Chapter Four

A Case Study of the Petroleum Geological Potential and Potential Public Health Risks Associated with Hydraulic Fracturing and Oil and Gas Development in The Los Angeles Basin

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4.1. Introduction to the Los Angeles Basin Case Study

The Los Angeles Basin is unique in its exceptional natural concentration of oil directly beneath a dense urban population. In few other places in the world has simultaneous petroleum development and urbanization occurred to such an extent. Conflicts of oil and city life are not new to Los Angeles, but recent reports suggesting the possibility of additional large-scale oil production enabled by hydraulic fracturing, coupled with the ever increasing encroachment of urbanization on the existing oil fields, lends a particular urgency to the need to understand the public health implications of having millions of people who live, work, play, and learn in close proximity to billions of barrels of crude oil.

The Los Angeles Basin Case Study contains two components. In Section 4.2, Gautier reviews the history and current trends of oil production in the Los Angeles Basin combined with a geology-based analysis of the potential for additional petroleum development. We conclude in this section that oil production in the Los Angeles Basin has been in decline for years, and that continued oil development is likely to be within existing oil fields rather than widespread development of previously undeveloped source-rock (shale tight oil) resources outside of these boundaries. Based on this scenario of future oil development, in the second part of the Los Angeles Basin Case Study, Section 4.3, Shonkoff and colleagues review the numbers and demographics of residents, schools, daycare centers and other "sensitive receptors" in proximity to existing active oil and gas development operations. The authors then use criteria air pollutant and toxic air contaminant data from southern California and elsewhere to evaluate the potential implications of oil and gas activities for public health. Next, Shonkoff and colleagues assess the potential for protected groundwater contamination attributable to hydraulic fracturing-enabled oil and gas development and potential exposure pathways. Finally, conclusions, research needs, and recommendations are presented.

4.2. History, Distribution, and Potential for Additional Oil Production in the Los Angeles Basin

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4.2.1. Abstract

Beneath the city of Los Angeles is a deep geological basin with all the components and timing of a nearly ideal petroleum system. As a consequence, the basin has one of the highest known natural concentrations of crude oil, located directly beneath a modern megacity. Petroleum has been exploited in Los Angeles since prehistoric times, but more than 90 percent of the known oil was found during a 15-year flurry of exploration in the first half of the twentieth century. Petroleum development and urbanization have gone hand in hand and been in conflict since the beginning. In spite of intense development, large quantities of recoverable oil probably remain. Besides known oil, the basin has resource potential in three categories: (1) Relatively small volumes of oil in undiscovered conventional oil fields, (2) Large volumes of additional recoverable oil in existing fields, and (3) The possibility of unconventional "shale oil" resources in Monterey-equivalent source rock systems near the center of the basin. Extensive development of any of these resources with existing technology would entail conflicts between oil production and the needs of the urban population. Therefore, technological innovations would probably be required for large-scale additional petroleum development in the Los Angeles Basin.

4.2.2. Introduction

The City of Los Angeles (L.A.) is unique in the large volumes of petroleum that underlie the city. Close proximity of a large urban population to intensive oil development poses potential hazards not necessarily present in areas of lower population density. Therefore, the possibility of extensive new development of additional petroleum resources raises concerns about potential consequences to human health. This part of the Los Angeles Basin Case Study discusses the petroleum resources of the basin and the potential for additional development.

4.2.3. Historical Summary of Petroleum Development

Native Americans used oil from natural seeps long before Europeans arrived in southern California (Merriam, 1914; Harris and Jefferson, 1985; Hodgson, 1987), and commercial production came in the mid-nineteenth century from hand-dug pits. In 1880 the Puente Oil Company drilled an exploratory well near the seeps in Brea Canyon and found Brea-Olinda oil field. At that time, Los Angeles had a growing population of about 11,000 people. In 1890, Edward Doheny and Charles Canfield started developing Los Angeles City Field; the ensuing oil boom made them rich, but also upset locals with its noise, smell, and mess. Only 50,000 people then lived in L.A., but conflicts between oil and the urban population had already begun (Rintoul, 1991).

Exploratory drilling was wildly successful in the second and third decades of the twentieth century. The biggest fields were found in a 15-year period beginning with Montebello in 1917 and ending with Wilmington-Belmont in 1932. In the frenzy of the early years of the petroleum boom, operators seemed to have little regard for efficiency, safety, human health, or environmental consequences. Wells interfered with one another and reservoirs were ruined; spills, well failures, fire, injury, and death were common.

With unrestricted production, output from each giant field spiked, flooding the market and collapsing prices. Wells on Signal Hill flowed 41,200 m^3 (259,000 barrels) per day in October of 1923 (Rintoul, 1991). That year, Long Beach field produced more than 11 million m^3 (68 million barrels) and Santa Fe Springs field more than 13 million m^3 (81 million barrels). Inglewood output exceeded 2.9 million m^3 (18 million barrels) in 1925, and Huntington Beach yielded more than 4.1 million m^3 (26 million barrels) in 1927. Wilmington-Belmont was the only giant field initially developed in a more orderly fashion, and as production from other fields declined, it provided an ever-greater share of L.A. production. In 1969 Wilmington gave up more than 14 million m^3 (89 million barrels) of oil, while all of California Division of Oil, Gas, and Geothermal Resources (DOGGR) District 1 (L.A., Orange and San Bernardino counties), including Wilmington, produced about 26.9 million m^3 (169 million barrels). By the late 1970s, with few new discoveries and increasing pressure from urbanization, wildcat drilling at had all but ceased in the Los Angeles Basin (Figure 4.2-1).

Greater L.A. is now home to more than 18 million people, many of who have a high demand for refined petroleum, but who struggle to reconcile oil production and city life. Field operations are increasingly constrained by federal, state, county, and local policies, and by competing commercial interests. Many small fields have been shut in with reservoirs still on primary production, and operations of most large fields have been contracting for years. In 2013, all onshore wells in District 1 produced just 2.2 million m^3 (14 million barrels) of oil, less than 10% of the 1969 output.

Inefficient development practices and highly restricted application of secondary and tertiary recovery technologies are the main reasons for the low recovery efficiencies (the portion of the original oil in place that has been produced or is in remaining proved reserves) now observed in the Los Angeles Basin oil fields (Gautier et al., 2013. Geologists and engineers who know the basin believe that large amounts of additional oil could be recovered with the systematic application of modern technology (Gautier et al., 2013). However, even when oil prices soared between 2007 and 2014, operator’s efforts in Brea Olinda, Huntington Beach, Long Beach, Inglewood, Santa Fe Springs, Wilmington, and other fields only managed to flatten the decline (Figure 4.2-2), suggesting that without some sort of technological innovation, the petroleum era in southern California could end with billions of barrels of recoverable oil still in the ground.

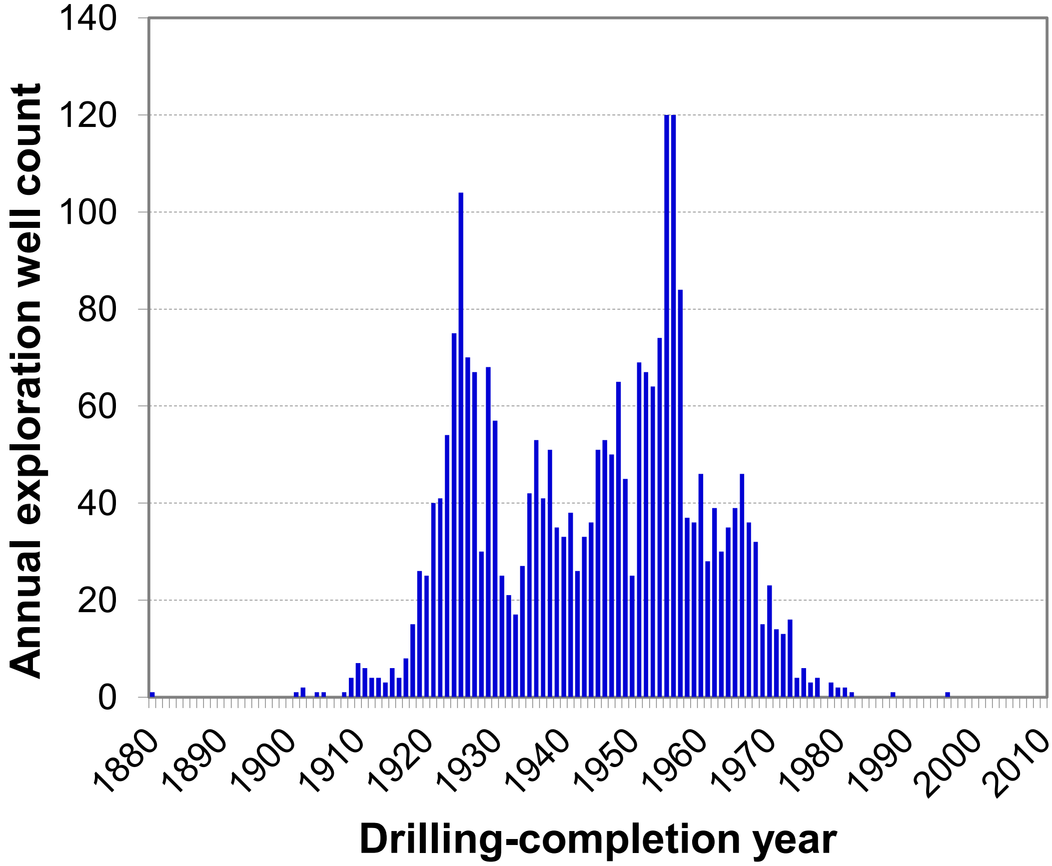

Figure 4.2-1. Numbers of wildcat exploration well drilled as a function of time in the Los Angeles Basin (Figure courtesy of T.R. Klett, U.S. Geological Survey).

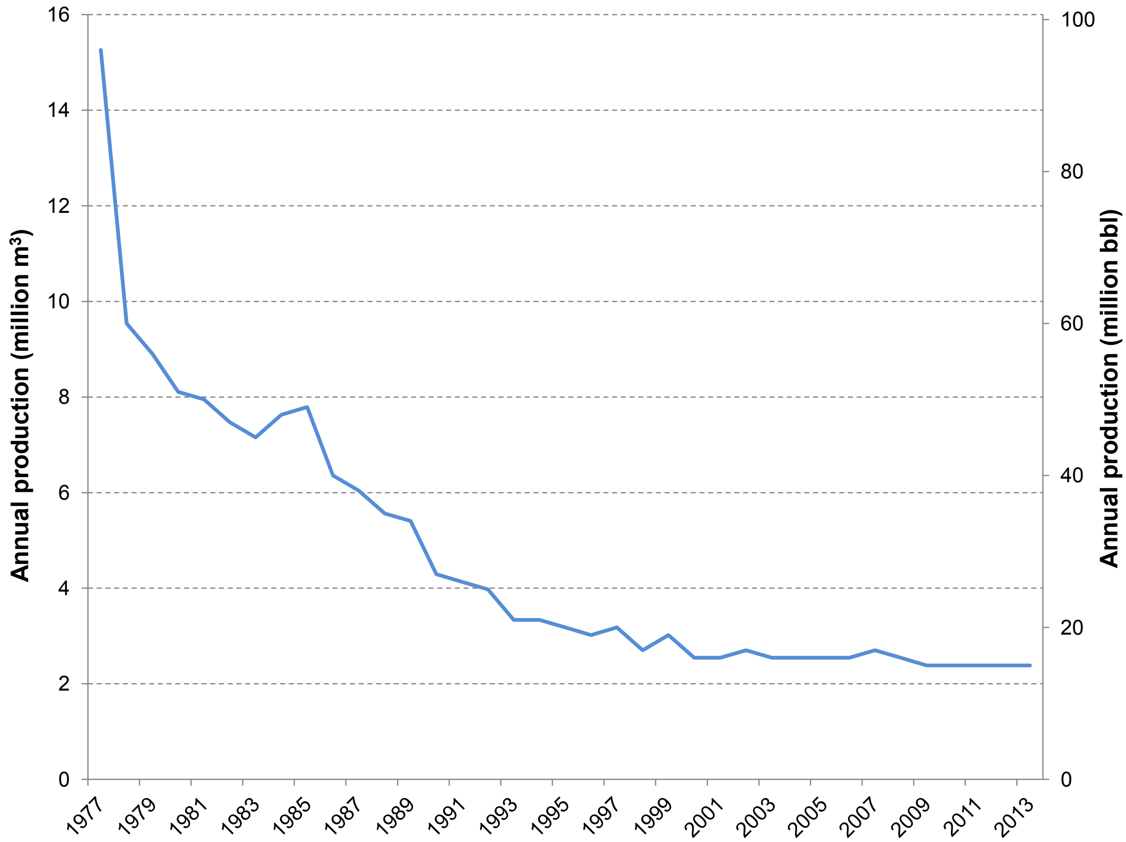

Figure 4.2-2. Graph showing onshore production of crude oil from reserves in the Los Angeles Basin between 1977 and 2015. Data from the Energy Information Administration (downloaded 2 May 2015).

4.2.4. Distribution of Known Petroleum

To geologists, the Los Angeles Basin is a small (5,700 km²; 2,200 mi²) but deep structural chasm filled with more than 8,000 meters (>26,000 feet) of sediments and sedimentary rock. A nearly ideal petroleum system and fortuitous timing of geological events have endowed the basin with what may be the world's highest concentration of crude oil (Barbat, 1958; Biddle, 1991; Gardett, 1971; Wright, 1987; Yerkes et al., 1965) (Figure 4.2-3). Petroleum is still forming in Los Angeles, as demonstrated by numerous oil and gas seeps such as those at Rancho La Brea (Hancock Park) and Brea Canyon. The fact that gas caps are almost nonexistent in the oil fields suggests that most gas-phase hydrocarbons have been naturally lost to the atmosphere, while much of the migrated oil has accumulated in conventional traps.

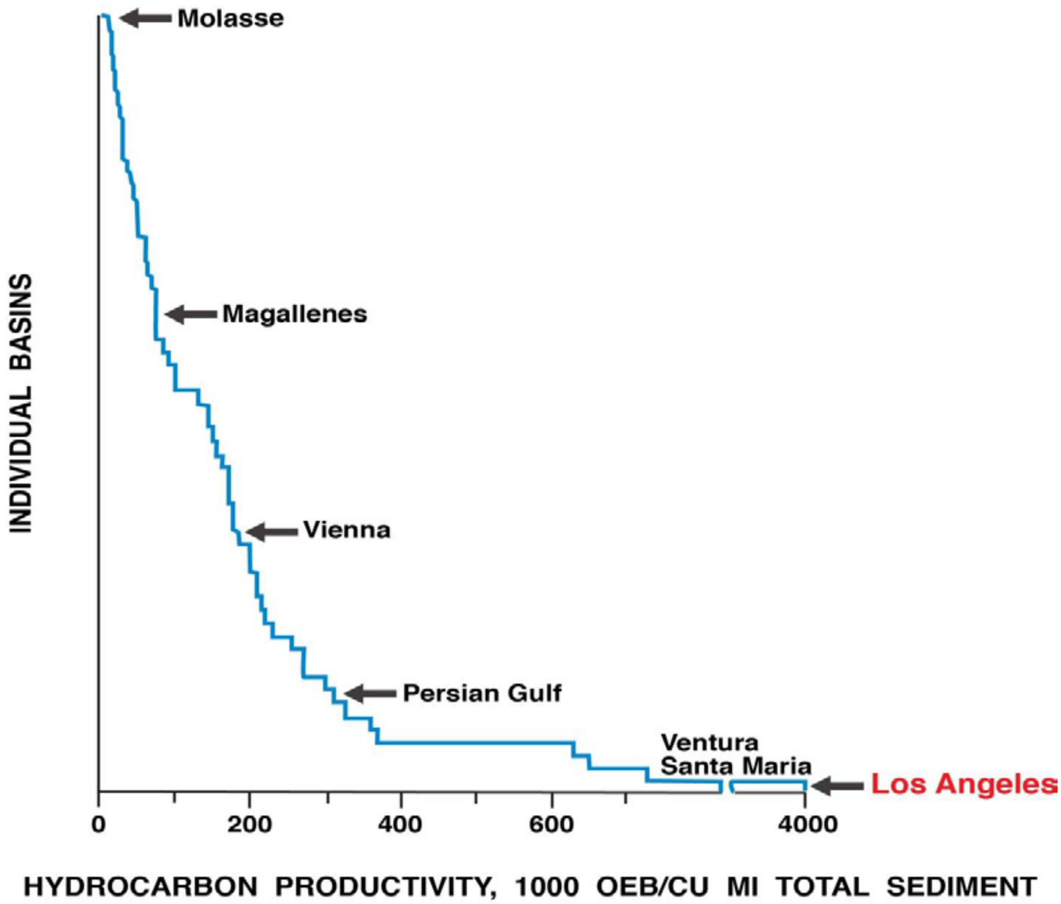

Figure 4.2-3. Relative hydrocarbon concentration by basin. Source: Kevin Biddle 1991: American Association of Petroleum Geologists Memoir 52 (OEB/CU MI = Oil equivalent barrels per cubic mile).

No petroleum province of comparable richness exists in the midst of a megacity. Petroleum has been produced from 68 named fields, most of which are closely related to the basin's principal structures (Wright, 1991). The largest oil accumulations, by known oil (cumulative production and reported remaining reserves), are: Wilmington-Belmont, Huntington Beach, Long Beach, Santa Fe Springs, Brea-Olinda, Inglewood, Dominguez, Coyote West, Torrance, Seal Beach, Richfield, Montebello, Beverly Hills East, Coyote East, Rosecrans, and Yorba Linda. These 15 accumulations, which account for more than 91 percent of recoverable oil in the basin, were all found before 1933. The most recent discoveries occurred during the early-to-mid 1960s when Beverly Hills East, Las Cienegas (Jefferson area), Riviera, and San Vicente were found. Another large field, Beta Offshore, was found in federal waters in 1976.

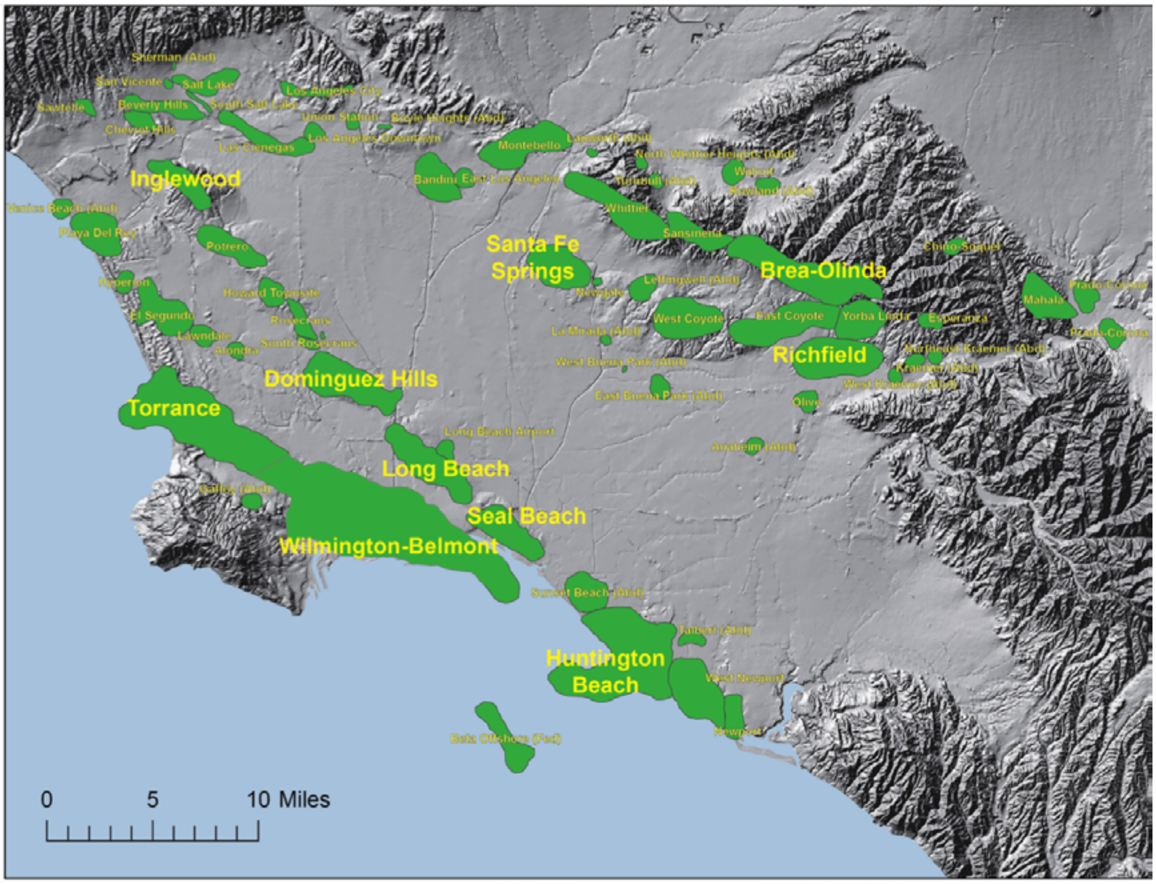

Figure 4.2-4. Map showing shaded relief topography and named oil fields of the Los Angeles Basin. The ten largest fields, studied by Gautier et al. (2013) are labeled in bold type.

