS and thus was not sufficiently protective of potential drinking water as required by state law.

An October 2015 internal investigation by DOGGR found a number of additional problems with the state's UIC program, including inconsistent permitting, monitoring and enforcement of well construction and operation, and failure to ensure that injected fluids are confined to a project area or geologic zone (DOGGR 2015c). Since then, the state has taken a number of steps to correct these problems and "overhaul its regulatory program," which included ordering the closure of certain wells (DOGGR 2015c). Further, DOGGR has begun holding public hearings to determine whether certain aquifers should be considered "exempt," which would allow the disposal of oil-field wastes in these aquifers to continue, a process that has proven to be contentious (Carls 2015).

State regulators have ordered the review nearly 30,000 active injection wells. Figure 9 shows the location of disposal wells for oil and gas wastes in the San Joaquin Valley, including wells deemed a potential threat to underground sources of drinking water. A majority of these wells inject water and steam into hydrocarbon-bearing formations for enhanced oil recovery and are deemed the lowest risk. Because the formations contain oil, the water is of low quality and unlikely to ever serve as drinking water, and thus

Figure 9.

Location of disposal wells for oil and gas wastes in the San Joaquin Valley, including wells recently identified as a potential threat to underground sources of drinking water.



Source: Data from DOGGR, "List of Permitted Wells Sent to EPA.xlsx." February 10, 2015.

are considered exempt aquifers where injection is allowed. A smaller number of wells (2,812) are disposal wells for oil and gas wastes, mostly produced water. Of these, 532 wells were injecting into non-hydrocarbon-producing zones which have a higher likelihood of containing drinkable water. However, some of these are salty and are not likely to be usable. The state identified 176 wells injecting into freshwater, defined as zones with total dissolved solids less than 3,000 mg/L. Of these, regulators found 33 wells that were near water supply wells (21 of which were actively injecting) and ordered them shut down as posing an immediate threat to drinking water. However, DOGGR has said that, so far, "limited testing" by the State Water Resources Control Board (SWRCB) has not revealed contamination of any wells used for irrigation or water supply caused by the closed injection wells, but that "finely-detailed project-by-project review of each UIC project" would be conducted to continue assessing threats to drinking water sources (DOGGR 2015c).

Some localities have begun phasing out the use of underground injection on or near agricultural lands. For example, Ventura County changed its county zoning laws in 2000 to disallow commercial oil disposal sites on agricultural land (Wilson and Carlson 2014). The county is home to the Oxnard oil field, adjacent to the Oxnard Plain, a fertile agricultural area especially known for its strawberries. In 2015, the county's Board of Supervisors denied a request for a zoning change that would have allowed expansion of an existing underground injection facility that accepts wastewater from nearby oil fields but is also in a farming area. The applicant, Anterra Energy, stated that because the county was the third-largest oil producer in the state, the county should "allow brines to be disposed of effectively and cheaply." The supervisors countered that the injection sites posed an unacceptable risk to the region's "health, safety, public welfare," and that nearby industrial areas or open space would be more suitable for injection (Wilson 2015). In this case, the county government used zoning laws to limit a potentially polluting activity on sensitive lands. Nonetheless, a local government would not have the authority to pass an outright ban on underground injection, based on the legal doctrine of preemption, which prevents states or local governments from exercising authority over matters in which the federal government has asserted exclusive control.

Idle and Orphan Wells

Old wells that have not been properly sealed can allow contaminants to travel from deep underground into soils or groundwater aquifers. This is a problem in oil and gas fields across the country, and California is no exception. Even wells that have been properly plugged can become pathways for pollutants to contaminate soil and water, due to degradation of cement or casings caused by faults or compaction, for example (CCST and LBNL 2015b, II:122–123). California has nearly 116,000 wells that have been plugged and abandoned.[9] In addition, there are 21,347 idle wells that have not been in use in over six months, as well as 110 "orphaned wells," whose owner is unknown (CCST and LBNL 2015b, II:122).

Idle, abandoned, and orphaned wells may allow chemicals to move upward to shallow aquifers or the land surface, "especially wells that have not been adequately sealed or properly abandoned" (Esser et al. 2015). The Government Accountability Office (GAO) identified this as an important pathway by which injected wastes had contaminated drinking water: "in more than a third of the known cases, drinking water became contaminated when injected brines traveled

9 An "abandoned" well is one that has been plugged and is no longer in use.

up into improperly plugged abandoned wells. Contamination was not discovered, for the most part, until water supplies became too salty to drink or crops were ruined" (GAO 1989).

Since 1976, DOGGR has had a program to plug idle and orphan wells. To date, the division has plugged 1,307 idle and orphan wells at a total cost of $23.7 million, an average cost of about $18,000 per well (DOGGR 2015). To fund well closure in the event that an operator goes out of business, the state requires operators to post a surety bond of $5,000, to reimburse the state for any expenses incurred in closing idle wells. Based on the average cost of plugging wells noted above, this amount is insufficient to properly close an abandoned well, to say nothing of cleaning up any contaminated soil or groundwater that may result from an abandoned well.

Some states pay for the closure of orphan wells through a severance tax on oil and gas production. For example, in 2001, the Texas legislature voted to increase the severance tax in order to increase funds to plug orphaned wells and remediate contaminated oil and gas production sites (Kell 2011, 97). California is the only major oil-producing state without a severance tax. While one has been proposed several times, it remains controversial, in part because California already has sales, property, and corporate taxes that are higher than other oil states (Cox 2015b). According to the National Council of State Legislators, "severance taxes help insure that costs associated with resource extraction—such as road construction and maintenance, and environmental protection—are paid by the producers, helping to alleviate potential impacts on state and local taxpayers" (Pless 2012). (Most states deposit revenues into the general fund; where revenues are intended to cover the cost of providing a particular service, it is more properly called a fee.)

Accidental Spills and Leaks, and Illicit Discharges

Spills of oil, wastewater, or other chemicals—whether accidental or intentional—occur in California and are harmful to crops and the environment. For example, in 1986, a heavy rainstorm damaged a disposal pit in Crocker Canyon in Kern County, causing the release of oil and produced water into a wildlife habitat. A total of 116 animals were confirmed to have been killed, and hundreds more are believed to have died as a result (U.S. EPA 1987, C–81 to C–82).

The true extent of contaminant releases into the environment in California is unknown due to insufficient and improper reporting. According to the best available information, an average of about 100 produced-water spills were reported annually to the state's Office of Emergency Services over the five-year period from 2009 to 2014 (CCST and LBNL 2015b, II:127–128).[10] Without knowing the extent of spills, leaks, and illegal discharges, it is difficult to fully gauge the threat to farmland and grazing in oil-producing regions.

Illegal discharges are also a problem, specifically because the extent to which they occur is not known. Illegal discharges do occur in California. In the 1986 Crocker Canyon spill described above, the report of the spill notes that the presence of older, accumulated oil indicates that the area had, prior to the spill, been used for illegal transport and discharge of oil and produced water. In the past few years, oil companies in California have been fined for illegally disposing of fracking waste

10 The number of reported spills may not be accurate, as the Office of Emergency Services database contains all hazardous releases in the state and does not easily allow identification of spills relevant to oil fields. Moreover, the database itself represents the details at the time of the initial notification and is not updated once all the details have been confirmed. Specifically, the total amount of contaminants is not known.

into percolation pits in a number of instances (CVRWQCB 2013; CVRWQCB 2014; CVRWQCB 2015b). This poses a particular threat due to the unknown composition of hydraulic fracturing waste. More recently, Vintage Production California LLC was fined for periodically discharging saline water, formation fluids, and hydraulic fracturing fluid to an unlined percolation pit in an area with good-quality groundwater near the City of Shafter in Kern County (CCST and LBNL 2015b). The CVRWQCB stated that "several" illegal discharge incidents had been found to have occurred between January 2012 and December 2013 (CCST and LBNL 2015b).

