SETBACKS
contribution of emissions from hydraulically fractured wells. Because well stimulation facilitates or enables about 20% of California's oil recovery, indirect air impacts from well stimulation are likely on the order of one-fifth of total upstream oil and gas air impacts.

Even if upstream oil and gas operations are not a large part of basin-wide air pollution load, at the scale of counties, cities or neighborhoods, oil and gas development can have larger proportional impacts. Even in regions where well stimulation-related emissions represent a small part of overall emissions, local air toxic concentrations near drilling and production sites may be elevated. This could result in health impacts in densely populated areas such as Los Angeles, where production wells are in close proximity to homes, schools, and businesses. Public datasets do not provide specific enough temporal and spatial data on air toxics emissions that would allow any realistic assessment of these impacts.

**Recommendation 6.2. Control toxic air emissions from oil and gas production wells and measure their concentrations near productions wells.**

Apply reduced-air-emission completion technologies to production wells, including stimulated wells, to limit direct emissions of air pollutants, as planned. Reassess opportunities for emission controls in general oil and gas operations to limit emissions. Improve specificity of inventories to allow better understanding of oil and gas emissions sources. Conduct studies to improve our understanding of toxics concentrations near stimulated and un-stimulated wells (Volume II, Chapter 3; Volume III, Chapter 4 [Los Angeles Basin Case Study]).

**Conclusion 6.3. Emissions concentrated near all oil and gas production could present health hazards to nearby communities in California.**

Many of the constituents used in and emitted by oil and gas development can damage health, and place disproportionate risks on sensitive populations, including children, pregnant women, the elderly, and those with pre-existing respiratory and cardiovascular conditions. Health risks near oil and gas wells may be independent of whether wells in production have undergone hydraulic fracturing or not. Consequently, a full understanding of health risks caused by proximity to production wells will require studying all types of productions wells, not just those that have undergone hydraulic fracturing. Oil and gas development poses more elevated health risks when conducted in areas of high population density, such as the Los Angeles Basin, because it results in larger population exposures to toxic air contaminants.

California has large developed oil reserves located in densely populated areas. For example, the Los Angeles Basin reservoirs, which have the highest concentrations of oil in the world, exist within the global megacity of Los Angeles. Approximately half a million people live, and large numbers of schools, elderly facilities, and daycare facilities exist, within one mile of a stimulated well, and many more live near oil and gas development of all types (Figure 1.3-12). The closer citizens are to these industrial facilities, the higher their potential exposure to toxic air emissions and higher risk of associated health effects. Production enabled by well stimulation accounts for a fraction of these emissions.
Figure 1.3-12. Population density within 2,000 m (6,562 ft) of currently active oil production wells and currently active wells that have been stimulated (figure from Volume III, Chapter 4 [Los Angeles Basin Case Study]).

Studies from outside of California indicate that, from a public health perspective, the most significant exposures to toxic air contaminants such as benzene, aliphatic hydrocarbons and hydrogen sulfide occur within 800 m (one-half mile) from active oil and gas development. These risks depend on local conditions and the type of petroleum being produced. California impacts may be significantly different, but have not been measured.
Chapter 1: Introduction

Recommendation 6.3. Assess public health near oil and gas production.

*Conduct studies in California to assess public health as a function of proximity to all oil and gas development, not just stimulated wells, and develop policies such as science-based surface setbacks, to limit exposures* (Volume II, Chapter 6; Volume III, Chapters 4 and 5 [Los Angeles Basin and San Joaquin Basin Case Studies]).

Conclusion 6.4. Hydraulic fracturing and acid stimulation operations add some occupational hazards to an already hazardous industry.

*Studies done outside of California found workers in hydraulic fracturing operations were exposed to respirable silica and VOCs, especially benzene, above recommended occupational levels. The oil and gas industry commonly uses acid along with other toxic substances for both routine maintenance and well stimulation. Well-established procedures exist for safe handling of dangerous acids.*

Occupational hazards for workers who are involved in oil and gas operations include exposure to chemical and physical hazards, some of which are specific to well stimulation activities and many of which are general to the industry. Our review identified studies confirming occupational hazards directly related to well stimulation in states outside of California. The National Institute for Occupational Safety and Health (NIOSH) has conducted two peer-reviewed studies of occupational exposures attributable to hydraulic fracturing across multiple states (not including California) and times of year. One of the studies found that respirable silica (silica sand is used as a proppant to hold open fractures formed in hydraulic fracturing) was in concentrations well in excess of occupational health and safety standards (in this case permissible exposure limits or PELs) by factors of as much as ten. Exposures exceeded PELs even when workers reported use of personal protective equipment. The second study found exposure to VOCs, especially benzene, above recommended occupational levels. The NIOSH studies are relevant for identifying hazards that could be significant for California workers, but no study to date has addressed occupational hazards associated with hydraulic fracturing and other forms of well stimulation in California.

While both hydrochloric acid and hydrofluoric acid are highly corrosive, hydrofluoric acid can be a greater health risk than hydrochloric acid in some exposure pathways because of its higher rate of absorption. State and federal agencies regulate spills of acids and other hazardous chemicals, and existing industry standards dictate safety protocols for handling acids. The Office of Emergency Services (OES) reported nine spills of acid that can be attributed to oil and gas development between January 2009 and December 2014. Reports also indicate that the spills did not involve any injuries or deaths. These acid spill reports represent less than 1% of all reported spills of any kind attributed to the oil and gas development sector in the same period, and suggest that spills of acid associated with oil and gas development are infrequent, and industry protocols for handling acids protect workers.
### Chapter 6: Potential Impacts of Well Stimulation on Human Health in California