4.2.5. Resource Potential of the Los Angeles Basin

In addition to its cumulative production and reported remaining reserves, the basin has resource potential in three categories: (1) Undiscovered conventional oil fields, (2) Growth of reserves in existing fields, and (3) Development of unconventional resources.

4.2.5.1. Undiscovered Conventional Oil Fields

The last systematic assessment of undiscovered conventional oil and gas resources in the Los Angeles Basin was conducted by the United States Geological Survey (USGS) and published in 1995 (Beyer, 1995; Gautier et al., 1995). At that time, the mean undiscovered conventional oil resource for the basin, including state waters but excluding federal waters, was estimated to be approximately 980 million barrels of technically recoverable oil (MMBO).

These estimated undiscovered resources were distributed among seven confirmed (meaning historically productive) USGS-defined plays (Volume I, Chapter 4,) having an aggregated mean estimated undiscovered conventional resource of 160 million m^3 (1 billion barrels) of oil (Gautier et al., 1995). A mean basin-level estimate of almost 0.16 billion m^3 of oil (1 billion barrels of oil (BBO)) would be considered quite significant in almost any untested petroleum basin. However, in Los Angeles, where the original oil in place probably exceeded 6.4 billion m^3 of oil (40 BBO), an undiscovered technically recoverable volume of less than 0.16 billion m^3 of oil (1 BBO) represents the aggregate recoverable resource remaining in many small and hard-to-find accumulations that may not warrant much expensive exploration effort. If found, these undiscovered accumulations would be expected to share many of the geological features of the known field population.

4.2.5.2. Growth of Reserves in Existing Fields

In order to evaluate the volumes of potentially recoverable oil remaining in existing fields of the Los Angeles Basin, the USGS recently assessed the 10 largest fields in the basin (Figure 4.2-4) (Gautier et al., 2013), using production, reserves, and well data published by the California Division of Oil, Gas, and Geothermal Resources. The geology of each field was analyzed, and the history of its engineering and development practices was reviewed. Probability distributions for original oil in place and maximum potential recovery efficiency were developed. The maximum recovery was evaluated on the basis of recovery efficiencies that have been modeled in engineering studies, achieved in similar reservoirs elsewhere, or indicated by laboratory results reported in technical literature. Probability distributions of original-oil-in-place and recovery efficiency were combined in a Monte Carlo simulation to estimate remaining recoverable oil in each field. The results were then probabilistically aggregated. Those aggregated results from the USGS study suggest that between 0.22 and 0.89 billion m^3 (1.4 and 5.6 billion barrels) of additional oil, recoverable with current technology, remain in the 10 analyzed fields, with a mean estimate is approximately 0.51 billion m^3 (3.2 billion barrels). In addition to the estimated remaining recoverable resources in the ten largest fields, recoverable oil likely also remains in the other 58 oil fields in the Los Angeles Basin. It is likely that some of these fields contain reservoirs that are of low permeability.

Recovery of these resources would probably require field-level redevelopment and unrestricted application of current technology, including use of improved imaging and widespread application of directional drilling, combined with extensive water, steam, and carbon dioxide flooding. Because the majority of petroleum reservoirs of the giant Los Angeles Basin fields are sandstones with high porosity and permeability, redevelopment of these fields would not generally require hydraulic fracturing as a common practice. However, certain lower permeability reservoirs are probably present in many of these large fields, the development and production of which could require the local and limited application of hydraulic fracturing in conjunction with other techniques.

4.2.5.3. Unconventional Resources

In principal, any petroleum source rock in the proper state of thermal maturation could be a reservoir for shale oil or shale gas production. Given the large concentrations of petroleum in the Los Angeles Basin, it is certain that prolific organic-rich source rocks are present in the basin, and that they are thermally mature for oil generation. Therefore, it is possible that thermally mature source rocks might be directly developed for oil in the Los Angeles Basin as they have been in Texas, North Dakota, and elsewhere.

During its 1995 National Assessment (Gautier et al., 1995), the USGS described a potential play involving technically recoverable resources in source rocks and adjacent strata in the Los Angeles Basin (Beyer, 1995). Although the play was not quantitatively assessed at the time, its resource potential and geological properties were described. The identification and descriptions of this postulated petroleum accumulation, named the "Deep Overpressured Fractured Rocks of Central Syncline Play", were based largely on the results of the American Petrofina Central Core Hole No. 1 (Redrill) well (APCCH). The APCCH, located in Sec. 4, T. 3 S., R. 13 W., is the deepest well yet drilled in the Los Angeles Basin (Wright 1991; Beyer 1995). It encountered abnormally high pore fluid pressures and tested moderately high-gravity oil below about 5,500 m (18,000 ft). The well bottomed in lowermost Delmontian (Late Miocene) rocks at a measured depth of 6,466.3 m (21,215 ft) and did not reach the presumed Mohnian (Late Middle Miocene) Monterey-equivalent source rock. The unconventional reservoir was postulated to consist of fractured strata within and immediately adjacent to the source rock interval.

The potentially productive area of the postulated source-rock play includes most of the Central Syncline and its deep flanks, at depths below which the source rock interval has been heated sufficiently for maximum petroleum generation and formation of an over-pressured condition (Figure 4.2-5). The deep southwestern flank of the Central Syncline was regarded by Beyer (1995) as the most favorable location for potentially productive continuous source-rock reservoirs.

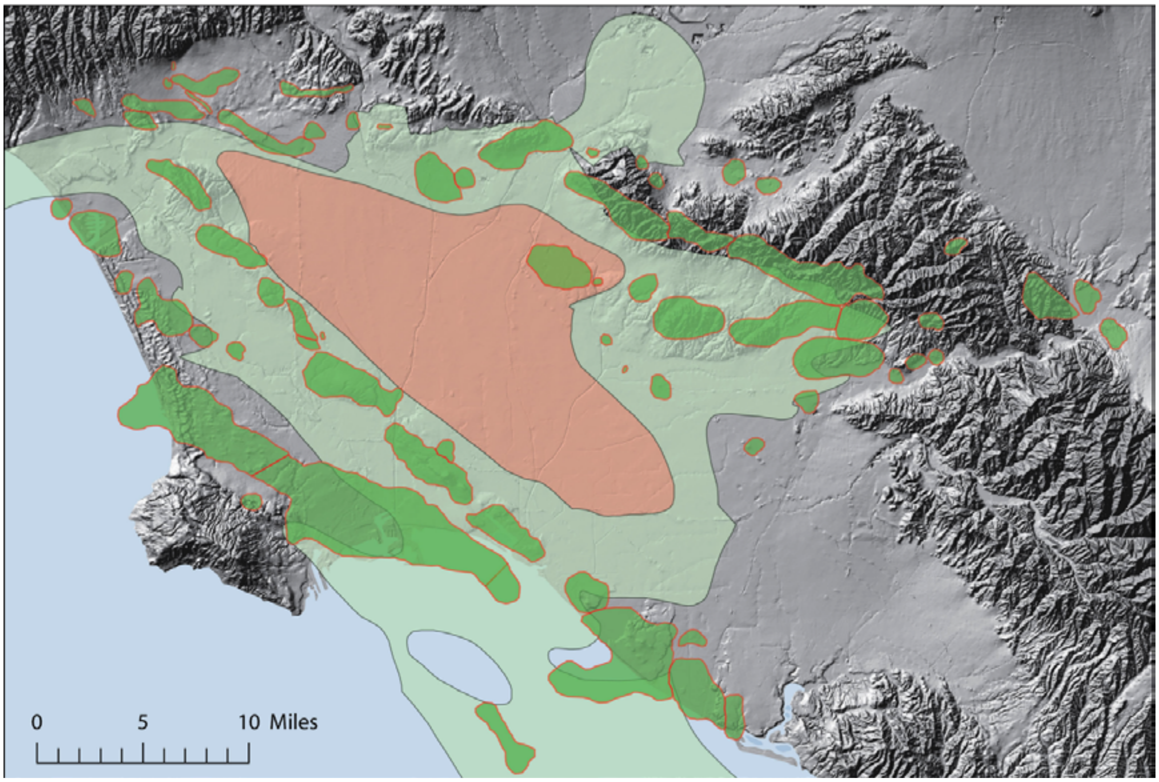

Figure 4.2-5. Map showing shaded relief topography of the Los Angeles Basin, with oil fields shown on Figure 4.2-4 in dark green and the areas where Monterey-equivalent (Mohnian-age) strata are at depths of 2,400 m (8,000 ft) or more and 14,000 feet (4,300 m) or more,shown in light green and red, respectively. Oil field outlines from DOGGR, and Monterey-equivalent depths from Wright (1991). There area in red approximately corresponds to the deepest part of the Central Syncline of the basin.

The postulated fracturing of potential reservoir rocks is inferred to result from extremely high pore fluid pressures formed during maturation of kerogen in organic-rich shales. Late Miocene and early Pliocene extensional faulting and more recent tectonic compression may also contribute to fracturing. Natural fractures are thought to provide efficient pathways for oil expulsion and migration away from source rocks. The likelihood of natural fracturing thus may constitute a technical risk to the potential shale oil play. However, the presence of overpressuring in the APCCH suggests that at least some seals remain intact and that at least some oil is retained. Several petroleum geochemists, including Price (1994), have suggested that large amounts of generated hydrocarbons may remain in or near source rocks in basins where expulsion routes have not been effectively provided by tectonics; an example of this phenomenon would be the large quantity of oil retained by the Bakken Formation in North Dakota.

The postulated continuous-type play is unexplored. The APCCH confirmed the presence of hydrocarbons and overpressuring, but did not directly demonstrate the play, as its total depth did not reach the reservoir level. Other, less deep, wells west of the Central Syncline on the east flank of the Newport-Inglewood Zone have penetrated interbedded sandstone and shale containing marine kerogen in lower Mohnian strata. Recently, hydraulic fracturing has been applied to a number of deep wells in the Inglewood oil field to enhance oil recovery (Cardno ENTRIX, 2012), and perhaps to test the concept of an unconventional source-rock system play in the Los Angeles Basin.

The geological evidence suggests that large volumes of hydrocarbons were generated from source rocks in the Central Syncline, and that at least some oil remains. However, the idea that large recoverable volumes of petroleum are present at great depth in suitable reservoir rocks is hypothetical. Moreover, because of the likely highly fractured condition of the potentially productive source rock intervals, the degree to which hydraulic fracturing would be needed for development of this hypothetical play is also a subject of speculation. The presence of at least some recoverable oil in fractured reservoirs closely associated with source rocks in the deep Central Syncline has been demonstrated by the APCCH. Burial history modeling and the occurrence of overpressured oil in the APCCH suggests that the potential shale play would be at depths of 4,270 m (14,000 ft) or more in the Central Syncline. These possible “shale oil” resources would be located beneath the central Los Angeles Basin, largely outside existing oil field boundaries (Figure 4.2-5). Testing their development potential would require drilling deep wells specifically targeting the shale oil potential.

4.2.5.4 Summary of Resource Potential

The available geological, drilling, and production data suggest that oil development in the Los Angeles Basin is likely to continue to focus on existing fields rather than on widespread development of previously undeveloped source-rock (shale tight oil) resources. Undiscovered conventional fields may contain hundreds of millions of barrels of oil, but they would probably be scattered around the basin in mostly small to medium-size accumulations. The largest remaining quantities of recoverable oil are believed to be in existing fields. The ten largest conventional fields are estimated to still contain in the range of 0.22 to 0.89 billion m^3 (1.4 billion to 5.6 billion barrels) of oil that could be recovered with today’s technology, and large volumes of additional oil may be present in the other 58 named fields of the basin. This remaining oil would probably be easier and cheaper to develop on a large scale than would postulated unconventional resources in deeply buried source rocks outside of existing fields.

Production of the remaining recoverable oil in existing fields might be enhanced by hydraulic fracturing, such as has been used recently in Inglewood, Brea-Olinda and Wilmington-Belmont fields. As costs of hydraulic fracturing have come down, it is becoming a common practice, even in Los Angeles. Widespread massive hydraulic fracturing is probably not essential for additional oil production. Instead, water flooding, carbon dioxide injection, and thermally enhanced oil recovery methods such as steam injection, could probably be used to produce most of the remaining oil, with or without hydraulic fracturing. However, any large-scale new petroleum development in Los Angeles would probably require technological innovations to reduce potential conflicts with the urban population.

Assuming the recoverable source-rock resources exist, our analysis suggests that even with social acceptance by the local population, geological and petroleum engineering obstacles would need to be overcome prior to a full build-out of a source-rock play in the Los Angeles Basin. Moreover, the quantity of oil that could be recovered from such source rocks is highly uncertain.

4.2.6. Summary of Findings

- The Los Angeles Basin is extremely rich in petroleum.
- No petroleum province of comparable size underlies such a populated urban area.
- The largest onshore fields in the basin were discovered before 1933.
- Exploratory (“wildcat”) drilling largely ceased by 1980.
- Oil production in most fields has been declining for years.
- Oil fields were developed inefficiently, and much recoverable oil remains in existing fields. Remaining undiscovered conventional oil fields are probably relatively small and scattered.
- A source-rock (shale oil) play is hypothetically possible in the deeper parts of the basin, largely outside of existing fields.
- Given the large quantities of recoverable petroleum remaining in conventional oil fields, large-scale development of continuous-type oil source rocks outside of existing fields is considered unlikely in the near future.
- Technological innovation is probably necessary for any widespread new petroleum development in the basin.

4.3. Public Health Risks Associated with Current Oil and Gas Development in The Los Angeles Basin

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4.3.1. Abstract

The Los Angeles Basin has among the highest concentrations of oil in the world, and simultaneously is home to a global megacity. Oil and gas development in Los Angeles occurs in close proximity to human populations. In this case study, we investigate locations of currently active oil and gas development, the proportion of these wells that have been enabled or supported by well stimulation treatments, the emissions of criteria air pollutants and toxic air contaminants from this development, and the numbers and demographics of residents and sensitive receptors (schools, daycare centers, residential elderly care facilities) in close proximity to these operations. We then assess potential risks to potable groundwater posed by hydraulic fracturing in the Los Angeles Basin.

The public health proximity analysis elucidates the location of populations that might be disproportionately exposed to emissions of criteria air pollutants and toxic air contaminants from the development of oil and gas. With few exceptions, most of the documented air pollutant emissions of concern from oil and gas development are associated with oil and gas development in general and are not unique to the well stimulation process. In the Los Angeles Basin, approximately 1.7 million people live, and large numbers of schools, elderly facilities, and daycare facilities are sited, within one mile of an active oil and gas well—and more than 32,000 people live within 100 meters (328 feet) of such wells. Even where the proportion of the total air pollutant emission inventory directly or indirectly attributable to well stimulation and oil and gas development in general is small, atmospheric concentrations of pollutants near oil and gas production sites can be much larger than basin or regional averages, and can present risks to human

health. Studies from outside of California indicate that community public health risks of exposures to toxic air contaminants (such as benzene and aliphatic hydrocarbons) are most significant within ½ mile (800 meters or 2,625 feet) from active oil and gas development. These risks will depend on local conditions and the types of gas and petroleum being produced. Actual exposures and subsequent health impacts in the Los Angeles Basin may be similar or different, but they have not been measured.

The results of our groundwater risk investigation, based upon available data, indicate that a small amount of hydraulic fracturing in the Los Angeles Basin has occurred within groundwater with <10,000 mg/L total dissolved solids (TDS) and in close proximity to groundwater with <3,000 mg/L TDS. This creates a risk of hydraulic fractures extending into or connecting with protected groundwater and creating a possible pathway for human exposures to chemicals in fracturing fluids for those that rely on these water resources.

4.3.2. Introduction

As described by Gautier in Section 4.2 above, the Los Angeles Basin is one of the most petroleum-rich basins on earth (Barbat, 1958; Biddle, 1991; Gardett, 1971; Wright, 1987; Yerkes et al., 1965). Oil development has occurred in this region since the 1800s and continues today. As reported in Volume I, well stimulation—hydraulic fracturing and acidizing—occurs in this basin, but the Los Angeles Basin is a distant second to the San Joaquin Valley in terms of total oil development and the fraction of oil and gas production enabled with stimulation treatments.

The Los Angeles Basin, in general, has relatively high population density and simultaneously hosts intensive oil and gas development. Given this high population density, the environmental public health dimensions of upstream oil and gas development in the Los Angeles Basin differ from those in other basins. For instance, while any industrial activities that emit criteria air pollutants and toxic air contaminants (TACs) in areas of low human population density create human health risks, conducting the same industrial processes in dense urban areas exposes a larger number of people to risks and as such, increases population health risks.

In this case study we examine the proximity of human populations—including vulnerable populations and sensitive receptors such as schools, daycare centers and residential elderly care facilities—to currently active oil and gas wells and those wells that have been stimulated. Many health hazards of well-stimulation-enabled oil and gas development that have been identified in the peer-reviewed literature and in Volume II, Chapter 6 of this report are indirect; that is, the hazards are not directly attributable to well stimulation. However, these hazards are an effect of potential exposures associated with enabled oil and gas development. The corollary to this is that many of the health impacts we discuss as due to proximity to stimulated wells will likely be the same for proximity to all oil and gas wells, whether they are stimulated or not. This is particularly relevant in California, where high-volume hydraulic fracturing—which, due to its large scale, is a far more industrially intensive process—is rarely conducted in California and only once in the Los Angeles Basin (Cardno ENTRIX, 2012) as a test well under likely non-generalizable conditions. In Volume II, Chapter 3 (Air Quality) the TACs that are known to be emitted from oil and gas development are not specific to stimulation fluids or stimulation processes (also see Volume II, Chapter 6 for a deeper explanation of this issue). Further, available data in California only allows for analyses of total air pollutant emissions from all oil and gas development, and the proportion from stimulation can only be estimated.

In light of the urban density of the Los Angeles Basin and findings from Volume II, Chapter 3 (Air Quality), this case study focuses primarily on potential public health hazards and risks associated with the development of oil and gas—in general and from wells that have been stimulated—from an air quality perspective. As such, this case study evaluates existing data about the public health implications of oil and gas development in a densely populated mega-city. In turn, it compensates for the lack of adverse health outcome data by investigating information on risk factors that suggest, but does not confirm with certainty, the risks to human health. The precepts of the field of public health include an emphasis on the anticipation of risk to human health even though the impact of these risks has not been proven. A primary goal of public health research is to anticipate and prevent harm rather than observe harm after if has occurred.

First, we examine the public health literature pertinent to the intersection of public health and oil and gas development. We then analyze available California state inventories on emissions of criteria air pollutants and TACs from upstream oil and gas development. From our assessment of air pollutant emissions, we distinguish which contaminants from oil and gas development in the Los Angeles Basin pose concerns, and we look more closely at the health risks of inhalation of benzene in particular. Given the fact that benzene levels may be elevated near active oil and gas production wells of all sorts, we examine the proximity of the population to active oil and gas wells, as well as the fraction of those active wells that were stimulated. With this approach, we assess human health risks in the context of all oil and gas development, rather than the smaller portion of the risks associated with only stimulation-enabled oil and gas development.

Finally, we examine the possibility that water supply in the Los Angeles Basin could become contaminated due to hydraulic fracturing and oil and gas development enabled by hydraulic fracturing.

Noise pollution, light pollution, industrial accidents, and truck traffic are also potentially important environmental stressors associated with well-stimulation-enabled and other types of upstream oil and gas development. These factors are covered in Volume II, Chapter 6, but are outside of the scope of this case study.

4.3.3. Air Pollution Attributable to Upstream Oil and Gas Development and Public Health Risks in the Los Angeles Basin

4.3.3.1. Background and Scientific Basis for Focus on Air Quality

There have been few epidemiological studies that measure health effects associated with oil and gas development enabled or supported by well stimulation, and there have been none in California. The studies that have been published are focused on exposures to toxic air contaminants or TACs (many TACs are referred to as "hazardous air pollutants" outside of California) while fewer studies have evaluated associations between oil and gas development and exposure to water contamination.

Each of the studies discussed in Volume II, Chapter 6 (Human Health), and again discussed below in this subsection has limitations in study design, geographic focus, and capacity to evaluate associations between cause and effect. These studies suggest that health concerns attributable to air pollution from oil and gas development are not specifically direct effects of the well stimulation process, but rather health damaging air pollutant emissions are associated with indirect effects of oil and gas development in general. For example, the studies in Colorado (McKenzie et al., 2012; McKenzie et al., 2014) found that the most likely driver of poor health outcomes were aliphatic hydrocarbons and benzene. These compounds are part of the hydrocarbons in the reservoir and so they are co-produced and co-emitted with oil and gas production and processing. It is important to note that available human health studies are insufficient to accurately understand the potential air impacts of direct well stimulation activities, which may expose both site workers and local communities to higher air concentrations of a different mixture of chemicals than would be experienced during enabled-production activities.

Finally, a broad conclusion in many of the studies discussed in Volume II, Chapter 6 (Human Health) and below is that distance from oil and gas development matters in terms of potential human health hazards, primarily associated with exposure to TACs.

