Appendix 6.A

Toward an Understanding of the Environmental and Public Health Impacts of Shale Gas Development: An Analysis of the Peer-Reviewed Scientific Literature, 2009-2015: Methods, Limitations and Peer-Reviewed Literature List

6.A.1. Methods and Findings from the Literature Review

6.A.1.1. Database Assemblage and Review

This analysis was conducted using the PSE Study Citation Database on Shale & Tight Gas Development (available at: http://psehealthyenergy.org/site/view/1180). This near exhaustive collection of peer-reviewed literature on shale gas development is divided into 12 topics that attempt to organize the papers in a useful and coherent manner. These topics include air quality, climate, community, ecology, economics, general (comment/review), health, regulation, seismicity, waste/fluids, water quality, and water usage. This study database has been assembled over several years using a number of different search strategies, including the following:

- Systematic searches in scientific databases across multiple disciplines: PubMed (http://www.ncbi.nlm.nih.gov/pubmed/), Web of Science (http://www.webofknowledge.com), and ScienceDirect (http://www.sciencedirect.com)

- Searches in existing collections of scientific literature on shale gas development, such as the Marcellus Shale Initiative Publications Database at Bucknell University (http://www.bucknell.edu/script/environmentalcenter/marcellus), complemented by Google (http://www.google.com) and Google Scholar (http://scholar.google.com)

- Manual searches (hand-searches) of references included in peer-reviewed studies and government reports that pertain directly to shale gas development.

For scientific literature search engines we used a combination of Medical Subject Headings (MeSH)-based and keyword strategies, which included the following terms as well as relevant combinations thereof:

> shale gas, shale, hydraulic fracturing, fracking, drilling, natural gas, air pollution, methane, water pollution, public health, water contamination, fugitive emissions, air quality, climate, seismicity, waste, fluids, economics, ecology, water usage, regulation, community, epidemiology, Marcellus, Barnett, Fayetteville, Haynesville, Denver-Julesberg Basin, unconventional gas development, and environmental pathways.

This database and subsequent analysis excluded technical papers on shale gas development not applicable to determining potential environmental and public health impacts. Examples of literature that we exclude are papers on optimal drilling strategies, reservoir evaluations, estimation algorithms of absorption capacity, patent analyses, and fracture models designed to inform stimulation techniques. Because our analysis is limited to papers subjected to external peer-review, it does not include government reports, environmental impact statements, policy briefs, white papers, law review articles, or other grey literature. Our analysis also excludes studies on coalbed methane, coal seam gas, tar sands and other forms of fossil fuel extraction.

We have tried to include all literature that meets our criteria in our collection of the peer-reviewed science; however, it is very possible that some papers may be missing from our analysis. Thus, we refer to the collection as near exhaustive. We are sure, however, that the most seminal studies on the environmental public health dimensions of shale gas development in leading scientific journals are accounted for.

The PSE Study Citation Database has been used and reviewed by academics, experts, and government officials throughout the U.S. and internationally and has been subjected to public and professional scrutiny before and after this analysis. It represents the most comprehensive public collection of peer-reviewed scientific literature on shale and tight gas development in the world and has been accessed by thousands of people. Again, many of the publications in this database are discussed in greater detail in published review articles (Shonkoff et al. 2014; Adgate et al. 2014; Werner et al. 2015) and government reports.

6.A.1.2. Scope of Analysis and Inclusion/Exclusion Criteria

There has been great confusion about the environmental dimensions of shale and tight gas development (often termed “fracking”) because of the lack of uniform, well-defined terminology and boundaries of analysis. The public and the media use the term fracking as an umbrella term to refer to the entirety of shale gas development (and often other forms of oil and gas development), including processes ranging from land clearing to well stimulation, to hydrocarbon production, to waste disposal. On the other hand, the oil and gas industry and many in the scientific community generally use the term, "fracking" as shorthand for one particular type of well stimulation method used to enhance the production of oil and natural gas – hydraulic fracturing.

The PSE Study Citation Database and this analysis are both focused on shale gas development in its entirety, enabled by hydraulic fracturing, and not just the method of well stimulation. Environmental and public health analyses that include only the latter should have a limited role in policy discussions. In order to understand the environmental and public health dimensions of shale gas development any reasonable approach must engage beyond a narrow view of only the well stimulation process of hydraulic fracturing, especially when the scientific literature indicates that other aspects of the overall shale and tight gas development process warrant greater concern. As such, the boundaries of this analysis include scientific literature on hydraulic fracturing and the associated operations and ancillary infrastructure required to develop shale and tight gas.

The focus of this analysis is, first and foremost, on the primary research on shale gas development published between 1 January 2009 and 16 June 2015. The reason for starting this analysis in 2009 is that research on shale gas development did not appear until this time. We include papers that evaluate environmental and public health hazards, risks, and impacts of shale gas development. As such, most publications in the PSE Study Citation Database were not used in this analysis. We exclude the following topics: climate, community, ecology, economics, regulation, seismicity, waste/fluids, and water usage.

We also exclude some papers that fall under the three topics used in this analysis (health, water quality, and air quality). With the exception of public health papers, for which there has been very little primary research, we exclude commentaries and review articles. We exclude papers that only provide baseline data or address research methods but fail to assess hazards, risks, and impacts. Finally, we exclude letters to the editors of scientific journals that critique a particular study or the subsequent response of the author(s).