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<td>Spills and leaks</td>
<td>Well stimulation chemicals Recovered fluids &amp; produced water</td>
<td>Surface spills and leaks are common occurrences in the oil and gas industry and must be reported and cleaned up.</td>
<td>Information recorded on spills and leaks is insufficient to determine whether stimulation chemicals could be involved.</td>
<td>Require public reporting about whether the source of the leak could contain well stimulation chemicals.</td>
<td>Vol. II Ch. 2 S 2.6.2.9</td>
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<td>Oil and gas development near human populations</td>
<td>Well stimulation chemicals Recovered fluids &amp; produced water Air and other pollutant emissions associated with hydraulic fracturing-enabled development Other</td>
<td>California has large oil reserves located under densely populated areas primarily in the San Joaquin and Los Angeles Basins. In Los Angeles, oil and gas production developed simultaneously with the growth of the city. The Los Angeles Basin has world-class oil reservoirs, with the most concentrated oil in the world. Los Angeles is also a global megacity.</td>
<td>Proximity to production increases exposures to air pollutant emissions and other results of oil and gas development activities (e.g., dust, chemicals, noise, light). Households that use groundwater from private drinking water wells in close proximity to oil and gas development may be at increased risk of exposure to potential water contamination.</td>
<td>Identify and apply appropriate measures to limit exposure by residents and sensitive receptors such as schools, daycare facilities and elderly care facilities such as scientifically based setback requirements.</td>
<td>Vol. II Ch. 6S. 6.8.1 &amp; Vol. III Ch. 4.3 &amp; Summary Report S. 3.2</td>
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<td>Acid use</td>
<td>Well stimulation chemical</td>
<td>Operators in California commonly use mixtures of hydrochloric acid and hydrofluoric acid with other sources of fluoride anions as the most economical reagent for cleaning out wells or enhancing geological formation permeability. Reported use of hydrofluoric acid in the SCAQMD data lists the concentration as percent mass in the ingredient as 1%-3%.</td>
<td>Spills and leaks of undiluted acids may present an acute toxicity and corrosion hazard. The use of acid can also mobilize naturally occurring heavy metals and other compounds that are known to be health hazards and these compounds could therefore be present in recovered fluids and produced water which humans could be exposed to if treatment and disposal is not sufficiently undertaken.</td>
<td>Evaluate the chemistry of recovered fluids and produced water for wells that have used acids and the potential consequences for the environment. Require reporting of significant chemical use for oil and gas development based on these results.</td>
<td>Vol. II Ch. 2 Ss. 2.4.3.2, 2.6.2.9 &amp; Summary Report S. 3.2</td>
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II, Chapters 2 and 3. These strategies are to be considered in addition to employment of best practices in well-stimulation-enabled oil and gas development, which are employed to avoid exposure to a given hazard in the first place. It should be noted that mitigation and “best practices” should be systematically evaluated for effectiveness in the field, and even those mitigation practices with high efficacy are not effective if they are not properly executed and enforced.

6.8.1. Community Health Mitigation Practices

6.8.1.1. Setbacks

Exposures to environmental pollution and physical hazards such as light and noise falls off with distance from the source. The literature on oil and gas production suggests that the closer a population is to active oil and gas development, the more elevated the exposure, primarily to air pollutants but also to water pollutants, if a community relies on local aquifers for their drinking water, and zonal isolation of gases and fluids from aquifers is not achieved (see Section 6.4.1 above). While some California counties and municipalities have minimum surface setback requirements between oil and gas development and residences, schools, and other sensitive receptors, there are no such regulations at the state level. Further, the scientific literature is clear that certain sensitive and vulnerable populations (e.g., children, asthmatics, those with pre-existing cardiovascular or respiratory conditions, and populations already disproportionately exposed to elevated air pollution) are more susceptible to health effects from exposures to environmental pollutants known to be associated with oil and gas development (e.g., benzene) than others. The determination of sufficient setback distances should consider these sensitive populations.

Setback requirements have been instituted in some locales to decrease exposures to air pollutants, especially to VOCs that are known to be health damaging (e.g., benzene). The Dallas-Fort Worth area recently instituted a 460 meters (1,500 foot) minimum setback requirement between oil and gas wells and residences, schools, and other sensitive receptors. In summary, the scientific literature supports the recommendation for setbacks (City of Dallas, 2015). The distance of a setback would depend on factors such as the presence of sensitive receptors, such as schools, daycare centers, and residential elderly care facilities. The need for setbacks applies to all oil and gas wells, not just those that are stimulated.

6.8.1.2. Reduced Emission Completions and Other Air Pollutant Emission Reduction Technological Retrofits

As discussed in Volume II, Chapter 3, reductions of air pollutant emissions from well completions and other components of ancillary infrastructure have been demonstrated to reduce emission of methane, non-methane hydrocarbons, and VOCs during the oil and gas development process. Many of the non-methane VOCs contribute to background and
SHALLOW FRACKING
Changing the method of produced water disposal or reuse will incur tradeoffs. Any attempt to reduce one disposal method must consider the likely outcome that other disposal methods will increase. For example, eliminating disposal in evaporation–percolation pits can lead to an increase in other disposal methods to make up the difference. In particular, closure of percolation pits or injection wells found to be contaminating protected aquifers would increase the use of other disposal methods, and this will require careful planning and management on a regional basis.

**Recommendation 4.6. Evaluate tradeoffs in wastewater disposal practices.**

*As California moves to change disposal practices, for example by phasing out percolation pits or stopping injection into protected aquifers, agencies with jurisdiction should assess the consequences of modifying or increasing disposal via other methods (Volume II, Chapter 2; Volume II, Chapter 4).*

1.3.3. Protections to Avoid Groundwater Contamination by Hydraulic Fracturing

Hydraulic fracturing operations could contaminate groundwater through a variety of pathways. We found no documented instances of hydraulic fracturing or acid stimulations directly causing groundwater contamination in California. However, we did find that fracturing in California tends to be in shallow wells and in mature reservoirs that have many existing boreholes. These practices warrant more attention to ensure that they have not and will not cause contamination.

**Conclusion 5.1. Shallow fracturing raises concerns about potential groundwater contamination.**

*In California, about three quarters of all hydraulic fracturing operations take place in shallow wells less than 600 m (2,000 ft) deep. In a few places, protected aquifers exist above such shallow fracturing operations, and this presents an inherent risk that hydraulic fractures could accidentally connect to the drinking water aquifers and contaminate them or provide a pathway for water to enter the oil reservoir. Groundwater monitoring alone may not necessarily detect groundwater contamination from hydraulic fractures. Shallow hydraulic fracturing conducted near protected groundwater resources warrants special requirements and plans for design control, monitoring, reporting, and corrective action.*

Hydraulic fractures produced in deep formations far beneath protected groundwater are very unlikely to propagate far enough upwards to intersect an aquifer. Studies performed for high-volume hydraulic fracturing elsewhere in the country have shown that hydraulic fractures have propagated no further than 600 m (2,000 ft) vertically, so hydraulic fracturing conducted many thousands of feet below an aquifer is not expected to reach a protected aquifer far above. In California, however, and particularly in the San Joaquin Basin, most hydraulic fracturing occurs in relatively shallow reservoirs, where protected groundwater might be found within a few hundred meters (Figure 1.3-8). A few instances
of shallow fracturing have also been reported in the Los Angeles Basin (Figure 1.3-9), but overall much less than the San Joaquin Basin. No cases of contamination have yet been reported, but there has been little to no systematic monitoring of aquifers in the vicinity of oil production sites.