Threat from Groundwater Overdraft and Land Subsidence

An emerging threat is related to land subsidence from groundwater overdraft, which can damage pipelines and other infrastructure and can lead to spills and releases. The majority of California's oil production takes place in the San Joaquin Valley, where groundwater has been overdrafted by agriculture for over 80 years. The eight-meter drop measured in the land surface near Mendota in 1970 is among the largest ever attributed to groundwater pumping (Galloway, Jones, and Ingebritsen 1999). Subsidence in the valley slowed when the State Water Project was completed and began delivering water to farmers via canals. However, threats due to subsidence have re-emerged due to drought, particularly the drought that began in 2011, as surface water deliveries have been cut and farmers have dramatically increased groundwater pumping. A recent analysis by NASA found that some areas of the San Joaquin Valley have sunk by as much as 14 inches from May 2014 to January 2015(Farr, Jones, and Liu 2015).

The California Energy Commission is concerned that land subsidence "may pose a danger to natural gas pipelines, oil and gas wells, natural gas storage systems, aqueducts, and other facilities" (CEC 2015). Experience has shown that surface subsidence, along with reservoir compaction or heaving, can damage wells by causing their casing to shear or break due to strain placed on the casing material. In the 1950s, the Wilmington Oil Field in Long Beach experienced dramatic subsidence due to oil pumping, which triggered a number of small, shallow earthquakes, causing hundreds of oil-well casings to shear (Dusseault, Bruno, and Barrera 2001, 102). While the subsidence was controlled beginning in 1958 by requiring oil companies to inject saltwater to replace oil extracted from underground, well damage continued up until the 1980s (Waldie 2015; Dusseault, Bruno, and Barrera 2001, 102). Today, land subsidence could potentially affect companies' ability to produce oil by damaging production wells and injection wells. Further, damage to abandoned wells that have been cemented in place could provide a conduit for wastes to contaminate soil or groundwater. Finally, damage to pipelines or other surface infrastructure could cause spills of oil, wastewater, or chemicals.

Legacy Pollution from Drilling Mud Disposal

Areas that have been used for the disposal of drilling mud also threaten California agriculture. Until 2013, oil companies in the Central Valley could legally dump drilling muds on land without reporting or a permit. Under California water law, waste discharges to land must receive a permit—called Waste Discharge Requirements (WDR)—from the appropriate Regional Water Quality Control Board. (WDRs are discussed in more detail below, in the section Rules and Regulations Governing the Reuse of Oil-field Wastewater, beginning on page 39). For years, the Central Valley board had determined that disposing of drilling muds on land did not pose a threat and issued a blanket waiver, meaning that companies did not have to apply for an individual permit. In 2013, after advocacy groups raised concerns about the risks of these drilling muds, the board allowed the waiver to expire (Center for Biological Diversity 2013). Up until 2013, there were a number of places where drilling muds had been dumped on farm fields or where unlined drilling-mud pits had been buried and were found to contain drilling mud, as well as other wastes such as cuttings, drilling chemicals, and flowback fluids. Some of these are located on farmland and farmers are trying to plant crops above these buried pits (Frantz 2015).

BENEFICIAL REUSE OF OIL-FIELD WASTEWATER

At present, reused oil-field wastewater is important for irrigation water supply within certain districts. In California, produced water from five oil fields is currently recycled for irrigation: Deer Creek, Jasmin, Kern River, Kern Front, and Mount Poso (CCST and LBNL 2015b, 114). These projects are listed in Table 3 on the following page. However, this water remains a relatively small proportion of overall supplies. Within Kern County, for example, the USGS estimated total freshwater withdrawals for irrigation at 1,800 million gallons per day, or about two million acre-feet per year (Maupin et al. 2014). Currently, recycled produced water accounts for about 1% of irrigation water use in the county.

In Kern County, farmers in the Cawelo Water District have been using oil-field produced water for over two decades to irrigate almonds, citrus, and a variety of vegetable crops. In 1994, Chevron signed an agreement with the water district to recycle some of the wastewater from its Kern River field for irrigation. The oil is separated from the produced water, which is then lightly treated before being delivered to farmers.[11] This is possible since the produced water from the Kern River field has relatively low levels of salts, reducing the cost of treatment (Miller 2010a). Chevron sells about 21 million gallons of water per day, or about 24,000 acre-feet per year, to the irrigation district. This water makes up about half of the water supply for the Cawelo Water District in normal years, and a higher proportion during drought years. Importantly to area farmers, the supply is also reliable from year to year, unlike canal water deliveries, which may be cut back during drought years. This is particularly crucial to farmers in the district, where 95% of the crops grown are permanent plantings of fruit and nut trees or grapevines.

In other cases, treated produced water is being reused indirectly to irrigate crops. That is, rather than delivering produced water directly to irrigators via a pipeline or a canal, wastewater is discharged to a creek or infiltrates into the ground and is later withdrawn by irrigators. For example, in the Arroyo Grande Oil Field in San Luis Obispo County, Freeport-McMoRan's Price Canyon operation treats oil-field produced water by using reverse osmosis before discharging it directly into Pismo Creek. Under a permit approved by the Central Coast Regional Water Quality Control Board (CCRWQCB) in the winter of 2013 (CCRWQCB 2013) , the discharged water may be reused directly for irrigation use as well, although this is not happening yet. According to John McKenzie, a planner working for the county, the county "heavily conditioned" the oil company's Conditional Use Permit by requiring continuous monitoring for temperature and flow, and periodic sampling for other chemicals. While the main purpose of the discharge is to improve

11 Treatment consists of mechanical separation, sedimentation, air flotation, and filtration using walnut hull filters.

Table 3.

Projects where oil-field wastewater is permitted for reuse for crop irrigation in California.

Date permitted	County	Oil field	Operator	Permitted Volume (acre-feet per year)	Water treatment	Blending	Application	Crops irrigated	User	Data source
	Tulare	Deer Creek			Mechanical separation with addition of coagulants	No	Irrigation	Alfalfa	Private land	1
	Tulare	Deer Creek			Mechanical separation with addition of coagulants	No	Irrigation	Alfalfa	Private land	1
	Kern	Jasmin			Mechanical separation with addition of coagulants	Blended with canal water some of the time	Irrigation	Citrus	Jasmin Ranchos Mutual Water Company	1
	Kern	Mount Poso					Irrigation		Cawelo Water District	1
2012	Kern	Kern River	Chevron	37,500	Mechanical separation, sedimentation, air flotation, and filtration (walnut hull filters)	Treated wastewater, imported surface water, groundwater	Irrigation, groundwater recharge	99% permanent crops (citrus, almonds, pistachios, apples, peaches, plums, and vineyards); 1% (alfalfa, potatoes, corn, grains, vegetables, melons)	Cawelo Water District	1, 2
2012	Kern	Kern Front	California Resources Corporation	16,600		Treated wastewater, imported surface water, groundwater	Irrigation, groundwater recharge	Same as above	Cawelo Water District	1, 4
2011	Kern	Kern Front	Hathaway LLC	70	No treatment requirements	7% wastewater; 93% groundwater	Irrigation; during non-irrigation season, disposed of via underground injection	Citrus	Concordia Ranch	3, 7

Table 3. (continued)

Date permitted	County	Oil field	Operator	Permitted Volume (acre-feet per year)	Water treatment	Blending	Application	Crops irrigated	User	Data source
2015	Kern	Kern Front	California Resources Corporation	21,200	Gas separation, free-water knock-out tanks, air flotation, and skimming	Produced water, surface water, and groundwater blended in the Lerdo Canal	Irrigation, groundwater recharge in the Rosedale Basin	80% permanent crops of nuts, vineyards, and fruit	North Kern Water Storage District	5
2014	San Luis Obispo	Arroyo Grande	Freeport-McMoran Price Canyon	940	Mechanical, chemical, reverse osmosis	Yes (indirect reuse)	Discharged to Pismo Cree to improve habitat and water quality in the creek. Water in the creek is recharging groundwater and reused indirectly by downstream irrigators with wells.	Vineyards, row crops	Private land	6

Notes: Blanks indicate unknown or missing data.