As previously mentioned, we restrict the studies included in this analysis to those published from 1 January 2009 through 16 June 2015. There are studies on conventional forms of oil and natural gas development that are relevant to shale gas, but to maintain greater consistency we have decided to exclude those prior to 2009 from the analysis. For instance, we did not include a study published in The Lancet that examined the association between testicular cancer and employment in agriculture and oil and gas development published in 1984 (Mills et al. 1984). Relatedly, the scope of some of the studies included in this analysis may go beyond shale gas and could potentially include other forms of both conventional and unconventional oil and gas development. This is true for some of the top-down, field based air pollutant emissions studies that gauge leakage rates and emission factors in Western oil and gas fields. Studies not exclusively related to shale gas development were included only when the focus of the studies were relevant (e.g., VOC emissions in a region with shale and tight gas development along with other forms of oil and gas development) and were published within our specified timeframe.

Again, it is important to note that scientists are only beginning to understand the environmental and public health dimensions of these rapidly expanding industrial practices. This analysis represents a survey of the existing science to date in an attempt to determine the direction in which scientific consensus may be headed and to achieve a better understanding of the environmental and public health impacts of this form of energy development. What we know at this time is based on modeling and field-based studies on unconventional oil and gas development (primarily from shale) in parts of the United States, such as Texas, Colorado, and Pennsylvania, where the extraction of natural gas from shale formations has only been scaled relatively recently.

6.A.1.3. Categorical Framework

We have created categories for each topic in an attempt to identify and group studies in intuitive ways. There are limitations to this approach and many studies are nuanced or incommensurable in ways that may not be appropriate for this type of analysis. Additionally, some studies belong in more than one topic. A few studies that contain data that are relevant to both air quality and public health have been included in both of these topics (Ethridge et al. 2015; Bunch et al. 2014; Macey et al. 2014). Despite these limitations, in order to glean some kind of emerging scientific consensus on the environmental public health dimensions of shale gas development we strived to create the most simple and accurate approach possible. Table 6.A-1 provides a summary of our topic/categories organization for the literature review and section 6.A.2.1 at the end of this appendix has a detailed summary by topic of the citations, which are listed alphabetically by author within a topic.

Table 6.A-1. Topics and categories used to organize the literature review.

Topics	Categories
Health	• Indication of potential public health risks or actual adverse health outcomes • No indication of significant public health risks or actual adverse health outcomes
Water Quality	• Indication of potential, positive association, or actual incidence of water contamination • Indication of minimal potential, negative association, or rare incidence of water contamination
Air Quality	• Indication of elevated air pollutant emissions and/or atmospheric concentrations • No indication of significantly elevated air pollutant emissions and/or atmospheric concentrations

6.A.1.4. Health

Studies that assess public health hazards and risks as well as epidemiologic investigations continue to be particularly limited. Most of the peer-reviewed papers to date are commentaries and literature reviews. Accordingly, we have separately analyzed peer-reviewed scientific commentaries and review articles for this topic (we term this category, “all papers”). Although commentaries should essentially be acknowledged as opinions, they are the opinions of experts formed from the available literature and have also been subjected to peer review.

We have included in this topic papers that consider the question of public health in the context of shale gas development. Of course, research findings in other categories such as air quality and water quality are relevant to public health, but here we only include those studies that directly consider the health of human populations and individuals as well as studies that have examined animal disease events as sentinel information for human health risks. We only consider research to be original if it measures potential or actual health outcomes or complaints (i.e., not health research that only attempts to determine public opinion or consider methods for future research agendas).

6.A.1.5. Water Quality

The allocation of water quality papers to binary categories is more complex than those focused on human health hazards and risks in that some rely on empirical field measurements, while others explore mechanisms for contamination or use modeled data to assess or predict water quality risks. Some of these studies explore only one aspect of shale gas development, such as the well stimulation process enabled by hydraulic fracturing. These studies do not always indicate whether or not shale gas development as a whole is associated with water contamination and are therefore limited in their utility for gauging water quality impacts. Nonetheless, we have included all original research, including modeling studies as well as those that consider contamination mechanisms and/or exposure pathways. We have excluded studies that explore only evaluative methodology or baseline assessments as well as papers that simply comment on or review previous studies. Here we are only concerned with actual findings in the field or modeling studies that specifically address the risk or occurrence of water contamination.

6.A.1.6. Air Quality

The papers in this topic are those that specifically address air emissions and air quality from unconventional oil and gas development at either a local or regional scale. These primarily include local and regional measurements of non-methane volatile organic compounds and tropospheric ozone. Air quality is a more complex, subjective measure that beckons comparison to other forms of energy development or industrial processes. Yet a review and analysis of air quality studies is still useful and relevant to potential population health outcomes.

Although methane is a precursor to tropospheric ozone we have excluded studies that focus exclusively on methane emissions from this topic. However, studies that address emissions of methane and non-methane volatile organic compounds (VOC) are included, given the known health-damaging dimensions of a number of VOCs (i.e., benzene, toluene, ethylbenzene, xylene, 1,3 butadiene, acetaldehyde, etc.) and the role of light alkane VOCs in the production of the strong respiratory irritant, tropospheric ozone. A few studies that explore the public health risks associated with air pollutant emissions are included in both the air and the public health category.