4.3.3.2. Summary of Air Pollution and Public Health Study Findings

The environmental public health literature suggests that one of the primary toxic air contaminant (TAC) exposure risk factors associated with oil and gas development is geographic proximity to active oil development (see Volume II Chapter 6). This is further corroborated by atmospheric studies on dilution of conserved pollutants such as benzene once emitted to the atmosphere (United States Environmental Protection Agency (U.S. EPA), 1992). While oil and gas development throughout the U.S.—both enabled by hydraulic fracturing and in general—has been linked to regional air quality impacts (Pétron et al., 2012; Pétron et al., 2014; Thompson et al., 2014; Helmig et al., 2014; Roy et al., 2013), a number of TACs have been observed at even higher concentrations in close proximity to where active oil and gas development takes place (Macey et al. 2014;

Colborn et al., 2014; Brown et al., 2014; Brown et al., 2015). Additionally, an analysis by Brown et al. (2014) found that there might be intermittent spikes in emissions from activity and infrastructure during oil and gas development. A study on air pollutant emissions during hydraulic fracturing activities conducted by Allen et al. (2013) also found that spikes in emissions of methane and associated volatile organic compounds (VOCs) occurred during liquid unloadings. While intermittent spikes in emission may not impact regional atmospheric concentrations, they are likely to be associated with increased exposures to local populations in close proximity to the source of emission activity. Thus, regional concentrations of air pollutants may provide estimates of low- to moderate-level chronic exposures experienced by a regional population, but it is important to consider the proximity of receptors to sources in order to capture the range of potential public health risks.

Using United States Environmental Protection Agency (U.S. EPA) guidance to estimate chronic and sub-chronic non-cancer hazard indices (HIs) as well as cancer risks, a study in Colorado suggested that those living in closer geographical proximity to active oil and gas wells (≤ 800 m; 0.5 mile or ≤ 2,640 feet) were at an increased risk of acute and sub-chronic respiratory, neurological, and reproductive health effects, driven primarily by exposure to trimethyl-benzenes, xylenes, and aliphatic hydrocarbons. It also suggested that slightly elevated excess lifetime cancer risk estimates were driven by exposure to benzene and aliphatic hydrocarbons (McKenzie et al., 2012). The findings of this study are corroborated by atmospheric dilution data of conserved pollutants, for instance a U.S. EPA report on dilution of conserved TACs indicates that the dilution at 800 m (0.5 mile) is on the order of 0.1 mg/m^3 per g/s (U.S. EPA, 1992). Going out to 2,000 m (6,562 ft) increases this dilution to 0.015 mg/m^3 per g/s, and going out to 3,000 m (9,843 ft) increases dilution to 0.007 mg/m^3 per g/s. Given that, for benzene, there is increased risk at a dilution of 0.1 mg/m^3, it is not clear that atmospheric concentrations of benzene out to 2,000 m and 3,000 m (6,652 ft and 9,843 ft) can necessarily be considered safe. However, beyond 3,000 m (9,843 ft), where concentrations fall more than two orders of magnitude via dilution relative to the ½ mile radius, there is likely to be a sufficient margin of safety for a given point source.

In contrast, an oil and gas industry study in Texas compared volatile organic compound (VOC) concentration data from seven air monitors at six locations in the Barnett Shale with federal and state health-based air concentration values (HBACVs) to determine possible acute and chronic health effects (Bunch et al., 2014). The study found that shale gas activities did not result in community-wide exposures to concentrations of VOCs at levels that would pose a health concern. The key distinction between McKenzie et al. (2012) and Bunch et al. (2014) is that Bunch and colleagues used air quality data generated from monitors focused on regional atmospheric concentrations of pollutants in Texas, while McKenzie et al. (2012) included samples at the community level. Finer geographically scaled air sampling often captures local atmospheric concentrations that are more relevant to human exposure than sampling at the regional scale (Shonkoff et al., 2014).

Arriving at similar results as the Bunch et al. (2014) study, a cursory public health outcome study was conducted by the Los Angeles County Department of Public Health near the Inglewood Oil Field in Los Angeles County in 2011 (Rangan et al., 2011). This study compared incidence of a variety of health endpoints including all cause mortality, low birth weight, birth defects, and all cancer among populations nearby the Inglewood Oil Field and Los Angeles County as a whole. The study found no statistically significant difference in these endpoints between these two populations. While this may seem to indicate that there is no health impact from oil and gas development, as the study notes, the epidemiological methods employed in this study do not allow it to pick up changes in "rare events" such as cancer and birth defects in studies with relatively small numbers of people. In addition to this study being underpowered, the Inglewood Oil Field Study is a cluster investigation with exposure assigned at the group level (i.e., an ecological study). It also appears that only crude incidence ratios were calculated. This type of study design is insufficient for establishing causality and has many major limitations, including exposure misclassification and confounding, which may have obscured associations between exposure to environmental stressors from oil and gas development and health outcomes.

Using a community-based monitoring approach, Macey et al. (2014) analyzed air samples from locations near oil and gas development in Arkansas, Colorado, Ohio, Pennsylvania, and Wyoming found levels for eight volatile chemicals, including benzene, formaldehyde, hexane, and hydrogen sulfide, exceeded federal guidelines Agency for Toxic Substances and Disease Registry (ATSDR) minimal risk levels (MRLs) and U.S. EPA Integrated Risk Information System (IRIS) cancer risk levels in a number of instances (Macey et al., 2014). Of the 35 grab samples taken in the study, 16 contained chemicals at concentrations that exceeded these health-based risk levels, and those samples that exceeded thresholds were mostly collected in Wyoming and Arkansas. Fourteen out of 41 passive samples collected for formaldehyde exceeded health-based risk levels, and these were mostly collected in Arkansas and Pennsylvania. No samples collected in Ohio contained chemicals with concentrations exceeding health-based risk levels. The Macey et al. (2014) study does not specify whether or not well stimulations were used in the oil development being monitored. Importantly, the chemicals that exceeded health-based risk levels were primarily detected in samples collected near separators, gas compressors, and discharge canals.

Macey et al. (2014) noted two exceedances of hydrogen sulfide concentrations reported in samples collected near an operation that may have involved well stimulation. One was collected near a work-over rig and the other near a well pad. The residents who collected the samples self-reported a number of common health symptoms, including "headaches, dizziness or light-headedness, irritated, burning, or running nose, nausea, and sore or irritated throat" (Macey et al., 2014). This study suggests that concentrations of hazardous air pollutants near oil and gas development operations may be elevated to levels where health impacts could occur, although epidemiological studies would need to be performed to understand the extent to which health impacts have occurred. As noted elsewhere in Volume II, Chapter 6, and throughout this case study, the hazardous air pollutants observed in this study are all not directly attributable to well stimulation (e.g., they are not often added to well stimulation fluids), but rather are compounds that are co-produced with the development of oil and gas in general.

In addition to population health hazards at varying distances from active oil and gas development, other studies have assessed the effect of the density of oil and gas development on health outcomes. In a retrospective cohort study in Colorado, McKenzie et al. (2014) examined associations between maternal residential location and density of oil and gas development. The researchers found a positive dose-response association between the prevalence of some adverse birth outcomes, including congenital heart defects and increasing density of natural gas development (McKenzie et al., 2014). The observed risk of congenital heart defects in neonates was 30% (odds ratio (OR) = 1.3 (95% confidence interval (CI): 1.2, 1.5)) greater among those born to mothers who lived in the highest density of oil and gas development (> 125 wells per mile) compared to those neonates born to mothers who lived with no oil and gas wells within a 16 km (10-mile) radius. Similarly, the data suggest that neonates born to mothers in the highest density of oil and gas development were twice as likely (OR = 2.0, 95% CI: 1.0, 3.9) to be born with neural tube defects than those born to mothers living with no wells in a 10-mile radius (McKenzie et al., 2014). The study, however, showed no positive association between the density and proximity of wells and maternal residence for oral clefts, preterm birth, or term low birth weight. The authors of this retrospective cohort study report that one explanation given for the observed increased risk of neural tube defects and congenital heart disease with increasing density of gas development could be increased atmospheric concentrations of benzene, a compound known to be associated with both of these conditions (Lupo et al., 2011). However, given that there was no air quality monitoring or field-based exposure assessment, this study may suffer from exposure misclassification.

It should be noted that the presence and concentration of VOCs that are known air toxics associated with oil and gas development, such as benzene, varies between and within oil and gas reservoirs throughout the United States and abroad. The presence and concentration of these TACs in the source (the oil and gas reservoir) partially drives the potential emissions of benzene and other natural gas liquids; if they are more concentrated, it is more likely that they could be emitted. As such, on this point, there is uncertainty as to how directly applicable current out-of-state public health studies on oil and gas development may be to California. However, as noted in our analysis below, benzene emissions from upstream oil and gas development in the Los Angeles Basin are a significant percentage of the total South Coast Air Basin benzene emission inventory from all sources.

Given that exposures to conserved air pollutants (that tend to not be strongly reactive in the atmosphere) such as benzene decrease with distance from a pollutant source and approach background or regional exposures at some distance (U.S. EPA, 1992)—as explained above and in Volume II, Chapter 6 (Human Health)—the question arises, “How far is far enough to protect human health?" Residents and sensitive receptors near oil and gas wells—stimulated or not—may be more exposed either acutely or chronically to TACs emitted by oil and gas development compared to the general population. California has no setback requirement for oil and gas development, well-stimulation-enabled or otherwise, but some local jurisdictions have set minimum distances from which oil and gas development and associated ancillary infrastructure is allowed to be from residences and sensitive receptors. In the United States, setback distances range from 91 m (300 ft) in Pennsylvania to 457 m (1,500 ft or 0.28 miles) in the Dallas-Fort Worth metropolitan area, in order to reduce potential exposures of human populations to air pollutant emissions, odors, noise, and other environmental stressors (City of Dallas, 2013; Richardson et al., 2013).

4.3.3.3. The Context of Air Quality Non-Attainment in the Los Angeles Basin

The South Coast Air Basin has historically had very poor air quality, with portions of the region often in non-attainment for national and state ambient air quality standards. For example, in 2014, the Los Angeles-Long Beach area was listed #1 in ozone pollution (see Figure 4.3-1), #3 in year-round particulate matter pollution, and #4 in short-term particle pollution (see Figure 4.3-2) out of all cities in the United States (American Lung Association (ALA), 2015). The reasons for poor air quality in the Los Angeles Basin are myriad—from the diverse mobile and stationary emission sources to the topographical characteristics that discourage the transport of atmospheric pollutants out of the basin (ALA, 2015).

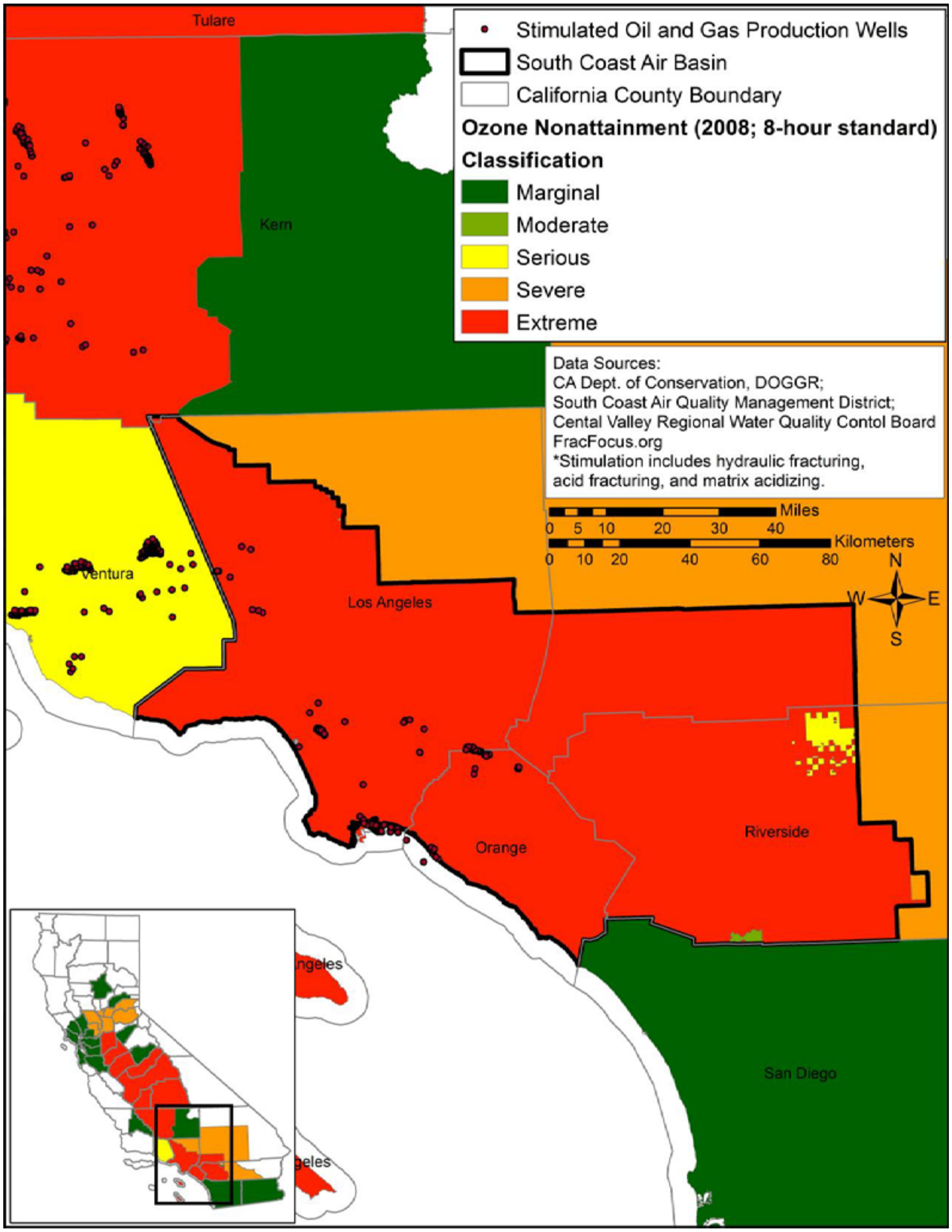


Figure 4.3-1. Ozone attainment by county in California. Note that the South Coast Air Basin (Los Angeles County, Orange County, and part of Riverside Countyy are in extreme non-attainment status.

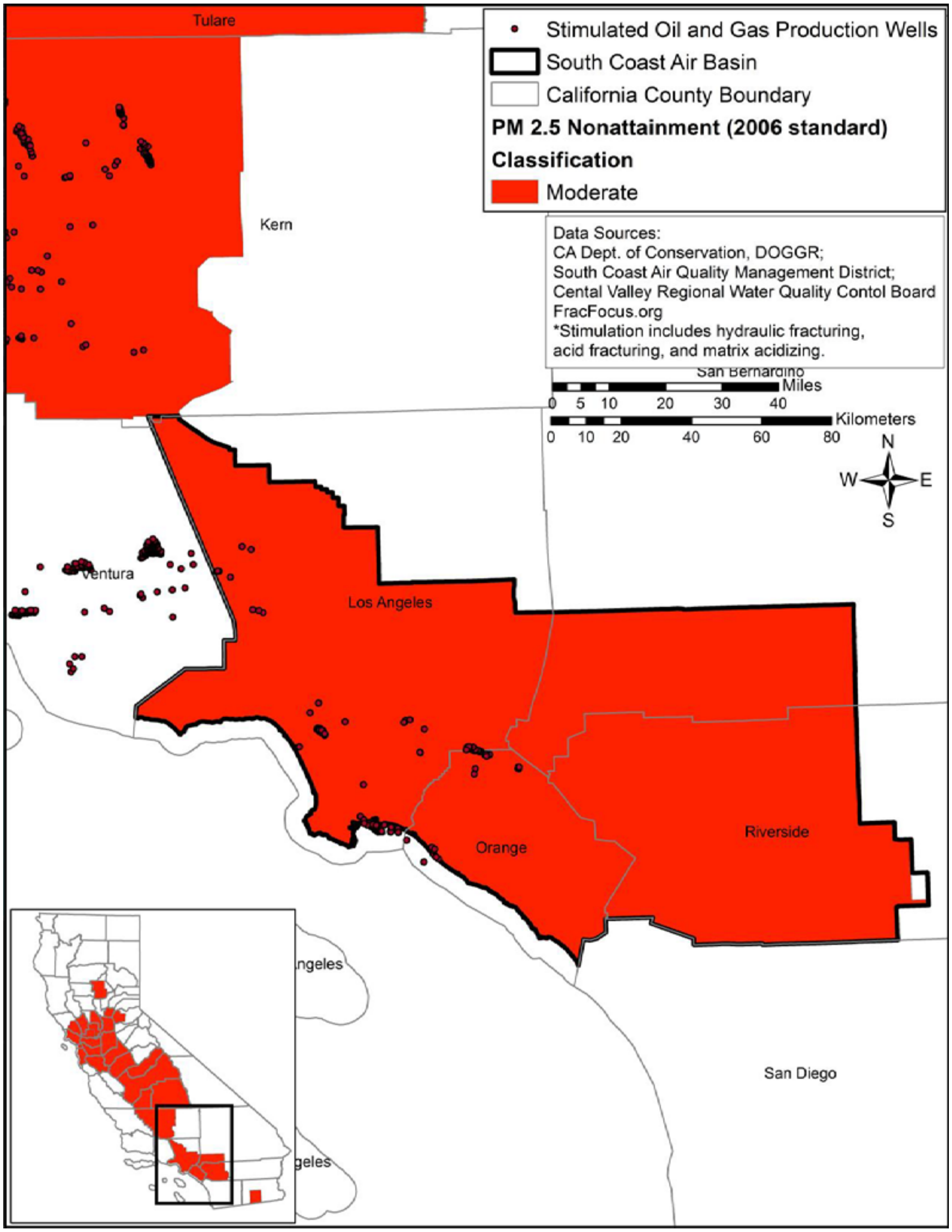


Figure 4.3-2. PM$_{2.5}$ attainment by county in the South Coast Air Basin on California. Note that. the South Coast Air Basin is in moderate non-attainment status.

Data suggests that environmental public health risks associated with an emission source should be approached from a cumulative risk perspective that takes into account the air pollution context within which these emissions occur (Pope et al., 2009). The California Air Resources Board (CARB) and the United States Environmental Protection Agency (U.S. EPA) have noticed this issue and now conduct air pollution and public health assessments in the context of a cumulative risk framework (Sadd et al., 2011). Populations exposed to cumulative air pollution burdens from multiple sources tend to be at increased risk of negative health impacts compared to populations that are exposed to lower concentrations of air pollutants from fewer sources (Morello-Frosch 2002; Morello-Frosch et al., 2010; Morello-Frosch et al., 2011).

Due to the air quality issues of the Los Angeles Basin, populations in this region are often exposed to elevated atmospheric concentrations of air pollutants (e.g., benzene, particulate matter, and VOCs), many of which are emitted by oil and gas development as well as numerous other sources within the Basin. Any additional emissions of volatile organic compounds, reactive organic gases (ozone precursors), nitrogen oxides, particulate matter, and TACs from the development of oil and gas (enabled by stimulation or not) in this region stacks additional emissions upon the cumulative air pollution burden that populations are already disproportionately exposed to.

4.3.3.4. Regional Air Pollutant Emissions in the Los Angeles Basin

Air pollutant emissions in the South Coast Region are discussed in Volume II, Chapter 3. In that volume, emissions of criteria air pollutants, greenhouse gases, and TACs are discussed, and emissions by air districts are derived from regional inventories. In Volume II, the South Coast Air Quality Management District (SCAQMD) is used as the indicator region of interest for the Los Angeles Basin.

Counties are the only common jurisdiction where all oil and gas development occurs in the Los Angeles Basin. We henceforth focus our regional air pollutant emission analysis on Los Angeles and Orange counties (See Figure 4.3-1. above), including fields partially or fully contained in the offshore areas of these counties, as per DOGGR definitions. These counties contain nearly all oil production in the greater Los Angeles metropolitan area. These counties also line up with the most populous regions of the South Coast Air Quality Management District, although that district contains some portions of nearby suburban regions (e.g., parts of Riverside and San Bernardino counties). Therefore, the alignment between these counties and the SCAQMD is expected to be generally close. These counties also do not contain production in the Santa Barbara/Ventura regions, which are not included in the SCAQMD and suffer from fewer air quality impacts.

In this case study, we take a more detailed look at regional contributions of air pollutants from all active oil and gas development, as well as that enabled or supported by well stimulation within the South Coast Region. In order to make these estimations, we join datasets from DOGGR and CARB air pollution inventories. Because DOGGR regional jurisdictions do not align with CARB air districts, we perform an analysis using counties as the regions of interest.

The data in regional inventories are not of sufficient spatial resolution to allow emissions estimates of TACs and reactive organic gases (ROGs) at the local level, and a full photochemical modeling assessment is beyond the scope of this report. Only two studies, neither of which is peer-reviewed, have attempted to answer these questions. Sonoma Technology, Inc. (2015) conducted monitoring of particulate matter (measured as black carbon as a surrogate) and limited monitoring of VOCs and heavy metals at four sites near the periphery of the Inglewood oil field. The study found a marginal contribution of particulate matter (PM) emissions that was only a small fraction of total PM emissions in the region. There were similar findings for VOCs. It is not clear, however which operations were active and at what geographic distance from the air pollutant monitors, and as such, the interpretation of these data is limited.