Sources:

(1) Email to the authors from Dane Johnson, Senior Engineering Geologist, Central Valley Regional Water Quality Control Board, 2014.
(2) Central Valley Regional Water Quality Control Board (CVRWQCB). (2012). Waste Discharge Requirements for Chevron USA, Inc., and Cawelo Water District, Produced Water Reclamation Project, Kern River Area Station 36, Kern River Oil Field, Kern County. http://www.waterboards.ca.gov/centralvalley/board_decisions/adopted_orders/kern/r5-2012-0058.pdf
(3) CVRWQCB. (2011). Conditional Waiver of Waste Discharge Requirements and Monitoring and Reporting Program for Hathaway, LLC Reuse of Oil Field Production Wastewater for Irrigation. http://www.waterboards.ca.gov/centralvalley/board_decisions/tentative_orders/1110/hathaway/3_hathaway_waiver_res.pdf
(4) CVRWQCB. (2012). Order No. R5-2012-0059 Waste Discharge Requirements for Valley Water Management Company and Cawelo Water District, Produced Water Reclamation Project, Kern Front No. 2 Treatment Field, Kern Front Oil Field, Kern County. http://www.waterboards.ca.gov/centralcoast/board_decisions/adopted_orders/2013/2013_0029_freeport_npdes_permit.pdf
(5) California Regional Water Quality Control Board, Central Valley Region Monitoring And Reporting Program, No. R5-2015-XXXX for California Resources Corporation, LLC And North Kern Water Storage District, Oil Field Produced Water Reclamation Project, Kern County. http://www.waterboards.ca.gov/centralvalley/board_decisions/tentative_orders/calrescorp/crcnkwsd_mrp.pdf
(6) CVRWQCB. "Notice Tentative Waste Discharge Requirements for California Resources Corporation, LLC and North Kern Water Storage District Oil Field Produced Water Reclamation Project Kern County," September 18, 2015. http://www.waterboards.ca.gov/centralvalley/board_decisions/tentative_orders/calrescorp/crcnkwsd_cov.pdf
(7) California Regional Water Quality Control Board, Central Valley Region Monitoring and Reporting Program, R5-2011-XXXX for Hathaway, LLC, Reuse Of Oil Field Production Wastewater for Irrigation, Kern Front Oil Field, Kern County. http://www.waterboards.ca.gov/rwqcb5/board_decisions/tentative_orders/1110/hathaway/4_hathaway_mrp.pdf

habitat and water quality in Pismo Creek, water in the creek is also recharging groundwater, and there are neighboring farms (mostly vineyards but also some row crops) irrigating with this groundwater.

A second case of indirect reuse of produced water occurs in the San Ardo Oil Field in Monterey County's Salinas Valley. Chevron operates a reverse osmosis plant to treat produced water that is then "discharged to post-treatment constructed wetlands and aquifer recharge basins" (Webb et al. 2009). This water makes its way downslope, where water from the Salinas River and the Salinas Valley aquifer are used for municipal and industrial supply, as well as for irrigation in one of the most productive and intensively-farmed areas in California (CCRWQCB 2005).

In drought-prone California, irrigators and water managers are increasingly looking at wastewater from oil fields as a potential resource. The Tulare Basin Plan[12] specifically encourages recycling of oil-field wastewater for beneficial uses: "Discharges to surface water and evaporation of reclaimable wastewater will not be acceptable permanent disposal methods where opportunity exists to replace an existing use or proposed use of fresh water with reclaimed water" (CVRWQCB 2004, IV–12). More recently, there have been calls for an increased use of oil-field produced water to help offset decreased water availability during drought (Cox 2015a). David Ansolabehere, general manager of the Cawelo Water District, said, "Lately, I've been getting a lot of phone calls, meeting with people that want to do the same type of thing." According to Tupper Hull of the Western States Petroleum Association, "It's very conceivable that in the very near future, oil production could be a net provider of water for California ag and other purposes, as opposed to a consumer" (quoted in Sommer 2014a).

Recycling produced water could have a greater impact in chronically water-short regions, such as the San Joaquin Valley. Table 4 shows the volume of water used for various purposes in major oil-producing counties in California compared to the volume of produced water generated in the county by oil and gas production. The right-most column of Table 4 reports the fraction of the county's irrigation water use that could theoretically be fulfilled by produced water, assuming that 100% of produced water could be reused. In Kern County, the largest oil-producing region of the state, oil companies generated 240,000 acre-feet of produced water in 2013, equivalent to 210 million gallons per day (mgd). If all of this water were treated and reused, it could satisfy about 12% of the county's annual water use for crop irrigation. In other counties, produced water could theoretically fulfill a smaller percentage of the county's water use.

We note, however, that the actual volume of water that could practically be reused is likely far less than the theoretical estimate above because the water is being reused within oil fields for other purposes (specifically, EOR). In addition, most produced water would likely be too expensive to treat and transport for irrigation, based on current prices paid by California farmers. In some areas, farmers pay as little as $17 per acre-foot (Central California Irrigation District 2014).[13]

Despite this, there are two factors which may make even expensive water economically viable. First,

12 Basin Plans – or Water Quality Control Plans – outline the water quality objectives and beneficial uses of the region's waters.

13 Irrigation water prices tend to be higher in water-scarce regions where delivery costs are higher. For example, before the drought began in 2011, farmers paid $140 per acre-foot in the Westlands Water District near Fresno, and $250 per acre-foot in the Western Canal Water District north of Sacramento (Vekshin 2014).

Table 4.

Produced water volume in major oil-producing counties in California compared to water use for other purposes. All values are in million gallons per day (mgd).

County	Public supply & domestic	Industrial (self-supplied)	Irrigation	Mining	Total water use in county	Produced water volume in 2013	Potential for produced water reuse as fraction of total water use
Kern	228	2	1,810	93	2,160	**210**	10%
Los Angeles	1,413	103	91	94	3,064	**98**	3%
Monterey	50	2	479	5	546	**13**	2%
Santa Barbara	74	6	177	6	264	**13**	5%
Orange	520	18	18	8	765	**10**	1%
Ventura	167	10	226	9	719	**8**	1%
Fresno	266	11	2,493	7	2,813	**7**	0.2%

Notes: Water use estimates are from the U.S. Geological Survey for the year 2010 (Maupin et al. 2014).

water prices often spike during times of drought and shortage, with reports of irrigators paying up to $2,000 per acre-foot in 2014 (Vekshin 2014). Oil companies may also choose to treat and sell produced water if other disposal options become impractical or expensive due to future regulatory requirements. In addition, oil companies may elect to absorb some of the cost rather than passing it on to agricultural buyers because it reduces their disposal cost or helps win favor among growers and the public. Chevron, for example, is already using their recycled water discharges to the Cawelo Water District to help improve their public image. In 2013, Chevron created a video about the sale in which the water district manager is quoted as saying, "Chevron is being environmentally conscious, and this is a very beneficial program, and it's helped a lot of our farmers, helped our district tremendously" (Chevron 2013).