6.A.2. Discussion

In this analysis, we reviewed the direction of findings among scientific studies and other peer reviewed papers that assessed associations between shale and tight gas development and air, water, and public health hazards, risks, and impacts. For each topic we found that the majority of original research indicated substantial risks from shale and/or tight gas development on the outcome of interest. Scientific consensus is not yet achievable given comparison limitations due to differences in geology, geography, regulation, engineering, and other attributes, as well as methodological differences between studies. However, these results indicate that shale and tight gas development has known public health hazards and risks. Regulators, policy makers, and others who are charged with determining how, where, when, and if the development of shale gas should be deployed in their jurisdictional boundaries should take these findings into account.

There are limitations to this analysis. While our database is – to our best understanding – exhaustive, our literature search may not have captured all relevant scientific literature. Additionally, differences in geography, geology, gas type, and regulatory regime may render some studies less relevant when interpreted across geographic space.

Despite its limitations, our analysis provides a general understanding of the weight of the scientific evidence of possible impacts arising from shale gas development. This analysis only concerns itself with current empirical evidence in the peer-reviewed literature and does not consider different regulatory regimes that could potentially influence environmental and public health outcomes in positive or negative ways. For instance, technological improvements such as universal deployment of reduced emission completions may mitigate some existing air pollutant emission issues, but as development continues, well pad intensities increase, and novel geologies and practices are encountered, deleterious impacts could increase.

Finally, all forms of energy production and industrial processing have environmental impacts. This report is only focused on reviewing and presenting the available science on some of the most salient environmental and public health concerns associated with the development of gas from shale and tight formations. We make no claims about the level of impacts that should be tolerated by society – these are ultimately value judgments.

6.A.2.1. Literature-Review Citations

Below are all the literature review citations, listed alphabetically by author within a topic.

Health: Original Research (n=25)

- *Indication of potential public health risks or actual adverse health outcomes (n=21)*

1. Bamberger M, Oswald RE. 2012. Impacts of Gas Drilling on Human and Animal Health. NEW SOLUTIONS: A Journal of Environmental and Occupational Health Policy 22:51–77; doi:10.2190/NS.22.1.e.

2. Bamberger M, Oswald RE. 2015. Long-term impacts of unconventional drilling operations on human and animal health. Journal of Environmental Science and Health 50: 447–459.

3. Brown D, Weinberger B, Lewis C, Bonaparte H. 2014. Understanding exposure from natural gas drilling puts current air standards to the test. Rev Environ Health; doi:10.1515/reveh-2014-0002.

4. Brown DR, Lewis C, Weinberger BI. 2015. Human exposure to unconventional natural gas development: A public health demonstration of periodic high exposure to chemical mixtures in ambient air. Journal of Environmental Science and Health, Part A 50: 460–472.

5. Casey JA, Ogburn EL, Rasmussen SG, Irving JK, Pollak J, Locke PA, et al. 2015. Predictors of Indoor Radon Concentrations in Pennsylvania, 1989–2013. Environmental Health Perspectives; doi:10.1289/ehp.1409014.

6. Colborn T, Kwiatkowski C, Schultz K, Bachran M. 2011. Natural Gas Operations from a Public Health Perspective. Human and Ecological Risk Assessment: An International Journal 17:1039–1056; doi:10.1080/10807039.2011.605662.

7. Colborn T, Schultz K, Herrick L, Kwiatkowski C. 2014. An Exploratory Study of Air Quality near Natural Gas Operations. Human and Ecological Risk Assessment: An International Journal 0:null; doi:10.1080/10807039.2012.749447.

8. Esswein EJ, Breitenstein M, Snawder J, Kiefer M, Sieber WK. 2013. Occupational exposures to respirable crystalline silica during hydraulic fracturing. J Occup Environ Hyg 10:347–356; doi:10.1080/15459624.2013.788352.

9. Esswein EJ, Snawder J, King B, Breitenstein M, Alexander-Scott M, Kiefer M. 2014. Evaluation of Some Potential Chemical Exposure Risks During Flowback Operations in Unconventional Oil and Gas Extraction: Preliminary Results. Journal of Occupational and Environmental Hygiene 11:D174–D184; doi:10.1080/15459624.2014.933960.

10. Ferrar KJ, Kriesky J, Christen CL, Marshall LP, Malone SL, Sharma RK, et al. 2013. Assessment and longitudinal analysis of health impacts and stressors perceived to result from unconventional shale gas development in the Marcellus Shale region. International Journal of Occupational and Environmental Health 19:104–112; doi:10.1179/2049396713Y.0000000024.

11. Kassotis CD, Tillitt DE, Davis JW, Hormann AM, Nagel SC. 2013. Estrogen and Androgen Receptor Activities of Hydraulic Fracturing Chemicals and Surface and Ground Water in a Drilling-Dense Region. Endocrinology 155:897–907; doi:10.1210/en.2013-1697.

12. Macey GP, Breech R, Chernaik M, Cox C, Larson D, Thomas D, et al. 2014. Air concentrations of volatile compounds near oil and gas production: a community-based exploratory study. Environmental Health 13:82; doi:10.1186/1476-069X-13-82.