4.3.3.4.1. Emission Inventory Estimate of Air Pollutants from All Sources in the South Coast Region

Estimates of criteria air pollutant and TAC emissions from all active upstream oil and gas activities, and the fraction of these activities that are supported or enabled by well stimulation, requires information on total emissions of criteria air pollutants and TACs in the region of interest. From the most recent CARB criteria air pollutant inventory from 2012, emissions of criteria air pollutants from all sources in the South Coast Region are summarized in Table 4.3-1. TAC emissions for ten indicator TACs discussed in Volume II, Chapter 3, are listed in Table 4.3-2. These TAC emissions are derived from the California Toxics Inventory for 2010, reported by county for all sources, including point sources, aggregated point sources, area wide sources, diesel sources, gasoline sources, and natural sources. While many TAC species are co-emitted during hydrocarbon development (see Volume II, Chapter 3), these 10 species are prevalent in hydrocarbon production and of human health relevance. In the following sections, we evaluate the subset of these data that is attributable to all active oil and gas development, and then the portion of that which is associated with active oil development from wells that have been stimulated.

Table 4.3-1. Total emissions in 2012 of criteria air pollutants and ROGs in the South Coast Region from all sources (tones/d).

Pollutant	Los Angeles County	Orange County	South Coast Region
Reactive organic gases (ROG)	267.8	87.2	355.0
Nitrogen oxides (NO_x)	330.2	79.0	409.2
Sulphur oxides (SO_x)	14.5	1.5	16.0
PM_{10}	90.3	21.4	111.7
$PM_{2.5}$	39.1	9.7	48.8

Table 4.3-2. Total emissions in 2010 of selected TACs in the South Coast Region from all sources (tonnes/y). Data from California Toxics Inventory (CTI) county-level data.

	Los Angeles County	Orange County	South Coast Region
1,3-Butadiene	293.2	89.1	382.3
Acetaldehyde	1,238.7	313.5	1,552.1
Benzene	1,239.6	419.6	1,659.2
Carbonyl sulfide	0.0	0.0	0.0
Ethyl Benzene	749.1	251.1	1,000.2
Formaldehyde	1,827.0	548.2	2,375.1
Hexane	1,197.6	410.7	1,608.3
Hydrogen Sulfide	6.2	0.0	6.2
Toluene	5,050.1	1,810.0	6,860.2
Xylenes (mixed)	937.2	338.3	1275.5

4.3.3.4.2. Emission Inventory Estimate of Air Pollutants from All Upstream Oil And Gas Development Activities in the South Coast Region.

Here, we estimate the contribution to South Coast air pollutant emissions from all upstream oil and gas development activities. We combined emissions of criteria pollutants and TACs reported above in Tables 4.3-1 and 4.3-2 with estimates of active oil development activities in the counties of interest. As described in detail in Volume II, Chapter 3, a variety of sources in the criteria pollutants inventory and facility-level toxics database can be linked to the oil and gas industry.

In order to estimate criteria pollutant emissions from the oil and gas sector in the South Coast Region, we sum the emissions from the following sources (see Volume II, Chapter 3, for a detailed listing of the constituent subsectors and sources and attributes of each emission inventory):

- Stationary sources + petroleum production and marketing + oil and gas production + all subsectors and sources
- Stationary sources + fuel combustion + oil and gas production (combustion) + all subsectors and sources
- Mobile sources + other mobile sources + off-road equipment + oil drilling and workover

The oil and gas sector will also likely cause emissions from use of on-road light and heavy-duty trucks (e.g., maintenance trucks used in non-drilling operations and therefore not included in the “Oil drilling and workover” subsector). We cannot differentiate these emissions using reported inventory information (on-road vehicles are classified by weight class rather than industry).

Table 4.3-3 below shows the result of summing all oil- and gas-sector sources in the South Coast Region. We report the estimate from our bottom-up inventory analysis. It should be noted that recent top-down analyses of methane have noted that the methane emission inventory may be underestimated by two to seven times what is reported in the emissions inventories (Peischl et al., 2013; Jeong et al., 2013). Emissions of methane may provide insight into the emission of light alkane VOCs (a subset of ROGs) and to a certain extent, TACs, as they are often co-emitted during oil and gas development processes. As such, the values provided below should be taken as a conservative estimate of emissions from this sector. More field-based research should be conducted to understand to what degree the criteria air pollutant emission inventories are accurate and how to improve them. Additionally, these publicly available data do not allow us to analyze the geographic, corporate, or facility distribution of emissions, only the total amount emitted by the entire upstream oil and gas sector. For a detailed assessment of the discrepancy between these bottom-up inventories and recent field-based monitoring, see Volume II, Chapter 3.

Table 4.3-3. Contribution of upstream oil and gas sources to criteria pollutants and ROGs emissions in South Coast Region, data for 2012. (tonnes/d).

	ROG	**NO_x**	**SO_x**	**PM_{10}**	**$PM_{2.5}$**
Stationary oil and gas	0.99	1.64	0.02	0.09	0.09
Mobile oil and gas	0.09	1.06	0.00	0.04	0.04
Total oil and gas	1.08	2.70	0.02	0.12	0.12
Oil and gas fraction of all sectors	0.31%	0.66%	0.12%	0.11%	0.25%

Table 4.3-4. lists upstream oil and gas development stationary source facility-reported contributions to selected TACs in the South Coast Region. It also lists all source emissions of these TACs for 2010 in comparison (most recent year for which data are available). In addition, a number of potential TACs are injected into formations as part of fracturing fluids, as noted in SCAQMD datasets. These potential TACs are discussed in Volume II, Chapter 3.

Hydrogen sulfide and carbonyl sulfide emissions were not reported from the upstream oil and gas sector in the South Coast Region (Table 4.3-4). The reporting facilities in the state inventories include refineries and landfills, but none of the oil production sectors. As these compounds are reported in the San Joaquin Valley, they are likely also emitted in the South Coast Region. Moreover, a U.S. EPA preliminary risk assessment places carbonyl sulfide near the top of its table of emissions of TACs by mass from studied facilities (U.S. EPA, 2011). The lack of records could be a reporting loophole or an error in the database, and deserves further investigation. Because these data are missing, the proportion of the total emissions of hydrogen sulfide and carbonyl sulfide emissions attributable to upstream oil and gas development in the Los Angeles Basin remains unknown.

Table 4.3-4 Contribution of upstream oil and gas sources to TAC emissions in South Coast Region (kg/y). Fraction is approximate because all source inventory of TACs was last completed for year 2010 emissions.

	Stationary oil and gas sources (kg/y) (2012)	Fraction of emissions from stationary sources	Emissions from all stationary and mobile sources (kg/y) (2010)	Fraction of all emissions from all sources (kg/y) (stationary and mobile)
1,3-Butadiene	56	1.60%	382,307	0.01%
Acetaldehyde	1	0.00%	1,552,128	0.00%
Benzene	2,361	9.60%	1,659,155	0.14%
Carbonyl sulfide	not available	not available	20	not available
Ethyl Benzene	28	0.50%	1,000,213	0.00%
Formaldehyde	5,846	3.80%	2,375,149	0.25%
Hexane	1	0.00%	1,608,302	0.00%
Hydrogen Sulfide	not available	not available	6,238	not available
Toluene	1	0.00%	6,860,168	0.00%
Xylenes (mixed)	1	0.00%	1,275,480	0.00%

4.3.3.4.3. Emission Inventory Estimate of Air Pollutants Attributable to Well Stimulation-Enabled Upstream Oil and Gas Development in the South Coast Region

Following the methodology used in Volume I to identify hydrocarbon pools considered to be facilitated or enabled by well stimulation, we generated a list of stimulated pools and fields in the South Coast Region. This list is generated from Volume I, Appendix N. DOGGR county codes that represent the South Coast Region include Los Angeles (code 37), Los Angeles Offshore (code 237), Orange County (code 59) and Orange County Offshore (code 259). These pools are presented in Table 4.3-5.

Using queries to the DOGGR well-level production database, we can sum all production from these facilitated or enabled pools in 2013 and compare this to all production in the South Coast Region. As can be seen from Table 4.3-5, the well-stimulation-facilitated or -enabled pools represented a total of 874,430 m^3 (5.5 million bbl) of production, approximately 19% of production in the South Coast Region.

Table 4.3-5. Pools in South Coast Region determined to be facilitated or enabled by hydraulic fracturing. Production derived from queries to 2013 full-year well-level DOGGR database for wells that match the field, area, and pool combinations noted to be stimulated in Volume I, Appendix N.

DOGGR county code	Field	Area	Pool	Oil production (2013 bbl)
237, 259	Belmont Offshore	Surfside Area	No Pool Breakdown	243,034
37, 59	Brea-Olinda	Any Area	No Pool Breakdown	1,111,985
37	Inglewood	Any Area	No Pool Breakdown	2,731,733
37	Montebello	West Area	No Pool Breakdown	15,299
37	San Vicente	Any Area	Clifton, Dayton and Hay	271,235
37	Whittier	Rideout Heights Area	No Pool Breakdown	31,766
37	Whittier	Rideout Heights Area	Pliocene	39,982
37, 237	Wilmington	Fault Block 90	Ford	105,564
37, 237	Wilmington	Fault Block 90	Union Pacific	503,655
37, 237	Wilmington	Fault Block 98	237	0
37, 237	Wilmington	Fault Block 98	Ford	20,604
37, 237	Wilmington	Fault Block 98	Union Pacific	18,892
37, 237	Wilmington	Fault Block I	237	6,815
37, 237	Wilmington	Fault Block IV	Ford	15,442
37, 237	Wilmington	Fault Block VII	Union Pacific (ABD)	28,902
37, 237	Wilmington	Fault Block VIII	Terminal	212,055
37, 237	Wilmington	Fault Block VIII	Union Pacific	148,305
37, 59, 237, 259	Total production from facilitated pools			5,505,268
37, 59, 237, 259	Total production in South Coast Region			29,150,660
37, 59, 237, 259	Fraction of production from facilitated or enabled pools			18.9%

We use these activity factors for production and drilling to scale the stationary source and mobile source emissions from the entire oil and gas sector. (For more information on specific emission sources used for this analysis please see Volume II, Chapter 3.) This result then generates an estimate of those emissions enabled or facilitated by well stimulation. Note that we estimate added emissions resulting from stimulation-enabled production, but do not attempt to estimate the emissions associated directly with the well stimulation activity.

We scale all stationary oil and gas related source emissions (combustion and non-combustion) shown in Table 4.3-5 by the fraction of oil production in the facilitated or enabled pools (19%). We scale mobile source off-road emissions from rigs and workover equipment shown in Table 4.3-5 by the fraction of wells drilled in facilitated or enabled pools (31%). The results of this scaling for criteria air pollutants are shown below in Table 4.3-6 and the results for the representative TACs are shown in Table 4.3-7. An important assumption inherent to this analysis is that oil and gas development has the same emission intensity across all pools. This may or may not be the case and deserves further study.

Table 4.3-6. Fraction of South Coast total criteria and TAC emissions from well stimulation facilitated or enabled pools.

	ROG	NO_x	SO_x	PM_{10}	$PM_{2.5}$
Fraction of all criteria pollutants from well stimulation-enabled oil and gas activities	0.05%	0.14%	0.02%	0.01%	0.04%

Table 4.3-7. Fraction of South Coast total toxic air contaminant emissions from well stimulation facilitated or enabled pools.

	Fraction from well stimulation enabled or facilitated pools
1,3-Butadiene	0.000%
Acetaldehyde	0.001%
Benzene	0.000%
Carbonyl sulfide	0.020%
Ethyl Benzene	0.001%
Formaldehyde	0.009%
Hexane	0.000%
Hydrogen Sulfide	0.000%
Toluene	0.049%
Xylenes (mixed)	0.000%

4.3.3.4.4. Known TACs Added to Well Stimulation Fluids in the South Coast Air Quality Management District

As noted in Volume II, Chapter 3, there are more than 30 TACs that are reported to the SCAQMD as included in hydraulic fracturing and acidizing fluids in the South Coast. While the TACs are known (See Volume II, Chapter 3), there are no data on the rate at which these TACs are emitted and in what quantity (the emission factors have not been studied) these TACs are emitted during oil and gas development. As such, it is not possible to estimate their emissions and in turn their potential risks to public health.

4.3.3.4.5. Discussion of Regional Air Pollutant Emissions from Oil and Gas Development in the South Coast Region

California inventories suggest that the upstream oil and gas development sector is likely responsible for a small fraction (<1%) of criteria pollutants emitted in the South Coast

Region. This is expected, because the South Coast Region is a comparatively small oil production region compared to the San Joaquin Valley, and is also home to large numbers of other mobile and industrial emission sources of these pollutants. We found that 2,361 kg/year of benzene is emitted by the stationary components of upstream oil and gas development in the Los Angeles Basin. This amount represents a significant proportion of stationary sources (9.6%) and a smaller proportion of benzene emissions from all sources (including mobile source emissions) (0.14%) in the South Coast Air Basin. Our state inventory analysis also indicates that 5,846 kg/year or 3.8% of the stationary source emissions of formaldehyde and <1% of all source emissions (including mobile) are attributable to the upstream oil and gas sector. Smaller proportions of other indicator TAC species were identified. These indicator TAC species included in our assessment are not used in well stimulation fluids, but rather are co-produced with oil and natural gas during development.

Since approximately only 26% of the wells currently active in the Los Angeles Basin are hydraulically fractured, emissions of TACs and ROGs are a smaller subset of those emitted by the upstream oil and gas sector in general.

The proportion of the total TAC inventory (mobile and stationary sources) attributable to upstream oil and gas development is not high, and from a regional air quality perspective, these results seem to indicate that TAC emissions from the upstream oil and gas sector are unimportant. However, from a public health perspective, fractions of total emissions are not as important as the quantity or the mass of pollutants emitted, or the location and proximity to humans where the emissions occur. Some of the TACs—especially benzene and formaldehyde and potentially hydrogen sulfide, but problems with the inventory does not allow us to be sure—are emitted in large masses (but not in large fractions of the total inventory) in the upstream oil and gas sector in a densely populated urban area. In the sections below, we discuss the implications of these TAC emissions occurring in the Los Angeles Basin in close proximity to people in general and sensitive demographics in particular.

Given that benzene is known to be highly toxic (Lupo et al., 2011) and emissions from upstream oil and gas development in the Los Angeles Basin constitute more than 2,360 kg/year (9.6%) of the total stationary source emission inventory, we briefly review the public health literature and current exposures to benzene in the South Coast Region below. Benzene is generally not included in stimulation fluids, but rather is a compound that is co-produced (and co-emitted) with oil and gas during production, processing, and other processes.

4.3.3.4.6. Discussion of Benzene and Human Health Risks

Benzene is naturally occurring in hydrocarbon deposits and is released into the air throughout the oil and gas development process (Adgate et al., 2014; Werner et al., 2015; Shonkoff et al., 2014). Other large environmental sources of benzene emissions in the Los Angeles Basin are the burning and refining of oil and gasoline, environmental tobacco smoke (second-hand cigarette smoke), and vapors emitted from gas stations (Centers for Disease Control and Prevention (CDC), 2013). Active cigarette smoking exposes individuals to elevated dosages of benzene as well, but is not considered to be an environmental source as it is at an individual level. Comparing the mass of benzene and other TAC emissions among the largest sources in the South Coast, we see that in the south coast region, mobile emissions (gasoline and diesel vehicles) are the largest contributor in the total inventory (See Volume II, Chapter 3, Table 9). In our analysis of publicly available TAC inventories, we found that 2,361 kg/year of benzene is emitted by the stationary components of upstream oil and gas development in the Los Angeles Basin. This amount represents a significant proportion of stationary source (9.6%) and a small proportion of all benzene source emissions (including mobile source emissions) (0.14%) in the South Coast Air Basin.

With the exception of when diesel is used as an ingredient—and available data suggests that such use is rare in California, as noted in Volume II, Chapter 2 and Chapter 6—benzene is not found in well stimulation fluids. Thus, benzene is a hazard that is not specific to oil and gas development that is enabled or supported by well stimulation; rather, it is a compound intrinsic to the oil and gas development process in general.

There are no studies on benzene exposure attributed to oil and gas development in the Los Angeles Basin; however, adverse human health outcomes can occur through inhalation, oral, or dermal exposure, and benzene can volatilize into the air from water and soil (ATSDR, 2007; U.S. EPA, 2007). In the Los Angeles Basin context, however, potential exposures to benzene attributable to oil and gas development are likely to occur via inhalation. Benzene is a known carcinogen (Glass et al., 2003; Vlaanderen et al., 2010) and is associated with various other health outcomes associated with chronic and acute exposures, including birth defects (Lupo et al., 2011) and respiratory and neurological effects (ATSDR, 2007). Numerous studies on oil and gas development out of state have identified benzene as a potential health risk (Helmig et al., 2014; Macey et al., 2014; McKenzie et al., 2012, 2014; Pétron et al., 2014).

Acute effects of benzene inhalation exposure in humans include the following: (1) neurological symptoms such as drowsiness, vertigo, headaches, and loss of consciousness; (2) respiratory effects such as pulmonary edema, acute granular tracheitis, laryngitis, and bronchitis; and (3) dermal and ocular effects such as skin irritation or burns and eye irritation (ATSDR, 2007; U.S. EPA, 2012). While it is not known if children are more susceptible to benzene poisoning than adults, there has been some research to measure the effects of benzene exposure among children. For instance, an association has been shown between benzene exposure and respiratory effects in children such as bronchitis, asthma, and wheezing (Buchdahl et al., 2000; Rumchev et al., 2004).

Chronic (noncancerous) effects of benzene inhalation in humans include the following: (1) hematological effects such as reduced numbers of red blood cells, aplastic anemia, excessive bleeding, and adverse effects on bone marrow; (2) immunological and lymphoreticular effects such as damage to both humoral (antibody) and cellular (leukocyte) responses; and (3) possible reproductive effects such a neural tube defects and low birth weight (Lupo et al., 2011; U.S. EPA, 2012) there have been no studies assessing the association between environmental levels of hazardous air pollutants, such as benzene, and neural tube defects (NTDs).

Cancer risks include acute and chronic nonlymphocytic leukemia, acute myeloid leukemia, and chronic lymphocytic leukemia. Based on human and animal studies, benzene is classified by the U.S. EPA in Category A (known human carcinogen).

In June 2014, the California Environmental Protection Agency Office of Environmental Health Hazard Assessment (OEHHA) finalized updated benzene reference exposure limits (RELs) (OEHHA, 2014). RELs are airborne concentrations of a chemical that are anticipated to not result in adverse non–cancer health effects for specified exposure durations in the general population, including sensitive subpopulations. The three RELs that OEHHA adopted on 27 June 2014 cover three different types of exposure to benzene in air: infrequent 1-hour exposures, repeated 8-hour exposures, and continuous long term exposure. These three RELs are as follows:

- 1-hour REL: 27 mg/m^3 (0.008 ppm; 8 ppb)
- 8-hour REL: 3 mg/m^3 (0.001 ppm; 1 ppb)
- Chronic REL: 3 mg/m^3 (0.001 ppm; 1 ppb)

Table 4.3-8 shows benzene exposure levels at multiple locations in the South Coast Air Basin. Note that while the mean exposure levels do not exceed 1 ppb on annual averages, these data do not describe 1-hour or 8-hour benzene exposure values. It should also be noted that in both years of sampling, the maximum benzene exposure values exceeded the benzene 8-hour and chronic RELs in some cases up to 350%. Moreover, in some cases, these average exposures are within 0.5 ppb and 0.18 ppb of exceeding the 8-hour and the chronic RELs, which does not leave a large margin of safety. Additionally, the standard deviations indicate that exceedances do occur, in some cases frequently. Average exposure does not take into account potentially more elevated exposures that can occur in close proximity to emission sources where atmospheric concentrations are most elevated.

Table 4.3-8. Average benzene levels (parts per billion (ppb)) at 10 fixed sites in South Coast in 2004 – 2006.

	Year 1 (4/2004 - 3/2005)				Year 2 (4/2005 – 3/2006)			
Location	Mean	SD	N	Max	Mean	SD	N	Max
Anaheim	0.44	0.28	118	1.44	0.42	0.33	115	2.06
Burbank	0.73	0.42	118	2.16	0.69	0.44	122	1.85
Central Los Angeles	0.59	0.30	117	1.83	0.57	0.31	121	1.53
Compton	0.82	0.70	118	3.50	0.78	0.67	118	3.53
Inland Valley	0.49	0.24	115	1.26	0.49	0.24	116	1.24
Huntington Park	0.76	0.46	98	2.20	-	-	-	
North Long Beach	0.56	0.35	119	1.62	0.48	0.34	118	1.70
Pico Rivera	0.57	0.32	121	1.86	-	-	-	
Rubidoux	0.45	0.25	114	1.23	0.43	0.26	120	1.32
West Long Beach	0.57	0.44	114	1.95	0.50	0.38	120	1.77

Source: OEHHA (2014)

4.3.3.5. Screening Exposure Assessment Approach for Air Pollutant Emissions in the Los Angeles Basin

In this screening exposure assessment approach, we focus on the jurisdictional boundaries of the South Coast Air Basin (SoCAB), which includes Los Angeles County, Orange County, and parts of both Riverside and San Bernardino counties and includes the active oil and gas wells within the Los Angeles Basin. In order to assess the public health risks of air pollutant emissions from oil development operations in a region such as the Los Angeles and South Coast Air Basin (SoCAB), one needs information on three factors—pollutant emission rates (mass per time), a population exposure assessment (mass of pollutant inhaled per mass emitted), and toxicity (health impact per mass inhaled) (Bennett et al., 2002).