POTENTIAL RISKS FROM BENEFICIAL REUSE

A major concern about reusing produced water for irrigation is the potential for humans and animals to be exposed to harmful contaminants in the water. Current monitoring efforts are insufficient to understand the risks to human and animal health. In the Cawelo Water District's produced water supply, the water is tested regularly for compounds that could affect plant growth, such as salinity and boron, but it is not regularly tested for other toxics known to occur in oil-field wastewater. In April 2015, in response to the concerns about chemicals in produced water, the CVRWQCB ordered recycled water suppliers to submit samples for laboratory analysis. Chevron's response indicated that "no heavy metals or chemical toxins were present in the water above maximum allowable levels" (Schlanger 2015). Those findings were contested by the advocacy group Water Defense, which reported having conducted its own sampling, which did find harmful chemicals in oil-field wastewater used to irrigate crops (Cart 2015b). These findings prompted some journalists and bloggers to question the safety of this practice (Ross 2015; Geiling 2015).

Harmful contaminants from hydraulic fracturing may be present in wastewater reused for crop irrigation. The 2015 report from CCST and LBNL found that several wells had been hydraulically fractured in the Kern River oil fields in the last five years (CCST and LBNL 2015b, II:27). Chevron denied that it had conducted hydraulic fracturing in these fields but admitted to having performed over 300 "frack packs," another type of stimulation that uses similar chemicals. The use of wastewater from these fields raises specific or unique concerns because of the variety of chemicals used during oil and gas production that may end up mingled with produced water and the unknowns concerning the toxicity and environmental profile of those chemicals.

Beneficial reuse poses additional threats to agriculture in ways that are currently not well understood. First, we do not have a clear picture of the potential for contamination of food crops. Because of this lack of understanding, there is a generally negative public perception of beneficial reuse of oil-field wastewater. Each of these issues is discussed in more detail below.

Potential Contamination of Crops

Chemicals from oil and gas wastes could potentially enter the food system in several ways. This could occur where soil and water are contaminated via one of the pathways discussed beginning on page 21 or when oil-field wastewater is reused for irrigation but has not been sufficiently treated. We are not aware of any studies evaluating the uptake or accumulation of chemicals in oil-field wastes in food crops. Nevertheless, evidence from related fields regarding the environmental transport and plant absorption of chemicals provides an indication of possible problems and suggests there is cause for concern.

Chemical contamination of food crops can occur in a number of ways. Some contaminants can be taken up into a plant through the roots or transferred directly from soil, water, or dust to the edible parts of the plant. Others—particularly lighter, volatile compounds, such as polycyclic aromatic hydrocarbons (PAHs)—can volatilize and be deposited on a plant's surfaces. PAHs are compounds that are present in the environment and result from nearly any process that involves combustion. They are volatile, which means they are lightweight and evaporate, qualities that give petroleum products their particular smell. They are a cause for concern because some of these compounds are water soluble, meaning they move readily through the environment, and most are toxic or carcinogenic to different degrees. Residues on the skin of fruits or vegetables can be ingested by consumers if the plant is not handled and cleaned properly before use. Plants can also take up contaminants directly from the air (McFarlane and Trapp 1994). Researchers in northern China studied the effects of lettuce irrigated with wastewater from industrial sources, showing that, as the concentrations of contaminants in the soil increased, so did the concentration in the plant. (Khan et al. 2008). This suggests that, for this class of pollutants at least, limiting the concentration in soil and water is of critical importance

The presence of a chemical in soil or water does not necessarily mean it will be taken up into the plant. Contaminants may enter the plant through its roots and accumulate in the plant's tissues; however, a plant may be able to exclude certain chemicals from crossing the cell membranes in its roots. According to UC Davis' Dr. Carl K. Winter, who studies toxics in food, "some plants can readily absorb toxins without transferring them to the leaves or the flesh of their fruit" (Cart 2015a). Research conducted in the 1990s on plant uptake of organic contaminants in sewage sludge or compost found that there was very little accumulation of most contaminants in the edible parts of plants above ground but that roots and tubers, such as carrots and potatoes, can be contaminated (Hellström 2004). The study from northern China showed that PAHs accumulate in both the roots and leaves of lettuce plants (S. Khan et al. 2008). Further, some compounds may be metabolized or broken down inside the plant into other end products, which may be toxic or benign, whereas other toxins can bioaccumulate, or become concentrated at higher levels than the background concentration in soil or water. For example, researchers have found that PAHs have a tendency to bioaccumulate in plant leaves (Hellström 2004, 19–20).

One type of oil-field contaminant of concern is a class of industrial surfactants known as nonylphenol polyethoxylates (NPEOs). These chemicals are known to affect aquatic organisms and are also classified as endocrine disruptors, substances that can interfere with the endocrine system in humans and other mammals, and can cause cancer, birth defects, and other developmental problems (Bergman et al. 2013). A study conducted in the United Kingdom (Sjöström et al. 2008) investigated crop uptake of NPEOs. The researchers found that these compounds accumulated in bean plants, more so in the roots than in shoots or seeds. Previous studies showed that very little nonylphenol accumulates in wheat, barley, or rapeseed (the source of canola oil) (Sjöström et al. 2008). The human health impacts of NPEOs have generated a great deal of debate, and Europe banned their manufacture and use in 2005 (EU Directive 76/769/EEC, described in Sjöström et al. 2008). However, they are still widely used elsewhere, including in California. According to voluntary disclosures by oil companies, these chemicals have been used in well stimulation in California over 50 times in the last five years (CCST and LBNL 2015b, II: Appendix 6, Table C–2).

Other contaminants of concern are heavy metals, such as lead, arsenic, cadmium, chromium, and mercury. Heavy metals concentrate in plant matter (particularly leafy vegetables) and can pose a threat to human and animal health (Muchuweti et al. 2006; Arora et al. 2008; Peralta-Videa et al. 2009; Singh et al. 2012). These metals can cause a variety of health problems, including cancers, kidney disease, endocrine disruption, neurotoxicity, immunological problems, and behavioral and psychological problems. Researchers in Pakistan studied the effect of irrigating a variety of food crops with wastewater containing elevated levels of heavy metals and found that metals accumulated in a the edible parts of a variety of vegetables and grains at levels that are cause for health concern when they are consumed regularly (Khan, Malik, and Muhammad 2013).

In studying the fate and transport of chemicals such as hydrocarbons and heavy metals, an important and often unknown factor is the degree to which they are broken down in the soil or immobilized, via processes referred to as biodegradation and adsorption. Microorganisms are the primary means by which petroleum and other hydrocarbons biodegrade; however, the degree to which this happens depends on the chemical composition, physical state, and concentration of hydrocarbons and microorganisms as well as temperature, oxygen, nutrients, salinity, pressure, water activity, and pH (Leahy and Colwell 1990). Heavy metals, on the other hand, do not biodegrade and tend to accumulate in the environment, although they chemically and physically interact with naturally-occurring substances, which alter their mobility. For example, some heavy metals are adsorbed, or bound to other particles, reducing their chance of migration or absorption into plants. The degree to which different heavy metals are immobilized in the soil is determined by the natural composition of the soil, pH, water content, and temperature (Dube et al. 2001).

Despite a number of field studies, many of which have focused on remediation of contaminated sites, there are big gaps in our knowledge of how plants take up various chemicals. According to one of the few literature reviews on the subject, "the large amount of chemicals and plant species make it impossible to analyse every combination, especially taking different environmental factors into account" (Hellström 2004, 29). Produced water and other oil-field wastes can contain hundreds of constituents; it is impractical to examine the potential for crop uptake of each chemical. Instead, priority research should focus on a handful of chemicals in produced water with known or suspected health impacts and should study their uptake in food crops. The goal should be to determine whether there is a pathway by which people are exposed to dangerous chemicals in food they consume.