13. McKenzie LM, Guo R, Witter RZ, Savitz DA, Newman LS, Adgate JL. 2014. Birth Outcomes and Maternal Residential Proximity to Natural Gas Development in Rural Colorado. Environmental Health Perspectives 122; doi:10.1289/ehp.1306722.

14. McKenzie LM, Witter RZ, Newman LS, Adgate JL. 2012. Human health risk assessment of air emissions from development of unconventional natural gas resources. Sci. Total Environ. 424:79–87; doi:10.1016/j.scitotenv.2012.02.018.

15. Paulik LB, Donald CE, Smith BW, Tidwell LG, Hobbie KA, Kincl L, et al. 2015. Impact of natural gas extraction on PAH levels in ambient air. Environ. Sci. Technol.; doi:10.1021/es506095e.

16. Rabinowitz PM, Slizovskiy IB, Lamers V, Trufan SJ, Holford TR, Dziura JD, et al. 2015. Proximity to Natural Gas Wells and Reported Health Status: Results of a Household Survey in Washington County, Pennsylvania. Environmental Health Perspectives 123:21–26; doi:10.1289/ehp.1307732.

17. Saberi P, Propert KJ, Powers M, Emmett E, Green-McKenzie J. 2014. Field Survey of Health Perception and Complaints of Pennsylvania Residents in the Marcellus Shale Region. Int J Environ Res Public Health 11:6517–6527; doi:10.3390/ijerph110606517.

18. Slizovskiy, Ilya B., Conti LA, Trufan SJ, Reif JS, Lamers VT, Stowe MH, et al. 2015. Reported health conditions in animals residing near natural gas wells in southwestern Pennsylvania. Journal of Environmental Science and Health, Part A 50: 473–481.

19. Stacy SL, Brink LL, Larkin JC, Sadovsky Y, Goldstein BD, Pitt BR, et al. 2015. Perinatal Outcomes and Unconventional Natural Gas Operations in Southwest Pennsylvania. PLoS ONE 10:e0126425; doi:10.1371/journal.pone.0126425.

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21. Williams JF, Lundy JB, Chung KK, Chan RK, King BT, Renz EM, et al. 2014. Traumatic Injuries Incidental to Hydraulic Well Fracturing: A Case Series. Journal of Burn Care & Research 1; doi:10.1097/BCR.0000000000000219.

- *No indication of significant public health risks or actual adverse health outcomes (n = 4)*

1. Bloomdahl R, Abualfaraj N, Olson M, Gurian PL. 2014. Assessing worker exposure to inhaled volatile organic compounds from Marcellus Shale flowback pits. J. Nat. Gas Sci. Eng. 21:348–356; doi:10.1016/j.jngse.2014.08.018.

2. Bunch AG, Perry CS, Abraham L, Wikoff DS, Tachovsky JA, Hixon JG, et al. 2014. Evaluation of impact of shale gas operations in the Barnett Shale region on volatile organic compounds in air and potential human health risks. Science of The Total Environment 468–469:832–842; doi:10.1016/j.scitotenv.2013.08.080.

3. Ethridge S, Bredfeldt T, Sheedy K, Shirley S, Lopez G, Honeycutt M. 2015. The Barnett Shale: From problem formulation to risk management. Journal of Unconventional Oil and Gas Resources; doi:10.1016/j.juogr.2015.06.001.

4. Fryzek J, Pastula S, Jiang X, Garabrant DH. 2013. Childhood cancer incidence in Pennsylvania counties in relation to living in counties with hydraulic fracturing sites. J. Occup. Environ. Med. 55:796–801; doi:10.1097/JOM.0b013e318289ee02.

Health: All Papers (n=62)

- *Indication of potential public health risks or actual adverse health outcomes (n=58)*

1. Adgate JL, Goldstein BD, McKenzie LM. 2014. Potential Public Health Hazards, Exposures and Health Effects from Unconventional Natural Gas Development. Environ. Sci. Technol. 48:8307–8320; doi:10.1021/es404621d.

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16. Finkel M, Hays J, Law A. 2013a. The Shale Gas Boom and the Need for Rational Policy. American Journal of Public Health e1–e3; doi:10.2105/AJPH.2013.301285.

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30. Law A, Hays J, Shonkoff SB, Finkel ML. 2014. Public Health England's draft report on shale gas extraction. BMJ 348:g2728–g2728; doi:10.1136/bmj.g2728.

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32. Mackie P, Johnman C, Sim F. 2013. Hydraulic fracturing: a new public health problem 138 years in the making? Public Health 127:887–888; doi:10.1016/j.puhe.2013.09.009.

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Water Quality: Original Research (n=48)

- *Indication of potential, positive association, or actual incidence of water contamination (n=33)*

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Air Quality: Original Research (n=34)

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- *No indication of significantly elevated air pollutant emissions and/or atmospheric concentrations (n=4)*

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Appendix 6.B

Chronic Toxicity Screening Values for Well Stimulation Chemicals Prepared by California Office of Health Hazard Assessment

The letter reproduced below was sent to an author of this chapter, Thomas E. McKone, by Dr. Ken Kloc of the California Office of Environmental Health Hazard Assessment (OEHHA).