4.3.3.5.1. Intake Fraction Analysis

In previous sections of this case study, we compiled information on the emissions attributable to oil and gas development, as well as the fraction associated with those that have been fractured in the region. Here, we consider an exposure assessment that relates emissions mass to population intake. This analysis provides the basis for assessing health risks. With unlimited resources, we would identify the location of each emission, track the dispersion of these emissions as they spread out over the regional landscape, and then track population density and activity of the entire regional population to assess the magnitude and range of population intake. Unfortunately, for this report there is neither time nor resources for an analysis with this level of detail. Thus, we rely on the extensive body of analyses of source receptor relationships that has been compiled over the last decade for distributed pollutant emissions in the SoCAB. In particular, we rely on the extensive research and analysis of "intake fraction" relationships in the SoCAB as a of way of gaining important insights without carrying out extensive new analyses.

For air pollutant emissions, intake fraction (iF) is the mass of a pollutant inhaled by all potentially exposed populations divided by the mass of the pollutant emitted (Bennett et al., 2002). In other words, an intake fraction is the number of kilograms inhaled divided by the number of kilograms emitted, typically reported as "mg inhaled per kg released" or ppm. Intake fraction provides a transparent and parsimonious description of the complex atmospheric transport and human activity patterns that define exposure (Bennett et al., 2002). Because mass inhaled is a more reliable metric of potential adverse health impacts to populations than either mass emitted or airborne concentration, iF also provides key insights for assessing health risks. However, there are limitations to iF. As a measure of cumulative intake among a population over time, it lacks the ability to track exposure variation among individuals or exposure variations within populations over relatively short time periods, such as one hour or less.

Intake fraction is a metric, not a method. Values of the intake fraction for the South Coast Region have been determined from models and from measurements. Typical values for the intake fraction for pollutants released to outdoor air are as low as 0.1 per million (ppm) for air pollutant releases in remote rural areas, to 50 ppm or more for releases near ground level in urban areas. Three factors are dominant in determining the magnitude of the intake fraction for air pollutant emissions—(1) the size of the exposed population within reach of the pollutant emission, (2) the proximity between the emission source and the exposed population, and (3) the persistence of the pollutant in the atmosphere. A useful attribute of intake fraction is that it can be applied to groups of pollutants, rather than one pollutant at a time. When two pollutants are emitted from the same source, and have the same fate and transport characteristics, their intake fraction values will be the same, even if their chemical composition and mass emission rates differ.

The literature on intake fraction is diverse and growing. We identified multiple studies that address inhalation exposures of primary and secondary pollutants from a variety of sources, such as motor vehicles, power plants, and small-scale area sources. We identified five studies that provide detailed calculations on intake fraction for the Los Angeles region, and we make use of the results from these studies to estimate the intake fraction of oil and gas development in the Los Angeles Basin. Although these studies are not directed specifically at oil and gas development, they are well suited to the type of screening exposure assessment that is within our goal of assessing exposure potential of oil and gas.

In the first study considered, we examined the results of Marshall et al. (2003), who focused on the SoCAB as a case study and combined ambient monitoring data with time-activity patterns to estimate the population intake of carbon monoxide and benzene emitted from motor vehicles distributed throughout the SoCAB.

In the second study, we consider results from Heath et al. (2006), who assessed the exposure implications of a shift toward distributed petroleum-powered generation (DG) in California. For this, they combined Gaussian plume modeling and a GIS-based inhalation exposure assessment applied to existing and hypothetical power-generation facilities in California. To carry out this study, they assessed intake fraction for hypothetical DG emissions sources originating in the downtown areas of the eleven most populous cities in California.

In a third relevant study, Lobsheid et al. (2012) used source-receptor relationships derived from the U.S. EPA's AERMOD steady-state plume model to quantify the intake fraction of conserved pollutants (pollutants that are not strongly reactive in air or rapidly deposited to surfaces) emitted from on-road mobile sources. For this analysis, they used source-receptor relationships at census-block scale, and then aggregated and reported results for each of the 65,000 census tracts in the conterminous United States. Their study includes iF values for every census tract and county of California—thus providing useful information for the current case study.

In a fourth considered study, Apte et al. (2012) modeled intra-urban intake fraction (iF) values for distributed ground-level emissions in all 3,646 global cities with more than 100,000 inhabitants. Among all these cities, they found that for conserved primary pollutants, the population-weighted median, mean, and interquartile range iF values are 26, 39, and 14–52 ppm, respectively. They found that intake fractions vary among cities, owing to differences in population size, population density, and meteorology. Their reported iF value for Los Angeles is 43.

For the four studies noted above, Table 4.3-9 provides a summary of the best estimate (typically the median) value as well as the range of iF values that are relevant to the Los Angeles region. We see here that most of the studies converge toward a value of 40 ppm as most typical for this region. In the Lobsheid et al. (2012) study, which calculated iF for every census tract in Los Angeles and Orange counties, we also list ranges that reflect the 95% value interval for all census tracts for which iF is calculated. Lobsheid et al. (2012) also gives insight on variability with iF by census tract, varying from less than 1 ppm to slightly over 100 ppm.

Table 4.3-9. Published values of intake fraction relevant to the well stimulation-enabled oil and gas development emissions in the South Coast Air Basin.

Sources	Region	Pollutants	Method	Best estimate (range) ppm	Reference
Motor vehicles	South Coast air basin	Primary pollutants (CO, benzene)	Data analysis of tracers of opportunity	47 (34-85)	Marshall et al. (2003)
Distributed generators	Central locations in the 11 most populous cities of California	Primary pollutants ($PM_{2.5}$, formaldehyde)	Dispersion modeling	16 (7 – 30)	Heath et al. (2006)
Motor vehicles and distributed sources	Los Angeles county (2052 census tracts)	Primary conserved pollutants	Source-receptor air modeling for 65,000 US census tracks	38 (29 – 77)*	Lobsheid et al. (2012)
Motor vehicles and distributed sources	Orange county (577 census tracts)	Primary conserved pollutants	Source-receptor air modeling for 65,000 US census tracks	27 (19 – 50)*	Lobsheid et al. (2012)
Distributed ground level emissions	Los Angeles city	Conserved primary pollutants	High resolution dispersion model	43 (n/a)	Apte et al. (2012)

** This range reflects the 95% value range (that is 2.5% lower bound and 97.5% upper bound) of the iF for all census tracts in the county.*

Because of the lack of TAC emissions data on the census and local levels, we are unable to estimate the iF of oil and gas development at the census tract and local levels in the SoCAB context. This type of study is an important next step to understanding exposure to benzene and other TACs emitted by oil and gas development in the Los Angeles Basin. Nonetheless, below, we walk through some of the preliminary steps necessary to conduct such an analysis.

The intake fraction values provided above can be used to translate emissions in kg/d of any conserved pollutant into population exposures, and also into exposure concentration estimates. The intake fraction values above (for example, 38 ppm) provide an estimate of how many mg/day of a pollutant enters the lungs of the South Coast Population for every kg/d emitted. This is a cumulative intake obtained by identifying source locations and tracking exposures out to the limits of the South Coast Region—the cumulative integral of population intake. In the case of Marshall et al. (2003), the sources were roadways; for Heath et al. (2006), the sources were located at the commercial centers of large cities; and for Lobsheid et al. (2012), sources were located at the center of all census tracts, with dispersion followed out to all other census tracts in the region. In all three studies, the intake was obtained from concentrations using representative breathing rates (~14 m^3/d per individual). We note that the high spatial resolution of the Lobsheid et al. (2012) study allows us to consider not only the middle range iF for South Coast emissions, but also the effect of releases to areas with very high population density. In Lobsheid et al. (2012), the mean iF value is 38 ppm, with an upper bound of 77.

The next step of this assessment would be to take the regional emissions of air pollutants from oil and gas development, and multiply by the regional iF, to get an estimate of population intake. To get an estimate of health effects, we would need to divide the iF by the appropriate regional population to get the median (or mean) individual intake estimate, which can be compared to RELS, reference doses (RfDs), or reference concentrations (RfCs).

We could add more detail to this effort by calculating the iF for each census tract in the region and use the population impacted by emissions from that tract to do a bottom-up estimate of the range of iF values. As an example, we can use the Lobsheid et al. (2012) results to determine the types of concentrations that are associated with an iF in smaller regions. In L.A. County, with a median iF of 38 and assuming that the substantial amount of intake occurs within 3 km of the source (impacting some 50,000 people), the concentration imposed on this population from an additional 1 kg/day emissions is 0.05 $\mu g/m^3$. In Orange County, a similar calculation gives 0.04 $\mu g/m^3$ for each additional kg emitted to a representative census tract.

While we know the intake fraction potential at the census tract level, we are unable to estimate the iF of oil and gas development at the census tract and local levels in the SoCAB context, due to the lack of TAC emissions data on the census and local levels. But this would be an important next step to understanding exposure to benzene and other TACs emitted by oil and gas development in the Los Angeles Basin.

4.3.3.5.2. Summary of Screening Exposure Assessment for Air Pollutant Emissions in the Los Angeles Basin

The high population intake fractions that are possible in the SoCAB are primarily due to the high population density of the region. In other words a larger proportion of air pollutant emissions in the South Coast Air Basin enter human lungs compared to places with lower population density (fewer breathing lungs).

Those living in close proximity to emitting sources will likely be more exposed to these emissions than those that live further away. The reason that proximity to the source is important is that the contaminant in question will be at its highest atmospheric concentration at the source. The concentration generally falls off exponentially with distance from the source (via dilution), so that exposures near the source can be much larger than average regional exposures. So, for example, the regional contribution of the oil and gas production for benzene is 2,361 kg/year and is dispersed throughout the air basin. However, near emission sources, on or near active well pads, the atmospheric concentrations can be much higher than the regional average.

4.3.3.6. Proximity Analysis of Oil and Gas Development and Human Populations

In the previous sections, we have identified that TACs are emitted by oil and gas development in general, and that the concentrations of these emissions may be elevated near active oil and gas development. Wells are considered to be active if they are categorized as such in the Oil and Gas Well Database maintained by DOGGR. In this section, we quantify and locate all currently active oil and gas wells, and also the fraction that are stimulated. We then conduct an analysis of spatial relationships between currently active oil and gas wells and those that are hydraulically fractured and surrounding human populations and sensitive receptors.

4.3.3.6.1. Study Area

The geographic focus of this proximity analysis includes the California Air Resources Board (CARB) South Coast Air Basin (SoCAB), which includes Los Angeles County, Orange County, and parts of both Riverside and San Bernardino counties and the active oil and gas wells within this jurisdictional boundary. For a list of the methods we used to determine the number of active oil and gas wells—and the numbers and locations of those wells that have been hydraulically fractured, frac-packed, high-rate gravel packed, or acidized in the Los Angeles Basin—please see Appendix 4.A.

4.3.3.6.2. Numbers and Types of Active Oil and Gas Wells by Oil Field in the Los Angeles Basin

We used the methodology for calculating the number and proportion of stimulated wells as was used statewide in Volume I, with only minor modifications and focused specifically on the Los Angeles Basin (see Appendix 4.A). Our results indicate that there are approximately 5,256 wells that are currently active, according to DOGGR. Of these wells, 3,691 are located in oil and gas pools with estimated stimulation rates. When the stimulations rates for the pools are applied to the total number of wells in each pool, there are an estimated 1,341 wells that have been enabled or supported by hydraulic fracturing, frac-packing, or high-rate gravel packing (hereafter referred to as fracturing) (Table 4.3-10). The estimated number of wells that have been fractured thus represents approximately 26% of the 5,256 currently active wells listed as active by DOGGR as of July 2014, and 36% of the active wells in pools that were queried. These numbers should be considered conservative, given that we only have oil pool-level information on type of oil development (stimulation) for approximately 29% of the wells listed as active by DOGGR. As such, it is probable that more pools may have been hydraulically fractured, frac-packed, or high-rate gravel packed, but we do not have access to these data. While a report by Cardno ENTRIX (2012) found that as of 2012 there were 23 hydraulically fractured wells in the Inglewood Oil Field, as discussed in Volume I, DOGGR data suggest that this might be an underestimate, or that most of the other wells were supported or enabled by frac-packing and high rate gravel packing which was not included in the Cardno ENTRIX estimate. For a more detailed explanation of methods and approaches, please see Appendix 4.A. Please also refer to

Volume II, Appendix 5.E, for more information.

Table 4.3-10. Numbers of all currently active wells and the proportion that are supported by hydraulic fracturing, frac-packing, or high-rate gravel packing (HRGP) in the Los Angles Basin by oil field.

Oil Field	Total Active Wells	Total Wells Fractured	% Fractured
Brea-Olinda	551	551	100%
Inglewood	503	503	100%
Wilmington	1,716	179	10%
San Vicente	35	32	91%
Aliso Canyon	50	21	42%
Whittier	29	18	62%
Las Cienegas	60	10	17%
Esperanza	11	6	55%
Temescal	5	5	100%
Newhall-Potrero	45	4	9%
Tapia	30	3	10%
Del Valle	37	3	8%
Montebello	123	2	2%
Salt Lake	24	2	8%
Huntington Beach	306	1	0%
Wayside Canyon	10	1	10%
Playa Del Rey	28	0	0%
Torrance	128	0	0%
Total Assigned to Fields	**3,691**	**1,341**	**36%**
Unassigned to Fields	1,565	unavailable	
TOTAL	**5,256**	**1,341**	**26%**

4.3.3.6.3. New Wells and Wells Going Into First Production (2002-2012)

There are 1,403 oil and gas wells that were either new or went into first production between 2002 and 2012 in the SoCAB. Of these wells, 435 (31%) have been identified as having been hydraulically fractured (Table 4.3-11). Given the uncertainty in the data, this proportion (31%) is similar to the 26% of all active wells, and thus shows agreement with and corroboration of our data analysis.

Table 4.3-11. New wells or wells going into first production and the proportion that are hydraulically fractured, frac-packed, or high-rate gravel packed (HRGP) (2002-2012).

Oil Field	Total New Wells (2002-2012)	Total New Wells Fractured	% New Wells Fractured
Inglewood	219	219	100%
Brea-Olinda	29	29	100%
Wilmington	831	159	19%
Aliso Canyon	26	0	0%
Cascade	7	0	0%
Long Beach Airport	2	0	0%
Los Angeles Downtown	1	0	0%
Newhall-Potrero	12	1	8%
Richfield	1	0	0%
San Vicente	6	6	100%
Sansinena	7	0	0%
Santa Fe Springs	57	3	5%
Tapia	21	1	7%
Wayside Canyon	4	0	0%
Playa Del Rey	3	3	100%
Beverly Hills	83	0	0%
Las Cienegas	9	3	33%
Del Valle	5	0	0%
Montebello	21	0	0%
Huntington Beach	8	4	47%
Belmont Offshore	32	0	0%
Torrance	12	0	0%
Whittier	7	7	100%
TOTAL	**1403**	**435**	**31%**

4.3.3.6.4. Acidizing

Hydrofluoric and hydrochloric acid are frequently used in the development of oil in the Los Angeles Basin. Based upon the SCAQMD dataset, there are ~20 events per month that use hydrofluoric acid (SCAQMD, 2015). The SCAQMD reports a total of 22.5 events per month, including both acidization and hydraulic fracturing (excluding gravel packing). As described in Volume I, there is insufficient data in available datasets to distinguish matrix acidizing from maintenance acidizing, although operators were required to distinguish starting April 02, 2014.

4.3.3.6.5. Summary: Numbers and Types of Oil and Gas Wells in the Los Angeles Basin

Approximately 26% of currently active oil and gas wells (1,341/5,256) and 31% of wells that went into first production between 2002 and 2012 (435/1,403) are likely enabled or supported by hydraulic fracturing, frac-packing, and high-rate gravel packing.

Data from the SCAQMD mandated reporting suggest that the use of hydrofluoric and hydrochloric acid in oil production wells is common in the Los Angeles Basin (SCAQMD, 2015). However, the use of acid is supportive of current development and unlikely to be used to significantly increase expanded development.

4.3.3.7. Proximity of Human Populations to Oil and Gas Development

Our analysis of available state emission inventories indicates that 2,361 kg/year of benzene is emitted by upstream oil and gas development in the Los Angeles Basin. This amount represents a significant proportion of stationary source (9.6%) and <1% from all sources (including mobile source emissions) in the South Coast Air Basin. Our analysis of California emission inventories also indicates that 5,846 kg/year or 3.8% of the stationary source emissions and <1% of all source emissions (including mobile sources) of formaldehyde are attributable to the upstream oil and gas sector (Table 4.3-4). As a basis for understanding potential public health hazards attributable to upstream oil and gas development, we evaluated the spatial relationships of all active oil and gas wells, and then those that are stimulated, to the surrounding population, and selected sites considered to be "sensitive receptors." We also characterized the demographics, vulnerability factors, and socioeconomic profiles of the communities in proximity to well stimulation events.

Our choice to include all oil and gas wells as opposed to only considering the fraction that are stimulated was based on our finding that benzene, a health-damaging indicator TAC as described above, is emitted from oil and gas development in general and is not specific to, or even related directly to, well stimulation. To evaluate proximity of populations within the Los Angeles Basin to only those wells that are stimulated is misleading and potentially would leave out communities that are potentially submitted to the same level of environmental public health hazard as those communities that live near stimulated wells.

For a complete description of our methods and approach to the spatial proximity analysis, please see Appendix 4.B.

4.3.3.7.1. Spatial Distribution of All Active Oil Wells and Active Stimulated Wells

Figure 4.3-3 shows the South Coast Air Basin with stimulated wells. As discussed in the methods above, we identified 4,487 active oil wells and 1,205 active wells that have been fractured, and at least 60 wells that have been supported by acidizing in the South Coast Air Basin that are still in production as of 14 December 2014. Figure 4.3-4 shows the density of active oil and gas wells in the SoCAB.