There are two major gaps in our approach to managing the risks chemicals in oil-field wastewater pose to food crops, in the face of these uncertainties. First, for most of the chemicals of concern, there are no standards for what level is safe to consume in fruits, vegetables, or grain. Moreover, chemicals that may threaten human health may be in oil-field wastes, but their presence is unknown due to lack of disclosure requirements. There are also, for most chemicals, no regulations for chemical concentrations in food or for residues on the surface of produce.

In addition, there is infrequent and insufficient monitoring of crop contamination. The California Department of Pesticide Regulation and the FDA take regular samples of domestic and imported produce to test for pesticide residues. The FDA also monitors food for a few additional dangerous chemicals: acrylamide, benzene, dioxins and PCBs, ethyl carbamate, furan, perchlorate, and radionuclides (FDA 2014). Within the FDA, the Center for Food Safety and Applied Nutrition (CFSAN) implements regulatory and research programs to address health risks associated with foodborne, chemical, and biological contaminants (Dennis et al. 2006). Indeed, one of the agency's stated goals for the next three years is to develop screening methods for new, emerging, and unidentified chemical contaminants of concern (CFSAN 2015). CFSAN should investigate the contaminants in oil-field wastes and conduct a formal assessment of human exposure and risk from these chemicals.

Marketing and Public Perceptions of Agricultural Products

An emerging issue with respect to oil production and agriculture in California is the issue of the public's perception of the safety of food produced using oil-field wastewater. Many people seek to avoid food that has been exposed to harmful substances and do not trust industry or government to keep food safe. For example, a recent poll by the U.S. Farmers and Ranchers Alliance showed that 53% of American consumers "frequently wonder if the food they buy is safe" (Duggan 2015). Some consumers may choose to avoid purchasing products that had been grown with oil-field-produced water or may even avoid purchasing products from an area where oil and gas production is occurring. For example, in 2010, the Park Slope Food Coop in Brooklyn, a large wholesale buyer of New York State agricultural products, announced that it would shift its purchases of food away from areas with natural gas drilling (Gas Drilling Awareness for Cortland County 2015).

This issue of public perception related to the reuse of oil-field wastewater on food crops may be coming to the fore in California. David Ansolabehere, general manager of the Cawelo Water District, told us that, following the publication of a Los Angeles Times article alleging that his district's irrigation water contained toxic chemicals (Cart 2015a), grocery store buyers have called growers in the district asking whether they should be concerned. The grower's response so far has been that "they have tested the fruit for all the required constituents based on the requirements from the retail companies, and all tests passed" (Ansolabehere 2015).

Some have called for labeling of agricultural products irrigated with oil-field waters. State Assembly member Mike Gatto (D-Glendale) introduced a bill in August 2015 (ABX2-14) which would have required labeling of foods grown with produced water to read "Produced using recycled or treated oil-field wastewater." This may not be the best approach, as it could unfairly hurt growers who are using water they are told is safe by state regulators. Further, there is some evidence that labeling may have unintended consequences. Following the passage of Proposition 65 in 1986, thousands of warning labels appeared on buildings and on products warning of the presence of "chemicals known to the State of California to cause cancer and birth defects or other reproductive harm." Proponents of the law assert that it has increased public awareness of toxic substances and encouraged companies to decrease their use of them. Critics state that, on the contrary, the law has done little to decrease health risk but has resulted in hundreds of frivolous lawsuits and millions of dollars of expenses to businesses (see, for example, Borrell 2009). Rather than requiring labeling of produce irrigated with recycled water from oil and gas operations, we recommend conducting a thorough scientific assessment of the safety of recycled water for food crops, similar to the effort in Monterey County discussed above. We describe this, along with other recommendations below, beginning on page 44.

RULES AND REGULATIONS GOVERNING THE REUSE OF OIL-FIELD WASTEWATER

There are few rules or regulations that specifically apply to the use of produced water for irrigation. According to the U.S. EPA's rules under the Clean Water Act, produced water may only be discharged to a waterway for wildlife or agriculture uses west of the 98th meridian.[14] The only federal requirement under these rules is that oil-field wastewaters for wildlife and agricultural uses must not have more than 35 mg/L of oil, equivalent to a volume of crude oil of 11 to 13 gallons per acre-foot.[15] This standard was developed 40 years ago and was based on the "best practicable control technology" in use for treating produced water at the time. In this context, "practicable" does not mean the best technology available at the time but takes into account treatment cost. Regulators assumed that the amount of oil in water is a useful proxy; i.e., if it is controlled, other harmful chemicals will also be minimized. However, environmentalists have challenged this standard, arguing that there is little evidence that it is safe (Grinberg 2015). Since water treatment technology has advanced greatly in the last 40 years, the U.S. EPA should conduct a scientific analysis to re-examine whether this water quality standard is sufficiently protective of the food supply, farmworkers, and the environment.

In California, state laws govern land application of wastes and discharges to an irrigation canal. An oil company wishing to discharge produced water to land or to an irrigation canal must obtain a permit, or waste discharge requirement (WDR), from their Regional Water Quality Control Board. These WDRs outline the requirements for water treatment, set limits for the quantity of the discharge, and establish the maximum

14 40 CFR §435.50

15 Calculation by the authors based on a density of crude oil from 870 to 1,000 kg/m^3.

allowed limit of certain pollutants. Further, the WDRs establish requirements for monitoring and reporting water quality. For example, the WDR for Chevron's delivery of water to the Cawelo Water District sets limits for flow, electrical conductivity, chloride (a surrogate for salinity), boron, arsenic, and oil and grease (CVRWQCB 2012). Table 5 shows the permitted limits set by the water board for Chevron's discharge of treated produced water to a holding pond that delivers water to the Cawelo Water District, along with the sampling type and frequency required.

One of the pitfalls of the WDR Program is that the WDR must identify and address all of the potential water quality concerns. As a result, the regional board would not be able to use the WDR to enforce monitoring of any potentially harmful constituents if they do not know it could be in the waste stream. The current WDR for the Cawelo Water District only mandates frequent monitoring of constituents such as TDS, nitrates, arsenic, and boron (Table 5). While the WDR requires monitoring of a lengthy list of "priority pollutants," these must be monitored only every five years, and the list does not necessarily include all potentially harmful constituents that could be in oil-field wastewater. In addition, as mentioned previously, the toxicity of many of the chemicals used in and produced by the oil and gas industry is not known. In areas where there is hydraulic fracturing, some contaminants might not be removed by current treatment methods or identified through current monitoring (CCST, LBNL, and Pacific Institute 2014).

Ultimately, who is responsible for ensuring the safety of the food supply where oil-field

Table 5.

Discharge limits and sampling required by the water board for Chevron's discharge of water to the Cawelo Water District.

Parameter	Maximum allowed under permit	Sample type	Minimum sampling frequency
Flow	33.5 million gallons per day	Meter	Continuous
Electrical conductivity	940 μmhos/cm	Meter	Continuous
Arsenic	10 μg/L (or 10 parts per billion)	Grab	Monthly
Oil and grease	35 mg/L	Grab	Monthly
Boron	1.3 mg/L, annual average	Grab	Monthly
Chloride	200 mg/L (or 200 parts per million)	Grab	Monthly
pH	No limit set by permit	Grab	Monthly
Total suspended solids	No limit set by permit	Grab	Monthly
Sodium	142 mg/L, annual average	Grab	Quarterly
General minerals[1]	No limit set by permit	Grab	Quarterly
Priority pollutants[2]	No limit set by permit	Varies	Every 5 years

1 Standard minerals shall include the following: boron, calcium, iron, magnesium, potassium, sodium, chloride, manganese, and phosphorus; total alkalinity (including alkalinity series); and hardness; as well as verification that the analysis is complete (i.e., cation/anion balance).