Shallow hydraulic fracturing presents a higher risk of groundwater contamination, which groundwater monitoring may not detect. This situation warrants additional scrutiny. Operations with shallow fracturing near protected groundwater could be disallowed or be subject to additional requirements regarding design, control, monitoring, reporting, and corrective action, including: (1) pre-project monitoring to establish a base-line of chemical concentrations, (2) detailed prediction of expected fracturing characteristics prior to starting the operation, (3) definition of isolation between expected fractures and protected groundwater, providing a sufficient safety margin with proper weighting of subsurface uncertainties, (4) targeted monitoring of the fracturing operation to watch for and react to evidence (e.g., anomalous pressure transients, microseismic signals) indicative of fractures growing beyond their designed extent, (5) monitoring groundwater to detect leaks, (6) timely reporting of the measured or inferred fracture characteristics confirming whether or not the fractures have actually intersected or come close to intersecting groundwater, (7) preparing corrective action and mitigation plans in case anomalous behavior is observed or contamination is detected, and (8) adaption of groundwater monitoring plans to improve the monitoring system and specifically look for contamination in close proximity to possible fracture extensions into groundwater.
Figure 1.3-8. Shallow fracturing locations and groundwater quality in the San Joaquin and Los Angeles Basins. Some high quality water exists in fields that have shallow fractured wells (figure from Volume II, Chapter 2).
The potential for shallow hydraulic fractures to intercept protected groundwater requires both knowing the location and quality of nearby groundwater and accurate information about the extent of the hydraulic fractures. Maps of the vertical depth of protected groundwater with less than 10,000 mg/L TDS for California oil producing regions do not yet exist. Analysis and field verification could identify typical hydraulic fracture geometries; this would help determine the probability of fractures extending into groundwater aquifers. Finally, detection of potential contamination and planning of mitigation measures requires integrated site-specific and regional groundwater monitoring programs.
The pending SB 4 well stimulation regulations, effective July 1, 2015, require operators to design fracturing operations so that the fractures avoid protected water, and to implement appropriate characterization and groundwater monitoring near hydraulic fracturing operations. However, groundwater monitoring alone does not ensure protection of water, nor will it necessarily detect contamination should it occur. The path followed by contamination underground can be hard to predict, and may bypass a monitoring well. Groundwater monitoring can give false negative results in these cases, and does nothing to stop contamination from occurring in any case.

**Recommendation 5.1. Protect groundwater from shallow hydraulic fracturing operations.**

Agencies with jurisdiction should act promptly to locate and catalog the quality of groundwater throughout the oil-producing regions. Operators proposing to use hydraulic fracturing operation near protected groundwater resources should be required to provide adequate assurance that the expected fractures will not extend into these aquifers and cause contamination. If the operator cannot demonstrate the safety of the operation with reasonable assurance, agencies with jurisdiction should either deny the permit, or develop protocols for increased monitoring, operational control, reporting, and preparedness (Volume I, Chapter 3; Volume II, Chapter 2; Volume III, Chapter 5 [San Joaquin Basin Case Study]).

**Conclusion 5.2. Leakage of hydraulic fracturing chemicals could occur through existing wells.**

California operators use hydraulic fracturing mainly in reservoirs that have been in production for a long time. Consequently, these reservoirs have a high density of existing wells that could form leakage paths away from the fracture zone to protected groundwater or the ground surface. The pending SB 4 regulations going into effect July 1, 2015 do address concerns about existing wells in the vicinity of well stimulation operations; however, it remains to demonstrate the effectiveness of these regulations in protecting groundwater.

In California, most hydraulic fracturing occurs in old reservoirs where oil and gas has been produced for a long time. Usually this means many other wells (called “offset wells”) have previously been drilled in the vicinity of the operation. Wells constructed to less stringent regulations in the past or degraded since installation may not withstand the high pressures out of the designed zone. However, the use of tracers does not guarantee that leaks to groundwater will be detected. Groundwater flow can be highly channelized and it can be difficult to place a monitoring well in the right place to intersect a possible plume of contaminant. The use of tracers is good practice, but does not “solve” the problem of detecting contamination.

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4. Chemical tracers (non-reactive chemicals that can be detected in small concentrations) can be added to hydraulic fracturing fluids and, if groundwater samples contain these tracers, it is evidence that the stimulation fluid has migrated out of the designed zone. However, the use of tracers does not guarantee that leaks to groundwater will be detected. Groundwater flow can be highly channelized and it can be difficult to place a monitoring well in the right place to intersect a possible plume of contaminant. The use of tracers is good practice, but does not “solve” the problem of detecting contamination.
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<td>Well stimulation chemicals and their reaction products may be toxic, persistent or bioaccumulative. Current water district requirements for testing such waters before they are used for irrigation are not sufficient to guarantee that stimulation chemicals are removed, although some local treatment plants do use adequate protocols. If produced water used in irrigation water contains well stimulation and other chemicals, this would provide a possible exposure pathway for farmworker and animals and could lead to exposure through the food chain. Currently, more than 60% of the fruits and vegetables consumed domestically come from the Central Valley.</td>
<td>Water districts in the SJV should explicitly disallow the use for irrigation of produced water from wells that have been hydraulically fractured, or demonstrate that their monitoring and treatment methods ensure that hydraulic fracturing chemicals and other contaminants are not present in water destined for irrigation.</td>
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<td>The groundwater in the vicinity of some shallow fracturing is protected. Contamination of usable groundwater presents environmental public health risks. Groundwater monitoring requirements are likely insufficient to determine whether water has been contaminated by well stimulation-enabled oil and gas development or not. The groundwater in the vicinity of much of the shallow hydraulic fracturing operations in California has high salinity and has no beneficial uses that might constitute environmental exposure pathways to humans.</td>
<td>The focus of regulations should be on preventing contamination of aquifers, not just monitoring for it. Operators should be required to demonstrate that stimulations could not intersect usable groundwater to receive a permit. A higher level of scrutiny should be applied to shallow stimulations. Groundwater monitoring plans should be adapted as part of the corrective action, to improve the monitoring system and specifically look for contamination in close proximity to possible fracture extensions into groundwater.</td>
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purposes such as groundwater recharge, wildlife habitat, surface waterways, irrigation, and other uses. If produced water comes from an oil field where well stimulation has been used, stimulation chemicals could also be present in the produced water and would not necessarily be detected by current testing. The presence of stimulation chemicals and other naturally occurring constituents, such as heavy metals that could be mobilized by stimulation chemicals makes it far more difficult to determine if the produced water can be safely reused. The presence of stimulation chemicals also makes it more difficult to determine the amount and type of water treatment required to make the water safe for beneficial use in agriculture from a public health perspective.