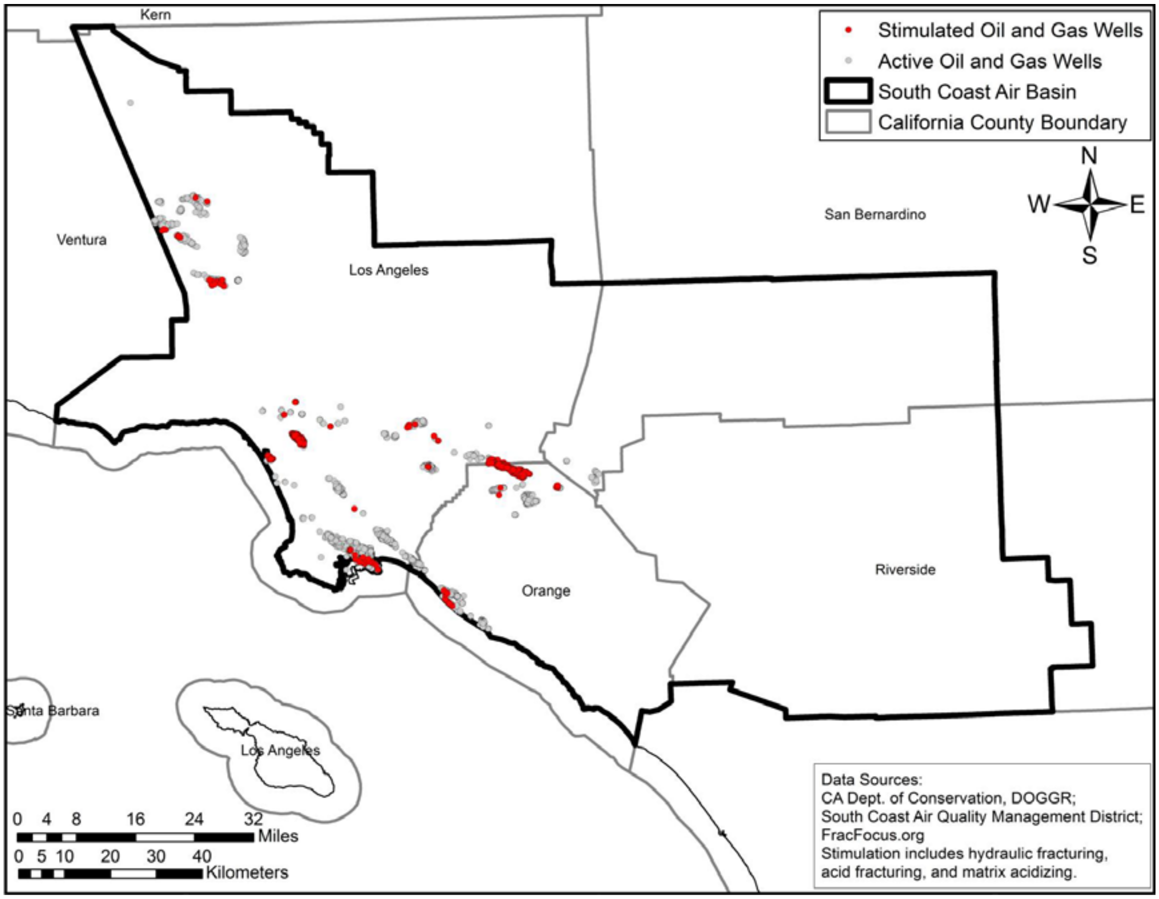
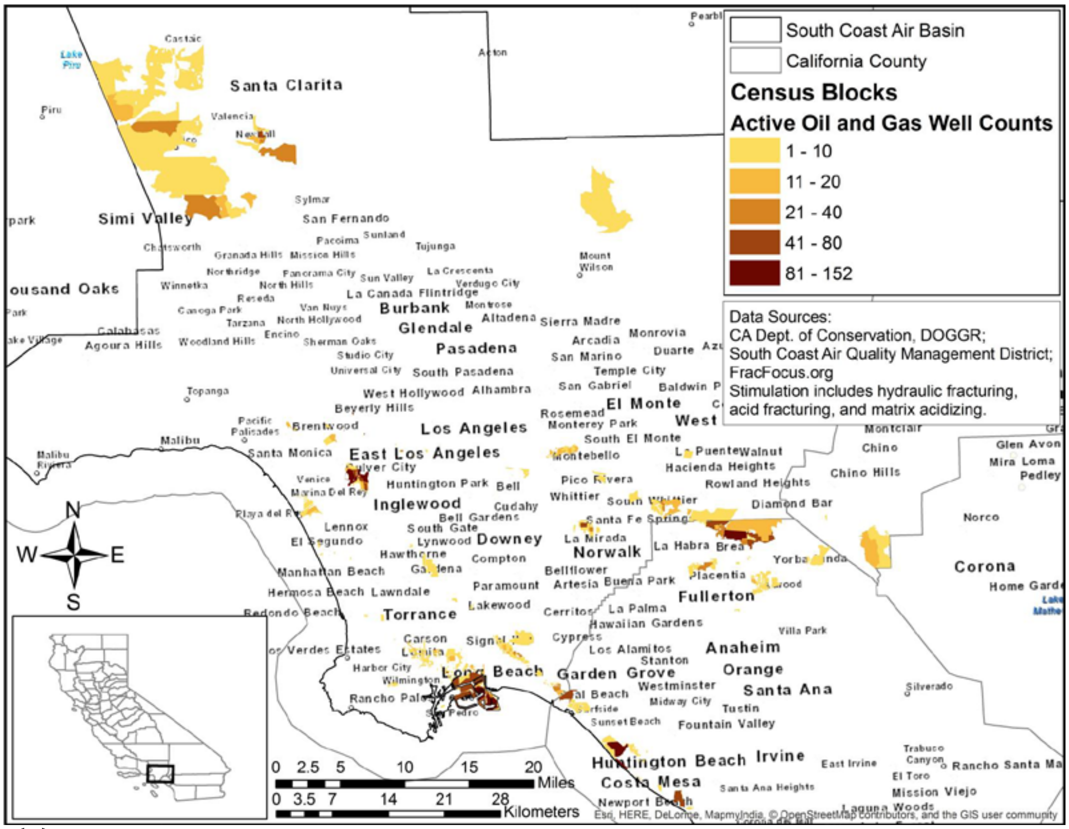


Figure 4.3-3. All active oil production wells in the South Coast Air Basin with those that are stimulated shown in red.



(B)

Figure 4.3-4. Density of active oil and gas well counts in the South Coast Air Basin.

4.3.3.7.2. Human Population Proximity Analysis

Figure 4.3-5 shows the population density in the Los Angeles Basin and the boundaries of 2,000 m (6,562 feet) distance from all active oil wells and the fraction of active oil wells that have been stimulated. It is evident that stimulated wells in the Los Angeles Basin exist both within and in close proximity to high population density areas. It is also evident that a slightly larger portion of the Los Angeles Basin population lives within 2,000 m (6,562 feet) of an active oil well than the population that lives within 2,000 m (6,562 feet) of a well that has been stimulated. This makes sense, because there are approximately 75% more oil wells that are not stimulated than those that are.

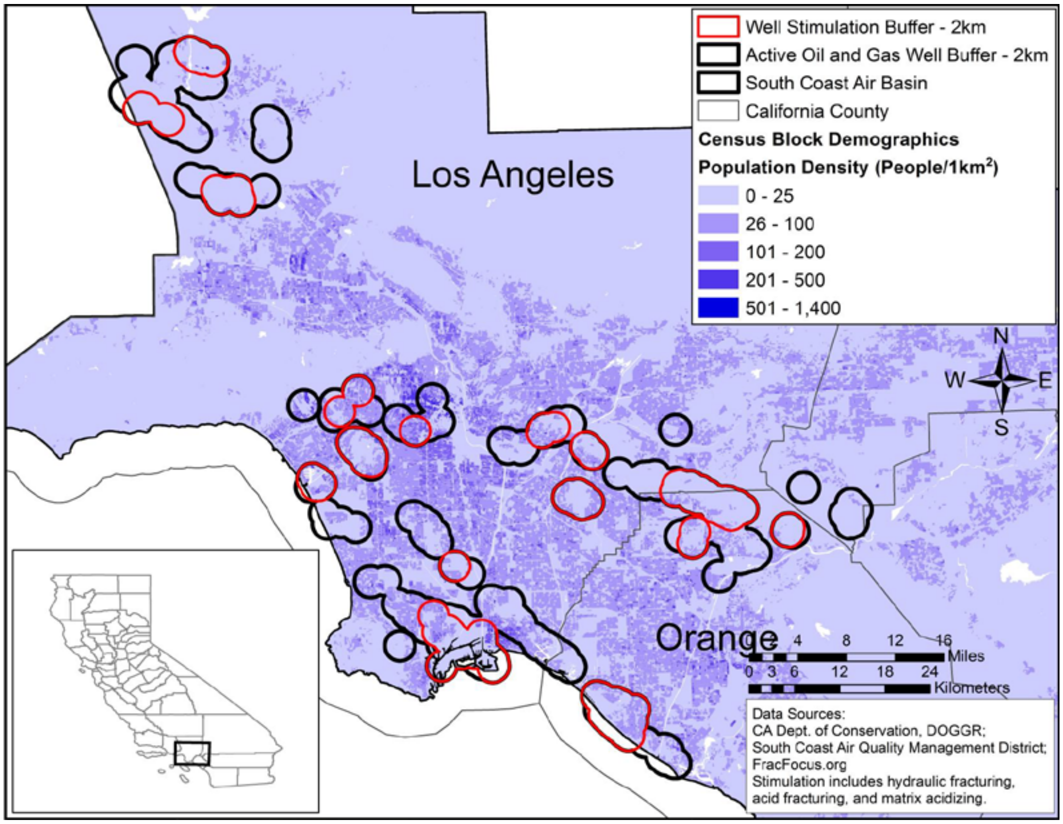


Figure 4.3-5. Population density within 2,000 m (6,562 feet) of currently active oil production wells and currently active wells that have been stimulated.

As summarized in Tables 4.3-12 and Table 4.3-13, a number of residents and sensitive receptors are in proximity to active oil development and the fraction of this development from wells that have been stimulated. Approximately 2,258,000 people (12% of the SoCAB population) live within 2,000 m (6,562 feet) of an active oil well. Additionally, there are 130 schools, 184 daycare facilities, 213 residential elderly homes and nearly 628,000 residents within 800 m (½ mile or 2,625 feet) of an active oil well. More than 50,000 children under the age of five, and over 43,500 people over the age of 75, live within 2,000 m (6,562 ft) of an active oil production well. Even within only 100 m (328 ft) of a well, there are more than 32,000 residents, nearly 2,300 of who are children under five (Table 4.3-12).

Fewer residents and sensitive receptors are located in close proximity to oil wells that have been stimulated in the SoCAB, largely because only a subset of the wells in this basin is stimulated. Approximately 760,000 people (4% of the SoCAB population) live within 2,000 m (6,562 feet) of a stimulated well. Additionally listed in Table 4.3-13 is the number of sensitive populations and facilities in proximity to stimulated wells. For instance, there are 20 schools, 39 daycare facilities, 27 residential elderly homes, and nearly 128,000 residents within 800 m (½ mile or 2,625 feet) of a stimulated well. More than 120,000 children under the age of five and over 90,000 people over the age of 75 live within a mile (1,600 m or 5,249 feet) of a stimulated well (Table 4.3-13).

Table 4.3-12. Proximity of human populations and sensitive human receptors to active oil wells in the South Coast Air Basin.

Buffer Distance (m)	Number of Residents	Number of Schools	Number of Children Attending Schools	Number of Elderly Facilities	Number of Daycare Facilities	Under 5	Over 75
100	32,071	4	3,290	12	5	2,295	1,664
400	233,102	50	34,819	94	72	16,685	14,005
800	627,546	130	89,241	213	184	45,050	35,189
1,000	866,299	180	135,797	258	262	62,547	47,759
1,600	1,677,594	348	242,833	429	524	122,321	91,452
2,000	2,257,933	470	332,855	582	718	164,992	122,737

Table 4.3-13. Proximity of human populations and sensitive human receptors to stimulated wells in the South Coast Air Basin.

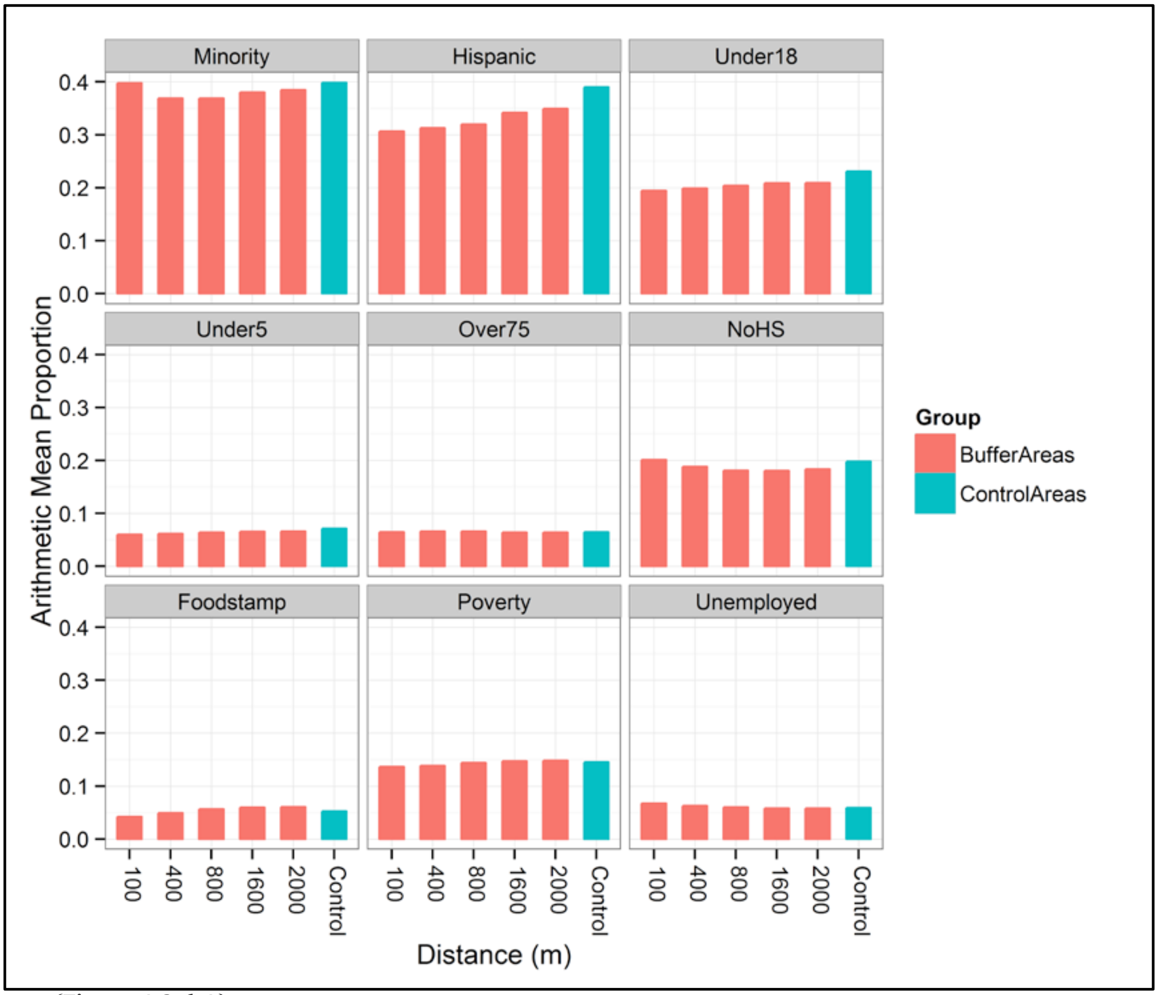
Buffer Distance (m)	Number of Residents	Number of Schools	Number of Children Attending Schools	Number of Elderly Facilities	Number of Daycare Facilities	Under 5	Over 75
100	3,661	2	2,135	1	0	285	163
400	33,928	7	3,738	4	8	2,170	2,301
800	127,896	20	12,302	27	39	7,653	8,849
1000	267,994	49	36,286	39	80	17,856	16,148
1600	494,831	125	91,585	111	181	31,199	29,827
2000	759,513	181	131,158	158	277	50,067	43,466

In summary, there are >65% more people that live within proximity of any active oil and gas well compared to those that live within proximity of only those active wells that are associated with well stimulation. As explained above, the TAC emissions of concern from a public health perspective do not differ between oil and gas wells that have been stimulated and those that have not, and the subsequent public health hazard associated with both are essentially the same as it pertains to TAC emissions.

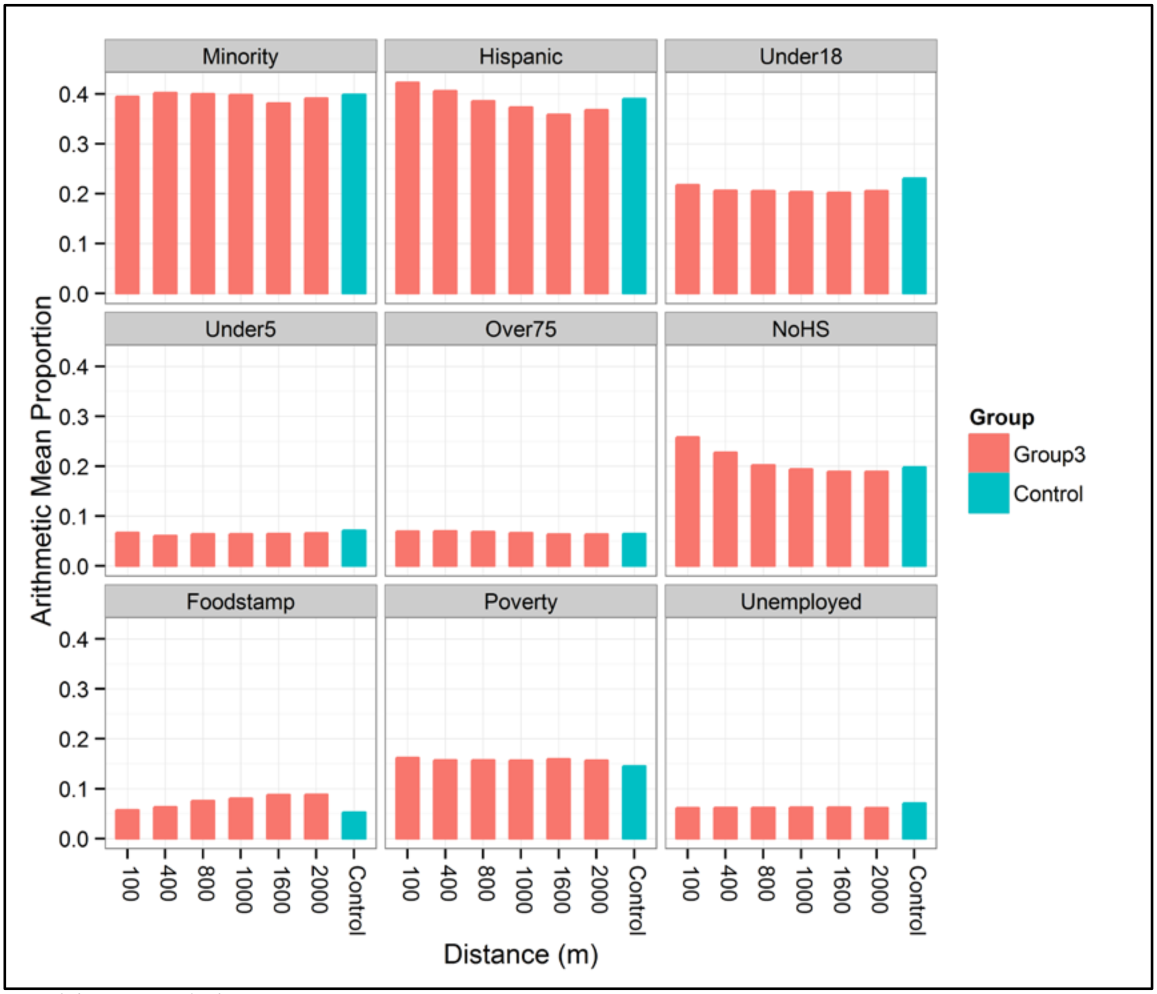
4.3.3.7.3. Comparing Population Demographics Near vs. Far from Oil and Gas Wells

At the regional scale, demographic characteristics of populations were similar among all studied distances from active oil and gas development and stimulation-facilitated development (Figure 4.3-6.A and Figure 4.3-6.B). Moreover, the studied distances were also similar in demographics compared to the control population, those farther than

2,000 m (6,562 ft) distance from the closest active well. As such, while it is clear that oil and gas is being developed in low-income communities and communities of color, there does not appear to be a disproportionate burden of oil and gas development on any one demographic in the Los Angeles Basin. In other words, oil and gas wells are not located disproportionately near the rich, the poor, or any race/ethnicity more than any other. Differences in average proportions were less than 0.05 (i.e., 5%) across buffer distances from active oil and gas wells and versus control areas (Figure 4.3-6.A). The only exception to this was that at the 100-meter (328 ft) buffer distances, the proportion of residents without high school education was more than 5% greater than the population at 800 m (2,625 ft), 1,000 m (3,280 ft), 1,600 m (5,249 ft) , and 2,000 m (6,562 ft) buffer distances and the control population. The proportion of individual households that qualify for food stamps and the proportion under the poverty line were slightly more elevated among residents close to hydraulically fractured wells compared to control sites (Figure 4.3-6.B). Residents that are under 18 years of age and those that are unemployed are slightly lower, and the non-Hispanic minority, those less than 5 years of age, and those more than 75 years of age, were essentially the same as control sites. Proportions of Hispanic residents exhibited variations with buffer distance, such that those at 100-meter (328 ft) and 400-meter (1,312 ft) distances were higher, whereas those at 1,000, 1,600, and 2,000-meter (3,280; 5,249; and 6,562 ft) distances were lower than control areas (Figure 4.2-2). Arithmetic averages, medians, standard deviation, and empirical 90th percentile values were also similar. Density plots also indicated similar distributional shape among the groupings and control population, suggesting that they represent samples from a similar population overall.


Minority
Hispanic
Under18
Under5
Over75
NoHS
Foodstamp
Poverty
Unemployed
Arithmetic Mean Proportion
0.0
0.1
0.2
0.3
0.4
100
400
800
1600
2000
Control
Distance (m)
Group
BufferAreas
ControlAreas

(Figure 4.3-6.A)



(Figure 4.3-6.B)

Figure 4.3-6.A and 4.3-6.B. Proportion of demographic characteristics at studied geographic distance from (A) all active oil and gas wells; and (B) stimulated wells compared to the control (areas beyond 2,000 meter buffer distance). Minority = non-Hispanic minorities; NoHS = not completed high school education; Foodstamp = household income qualifies for food stamps (< $15,000); Poverty = below poverty; Under5=Children less than 5 years of age; Over75=adult more than 75 years of age; Foodstamp=receives food stamps.

4.3.4. Potential Risks to Ground Water Quality in the Los Angeles Basin

Most water delivered to homes and businesses in the Los Angeles Basin is delivered via pipelines and canals from distant water sources. Los Angeles' Department of Water and Power (LADWP) brings water to its 3.9 million residents from the Owens Valley via the Los Angeles Aqueduct (LADWP, 2013). The Metropolitan Water District of Southern

California (MWD) indirectly serves another 14 cities and 12 municipal water districts, indirectly providing water to 18 million people. MWD obtains water from the State Water Project, a system of dams and reservoirs in Northern California, and an aqueduct to the Colorado River on California's border with Arizona (MWD, 2012). These water sources are far removed from oil and gas development and are unlikely to be contaminated by such operations. However, groundwater makes up one-third of the water supply for the 4 million residents of the Los Angeles coastal plain (Hillhouse et al., 2002), and chemicals from oil and gas development, including well stimulation, could possibly contaminate some groundwater wells.