The letter also included two tables that are available online. Table 6.B-1, Chronic Hazard Screening Criteria, Inhalation Route, provides the OEHHA chronic inhalation-hazard screening criteria for use in the Senate Bill 4 (SB 4) well-stimulation-treatment (WST) hazard evaluation along with the current list of California WST additives that has been developed by the California Council on Science and Technology/Lawrence Berkeley National Laboratory (CCST/LBNL) project team. Table 6.B-2, Chronic Hazard Screening Criteria, Oral Route, provides the OEHHA chronic oral-hazard screening criteria for use in the SB 4 WST hazard evaluation along with the current list of California WST additives that has been developed by the CCST/LBNL project team. The tables have two footnotes denoted with asterisks as follows:

* Prepared by the California Office of Environmental Health Hazard Assessment, Draft, December 5, 2014

** May also contain asbestos.

Both tables are available for download at:

http://ccst.us/projects/hydraulic_fracturing_public/SB4.php

Office of Environmental Health Hazard Assessment

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Secretary for
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December 8, 2014

Thomas E. McKone
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Sent by email: temckone@lbl.gov

Dear Dr. McKone:
With this letter, I've attached a short write-up and a spreadsheet containing two sets of draft chronic hazard screening criteria for your use in the SB4 WST hazard evaluation (also included in the spreadsheet is the current list of California WST additives that has been developed by the CCST/LBNL project team).

As explained in more detail in the write-up, these screening values were compiled from a variety of dose-response information sources, including OEHHA criteria as well as toxicity values from other state and federal agency databases. In order to allow for the ranking of chemicals according to their health hazard characteristics, various unit conversions were made to produce screening values with the same units of measurement (and without any associated exposure factors). In some cases additional uncertainty factors were applied. For the inhalation exposure route, the screening values are presented in units of milligrams per cubic meter (mg/m^3). For the oral exposure route, the values are in units of milligrams per kilogram body weight per day (mg/kg-d).

These values can be used for carrying out a simple hazard ranking. For more detailed risk calculations, however, the original dose-response criteria should be used in conjunction with the appropriate risk assessment exposure metrics. It is likely that we will update these tables with new information on WST additives as the SB4 hazard evaluation progresses.

In addition, we note that OEHHA has developed health-based criteria for a variety of additional constituents that are not WST additives *per se*, but are emitted into air or wastewater from oil and gas production processes during or as a result of WST. Hazard screening values should be developed for these additional constituents for the SB4 evaluation.

Best Regards,

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Toxicity Criteria for Use in the SB4 Human Health Hazard Screening Evaluation

(Office of Environmental Health Hazard Assessment, December 2014 Draft)

Health hazard screening values for fracking fluid constituents were developed from several sources of chronic dose-response information compiled by California and federal health agencies. These values, presented in the right-most column of the accompanying spreadsheets, can be used to rank chemicals according to their human health hazard potential. For risk-based calculations and risk-ranking, the original health-based criteria, as reported in the other spreadsheet columns, should be used in combination with the appropriate risk assessment exposure metrics.

Screening Values for the Inhalation Route

For hazards related to inhalation exposures, the following sources were used to define hazard screening values:

1. OEHHA-derived Reference Exposure Levels (RELs) for non-carcinogenic toxicants, and inhalation Unit Risk values (URs) for carcinogens (OEHHA, 2014a);

2. US EPA toxicity criteria, which are similar to the OEHHA criteria in both form and method of derivation. US EPA develops Reference Concentrations (RfCs) for non- carcinogens and Unit Risk Estimates (UREs) for carcinogens[1] (US EPA, 2014a,b);

3. Agency for Toxic Substances and Disease Registry (ATSDR) Minimal Risk Levels (MRLs) for non-carcinogens, also similar to the OEHHA REL values (ATSDR, 2014).

For purposes of comparison, the available dose-response values were converted into a consistent scale of measurement, namely, a reference concentration in units of mg/m^3. Since, US EPA RfCs are already reported in these units, they did not require conversion. OEHHA RELs, which are reported in $\mu g/m^3$, were multiplied by 0.001. ATSDR MRLs, which are reported in units of parts-per-million by volume, were converted by multiplying the MRL by the molecular weight of the substance and dividing by the volume of a mole of air at 25 deg.
Celsius (24.45 liters per mole (L/mol). Dose-response values for carcinogens were converted to reference concentrations by choosing an acceptable lifetime risk level of 1-in-100,000 and calculating the air concentration that would produce this risk over 70 years of continuous exposure. In cases where a screening value for a particular chemical was available from more than one of these information sources, the most restrictive value was chosen as the hazard screening value. In this manner, hazard screening values were obtained for 29 of the fracking fluid additive chemicals.