**6.4.1.3. Public Health Hazards of Shallow Hydraulic Fracturing**

Deep fracturing operations are unlikely to produce fractures and conduits that intersect fresh water aquifers far above them (See Volume I of this study for more details). However, in California, about three quarters of the hydraulic fracturing takes place in shallow wells less than 600 m deep. Where drinking water aquifers exist above shallow fracturing operations, there is an inherent risk that hydraulic fractures could intersect aquifers used for drinking, agriculture, and other uses and contaminate them, thus introducing human exposure pathways and public health risks. To the extent that human populations are drinking, washing, or using water that has been contaminated via this environmental exposure pathway, there exists a public health risk (See Chapter 2 of this volume for more details water exposure pathways).

**6.4.1.4. Leakage Through Wells**

One of the problems faced in a number of other states is oil and gas development in regions that have not previously had intensive oil and gas development. California’s experience with well stimulation is the opposite: most well stimulation is occurring in reservoirs where oil and gas has been produced for a long time. This means the operations are taking place where many wells have previously been drilled, plugged, abandoned, and orphaned. Leakage can occur if a hydraulic fracture intersects another well (offset well). Offset wells can also act as a conduit through which emissions to air and water resources can occur. If protected water is contaminated and if plants (including food crops), humans, fish, and wildlife use this water, it could introduce contaminants into the food web and expose human populations to known and potentially unknown toxic substances. Because geologic conditions in California result in almost no coal mining, we did not consider leakage facilitated by abandoned coal mines, which is a problem in other states.

**6.4.1.5. Injection Into Usable Aquifers**

In June 2014, the U.S. EPA expressed concerns to the state of California regarding an EPA evaluation of injection wells in California used to dispose of oil-field waste, primarily recovered fluids and produced water that returns to the wellhead along with oil (U.S. EPA, 2014c). The EPA found that some wells inappropriately allowed injection of waste
AGRICULTURE
IRRIGATION
appropriate testing and treatment protocols to ensure safe reuse of waters contaminated with stimulation chemicals presents significant challenges, because so many different chemicals could be present, and the safe concentration limits for many of them have not been established. Hydraulic fracturing chemicals may be present in extremely small concentrations that present negligible risk, but this has not been confirmed.

Limiting hazardous chemical use as described in Recommendation 3.2 would also help to limit issues with reuse. Disallowing the reuse of produced water from hydraulically fractured wells would also solve this problem, especially in the first years of production. This water could be tested over time to determine if hazardous levels of hydraulic fracturing chemicals remain before transitioning this waste stream to beneficial use.

**Recommendation 4.3. Protect irrigation water from contamination by hydraulic fracturing chemicals and stimulation reaction products.**

*Agencies of jurisdiction should clarify that produced water from hydraulically fractured wells cannot be reused for purposes such as irrigation that could negatively impact the environment, human health, wildlife and vegetation. This ban should continue until or unless testing the produced water specifically for hydraulic fracturing chemicals and breakdown products shows non-hazardous concentrations, or required water treatment reduces concentrations to non-hazardous levels* (Volume II, Chapter 2; Volume III, Chapter 5 [San Joaquin Basin Case Study]).

**Conclusion 4.4. Injection wells currently under review for inappropriate disposal into protected aquifers may have received water containing chemicals from hydraulic fracturing.**

*DOGGR is currently reviewing injection wells in the San Joaquin Valley for inappropriate disposal of oil and gas wastewaters into protected groundwater. The wastewaters injected into some of these wells likely included stimulation chemicals because hydraulic fracturing occurs nearby.*

In 2014, DOGGR began to evaluate injection wells in California used to dispose of oil field wastewater. DOGGR found that some wells inappropriately allowed injection of wastewater into protected groundwater and subsequently shut them down. DOGGR’s ongoing investigation will review many more wells to determine if they are injecting into aquifers that should be protected.

Figure 1.3-5 is a map of the Elks Hills field in the San Joaquin Basin showing one example where hydraulically fractured wells exist near active water disposal wells. The DOGGR review includes almost every disposal well in this field for possible inappropriate injection into protected water. Some of the produced water likely came from nearby production wells that were hydraulically fractured. Consequently, the injected wastewater possibly contained stimulation chemicals at some unknown concentration.
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(Section 2.6.2). Some of these release mechanisms are primarily relevant to California, and are uncommon elsewhere, such as disposal of wastewater in unlined percolation pits, which has been banned in many states, and potential siting of disposal wells into protected groundwater. However, many of the release mechanisms have also been noted in other parts of the country. Below, we briefly summarize the main findings from Chapter 2 with regard to release mechanisms and transport pathways of concern for human health impacts.

Stimulation fluids can move through the environment and come into contact with human populations in a number of ways, including surface spills, accidental releases (Rozell and Reaven, 2012), loss of zonal isolation in wellbores (Chilingar and Endres, 2005; Darrah et al., 2014), venting and flaring of gases (Roy et al., 2013; Warneke et al., 2014), and transportation and disposal of wastes (Rozell and Reaven, 2012; Warner et al., 2012; Warner et al., 2013a; Fontenot et al., 2013).

6.4.1.1. Disposal of Produced Water in Unlined Pits

As noted in Volume II, Chapter 2, the most commonly reported recovered fluids and produced water disposal method for stimulated wells in California is by evaporation and percolation in unlined surface impoundments, also referred to as unlined sumps or pits. Operators report that nearly 60% of the produced water from stimulated wells was disposed of in unlined sumps during the first full month after stimulation. There is no testing required, or thresholds specified, for the contaminants found in well stimulation fluids or other naturally occurring chemical constituents in produced water, such as benzene, heavy metals, and naturally occurring radioactive materials (NORMs). The primary intent of unlined pits is to percolate water into the ground, and as a result, this practice provides a potentially direct subsurface pathway for the transport of produced water constituents, including returned stimulation fluids, into groundwater aquifers that are or may be used for human consumption and agricultural use. Where groundwater intercepts rivers and streams, surface water resources could also be affected. If protected water were contaminated and if plants (including food crops), humans, fish, and wildlife use this water, it could introduce contaminants into the food web and expose human populations to known and potentially unknown toxic substances.

6.4.1.2. Public Health Hazards of Produced Water Use for Irrigation of Agriculture

As noted in Volume II, Chapter 2, large volumes of water of various salinities and qualities are produced along with oil. Most produced water is re-injected into the oil and gas reservoirs to help produce more oil, maintain reservoir pressure, and prevent subsidence. But some of this produced water is not highly saline, and small quantities of it are now being used by farmers for irrigation. As discussed in Chapter 2 of this volume, concerns arise that stimulation chemicals could be mixed with produced water and thus end up in irrigation water. Because of the growing pressures on water resources in the state, there is increasing interest in whether produced water could be used for a range of beneficial
purposes such as groundwater recharge, wildlife habitat, surface waterways, irrigation, and other uses. If produced water comes from an oil field where well stimulation has been used, stimulation chemicals could also be present in the produced water and would not necessarily be detected by current testing. The presence of stimulation chemicals and other naturally occurring constituents, such as heavy metals that could be mobilized by stimulation chemicals makes it far more difficult to determine if the produced water can be safely reused. The presence of stimulation chemicals also makes it more difficult to determine the amount and type of water treatment required to make the water safe for beneficial use in agriculture from a public health perspective.