2 Priority pollutants include several dozen inorganic and organic compounds, pesticides, and dioxin congeners.

Source: Order No. R5-2012-0058: Waste Discharge Requirements for Chevron U.S.A. Inc. and Cawelo Water District Produced Water Reclamation Project (CVRWQCB 2012).

wastewater is reused for crop irrigation? The California Department of Food and Agriculture said it does not have the jurisdiction to examine crops for heavy metal contamination (Schlanger 2015). The CVRWQCB requires limited monitoring of the discharge of recycled water but does not sample crops or soil where the water is applied.[16]

Currently, there are no such science-based statewide rules governing the reuse of oil-field wastewater. As noted, each of the nine Regional Water Quality Control Boards is responsible for issuing permits, and the conditions and requirements of such permits vary among the regions and for different projects. A set of statewide policies and rules should be developed for the recycling of oil-field wastewater, similar to what was done for municipal wastewater (see Box 2). The SWRCB and the state Department of Public Health should convene an expert panel to perform an independent scientific study of the safety of reusing oil-field wastewater to irrigate food crops. Finally, water quality criteria and monitoring requirements should be designed to protect farmworkers as well as consumers.

POTENTIAL RISKS TO FARMWORKERS

Those who live and work in communities where oil and gas extraction take place bear the most direct burden from air, water, and soil contamination. California farmworkers have a history of enduring long hours, low pay, discrimination, and unhealthy working conditions where they are exposed to heat, dust, sun, chemicals, and injuries. According to the National Safety Council, farm work is the most dangerous job in the United States (OSHA 2005). In this section, we describe the potential impacts of oil and gas production to farmworkers and residents of farming communities. This information was gathered through our review of the relevant literature and regulations, and by speaking with community groups in Kern County who have direct contact with residents of "fenceline" communities that live with pollution from both the oil and agricultural industries.

Farmworkers can be exposed to harmful chemicals that may be in water when growers or labor companies fail to provide clean drinking water. In field assessments done for this study, we heard accounts of foremen of work crews filling jugs of water straight from irrigation ditches, including in areas where produced water is used for irrigation and contains traces of oil and other chemicals that make it unfit for human consumption. Such accounts are believable, as there have been many documented cases in which farmers or their contractors failed to provide the basics necessary for safe work conditions, such as water, shade, or break time (Cernansky 2012).

We also heard reports of residents in Kern County fishing directly from irrigation canals in the Cawelo Water District, where the water is mixed with produced water from nearby oil fields. Fish are known to bioaccumulate certain toxins in their flesh and organs and, to our knowledge, no one has tested whether the fish in Kern County irrigation canals are safe to eat. At a minimum, signs should be posted along irrigation canals warning that the water is not suitable for drinking or fishing. These signs should be printed in multiple languages, following the example of the signs posted in fishing spots around San Francisco Bay, where certain fish caught in the bay are unhealthy to eat due to mercury and PCBs (Figure 10).

Contaminants from oil and gas production also contribute to air pollution, another health threat

16 In response to these concerns, the board has assembled a Food Safety Advisory Committee to look at this issue in more detail.

Box 2.

Reuse of Treated Sewage for Irrigation

The reuse of treated sewage to irrigate food crops offers an example for how to create science-based statewide rules that are protective of human health and the environment. Today, treated sewage (or recycled municipal wastewater) is widely used to irrigate crops all over the state. As of 2009, recycled water was reused for irrigation in 48 of California's 55 counties, and about 250,000 acre-feet was used for agricultural irrigation (SWRCB 2012). Statewide irrigation water use averages 30 to 40 million acre-feet per year, so this represents less than 1% of the state's agricultural water use. Yet, its use is steadily growing, and policymakers have made it a key goal of the California Water Action Plan (California Natural Resources Agency 2014).

Monterey County offers one example where regulators used a science-based approach to addressing the potential risks from irrigating with recycled wastewater. As described in the U.S. EPA's Guidelines for Water Reuse, this decision "was preceded by an intensive, 11-year pilot study to determine whether or not the use of disinfected filtered recycled water for irrigation of raw-eaten food crops would be safe for the consumer, the farmer, and the environment" (U.S. EPA 2012). The authors of the EPA guidelines describe how "the local farmers initially feared customer backlash and rejection of produce irrigated with 'sewer water.'" This process reflects a different culture and a different approach to risk; regulators approached this new, unknown practice with more caution and thorough study than has been seen in projects where oil-field-produced water is recycled to grow food crops.

Municipal wastewater recycling in California is regulated by Title 22 of the California Code of Regulations, which establishes water quality standards specific for different uses.[17] As the use of recycled wastewater expanded, the developed a comprehensive policy for water reuse, including uniform statewide rules. This policy, developed in 2008 by the SWRCB and the Department of Public Health, had as one of its goals to aid staff at the nine Regional Water Quality Control Boards and to give them direction for issuing permits for water recycling projects. Recognizing the need for the best available science, regulators assembled an expert panel managed by the National Water Research Institute (NWRI), a nonprofit research organization.

Regulators recognized that treated sewage was a valuable resource that could be reused for beneficial purposes, with benefits for water supply and the environment. But they also recognized that sewage contains pathogens and other potentially harmful chemicals, and that it needs to be properly treated and monitored to protect human health and the environment. An independent evaluation of these regulations in 2012 found that "because of adherence to these criteria, the use of recycled water for agricultural food crop irrigation has a history of safe use in California" (Cooper et al. 2012).

17 For example, "agricultural irrigation can occur with un-disinfected secondary recycled water for certain types of crops (fodder crops, non food-bearing trees, sod farms, etc.), disinfected secondary (crops where the edible portion is above ground and does not contact the recycled water, pasture for animals producing milk), or tertiary level recycled water (food crops where the recycled water comes into contact with the edible portion of a food crop eaten raw)." (SWRCB 2012).

Figure 10.

Warning sign for fishermen on San Francisco Bay.

Notes: These signs are posted by the California Department of Public Health and have printed warnings in English, Chinese, and Spanish.

Source: Photo by Patty McGinnis, National Oceanic and Atmospheric Administration (NOAA).

faced by farmworkers and residents of the San Joaquin Valley. The valley already has some of the most polluted and unhealthy air in California, a result of farming operations and dairies, vehicle traffic, and emissions from oil production. Contaminants from oil and gas production can enter the atmosphere via a number of pathways, including fugitive emissions (leaks) from wells, flaring, transportation, evaporation ponds, and spills. Farmworkers are among the most vulnerable groups to air pollution because they work outdoors, and because physical exertion on the job increases a person's respiration rate and the rate at which contaminants enter the lungs.

Chemical fumes or vapors can be inhaled or absorbed through the skin. Exposure to fumes can have a number of short-term and long-term (acute and chronic) health effects on the eyes, lungs, internal organs, and immune system. Short-term exposure to airborne contaminants from oil-field wastes such as benzene and PAHs can cause dizziness, headache, and nausea. Over the longer term, chronic exposure has been linked to asthma and low birth weight, birth defects, and other developmental problems.

In areas where oil-field-produced water is used to irrigate crops, farmworkers may be exposed to chemicals that volatilize from water. Farmworkers are occasionally on the field when irrigation systems are running, increasing their exposure to waterborne contaminants in aerosols or water droplets. Sprinklers may also increase volatilization of chemicals in water. We spoke with farmworkers who reported a strong chemical smell in and around the irrigation water in fields where they worked in the Cawelo Water District. On our visit to the area, we noted a strong hydrocarbon smell coming from the ponds that stored treated produced water destined for farm fields, but we are not aware of any official air quality testing that has been done to determine what chemicals are in the air in areas where crops are irrigated with oil-field wastewater nor any air quality testing that has been done at the field level to evaluate the exposure of farmworkers. Regional regulators should do more to measure and enforce air quality limits on volatile compounds that can contribute to asthma and respiratory problems (Esparza 2015).