Potential pathways for contamination of groundwater from well stimulation activities are described in Volume II, Section 2.6.2 (Table 2.6.2). For example, potential risks to groundwater may be related to subsurface leakage via loss of wellbore integrity or hydraulic fractures intercepting an aquifer, accidental releases at the surface, and inappropriate disposal of recovered and produced water, as described in detail in Volume II, Chapter 2 of this report. Regarding subsurface leakage, the risk of water contamination from a hydraulic fracture intercepting a protected aquifer is minimal if the hydraulic fracturing operation is sufficiently deeper than the aquifer. However, as described below, some hydraulic fracturing in the Los Angeles Basin takes place in close vertical proximity to protected aquifers.

Much of the groundwater consumed by the cities of Santa Monica, Long Beach, and other nearby districts is extracted from the coastal plain aquifer system, which underlies much of the coastal area of Los Angeles and Orange Counties. The portion of the coastal plain aquifer system in Los Angeles County is shown in Figure 4.3-7.

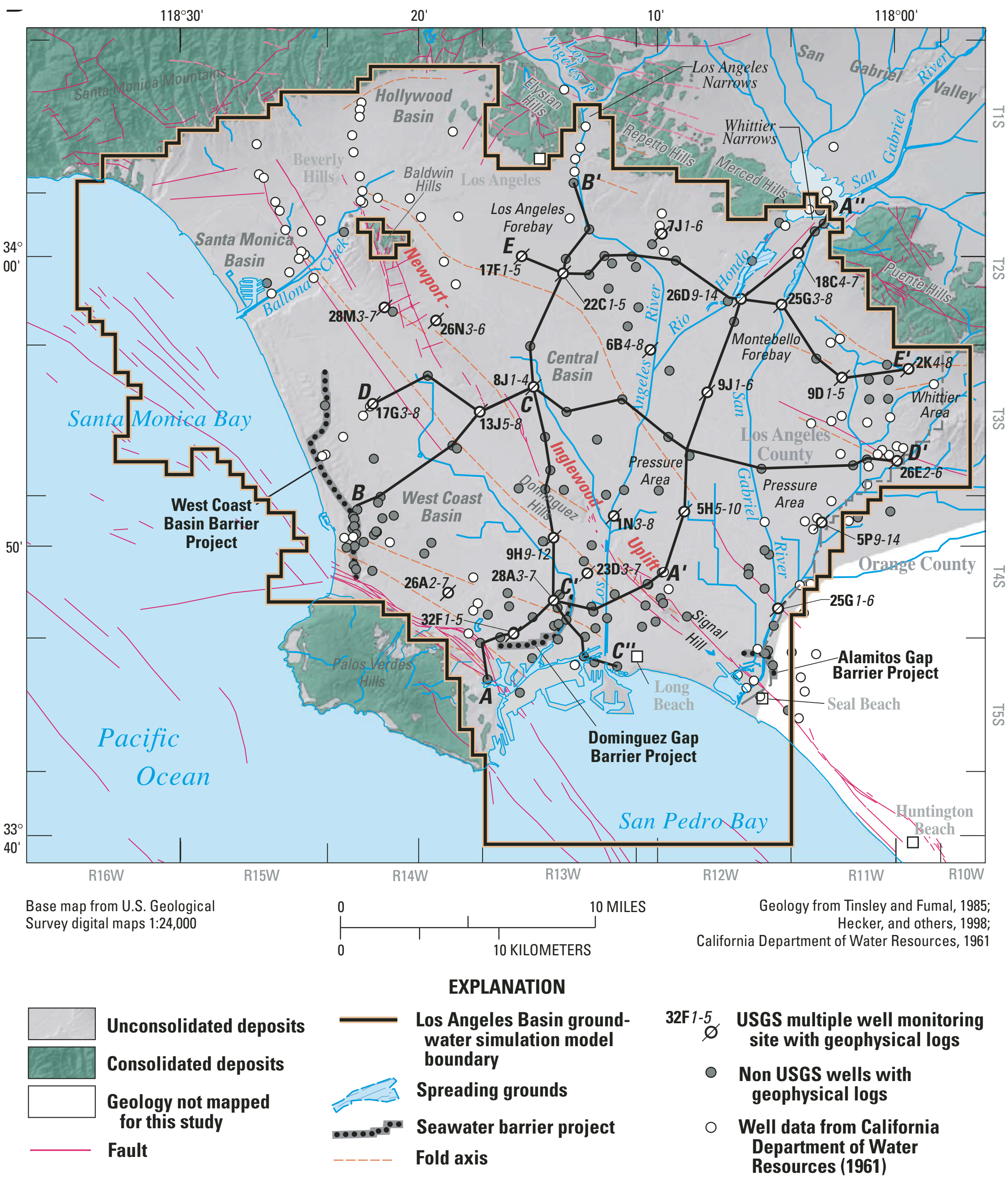
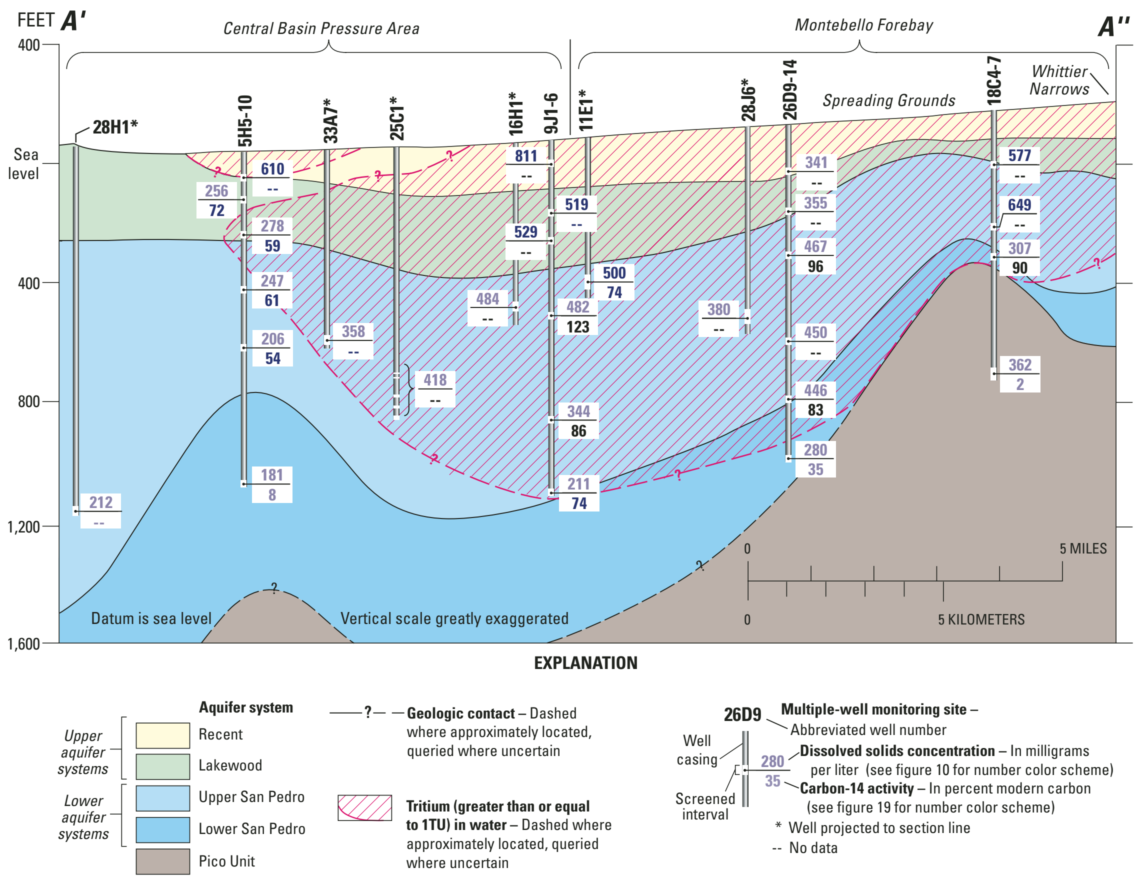


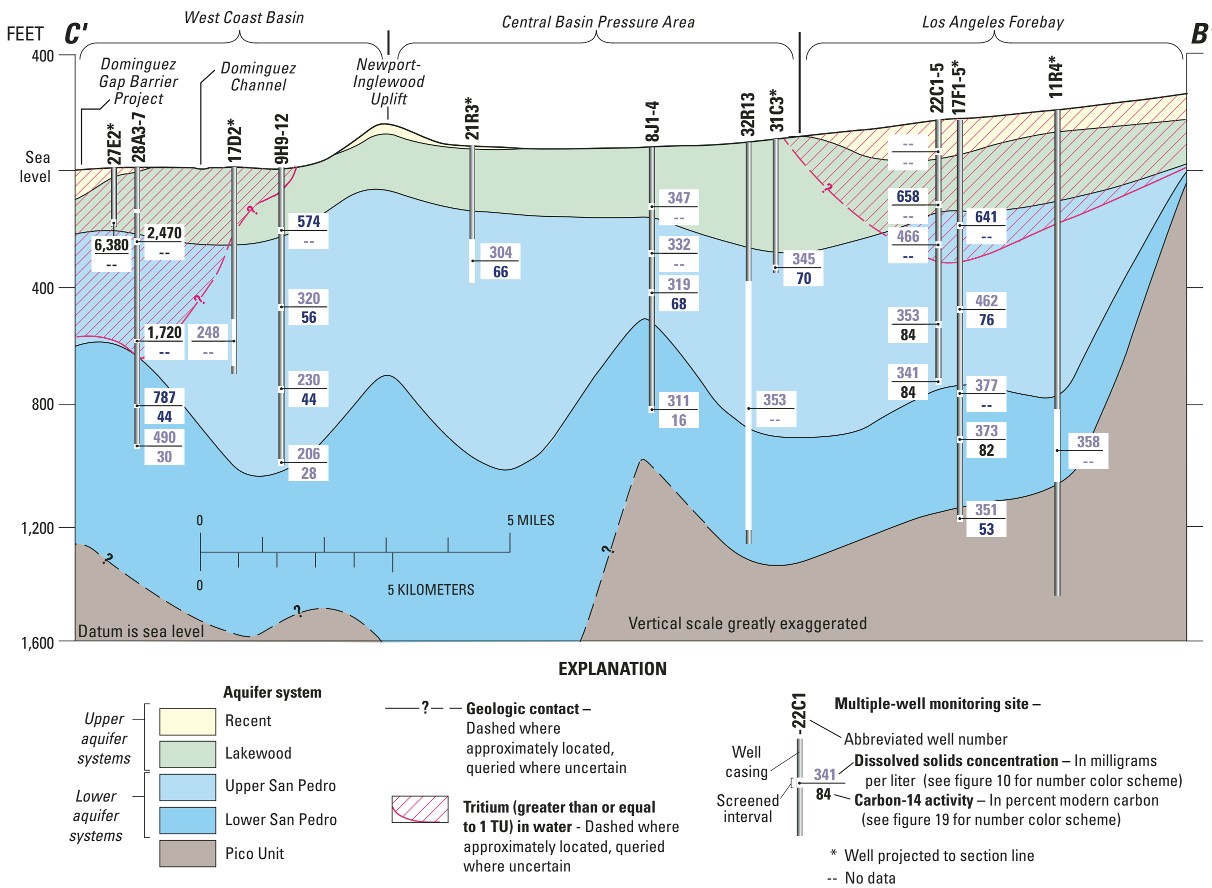
Figure 4.3-7. Coastal Plain of Los Angeles Groundwater Basin as defined by Department of Water Resources (DWR, 2012) consists of the contiguous unconsolidated deposits in the center of the figure. The unconsolidated deposits shown to the northeast are part of the San Gabriel Valley Groundwater Basin defined by DWR (2012). The geohydrologic sections shown on Figure 4.3-8 are located, along with some other sections not included in this report (Reichard et al., 2003).

Senate Bill 4 (SB 4) requires operators to monitor groundwater in aquifers in the vicinity of stimulated oil and gas wells. The main freshwater body of the coastal plain aquifer system extends from depths of less than 30 m up to 1,200 m (100 ft up to approximately 4,000 ft) (Planert and Williams, 1995). Two of the hydrologic sections located in Figure 4.3-7 are shown in Figure 4.3-8. Groundwater with less than 500 mg/L total dissolved solids (TDS) occurs at the lowest sampling points along the sections, which are typically 300 to 400 m (1,000 to 1,300 ft) deep. At many wells, the TDS concentration decreases with depth, indicating that water quality improves with increased depth. Most water supply wells in the Los Angeles coastal basin are drilled to depths of 155 to 348 m (510 to 1,145 ft) (Fram and Belitz, 2012), which accords with the TDS distribution on Figure 4.3-8 (Reichard et al., 2003).



a)

Figure 4.3-8. Dissolved-solids concentration, measurable tritium activity, and carbon-14 activity in ground water from wells sampled along geohydrologic sections A'–A'' (a) and C'–B' (b), Los Angeles County, California (Reichard et al., 2003).



b)

Figure 4.3-8. Continued.

Based on the hydraulic fracturing data for the last decade, we estimate about 40 to 80 fracturing operations are conducted each year on average in the Los Angeles Basin (see Volume I, Appendix K). Approximately three quarters of these are hydraulic fracturing operations, and one quarter are frac-packing operations (Volume I, Chapter 3). Volume I, Appendix M provides the well head locations for all wells where hydraulic fracturing operations were conducted, along with depths as available from the various data sets considered by this study. The appendix includes records of 314 fracturing operations in the Los Angeles Basin conducted from 2002 to mid-2014. Depths were available for 244 of these operations. All of these depths were either true vertical or measured total well depth. The shallowest well in these records was 401 m (1,320 ft), and 5% were shallower than 840 m (2,762 ft). This well depth distribution suggests that hydraulic fracturing may occur in close proximity to protected groundwater (defined as non-exempt groundwater with less than 10,000 TDS), and perhaps even in proximity to groundwater with less than 3,000 mg/L TDS. This is particularly the case, because the depth of the hydraulically fractured interval in an oil and gas well is less than the total well depth.

To assess the possibility that hydraulic fracturing is occurring at shallow depths, which may contaminate drinking water sources, we analyzed the spatial relationship between hydraulically fractured oil and gas wells and water wells in the Los Angeles Basin. The wellhead locations of hydraulically fractured wells were compared to the location of water wells in a database from the Department of Water Resources (DWR) provided by the United States Geological Survey (USGS) (Faunt, personal communication). The water well data are from well completion reports filed with the DWR.[1] These data are incomplete, and the California-wide dataset is missing at least 50,000 water wells drilled over the past 65 years plus wells drilled prior 1949 (Senter 2015, California Department of Water Resources, pers. comm.). However, the water well data does allow an initial screen for the proximity of hydraulically fractured wells.

The water well dataset indicates the purpose of the wells included in the set. For this study, we only included wells indicated as supply ("PROD") or with no purpose listed. The remainder of the dataset consists of wells involved in seawater barriers, groundwater remediation, and observation.

All hydraulically fractured wells in Volume I, Appendix M with a wellhead located within 1 km (0.6 mi.) laterally of the water wells considered were selected for further analysis. The locations of these 18 wellheads are shown in Figure 4.3-9. The true vertical depth to the top of the hydraulically fractured interval in each was collected from their well record, and is also shown in Figure 4.3-9.

1. Since 1949, California law has required that landowners submit well completion reports to DWR, containing information on newly constructed, modified, or destroyed wells.

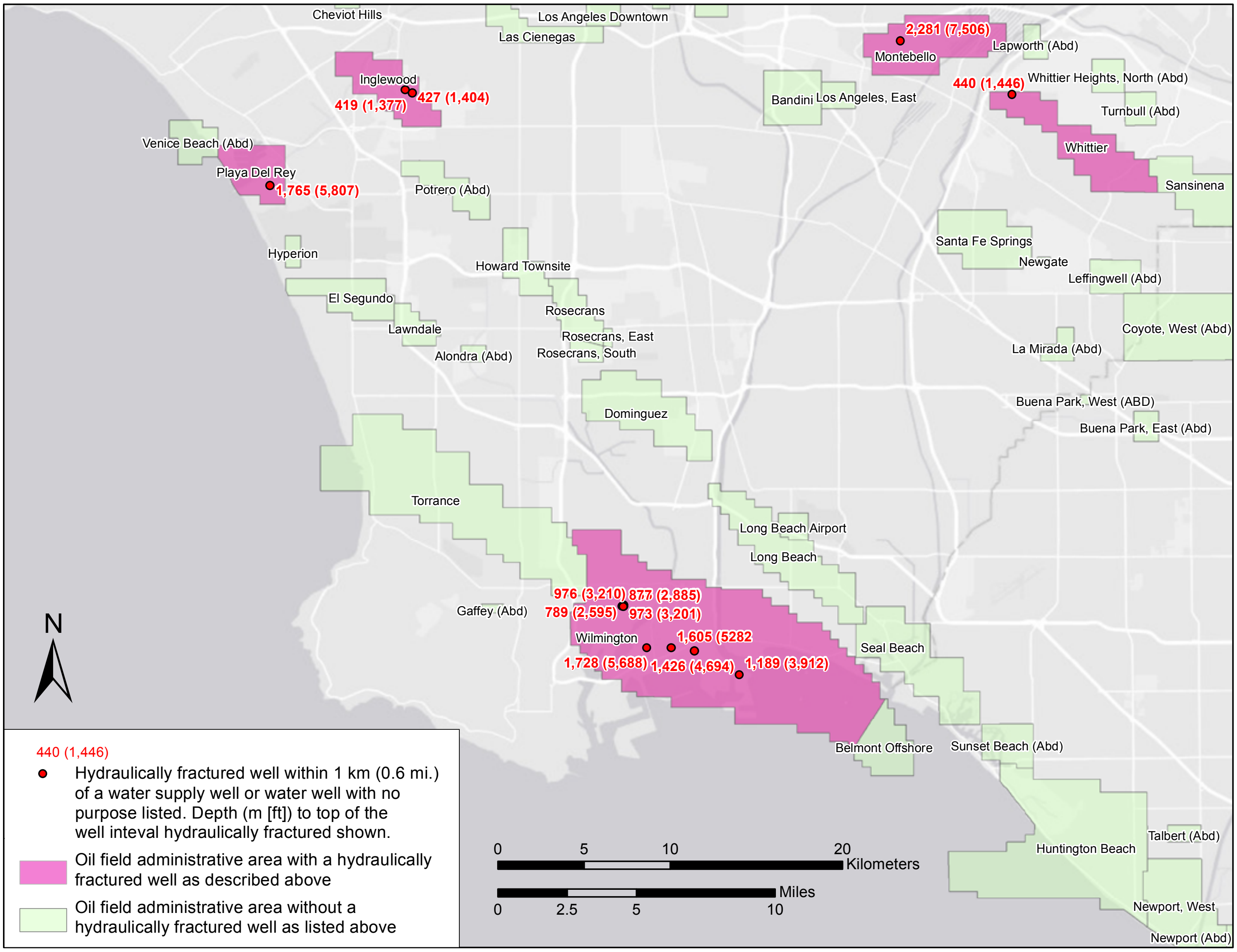


Figure 4.3-9. Depth in meters (and feet) to the top of the hydraulically fractured interval in each well in Volume I, Appendix M, with a wellhead within 1 km (0.6 mi.) laterally of a water supply well or a water well with no purpose stated. Note the depth to the top of the well interval hydraulically fractured is shown for 13 of the 18 wells assessed. The five wells without labels are in the northwestern-most cluster in the Wilmington field. Labels are shown for the four shallowest well interval tops in this cluster.

To assess the vertical separation between the hydraulic fracturing intervals and water wells, the depths of the water wells were subtracted from the depth to the top of each well interval hydraulically fractured for nearby wellheads. The depth to the base of the perforations were available for more than half of the water wells considered, and the total well depth was available for the rest. Figure 4.3-10 shows the depth separation between the base of the water well and the top of the well interval hydraulically fractured for each of the 18 wells stimulated, separated by the oil field in which they are located.