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Deep fracturing operations are unlikely to produce fractures and conduits that intersect fresh water aquifers far above them (See Volume I of this study for more details). However, in California, about three quarters of the hydraulic fracturing takes place in shallow wells less than 600 m deep. Where drinking water aquifers exist above shallow fracturing operations, there is an inherent risk that hydraulic fractures could intersect aquifers used for drinking, agriculture, and other uses and contaminate them, thus introducing human exposure pathways and public health risks. To the extent that human populations are drinking, washing, or using water that has been contaminated via this environmental exposure pathway, there exists a public health risk (See Chapter 2 of this volume for me details water exposure pathways).

6.4.1.4. Leakage Through Wells

One of the problems faced in a number of other states is oil and gas development in regions that have not previously had intensive oil and gas development. California’s experience with well stimulation is the opposite: most well stimulation is occurring in reservoirs where oil and gas has been produced for a long time. This means the operations are taking place where many wells have previously been drilled, plugged, abandoned, and orphaned. Leakage can occur if a hydraulic fracture intersects another well (offset well). Offset wells can also act as a conduit through which emissions to air and water resources can occur. If protected water is contaminated and if plants (including food crops), humans, fish, and wildlife use this water, it could introduce contaminants into the food web and expose human populations to known and potentially unknown toxic substances. Because geologic conditions in California result in almost no coal mining, we did not consider leakage facilitated by abandoned coal mines, which is a problem in other states.

6.4.1.5. Injection Into Usable Aquifers

In June 2014, the U.S. EPA expressed concerns to the state of California regarding an EPA evaluation of injection wells in California used to dispose of oil-field waste, primarily recovered fluids and produced water that returns to the wellhead along with oil (U.S. EPA, 2014c). The EPA found that some wells inappropriately allowed injection of waste
Unlined pits
Figure 1.3-3. Location of percolation pits in the Central Valley and Central Coast used for produced water disposal and the location of groundwater of varying quality showing that many percolation pits are located in regions that have potentially protected groundwater shown in color (figure from Volume II, Chapter 2).

Recommendation 4.1. Ensure safe disposal of produced water in percolation pits with appropriate testing and treatment or phase out this practice.

Agencies with jurisdiction should promptly ensure through appropriate testing that the water discharged into percolation pits does not contain hazardous amounts of chemicals related to hydraulic fracturing as well as other phases of oil and gas development. If the presence of hazardous concentrations of chemicals cannot be ruled out, they should phase out the practice of discharging produced water into percolation pits. Agencies should investigate any legacy effects of discharging produced waters into percolation pits including the potential effects of stimulation fluids (Volume II, Chapter 2; Volume III, Chapters 4 and 5 [Los Angeles Basin and San Joaquin Basin Case Studies]).
Chapter 2: Impacts of Well Stimulation on Water Resources

2.6.2.1. Use of Unlined Pits for Produced Water Disposal

As described above, evaporation-percolation in unlined surface impoundments (percolation pits) is a common disposition method for produced water from stimulated wells in California (Section 2.5). Because the primary intent of unlined pits is to percolate water into the ground, this practice provides a direct pathway for the transport of produced water constituents, including returned stimulation fluids, into groundwater. Some states, including Kentucky, Texas, and Ohio, have phased out the use of unlined pits for disposal (Kell, 2011; 401 KAR 5:090 Section 9(5)(b)(1)).

The state’s nine Regional Water Quality Control Boards have primary authority to regulate disposal pits in California. Most of the instances of discharge into percolation pits occurred in the region under the authority of the Central Valley Regional Water Quality Control Board. Within that region, disposal of produced water in percolation pits overlying groundwater with existing and future beneficial uses has been allowed if the wastewater meets certain salinity, chloride, and boron thresholds. Produced water that exceeds the salinity thresholds may also be discharged in “unlined sumps, stream channels, or surface water 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” (CVRWQCB, 2004). There was previously no testing required, nor thresholds specified, for other contaminants, including chemicals used for well stimulation or other routine oilfield activities. The Central Valley Regional Water Quality Control Board implemented an order on April 1, 2015 requiring operators to conduct a chemical analysis of wastewater disposed in active produced water disposal ponds in the Central Valley; however, the list of constituents to be analyzed does not include any indicators for stimulation fluid constituents (CVWQCB, 2015).

Figure 2.6-3 shows active and inactive unlined pits and ponds in the Central Valley and along the Central Coast. Presumably, the pits are largely used to deliberately percolate wastewater for the purpose of disposal. Active pits are primarily found on the east and west side of the southern San Joaquin Valley, although a small number of active pits can also be found in Monterey and Santa Barbara Counties. The Central Valley Regional Board is currently conducting an inventory of unlined pits in the Central Valley. As of April 2015, a total of 933 pits have been identified, of which 62% are active and 38% are inactive. An estimated 36% of the active unlined pits are operating without the necessary permits from the Central Valley Regional Board (Holcomb, 2015). Central Valley Regional Board

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5. Local Air Districts also regulate some aspects of oilfield pits, e.g., volatile organic carbon (VOC) emissions.
6. According to the Water Quality Control for the Tulare Basin, which was developed by the Central Valley Regional Water Quality Control Board, disposal of oil field wastewater in pits overlying groundwater with existing and future beneficial uses is permitted if the salinity of the wastewater is less than or equal to 1,000 micromhos per centimeter (μmhos cm⁻¹) electrical conductivity (EC), 200 milligrams per liter (mg L⁻¹) chlorides, and 1 mg L⁻¹ boron (CVRWQCB 2004).
staff expects to issue 180 enforcement orders for facilities that are not permitted or are operating with outdated permits by the end of 2015. Cease and desist orders have been issued for some facilities operating with outdated permits (Holcomb, 2015). An analysis of groundwater quality near these pits can be found in Section 2.7.