Kern County residents are concerned about air pollution, but there is insufficient data indicating the extent or the severity of the problem. The San Joaquin Valley Air Pollution Control District manages a set of air quality monitors that measures particulate matter and ozone, but it does not regularly test for volatile chemicals that come from oil operations. According the district's Air Monitoring Network Plan, the district maintains 38 monitoring sites, and at 3 of these, they take occasional 24-hour samples for toxics, including benzene and toluene, which are associated with oil and gas production (San Joaquin Valley Air Pollution Control District 2015).

In the 2015 CCST and LBNL report on well stimulation in California, researchers concluded that there is a possibility that farmworkers may be exposed to chemicals used in well stimulation, including hydraulic fracturing, but that "testing and treatment protocols are insufficient to guarantee that well stimulation and other chemical constituents are at sufficiently low concentrations not to pose public health and occupational (farmworker) risks" (CCST and LBNL 2015b, II:434). The authors recommended that state regulators develop and implement testing and treatment protocols for contaminants of concern prior to allowing the reuse of produced water. This recommendation included chemicals introduced by oil companies as well as those that are naturally occurring underground or in oil.

Workers in the United States are supposed to be protected from hazards under the federal Occupational Safety and Health Act enacted in 1970. As we saw earlier, the oil and gas industry is exempt from major federal environmental laws, and the same holds true for worker safety rules. The oil and gas industry is exempt from certain Occupational Safety and Health Administration (OSHA) rules, including the Process Safety Management and Prevention of Major Chemical Accidents standard. With respect to farmworkers, the law does not cover family members on small farms; however, it does cover other employees. It is conceivable that OSHA's labeling requirement could be used to compel agricultural employers in areas that irrigate with produced water to identify potential chemical hazards and communicate these hazards to employees. Such an analysis could reassure farmworkers if it revealed that there were no health or safety concerns, or it could lead to new regulatory protections if hazards were identified.

FINDINGS AND RECOMMENDATIONS

Oil and gas exploration and production have the potential to affect California's agricultural and food systems, from farmworkers to consumers of agricultural products. In this analysis, we described some of the challenges when these industries operate alongside one another. Many of these challenges are related to the potential for the oil industry to pollute soil and water, and the largely unknown impact of such pollution. Well stimulation such as hydraulic fracturing (often referred to as fracking), creates additional concerns due to the use of chemicals during the stimulation process. Below, we present our main findings and provide recommendations to better protect the safety of California agriculture and food supply.

Many of these recommendations would need to be implemented by the Division of Oil, Gas, and Geothermal Resources (DOGGR), the state agency that regulates oil and gas industry exploration and production in California. In the last few years, this agency has come under increased scrutiny and been rocked by a number of scandals. In the words of John Laird, Director of the Department of Conservation, DOGGR's parent agency, the Divisions troubles stem from its dual mandate. On the one hand, DOGGR's mission is to "facilitate oil and gas production," while on the other, to "protect life, health, property, and natural resources." Laird acknowledged that at DOGGR, "since 1983, there has not been the proper balance between these two mandates" (Pavley & Wieckowski 2015). Many of these recommendations, therefore, should be taken within the context of a need for reform at the state agency level. Although recommendations for such reform are beyond the scope of this document, they are nonetheless necessary for effective implementation of our recommendations.

FINDING 1:
The disposal of oil-field wastewater in unlined percolation pits poses a significant risk of contaminating groundwater resources that may, in turn, be used by agriculture. While this practice has been banned in several states, it is still widely used in California.

Recommendation 1(a): California should follow several of the largest oil-producing states in phasing out the use of unlined percolation pits. Even old percolation pits that are no longer in use can contaminate soil and groundwater when rain or irrigation water seeps through surface layers and carries pollutants into shallow groundwater.

Recommendation 1(b): The state should require cleanup of existing sites, where necessary, and require long-term monitoring of pollution that may migrate in groundwater.

FINDING 2:
There are serious deficiencies in the way California regulates underground injection of oil and gas wastewater. In particular, wastewater has been injected in potential underground sources of drinking water, irrigation water, and water for livestock.

Recommendation 2(a): The state should require oil companies to clean up contamination from injection wells that have failed.

Recommendation 2(b): Regulators should revisit old injection permits that were issued without an appropriate "area of review" calculation to determine the zone that would be affected by injection wells.

Recommendation 2(c): Given the potential to desalinate brackish groundwater to provide for agriculture and community water needs, policymakers should consider imposing more protective standards for brackish water above the federal requirement that requires protecting aquifers with total dissolved solids (TDS) of up to 10,000 parts per million.

FINDING 3:
Hundreds of chemicals are used in or produced from oil and gas exploration and production, many of which are harmful or have an unknown effect on livestock, crops, and farmworkers.

Recommendation 3(a): Where exposure pathways to humans or sensitive environments exist, oil and gas companies should eliminate or seek to minimize the use of hazardous chemicals that do not biodegrade or otherwise become immobilized.

Recommendation 3(b): The state should require oil and gas operators to disclose all chemicals that are injected into wells, including during drilling, well cleanout and maintenance, hydraulic fracturing, acid stimulation, and enhanced oil recovery.

Recommendation 3(c): State regulators should limit or eliminate the use of chemicals with suspected but unknown health impacts pending further study.

Recommendation 3(d): The chemical and petroleum industries should fund independent scientific studies to increase understanding of the health and environmental impacts of those chemicals whose impacts are not known, especially those that remain in waters after hydraulic fracturing and other oil-field operations. Priority research should focus on a handful of chemicals in produced water with known or suspected health impacts and should study their uptake in food crops to determine whether there are pathways by which people are exposed to dangerous chemicals in the food they consume. Until the health and environmental impact of a chemical is understood, state oil and gas regulators should not allow its use.

FINDING 4:
Federal regulations for toxic chemicals and waste handling are outdated and inadequate to protect human health, the environment, and the safety of our food supply.

Recommendation 4(a): Congress should pass meaningful reform of the Toxic Substances Control Act of 1976, the main federal law regulating the use of chemicals. Meaningful reforms would make more information available on the environmental and health effects of chemicals used by industry, including oil and gas exploration, and support the use of safer chemicals.

Recommendation 4(b): Congress should amend the Resource Conservation and Recovery Act to end the exemptions for oil-field wastes from being regulated as toxic chemicals. Most oil-field wastes contain hazardous chemicals as defined in the Act and regulating them as such would help ensure their safe handling and disposal.

Recommendation 4(c): Congress should close the loophole in the Safe Drinking Water Act that exempts hydraulic fracturing chemicals from the regulation under the Act. This would allow state and federal governments to regulate these chemicals where they may affect drinking water sources.

Recommendation 4(d): Congress should pass federal legislation clarifying the ability of the Bureau of Land Management (BLM) to regulate hydraulic fracturing on federally-owned lands.

FINDING 5:
Idle, orphaned, and abandoned wells can allow oil, wastes, and chemicals to move into soil and groundwater, posing a largely hidden threat in agricultural regions near or overlapping with oil and gas production.

Recommendation 5(a): To prevent contamination of near-surface groundwater resources, the state should ensure that idle wells are closed down and sealed properly.

Recommendation 5(b): Regulators should examine whether current bonding requirements are sufficient to cover the costs of well closure and any cleanup of contamination caused by abandoned or orphaned wells.

Recommendation 5(c): The legislature should ensure that impact fees on oil and gas production are sufficient to fund the closure of orphaned wells and cover other costs of programs to mitigate air and water pollution caused by the industry.