Occupational health criteria were then used to supplement the list of chemicals for which hazard information could be developed. Permissible Exposure Limits (PELs), compiled by

[1] US EPA's Integrated Risk Information System (IRIS) was used as the primary source of information from US EPA. In some cases, additional values were based on Provisional Peer Reviewed Toxicity Values (PPRTVs) derived by US EPA's Superfund Health Risk Technical Support Center, or US EPA's Health Effects Assessment Summary Tables.

the California Occupational Safety and Health Administration (CalOSHA), Recommended Exposure Limits (NIOSH RELs), developed by the National Institute for Occupational Safety and Health (NIOSH), and time Weighted Average (TWA) concentrations, published by the American Conference of Governmental Industrial Hygienists (ACGIH), were identified for additional fracking chemicals. The occupational criteria are intended to be protective of workers for average inhalation exposures over a typical work shift throughout a working life. In cases where several values were available for a particular chemical, the most restrictive one was chosen for the screening value. In order to make the occupational values consistent with the general public criteria developed above, the following conversions were made: (1) The occupational value in mg/m^3 was adjusted to an equivalent constant 24-hour exposure level by multiplying it by the ratio of the inhalation rate for workers during an 8-hour workday to a 24-hour inhalation rate (the default value used by OEHHA is 10 m^3/20 m^3), and (2) The adjusted value was then reduced by an uncertainty factor (UF) of 30 to achieve an equivalent level of protection to the general population as provided by the non-occupational criteria.
Since occupational standards are developed for healthy working adults, an intra-species UF of 30 was used (OEHHA, 2008) to account for children and other sensitive subpopulations.

It should be noted that occupational health criteria may, in some cases, be set at relatively high levels such that reduction by a UF of 30 would not be sufficiently protective of the general public. This is particularly the case for carcinogenic substances, for which risk-based public health criteria are typical much lower than current occupational health criteria. A UF of 30 may also be insufficient for developmental and reproductive toxicants. In this preliminary draft list of screening values, OEHHA has excluded several WST additive chemicals for which occupational values exist, but for which there is some evidence that these chemicals may be carcinogenic or mutagenic. We are continuing to review the occupational values for potential carcinogenic or developmental and reproductive toxicity issues, and may revise them based on additional review. We are also reviewing the magnitude of the UFs, and may modify them in a future version of these tables.

With the addition of values based on occupational health criteria, hazard screening values were obtained for a total of 46 fracking fluid additives.

Screening Values for the Oral Route

For hazards related to oral exposures, the following sources of toxicity information were used:

1. OEHHA-derived values: Public Health Goals (PHGs) and Maximum Contaminant Levels (MCLs) for drinking water, "No Significant Risk Levels" (NSRLs), and Maximum Allowable Dose Levels (MADLs) for carcinogens and reproductive toxicants listed under Proposition 65 (OEHHA, 2014a,c);

2. US EPA: oral Reference Doses (RfDs) and cancer Slope Factors (SFs) (EPA, 2014a,b);

3. ATSDR MRLs for oral exposure (ATSDR, 2014).

For consistency, the screening values were presented in terms of milligrams per kilogram

body weight per day of oral intake (mg/kg-d). The OEHHA oral criteria (PHGs, MCLs, NSRLs, and MADLs) include either additional exposure factors or are based on a defined risk level.
Therefore to obtain comparable screening values from these criteria the appropriate dose-response data were extracted from the criteria development documents. For criteria based on

non-cancer effects, the lowest effect level in mg/kg-d and applied uncertainty factors were used to define a screening value. In cases where the OEHHA criterion was based on carcinogenic potency value, the screening level in mg/kg-d was determined by calculating a daily intake that would result in a 1-in-100,000 lifetime risk over a 70-year exposure period. The units of the US EPA RfDs and ATSDR MRLs were already in the appropriate intake units and did not require conversion. EPA cancer slope factors were converted to hazard screening intakes as above, by assuming a 1-in-100,000 acceptable risk level. Using these sources of information, oral hazard screening values were developed for 37 of the fracking fluid additives.

Reference Compounds

For several of the fracking fluid additives, a reference chemical was identified that represented the most relevant hazardous substance to which an individual would be exposed. For example, while crystalline silica in the form of sand is one of the more common minerals used in fracking, other minerals, such as kyanite, bauxite, and talc have also been used.
Depending upon their geological sources, these minerals may contain significant crystalline silica impurities (e.g., some commercial sources of bauxite contain as much as 30 percent crystalline silica, according to their material safety data sheets). Thus, the potential hazards of exposure to these minerals would be dominated by the silica impurity. In addition, it should also be noted that talc may contain asbestos which would constitute a high hazard relative to talc without asbestos impurities.

In the case of the oral hazard criteria, several of the fracking additives undergo a relatively rapid conversion to other related species in dilute aqueous solutions typical of fracking fluid formulations. For example, the boron-containing additives are expected to convert primarily to boric acid and its conjugate base in dilute aqueous solution as well as in biological fluids (Smith, 2012). The reference chemical for the various borate additives in fracking fluid is thus boric acid. Along the same lines, the reference substance for copper, zirconium, and iron containing compounds is considered to be the respective metal ion in aqueous solution.

Data Gaps

An additional datasheet is included in the Excel spreadsheet file that provides the list of constituents identified by LBNL as WST fluid additives that have been used in California. This list contains more than 250 additive names, many of which are insufficiently specified as to chemical identity, or if specified, the chemicals have little or no published toxicity information. As a concluding note, OEHHA points out that the lack of information on the identity and toxicity of these WST additives represents a potentially significant data gap for the hazard screening analysis.