There is not one centralized location for reporting and tracking locations of unlined or disposal pits in California, so any list of disposal pits must be considered approximate. The Central Valley Regional Board, which recently launched an investigation into unlined pits, found that more than one-third of the pits located in their jurisdiction were functioning without the proper permits, indicating that there may be additional pits of which the state is unaware (Holcomb, 2015). The DOGGR production database indicates that produced water is sent to evaporation-percolation disposal ponds in counties where there are no reported pit locations, suggesting that there may be unreported pits in those counties. For example, according to the production database, 47,000 m$^3$ (38 acre-feet) were sent to evaporation-percolation ponds in Ventura County in 2013 (DOGGR, 2014c), despite there being no reported pit locations within or near the borders of that county (Holcomb, 2015).
Chapter 2: Impacts of Well Stimulation on Water Resources

Figure 2.6-3. Unlined pits used for produced water disposal in the Central Valley and the Central Coast, 2015. Data from CVRWQCB 2015; Borkovich 2015a; 2015b (Appendix 2.G).

There is ample evidence of groundwater contamination from percolation pits in California and other states (e.g. CVRWQCB, 2015; Holcomb, 2015; Kell 2011). For example, in California, the Central Valley Regional Water Quality Control Board determined that several percolation pits in Lost Hills and North and South Belridge had impacted groundwater, and ordered their closure (CVRWQCB, 2015). In these cases, monitored natural attenuation rather than active remediation was selected as the method for
corrective action for improving the groundwater quality. Groundwater contamination has also been associated with unlined pits in other states. Kell (2011) reviewed incidents of groundwater contamination caused by oil field activities in Texas between 1993 and 2008 and in Ohio between 1983 and 2007. Of the 211 incidents in Texas over the 16-year study period, 27% were associated with unlined infiltration pits, which have been phased out in Texas starting in 1969 (Kell, 2011). Of the 185 groundwater-contamination incidents in Ohio over a 25-year period, 5% (or 10 incidents) were associated with the failure of unlined pits. Like Texas, unlined disposal pits are no longer used in Ohio, and no incidents have been reported since the mid-1980s (Kell, 2011). While these studies and others linking wastewater percolation and unlined pits to groundwater contamination are not specific to well stimulation fluids, they are illustrative of the implications of this disposal method. Moreover, the presence of stimulation fluids in the produced water is likely to increase the risk of groundwater contamination.

A case in Pavillion, WY, raises additional concerns about the use of unlined pits for produced water disposal. According to the U.S. EPA draft report, released in 2011, high concentrations of hydraulic fracturing chemicals found in shallow monitoring wells near surface pits “indicate that pits represent a source of shallow ground water contamination in the area” (Digiulio et al., 2011). At least 33 unlined pits were used to store or dispose of drilling muds, flowback, and produced water in the area. Neither the company responsible for the natural gas wells, nor the other stakeholders contested these findings (Folger et al., 2012).

### 2.6.2.2. Injection of Produced Water into Protected Groundwater via Class II Wells

Subsurface injection was the second most common disposal method for produced water from stimulated wells (Section 2.5). Studies show that with proper siting, construction, and maintenance, subsurface injection is less likely to result in groundwater contamination than disposal in unlined surface impoundments (Kell, 2011). However, there are significant concerns about whether California’s Class II underground injection control (UIC) program is adequately protective of underground sources of drinking water (USDWs) – defined as groundwater aquifers that are used for water supply or could one day supply water for human consumption.7

In 2011, at the request of EPA Region 9, an independent consultant reviewed California’s UIC Program and found inconsistencies in how USDWs are defined (Walker, 2011). Specifically, the DOGGR program description refers to the protection of freshwater containing 3,000 mg L⁻¹ or less TDS. Current federal regulation, however, defines USDWs as containing less than 10,000 mg L⁻¹ TDS. This suggests that USDWs in California containing between 3,000 and 10,000 mg L⁻¹ TDS are not adequately protected. More recently, DOGGR acknowledged that it has approved UIC projects in zones with aquifers

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7. The UIC program was developed as a result of the 1974 Safe Drinking Water Act and was intended to protect USDWs.
# Chapter 6: Potential Impacts of Well Stimulation on Human Health in California

Table 6.2-1. Summary of human health hazards and risk factors in California substantiated with California-specific data.

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Hazard</th>
<th>Description of the issue</th>
<th>How the risk factor is expected to influence public health risks</th>
<th>Possible mitigation</th>
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<tbody>
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<td>Number and toxicity of chemicals in well stimulation fluids</td>
<td>Well stimulation chemicals</td>
<td>Operators have few restrictions on the types of chemicals they can use for hydraulic fracturing and acid stimulation. In California, oil and gas operators have reported the use of over 300 chemical additives. About 1/3 have not been assessed for toxicity. Of the chemicals for which there is basic environmental and health information, only a few are known to be highly toxic, but many are moderately toxic. There is incomplete information on which of the chemicals used have the potential to persist or bio-accumulate in the environment and may present risks from chronic low-level exposure.</td>
<td>If these chemicals are not released into usable water, including agricultural water and to the atmosphere then the risk is minimal. However, if there are leakage and emission pathways then it is nearly impossible to assess the risk because of the large number of chemicals, incomplete knowledge about which chemicals are present, how long these compounds persist and what their environmental and human health impacts are. Researchers and the public need access to sufficient levels of information on all chemicals involved in well stimulation, to begin an assessment of the toxicity, environmental profiles, and human health hazards associated with hydraulic fracturing and acidizing stimulation fluids.</td>
<td>Invoke Green Chemistry principles to reduce risk, that is, use smaller numbers and amounts of less toxic chemicals, and avoid chemicals with unknown impacts. Mitigate exposure pathways. Limit the chemical use in hydraulic fracturing to those on an approved list that would consist only of those chemicals with known and acceptable toxicity profiles.</td>
<td>Vol. II Ch. 2 S. 2.4 &amp; Summary Report S. 3.1</td>
</tr>
<tr>
<td>Disposal of water in unlined sumps</td>
<td>Recovered fluids &amp; produced water</td>
<td>The disposal of contaminated water in unlined pits is banned in nearly all other states because such fluids can migrate out of sumps into groundwater and move along with this water to wells or surface water where contamination can be a serious problem. Nearly 60% of wastewater from stimulated wells in California was disposed in unlined sumps.</td>
<td>Well stimulation and naturally occurring chemical constituents can evaporate from these ponds to the atmosphere as air pollutants, leak into aquifers, or migrate through the soil which could lead to food chain exposure to biota and humans. Chemicals in recovered fluids and produced water may be toxic, persistent, or bioaccumulative.</td>
<td>Test and appropriately treat water going in to unlined pits, or phase out the use of unlined sumps in the SJV for wastewater disposal.</td>
<td>Summary Report S. 3.2 &amp; Vol. II Ch. 2 S. 2.6.2.1 &amp; Vol. III Ch. 5</td>
</tr>
</tbody>
</table>
Chapter 6: Potential Impacts of Well Stimulation on Human Health in California

(Section 2.6.2). Some of these release mechanisms are primarily relevant to California, and are uncommon elsewhere, such as disposal of wastewater in unlined percolation pits, which has been banned in many states, and potential siting of disposal wells into protected groundwater. However, many of the release mechanisms have also been noted in other parts of the country. Below, we briefly summarize the main findings from Chapter 2 with regard to release mechanisms and transport pathways of concern for human health impacts.