Recommendation 5(d): The state should conduct an assessment of the over 116,000 plugged and abandoned oil and gas wells to determine which of these, if any, pose a risk to freshwater aquifers, and take appropriate steps to alleviate the threat of contamination.

FINDING 6:
There is growing potential for competition for water between oil and gas companies and farming communities, and concern that the use of this water by the oil industry will drive up the price that farmers pay for irrigation water.

Recommendation 6(a): Oil and gas companies should reduce or eliminate their use of freshwater that could otherwise be put to agricultural or municipal uses. Companies can do this by increasing the amount of water that they treat and recycle onsite, or by using recycled wastewater from cities or other industries.

Recommendation 6(b): The legislature can support this by declaring that freshwater use for oil and gas production does not constitute a "reasonable use" where recycled water use is available. Similar legislation was passed in 2010, declaring the use of potable water for landscape irrigation as a waste or unreasonable use of water if recycled water is available.[19]

FINDING 7:
There is an opportunity to expand the recycling of oil-field wastewater for "beneficial uses," such as for crop irrigation or livestock watering. However, the health and food safety impacts of this practice are poorly understood.

Recommendation 7(a): The state should develop a uniform set of guidelines for the reuse of oil and gas wastewater, similar to the Title 22 regulations for the reuse of treated sewage. This should include commissioning an independent scientific study to determine what level, if any, of chemicals in oil-field wastes are safe for farmworkers, animals, and consumers. This study could help identify any health or environmental issues associated with this practice, establish clear guidelines for water treatment and testing, and help reduce the fear, uncertainty, and doubt that currently surround the practice.

Recommendation 7(b): An independent scientific assessment of the safety of oil-field wastewater should include an assessment of whether contaminants can bioaccumulate in meat, eggs, or dairy products, and what the possible health impacts of this are. A useful parallel can be seen in the methods used by the FDA and NOAA to test seafood following oil spills, for example the 2010 Deepwater Horizon accident in the Gulf of Mexico. This risk-based approach is based on limiting consumption to levels that avoid cancers and chronic health effects.

Recommendation 7(c): The state should establish uniform and science-based water quality criteria and monitoring requirements. Regional water boards should not issue new permits for the reuse of oil-field wastewater for irrigation until the risks have been comprehensively assessed and appropriate monitoring and reporting requirements put in place. Water quality criteria and monitoring requirements should be designed to protect farmworkers as well as consumers.

Recommendation 7(d): Oil companies that provide water for irrigation should be required to provide a list of all chemicals used in the drilling, stimulation (if applicable), maintenance, and production process in oil fields to their Regional

19 California Water Code, Section 13550-13557.

Board and the water utility. This step that should be implemented immediately to help inform concerned growers and consumers about potential hazards, and discourage the use of dangerous chemicals in areas where water will be reused to irrigate food crops.

Recommendation 7(e): U.S. EPA should conduct a scientific analysis to re-examine whether the requirement that oil-field wastewaters for wildlife and agricultural uses must not have more than 35 mg/L of oil is sufficiently protective of the food supply, farmworkers, and the environment.

FINDING 8:

Pollution from past oil and gas exploration and production and waste disposal exist in the soil and groundwater throughout the state, often very near or upstream from agriculture. The full extent of "legacy pollution" is poorly understood.

Recommendation 8(a): Oil and gas companies should be required to conduct testing and remediation of soil in areas where drilling mud disposal has occurred.

Recommendation 8(b): Industry and water quality regulators should catalog and map the locations of drilling mud disposal areas and make this information publicly available, so that farmers are aware of the potential risk when deciding to farm that land or utilize local groundwater.

FINDING 9:

Missing and inaccurate data prevent better understanding the fate of oil-field wastes. In their submissions to DOGGR, oil and gas companies reported the disposal method for 18% of oil and gas wastewater (over 25 million gallons) as other, missing, or unknown.

Recommendation 9(a): DOGGR should better verify the data submitted by oil and gas companies on wastewater handling and its disposition to ensure that it is complete and accurate. These data should be expanded to include details on water recycling and beneficial reuse.

FINDING 10:

In areas where agriculture and oil production overlap, farmworkers are among the most vulnerable to the health effects of air and water pollution.

Recommendation 10(a): In areas where farmworkers may be exposed to oil-field wastes in air, soil, or water, regulators should analyze the associated health risks and, if important exposure pathways are found, identify how to avoid or lessen workplace exposures. In particular, regulators should do more to measure and enforce air quality limits on volatile compounds that can contribute to asthma and respiratory problems.

Recommendation 10(b): The Division of Occupational Safety and Health (Cal/OSHA) should require employers to analyze potential chemical hazards and communicate these hazards to employees. Such an analysis could reassure farmworkers if it revealed there were no health or safety concerns or lead to new regulatory protections if hazards are identified.

CONCLUSION

California is a major producer of oil, and oil and gas production have operated alongside agricultural operations for over a century. Projections of a massive increase in oil production in California and controversy over hydraulic fracturing have increased scrutiny on the oil and gas industry, with researchers attempting to better understand the industry's impacts on our health and the environment. This scrutiny has raised specific questions about how oil and gas production affects agriculture and the food supply, the focus of this assessment.

We conclude that oil and gas production presents many challenges for California agriculture but also some opportunities. One of the major concerns is the potential threat of air, soil, and water contamination and resulting impacts on the food supply, soil quality, and farmworkers. Hundreds of chemicals are used in or produced from oil and gas exploration and production. Many of these chemicals are known to be harmful or have unknown effects on livestock, and crops, as well as farmworkers, who are among the most vulnerable to the health effects of air and water pollution. Inadequate or unsafe waste disposal methods, accidental spills and leaks, and illegal dumping can release these chemicals into the environment. Regulations for toxic chemicals and waste handling are outdated and inadequate to protect human health, the environment, and the safety of our food supply.

The disposal of oil-field wastewater is a particular concern for agriculture. Disposal in unlined percolation pits poses a significant risk of contaminating groundwater resources that may, in turn, be used by agriculture. While this practice has been banned in several states, it is still widely used in California. There are also serious deficiencies in the way California regulates underground injection of oil and gas wastewater. In particular, wastewater has been injected in potential underground sources of drinking water, irrigation water, and water for livestock. In addition, idle, orphaned, and abandoned wells can allow oil, wastes, and chemicals to move into soil and groundwater, posing a largely hidden threat to surrounding agricultural areas.

There is growing concern that the use of freshwater by the oil industry will reduce the amount available for agriculture or drive up the price that farmers pay for water. On the other hand, wastewater from oil and gas production may be a new source of water for crop irrigation or livestock watering. Reuse of wastewater (including oil-field wastewater) for beneficial purposes has been occurring in California for decades and is likely to expand. While recycled oil-field wastewater can be an extremely valuable supply to growers in water-short regions, it is not likely to fulfill a significant percentage of the state's irrigation needs. Moreover, the health and food safety impacts of this practice are poorly understood, and the current regulatory system for using recycled oil-field wastewater for irrigation is insufficient to protect our agricultural lands, farmworkers, and the food supply. Finally, there is a fundamental lack of information about oil and gas production activities in California that precludes adequate risk management by and for nearby farms. More data and information are needed to protect human health, the environment, and California's agricultural industry.

While the state of California has set ambitious goals for increasing renewable energy supplies, oil and gas will be necessary to meet our energy needs for decades to come. With this in mind, oil industry wastes need to be more carefully managed to protect the state's land and water resources. Finally, changes to programs and policies can make oil and gas exploration and production safer for California's food and agricultural systems, and protect the health and safety of everyone from farmworkers to consumers.

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