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Figure 6.B-1. Letter sent to Thomas E. McKone by Ken Kloc of the California Office of Environmental Health Hazard Assessment (OEHHA).

Appendix 6.C

Chemical Hazard Ranking Matrices

Tables 6.C-1 through 4 give information on the hazard screening matrices developed for this report. The column headers have footnotes denoted with numbers; the text of the footnotes is given below.

Table 6.C-1. Hazard Screening Matrix for Acute Human Health Effects of Well Stimulation Fluid Substance.

1 GHS scores were calculated either from information derived from the literature or using information from MSDS sheets for each chemical. GHS w/o from the literature only includes oral and inhalation toxicity; 2 MSDS data used to calculated GHS also includes acute effects such as eye irritation, aspiration and skin sensitization; 3 EHMacute metrics listed as "NT" indicate that toxicity data was available but toxicity was above the range considered toxic, i.a., very low toxicity or GHS value = 6, EHMacute metrics listed as blank indicate insufficient data for chemical use and/or toxicity.

Table 6.C-2. Hazard Screening Matrix for Chronic Human Health Effects of Well Stimulation Fluid Substances.

[1] Aluminum oxide inhalation screening value is only for non-fibrous forms of aluminum oxide, and does not apply to fibrous forms because of carcinogenicity concerns; [2] Chronic screening values for aluminum oxide, titanium oxide, propargyl alcohol, glyoxal, butyl glycidyl ether, hydrogen peroxide, and ethanol are available for occupational health criteria but screening values are not provided because for each of these substances, there was an indication in the literature of possible mutagenicity or carcinogenicity such that the available occupational health criteria might not be sufficiently health protective of workers and the general population.

Table 6.C-3. Hazard Screening Matrix for Acute Human Health Effects of SCAQMD Acidization Fluid Substances.

[1] GHS scores were calculated both with and without information from MSDS sheets for each chemical. GHS w/o MSDS only includes oral and inhalation toxicity; [2]MSDS data used to calculated GHS also includes acute effects such as eye irritation, aspiration and skin sensitization; [3] EHU_{acute} metrics listed as "NT" indicate that toxicity data was available but toxicity was above the range considered toxic, i.a., very low toxicity, EHM_{acute} metrics listed as blank indicate insufficient data for chemical use and/or toxicity.

Table 6.C-4. Hazard Screening Matrix for Chronic Human Health Effects of SCAQMD Acidization Fluid Substances.

[1] Chronic screening values for aluminum oxide, titanium oxide, propargyl alcohol, glyoxal, butyl glycidyl ether, hydrogen peroxide, and ethanol are available for occupational health criteria but screening values are not provided because for each of these substances, there was an indication in the literature of possible mutagenicity or carcinogenicity such that the available occupational health criteria might not be sufficiently health protective of workers and the general population.

All tables are available for download at:

http://ccst.us/projects/hydraulic_fracturing_public/SB4.php

Appendix 6.D

Occupational Health Overview for the Oil and Gas Industry

According to the National Institute for Occupational Safety and Health (NIOSH) (http://www.cdc.gov/niosh/programs/oilgas/risks.html), the oil and gas extraction industry had an annual occupational fatality rate of 27.5 per 100,000 workers (2003-2009)—more than seven times higher than the rate for all U.S. workers. The fatality rate in 2012 was 25.2 per 100,000 (personal communication – Kyla Retzer, NIOSH, December 2014). Of the 716 fatalities that were reported during 2003-2009, the majority were either highway motor vehicle crashes (29%) or workers being struck by tools or equipment (20%). The next most common fatal events were explosions (8%), workers caught or compressed in moving machinery or tools (7%), and falls to lower levels (6%). The annual occupational fatality rate is highly variable, and correlates with the level of drilling activity. For example, the numbers of fatalities increased from 112 in 2011 to 138 in 2012, the largest number of deaths of oil and gas workers since 2003. This may be the result of an increase in the proportion of inexperienced workers, longer working hours (more overtime), and the utilization of all available rigs (older equipment with fewer safeguards).

According to the United States Bureau of Labor Statistics (U.S. BLS; 2015) over the five-year period from 2007 to 2011, there were 529 fatal injuries in the oil and gas industries. Texas recorded the highest number of fatalities (199), followed by Oklahoma (64) and Louisiana (62). Of the 112 fatalities in 2011, 70 percent were white, non-Hispanic, and 25 percent were Hispanic or Latino. Men accounted for all of these fatal work injuries in 2011. Transportation incidents led to just under half of the workplace fatalities (51 fatalities) while contact with objects and equipment accounted for 26 fatalities, and fires or explosions resulted in 12 fatal injuries. In 2011, 17 of the 112 fatal occupational injuries in the oil and gas industries were due to multiple fatality events in which at least two workers were killed in the same incident.

6.D.1. Injuries

According to the U.S. BLS, in 2011 there were an estimated 9,900 nonfatal injuries and illnesses in the North American Industry Classification System (NAICS) 211, 213111 and 213112. The total recordable rate of injuries and illnesses for support activities for oil and gas operations (NAICS 213112) was 2.1 cases per 100 full-time workers, and the rate for drilling oil and gas wells (NAICS 213111) was 3.0 cases per 100 full-time workers. This compares to a rate of 3.5 cases for all private industries combined.