Stimulation fluids can move through the environment and come into contact with human populations in a number of ways, including surface spills, accidental releases (Rozell and Reaven, 2012), loss of zonal isolation in wellbores (Chilingar and Endres, 2005; Darrah et al., 2014), venting and flaring of gases (Roy et al., 2013; Warneke et al., 2014), and transportation and disposal of wastes (Rozell and Reaven, 2012; Warner et al., 2012; Warner et al., 2013a; Fontenot et al., 2013).

6.4.1.1. Disposal of Produced Water in Unlined Pits

As noted in Volume II, Chapter 2, the most commonly reported recovered fluids and produced water disposal method for stimulated wells in California is by evaporation and percolation in unlined surface impoundments, also referred to as unlined sumps or pits. Operators report that nearly 60% of the produced water from stimulated wells was disposed of in unlined sumps during the first full month after stimulation. There is no testing required, or thresholds specified, for the contaminants found in well stimulation fluids or other naturally occurring chemical constituents in produced water, such as benzene, heavy metals, and naturally occurring radioactive materials (NORMs). The primary intent of unlined pits is to percolate water into the ground, and as a result, this practice provides a potentially direct subsurface pathway for the transport of produced water constituents, including returned stimulation fluids, into groundwater aquifers that are or may be used for human consumption and agricultural use. Where groundwater intercepts rivers and streams, surface water resources could also be affected. If protected water were contaminated and if plants (including food crops), humans, fish, and wildlife use this water, it could introduce contaminants into the food web and expose human populations to known and potentially unknown toxic substances.

6.4.1.2. Public Health Hazards of Produced Water Use for Irrigation of Agriculture

As noted in Volume II, Chapter 2, large volumes of water of various salinities and qualities are produced along with oil. Most produced water is re-injected into the oil and gas reservoirs to help produce more oil, maintain reservoir pressure, and prevent subsidence. But some of this produced water is not highly saline, and small quantities of it are now being used by farmers for irrigation. As discussed in Chapter 2 of this volume, concerns arise that stimulation chemicals could be mixed with produced water and thus end up in irrigation water. Because of the growing pressures on water resources in the state, there is increasing interest in whether produced water could be used for a range of beneficial
HAZARDOUS CHEMICALS
Chapter 1: Introduction

Conclusion 3.2. Operators have unrestricted use of many hazardous and uncharacterized chemicals in hydraulic fracturing.

The California oil and gas industry uses a large number of hazardous chemicals during hydraulic fracturing and acid treatments. The use of these chemicals underlies all significant potential direct impacts of well stimulation in California. This assessment did not find recorded negative impacts from hydraulic fracturing chemical use in California, but no agency has systematically investigated possible impacts. A few classes of chemicals used in hydraulic fracturing (e.g., biocides, quaternary ammonium compounds, etc.) present larger hazards because of their relatively high toxicity, frequent use, or use in large amounts. The environmental characteristics of many chemicals remain unknown. We lack information to determine if these chemicals would present a threat to human health or the environment if released to groundwater or other environmental media. Application of green chemistry principles, including reduction of hazardous chemical use and substitution of less hazardous chemicals, would reduce potential risk to the environment or human health.

Operators have few, if any, restrictions on the chemicals used for hydraulic fracturing and acid treatments. The state’s regulations address hazards from chemical use and eliminate or minimize many, but not necessarily all risks. Some of the chemicals used present hazards in the workplace or locally, such as silica dust or hydrofluoric acid. Other chemicals present potential hazards for the environment, such as biocides and surfactants that, if released, can harm fish and other wildlife. Many of the chemicals used can harm human health. If well stimulation did not use hazardous chemicals, hydraulic fracturing would pose a much smaller risk to humans and the environment. Even so, hazardous chemicals only present a risk to humans or the environment if they are released in hazardous concentrations or amounts, persist in the environment, and actually reach and affect a human, animal or plant. Even a very toxic or otherwise harmful chemical presents no risk if no person, animal or plant receives a dose of the chemical. Characterization of the risk posed by chemical use requires information on both the hazards posed by the chemicals and information about exposure to the chemicals (in other words, risk = hazard x exposure).

We have established a list of chemicals used in California based on voluntary disclosures by industry. In California, oil and gas production operators have voluntarily reported the use of over 300 chemical additives. New state regulations under SB 4 will eventually reveal all chemical use. However, knowledge of the hazards and risks associated with all the chemicals remains incomplete for almost two-thirds of the chemicals (Table 1.3-1). The toxicity and biodegradability of more than half the chemicals used in hydraulic fracturing remains uninvestigated, unmeasured, and unknown. Basic information about how these chemicals would move through the environment does not exist. Although the probability of human and environmental exposure is estimated to be low, no direct studies of environmental or health impacts from hydraulic fracturing and acid stimulation chemicals have been completed in California. To the extent that any hydraulic fracturing and acid stimulation fluids can get into the environment, reduction or elimination of the use of the most hazardous chemicals will reduce risk.
Table 1.3-1. Availability of information for characterizing the hazard of stimulation chemicals used in hydraulic fracturing. The Chemical Abstracts Service Registry Number (CASRN) is a unique numerical identifier assigned to chemical substances. Operators do not provide CASRN numbers for proprietary chemicals.

<table>
<thead>
<tr>
<th>Number of chemicals</th>
<th>Proportion of all chemicals</th>
<th>Identified by unique CASRN</th>
<th>Impact or toxicity</th>
<th>Quantity of use or emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>172</td>
<td>55%</td>
<td>Available</td>
<td>Available</td>
<td>Available</td>
</tr>
<tr>
<td>17</td>
<td>5%</td>
<td>Available</td>
<td>Available</td>
<td>Unavailable</td>
</tr>
<tr>
<td>6</td>
<td>2%</td>
<td>Available</td>
<td>Unavailable</td>
<td>Available</td>
</tr>
<tr>
<td>121</td>
<td>38%</td>
<td>Unavailable</td>
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</table>

For this study, we sorted the extensive list of chemicals reported in California to identify those of most concern or interest and created tables identifying selected chemicals for each category contributing to hazard (see Summary Report, Appendix H, and Volume II, Chapters 2 and 6). Chemicals used most frequently or in high concentrations rise to a higher level of concern, as do chemicals known to be acutely toxic to aquatic life or mammals. The assessment included chemicals used in hydraulic fracturing that can be found on the Toxic Air Contaminant Identification List, the Proposition 65 list of chemicals known to the State of California to cause cancer and reproductive harm, and the OEHHA list of chemicals with published reference exposure limits. Additional hazards considered include, flammability, corrosivity, and reactivity. These various criteria allow identification of priority chemicals to consider when reducing potential hazards from chemical use during well stimulation.