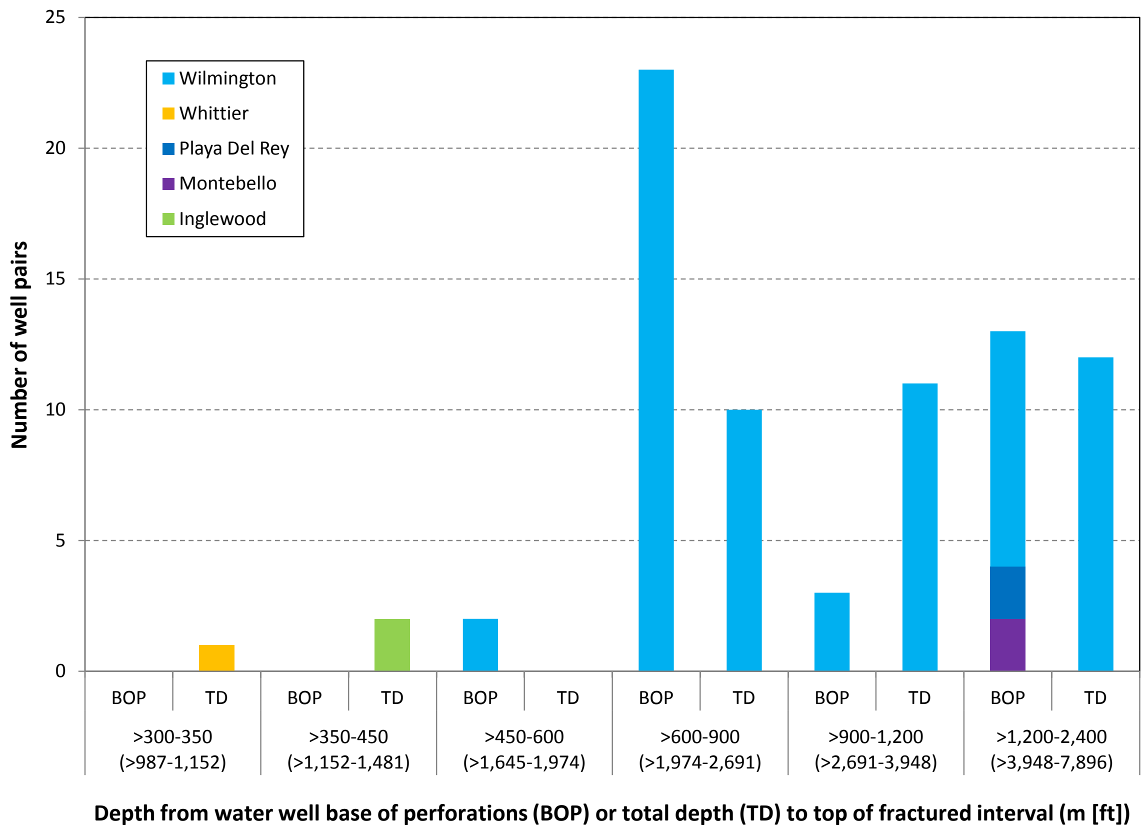


Figure 4.3-10. Depth separation between the base of each water well and the top of each well interval hydraulically fractured for wells with well heads within 1 km (0.6 mi.) of each other Note the bin intervals are not uniform in order to provide more detail for the smaller separations.

Figure 4.3-10 suggests that the vast majority of the selected hydraulic fracturing operations was conducted with large vertical separation to water wells between 600 m (1,974 ft) and 2,400 m (7,896 ft). The operations within four wells within the Wilmington and Inglewood oil fields had the vertical separation between 350 m (1,150 ft) and 600 m (1,974 ft). The operation in one well in the Whittier field has a vertical separation of

300 to 350 m (1,000 to 1,150 ft) from a water well. Given the small number of operations identified that are close to protected groundwater, and the relatively small overall number of hydraulic fracturing operations conducted in the basin, the risk of a hydraulic fracture impacting an existing water well is considered small, but does warrant further investigation (Volume II, Chapter 2).

Proximity to existing water wells is only one indicator of proximity to protected groundwater. Water supply wells typically only extend as deep as necessary to secure the desired supply of groundwater from aquifers that are reasonably secure from contamination by surface and near-surface releases. They typically do not necessarily extend to the base of protected groundwater (i.e., non-exempt groundwater with up to 10,000 mg/L TDS). For instance, most of the depths of the top of the fractured oil and gas well intervals are less than the maximum depth of the coastal plain aquifer of 1,200 m (3,900 ft). Some of these depths are also within 100 m (330 ft) of the deepest sampling intervals shown in Figure 4.3-8, which have water with <500 mg/L TDS, and deeper water supply wells.

A more detailed understanding of the depth to the base of protected water relative to the depth of the well intervals hydraulically fractured (Figure 4.3-9) is provided by the field rules from DOGGR, in combination with the reservoir water salinities listed in California Oil and Gas Field Volume II (DOGGR, 1992). Table 4.3-14 lists the TDS for each field indicated in Figure 4.3-9, along with the depth range of the top of the well interval hydraulically fractured from the 18 operations shown on Figure 4.3-9 for each field. The data in Table 4.3-14 are shown graphically on Figure 4.3-11.

The table and figure show that one fracturing operation in the Whittier field occurred within perhaps 300 m (1,000 ft) of water with <3,000 mg/L TDS, and actually within water with <10,000 mg/L TDS. Two fracturing operations occurred within 150 m (490 ft) of water with <10,000 mg/L TDS in the Inglewood field. The shallowest operation in the Wilmington field occurred within 200 to 350 m (660 to 1,100 ft) of water with <3,000 mg/L TDS. As these results are based on only 18 of the 341 known hydraulically fractured wells in the Los Angeles Basin, it is possible the minimum depth separation between well intervals hydraulically fractured and groundwater of these various qualities is even less.

Table 4.3-14. Groundwater TDS data compared to the depth to the top of select hydraulic fracturing well intervals (TDS data from field rules).

Field	Base of freshwater (<3,000 mg/L TDS) (m [ft])	Deepest reservoir with water <10,000 mg/L TDS (m [ft])	Shallowest reservoir listed with water >10,000 mg/L TDS (m [ft])	Top of stimulation well interval for selected operations (m [ft])
Inglewood	~90 (~300)	290 (950)	320 (1,050)	419-427 (1,377-1,404)
Montebello	490 (~1,600)	NA	670 (2,200)	2,281 (7,506)
Playa Del Rey	210 (~700)	NA	1,880 (6,200)	1,765 (5,807)
Whittier	46-200 (150-650)	490 (1,600)	1,230 (4,050)	440 (1,446)
Wilmington	~460-590 (~1,500-1,950)	NA	670 (2,200)	789-1,728 (2,595-5,688)

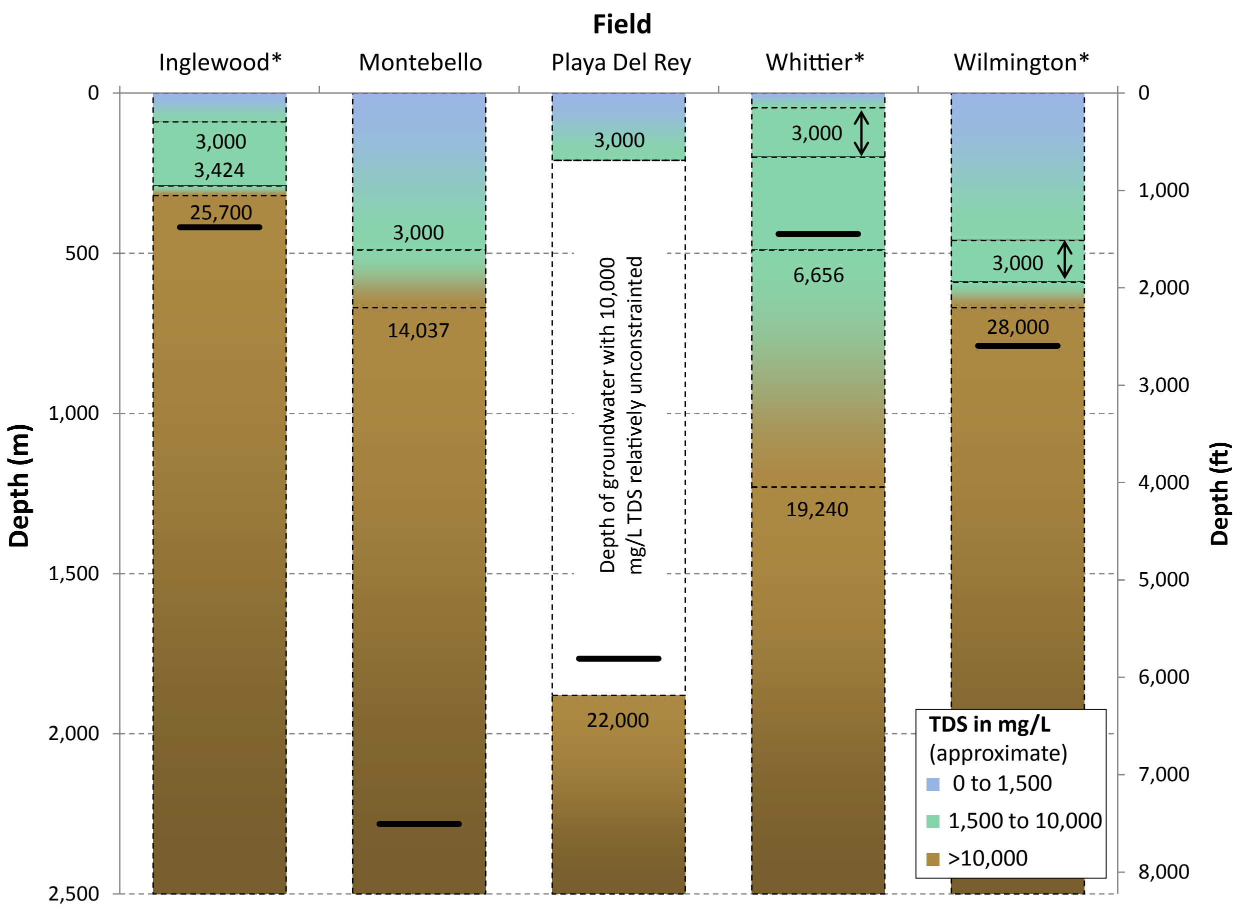


Figure 4.3-11. Depth of 3,000 mg/L TDS and data bracketing the depth of 10,000 mg/L TDS in each field with the hydraulically fractured wells selected for study (data from field rules and DOGGR (1992). The heavy black horizontal line indicates the shallowest well interval hydraulically fractured in each field.

4.3.4.1. Conclusion of Potential Risks to Ground Water Quality in the Los Angeles Basin and Potential Public Health Hazards

The results of our investigation, based upon the available data, indicate that a small amount of hydraulic fracturing in the Los Angeles Basin has occurred within groundwater with <10,000 mg/L TDS and in proximity to groundwater with <3,000 mg/L TDS, creating the risk of hydraulic fractures extending into or connecting with protected groundwater and contaminating aquifers with fracturing fluids and other compounds. If such contamination occurs, this could create an exposure pathway for people that rely on these water resources for drinking and other uses. As such, the recommendations regarding shallow fracturing near protected groundwater in Volume III, Chapter 5 should also be applied to such operations in the Los Angeles Basin if this practice continues. Among these recommendations we suggest there be special requirements to: 1) control fracturing stimulation design and reporting, 2) increase groundwater monitoring requirements; and 3) implement corrective action planning. Additionally, characterization of the base of the deepest groundwater with less than 10,000 mg/L TDS in the Los Angeles Basin is needed in some locations.

4.3.5. Conclusions of the Los Angeles Basin Public Health Case Study

In this case study, we investigated locations of currently active oil and gas development, the proportion of these wells that have been enabled or supported by well stimulation treatments, the emissions of criteria air pollutants and TACs from this development, and the numbers and demographics of residents and sensitive receptors that are in proximity to these operations. These components were discussed together in an effort to elucidate where and who might be exposed to emissions of air pollutants from the development of oil and gas in the Los Angeles Basin. We also examined the possibility that groundwater supplies in the Los Angeles Basin could become contaminated due to hydraulic fracturing-enabled oil and gas development. Our results, based upon available data, indicate that a small amount of hydraulic fracturing in the Los Angeles Basin has occurred within groundwater with <10,000 mg/L TDS, and in proximity to groundwater with <3,000 mg/L TDS. This creates a risk of hydraulic fractures extending into or connecting with protected groundwater, and could result in fracturing fluids mixing with these water resources, introducing a potential exposure hazard for populations that rely on these groundwater resources.

4.3.5.1. Air Pollutant Emissions and Potential Public Health Risks

Many of the constituents used in and emitted to the air by oil and gas development are known to be health damaging and pose risks to people if they are exposed—especially to sensitive populations, including children, the elderly, and those with pre-existing respiratory and cardiovascular conditions. We found that oil and gas development poses more elevated population health risks when conducted in areas of high population density, such as the Los Angeles Basin, because it results in larger population exposures to TACs (there are more breathing lungs nearby) than when conducted in areas of low population density (fewer breathing lungs nearby). Relatedly, emissions of TACs in close proximity to human populations often results in more elevated risks of exposures compared to those populations that are far from emission sources. Most of the documented public health risks associated with air pollutant emissions from oil and gas development are associated with oil and gas development in general, and are not unique to well stimulation.

Our emission inventory analysis found that 2,361 kg/year of benzene is emitted by the stationary components of upstream oil and gas development in the Los Angeles Basin. This amount represents a significant proportion of stationary source (9.6%) and a smaller proportion of benzene emissions from all sources (including mobile source emissions) (0.14%) in the South Coast Air Basin. Our state inventory analysis also indicates that 5,846 kg/year or 3.8% of the stationary source emissions of formaldehyde, and <1% of all source emissions (including mobile), are attributable to the upstream oil and gas sector. Smaller proportions of other indicator TAC species were identified. These indicator TAC species included in our assessment are not often used in well stimulation fluids, but rather are co-produced with oil and natural gas during development. Since only ~26% of the wells currently active in the Los Angeles Basin are hydraulically fractured and responsible for approximately 19% of oil production in the region, emissions of TACs and ROGs are a smaller subset of those emitted by the upstream oil and gas sector in general.

The proportion of the total TAC inventory (mobile and stationary sources) attributable to upstream oil and gas development is not high, and from a regional air quality perspective, these results seem to indicate that TAC emissions from the upstream oil and gas sector are unimportant. However, from a public health perspective, fractions of total emissions are not as important as the quantity or the mass of pollutants emitted at specific locations, as well as the proximity to humans where the emissions occur. Some of the TACs—especially benzene and formaldehyde and potentially hydrogen sulfide (but problems with the inventory do not allow us to be sure)—are emitted in large masses (but not in large fractions of the total inventory) in the upstream oil and gas sector in a densely populated urban area.

The Los Angeles Basin reservoirs have the highest concentrations of oil in the world, and Los Angeles is also a global megacity. Oil and gas development in Los Angeles occurs in close proximity to human populations. In the Los Angeles Basin, approximately 1.7 million people live, and large numbers of schools, elderly facilities, and daycare facilities are located within one mile of—and more than 32,000 people live within 100 m of—an active oil and gas well. The closer citizens are to these industrial facilities, the more likely they are to be exposed to TACs, and the more elevated their risk of associated health effects. Studies from outside of California indicate that community public health risks of exposures to TACs such as benzene and aliphatic hydrocarbons are most significant within 800 m (½ mile) from active oil and gas development. These risks will depend on local conditions and the type of petroleum being produced. California impacts may or may not be similar, but they have not been measured.

4.3.5.2. Potential Water Contamination Pathways in the Los Angeles Basin

Our assessment of hazards to groundwater by hydraulic-fracturing-enabled oil and gas development in the Los Angeles Basin indicates that while data is limited, a small amount of hydraulic fracturing in the Los Angeles Basin has occurred within a short vertical distance to potable aquifers. Given the small number of operations identified that are close to protected groundwater, and the relatively small overall number of hydraulic fracturing operations conducted in the basin, the overall risk of a hydraulic fracture impacting an existing water well is considered small, but the potential hazard to groundwater quality from shallow fracturing operations does warrant enhanced requirements to: 1) control fracturing stimulation design and reporting, 2) increase groundwater monitoring requirements; and 3) implement corrective action planning. No water contamination from well-stimulation-enabled oil and gas development has been noted in the Los Angeles Basin thus far, but this may be because there has been little to no systematic monitoring of aquifers in the vicinity of these oil production sites.

4.3.6. Data Gaps and Recommendations

An overarching recommendation from these analyses is to conduct studies in the Los Angeles Basin and throughout California to document public health risks and impacts as a function of proximity to all oil and gas development—not just those that are stimulated—and promptly develop policies that decrease potential exposures. Such policies might incorporate, for example, increased air pollutant emission control technologies, as well as science-based minimum surface setbacks between oil and gas development and places where people live, work, play and learn.

There are data gaps that contribute to uncertainty with regards to the environmental and public health dimensions of oil and gas development in the South Coast Air Basin. Below we have identified a number of important data gaps and recommendations that are pertinent to the issues explored in this case study:

- **Conduct epidemiological investigations designed to assess the association between proximity to producing wells and human health.** There has only been one epidemiological study that assessed the associations between oil and gas development (distance) and public health outcomes in the Los Angeles Basin, but this study was inappropriate for detecting statistical differences in disease outcomes between the population near the Inglewood Oil Field and Los Angeles County. Study designs—most likely longitudinal in nature and with good baseline environmental and public health measurements—are needed to understand the potential burden of adverse health outcomes associated with the development of oil and gas in the South Coast Air Basin, especially among groups in close proximity to these operations.

- **Study the numbers of residents with pre-existing respiratory and cardiovascular diseases in proximity to oil and gas development.** Populations with respiratory and cardiovascular diseases are disproportionately vulnerable to adverse health outcomes associated with exposures to criteria air pollutants and TACs. To date, no studies have investigated the numbers and concentrations of people with these conditions in close proximity to oil and gas development in the South Coast Air Basin or throughout California.

- **Conduct regional-scale field monitoring of VOC and TAC emission factors from oil and gas development in the South Coast Basin.** Top-down monitoring studies in the South Coast and throughout California have found oil and gas development-scale methane emissions to be potentially three to seven times greater than emissions reported in state inventories. There are no similar studies on the agreement or disagreement of state inventories (such as those analyzed for this case study) and field monitoring of TACs such as benzene (See Volume II, Chapter 3). Current state inventories on these TACs may agree with or be dwarfed by the findings of such field monitoring studies. Findings of such studies could hold policy implications for how VOC and TAC emissions are addressed in the South Coast Air Basin and throughout California.

- **Conduct community-scale monitoring of air pollutant emissions from oil and gas development.** Over the past two decades, the South Coast Region has made impressive strides in reducing criteria air pollutant and toxic air contaminant emissions, and the South Coast Air Basin has enjoyed cleaner air as a result. Nonetheless, the region still experiences severe non-attainment, especially with regards to tropospheric ozone and particulate matter concentrations, and only limited monitoring in close proximity to emitting facilities has been undertaken. Regional air pollutant concentrations, especially of toxic air contaminants and particulate matter, have limited relevance to public health assessments, largely due to the dilution of these air pollutants as they are transported in the atmosphere away from their sources. Exposures to air pollutants can increase with closer proximity to an emission source (e.g., active oil development operations). In order to more accurately understand the composition and magnitude of exposures to air pollutants emitted from the oil and gas development process, more community-scale monitoring activities and sufficient baseline environmental and public health measurements should be undertaken. Community-scaled air quality monitoring activities should be conducted collaboratively between air pollution researchers and community members to increase the relevance and representativeness of the sampling.

- **Investigate the emission and toxicological profiles of TACs associated with oil and gas development.** In this case study we examined the toxicological profiles and emission rates of only four indicator TACs, out of dozens that are known to be associated with oil and gas development. Investigations of emission and toxicological profiles of a larger subset of TACs associated with oil and gas development should be undertaken.

- **Conduct research on emission factors of TACs with no emission factors.** We identified more than 30 compounds known to be TACs that are added to hydraulic fracturing and acidizing fluids in the SoCAB in the SCAQMD oil and gas reporting dataset, yet none of them have known emission factors from oil and gas development processes. Research on the emission factors and the development of an emission inventory of these compounds should be a priority.

- **Require increased air pollutant emission reduction technologies on all processes and ancillary infrastructure.** All oil and gas development in the close proximity to human populations, especially in the dense urban context should be required to install air pollutant emission-reduction technologies, including but not limited to reduced emissions resulting from well completions. Emphasis should be placed on venting, flaring, and fugitive leakage that emit TACs and ROGs, given the non-attainment status and high population density of the Los Angeles Basin. Similar measures can be applied to limit emission of methane to reduce climate impacts.

- **Conduct research on the depth of hydraulic fracturing in relation to usable aquifers in the Los Angeles Basin, especially those used for drinking water.** Our research indicates that active oil and gas development is occurring in the same geographic extent as potable aquifers, such as the Coastal Plain aquifer, which underlies much of the coastal areas of Los Angles and Orange Counties. A full assessment of depth of fractures and the extent to which fractures intersecting aquifers in the Los Angeles Basin would inform regulators and the public as to whether this subsurface pathway presents a risk in this region.

- **Conduct research to identify exact locations of water wells, the use of their water, their geospatial relationship to active and historical oil and gas development, including that enabled by well stimulation, and potential for groundwater contamination.** Precise locations of water wells throughout California are not publicly available. As such, it is difficult to conduct accurate analyses on the potential risks posed by well-stimulation-enabled and other forms of oil and gas development to water quality used by human populations. Future research should identify locations of water wells and perform analyses on potential contamination pathways and potential contamination attributable to oil and gas development.

- **Implement the recommendations regarding shallow fracturing near protected groundwater from Volume III, Chapter 5 (San Joaquin Valley Case Study) should such operations in the Los Angeles Basin continue.** Among these recommendations and should this practice continue in the Los Angeles Basin we suggest there be special requirements to: 1) control fracturing stimulation design and reporting, 2) increase groundwater monitoring requirements; and 3) implement corrective action planning. Additionally, characterization of the base of the deepest groundwater with less than 10,000 mg/L TDS in the Los Angeles Basin is needed in some locations.

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