Strong acids, strong bases, silica, biocides, quaternary ammonium compounds, nonionic surfactants, and a variety of solvents are used frequently and in high concentrations in hydraulic fracturing and acid stimulation. Strong acids, strong bases, silica, and many solvents present potential exposure hazards to humans, particularly during handling, and of are of particular concern to workers and nearby residents. Use of appropriate procedures minimizes the risk of exposure and few incidences of the release of these materials during oil and gas development have been reported in California.

Biocides, quaternary ammonium compounds, nonionic surfactants, and some solvents present a significant hazard to aquatic species and other wildlife, particularly when released into surface water. The study found no releases of hazardous hydraulic fracturing chemicals to surface waters in California and no direct impacts to fish or wildlife. However, there is concern that well stimulation chemicals might have been released and potentially contaminated groundwater through a variety of mechanisms (see Conclusions 4.1, 4.3, 4.4, 5.1, 5.2 below). Many of the chemicals used in well stimulation, such as surfactants, are more harmful to the environment than to human health, but all of these chemicals are undesirable in drinking water. Determining whether chemicals that have been released pose an actual risk to human health or the environment requires further study, including a better understanding of the amounts of chemicals released and persistence of those chemicals in the environment.
Green Chemistry principles attempt to maintain an equivalent function while using less toxic chemicals and smaller amounts of toxic chemicals. It may be possible to forego or reduce the use of the most hazardous chemicals without losing much in the way of functionality. Chemical substitutions can present complications and can also introduce a new set of hazards and require a careful adaptive approach. For example, the use of guar in hydraulic fracturing fluids introduces food to bacteria in the reservoir, and this increases the need for biocides to prevent the buildup of toxic gases generated by bacterial growth. Operators moving to a less toxic but less effective biocide might also need to move away from guar to a less-digestible substitute. Then this choice could introduce new hazards instead of old hazards. For these reasons, the American Chemical Society currently sponsors a Green Chemistry Roundtable on the topic of hydraulic fracturing.

The state could also limit the chemicals used in hydraulic fracturing by disallowing certain chemicals or limiting chemicals to those on an approved list where approval depends on the chemical having an acceptable environmental profile. The latter approach reverses the usual practice, whereby an industry is permitted to use a chemical until a regulatory body proves that the chemical is harmful. Oil and gas production in the environmentally sensitive North Sea uses this pre-approval approach and might provide a model for limiting chemical risk in California. The EPA Designed for the Environment (DFE) list of chemicals may also be useful. Of course, any of these approaches requires that the operators report the unique identifier (CASRN number) of all chemicals.

**Recommendation 3.2. Limit the use of hazardous and poorly understood chemicals.**

Operators should report the unique CASRN identification for all chemicals used in hydraulic fracturing and acid stimulation, and the use of chemicals with unknown environmental profiles should be disallowed. The overall number of different chemicals should be reduced, and the use of more hazardous chemicals and chemicals with poor environmental profiles should be reduced, avoided, or disallowed. The chemicals used in hydraulic fracturing could be limited to those on an approved list that would consist only of those chemicals with known and acceptable environmental hazard profiles. Operators should apply Green Chemistry principles to the formulation of hydraulic fracturing fluids, particularly for biocides, surfactants, and quaternary ammonium compounds, which have widely differing potential for environmental harm. Relevant state agencies, including DOGGR, should as soon as practical engage in discussion of technical issues involved in restricting chemical use with a group representing environmental and health scientists and industry practitioners, either through existing roundtable discussions or independently (Volume II, Chapters 2 and 6).
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<td>If these chemicals are not released into usable water, including agricultural water and to the atmosphere then the risk is minimal. However, if there are leakage and emission pathways then it is nearly impossible to assess the risk because of the large number of chemicals, incomplete knowledge about which chemicals are present, how long these compounds persist and what their environmental and human health impacts are. Researchers and the public need access to sufficient levels of information on all chemicals involved in well stimulation, to begin an assessment of the toxicity, environmental profiles, and human health hazards associated with hydraulic fracturing and acidizing stimulation fluids.</td>
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</tr>
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6.11. Recommendations

This chapter provides findings about what can and cannot be determined about potential impacts of well stimulation technology on human health, based on currently available information. One of the challenges that arise in efforts to study health risks for well-stimulation-enabled oil and gas development is the lack of information available to carry out a standard hazard assessment and a broader risk characterization that requires information on exposure and dose-response. Here, we provide recommendations to address these information gaps.

6.11.1. Recommendation Regarding Chemical Use

The majority of important potential direct impacts of well stimulation result from the use of well stimulation chemicals. The large number of chemicals used in well stimulation makes it very difficult to judge the risks posed by accidental releases of stimulation fluids, such as those related to surface spills or unexpected subsurface pathways. Of the chemicals used, many are not sufficiently characterized to allow a full risk analysis.

**Recommendation:** Operators should report the unique CASRN identification for all chemicals used in hydraulic fracturing and acid stimulation and the use of chemicals with unknown environmental profiles should be disallowed. The overall number of different chemicals should be reduced, and the use of more hazardous chemicals and chemicals with poor environmental profiles should be reduced, avoided or disallowed. The chemicals used in hydraulic fracturing could be limited to those on an approved list that would consist only of those chemicals with known and acceptable environmental hazard profiles. Operators should apply Green Chemistry principles to the formulation of hydraulic fracturing fluids.

6.11.2. Recommendation Regarding Exposure and Health-Risk Information Gaps

This chapter identifies information gaps on hazards of substances used, the quantities and, in some cases, the identity of chemicals used for acidization and hydraulic fracturing, the magnitude of air emissions of well stimulation chemicals and fugitive emissions of oil and gas constituents, exposure pathways, and availability of acute and (in particular) chronic dose-response information.

**Recommendation:** Conduct integrated research that cuts across multiple scientific disciplines and policy interests at relevant temporal and spatial scales in California, to answer key questions about the community and occupational impacts of oil and gas production enabled by well stimulation. Provide verification and validation of reported chemical use data, and conduct research to characterize the fate and transport of both intentional and unintentional chemical releases during well stimulation activities.