The incidence rate for days-away-from-work cases (the more severe non-fatal cases) was 0.4 cases for 100 fulltime workers in NAICS 211, 0.8 per 100 fulltime workers for NAICS 213112, and 0.9 per 100 fulltime workers in NAICS 213111. The incidence rate for all private industry was 1.1 cases per 100 full-time workers. The median days away from work in NAICS 211 was 24, three times higher than the median of 8 days for all industries. Almost one-quarter of all injuries and illnesses with days away from work were fractures that may have greater severity and time away from work. Workers were frequently injured by being struck by objects (35 percent of cases), and occurred in multiple occupations such as extraction workers, metal or plastic workers, motor vehicle operators, and material movers. Workers who were injured were mostly white and non-Hispanic.

In California, injury and illness data is publically available only for mining (NAICS 21) but includes oil and gas extraction and related support activities. In 2013, the total recordable case rate for NAICS 21 was 1.6 per 100 workers, compared with an overall private sector rate of 3.5 per 100 full-time workers. The days-away-from-work cases for NAICS 21 was 0.6 cases for 100 full-time workers, compared with an overall incidence rate in private industry of 1.1 cases for 100 full-time workers.

An additional source of data on occupational injuries and illnesses in California is the Workers Compensation Information System (WCIS). The WCIS uses electronic data interchange (EDI) to collect comprehensive information from claims administrators on all work-related injuries and illnesses to help the Department of Industrial Relations oversee the state's workers' compensation system. Claims from the WCIS may be significantly higher than estimates from the BLS Survey of Occupational Illness and Injuries (Joe et al., 2014). A summary of number of claims is provided in Table 6.D-1.

Table 6.D-1. Injury and illness claims – California oil and gas extraction 2009-2013.

Year of Injury	Claims
2009	221
2010	267
2011	324
2012	312
2013	296

Source: Personal communication, Rebecca Jackson MPH, California Department of Industrial Relations Workers Compensation Information System.

The most frequent nature of injury in oil and gas operations was strain (22%) and contusion (13%) involving the finger (13%) and low back (10%). Injuries occurred most often among floor hands (18%), crew workers (12%), roustabouts (10%), and motormen (4%).

Five deaths were also reported to the WCIS as summarized in Table 6.D-2.

Table 6.D-2. Death claims – California oil and gas development 2009-2013.

Nature of injury	Cause of injury	Incident description	Occupation
Crushing	Motor vehicle	Thrown from top of vehicle hitting head on pavement	Floorhand
Myocardial infarction	Repetitive motion	Heart failure	Motorman
Crushing	Object handled by others	Employee climbing up a-leg when it came loose and fell on him	Driller
Cancer	Absorption, ingestion, inhalation, or not otherwise classified	Alleged death claim from skin cancer due to prolonged exposure to the sun	Tool pusher
Concussion	Struck or injured by	Blunt force injury to the head	Foam unit operator

Source: Personal communication, Rebecca Jackson MPH, California Department of Industrial Relations Workers Compensation Information System, December 2014.

Similar to many industries, under-reporting of injuries in oil and gas extraction may occur due to the use of safety incentives, poor safety culture, and/or concern about job loss (Witter et al., 2014). The use of newer drilling rigs appears to provide a safer working environment, especially for workers with the greatest exposure to heavy machinery, such as floormen and roughnecks (Blackley et al., 2014).

6.D.1.1. Hazardous Chemical Exposures

There have been three published peer-reviewed studies characterizing exposures to chemicals in onshore oil and gas production (Esswein et al., 2014; Verma et al., 2000; Esswein et al., 2013). Two of the studies evaluate VOCs—including benzene—and one study considered silica exposure. There are no published studies in the oil and gas industry on other chemical hazards such as diesel particulate matter, acids, or hydrogen sulfide.

Occupational exposures to benzene and total hydrocarbons (THC) were assessed in the Canadian upstream petroleum industry (conventional oil/gas, conventional gas, heavy oil processing, drilling and pipelines) (Verma et al., 2000). A total of 1,547 air samples taken by five oil companies included personal long- and short-term samples and area long-term samples. The percentage of personal long-term and area samples exceeding one part per million for benzene ranged from 0 to 0.7%, and 0 to 13% respectively. Five percent of short-term personal samples exceeded 5 parts per million (ppm) of benzene.

While there has been characterization of occupational exposures to benzene in the oil and gas industry, the data are limited on the exposures in well stimulation treatments. One study has been published by NIOSH researchers who characterize chemical exposure risks during flowback of hydraulic fracturing (Esswein et al., 2014). Full-shift exposure assessments were conducted during operations at six flowback sites across two states with 35 personal breathing zone (PBZ) samples analyzed. Benzene was identified as the primary VOC exposure hazard for workers and inhalation risks for benzene were associated with time spent working in close proximity to emission sources such as hatches on production and flowback tanks.

Opening thief hatches and gauging tanks were the two tasks identified by Esswein et al. (2014) that increased worker exposure risk for benzene. During tank gauging, 15 of the 17 samples met or exceeded the NIOSH recommended exposure limit (REL) for benzene of 0.1ppm as a full-shift time-weighted average (TWA), and 2 of the 15 met or exceeded the American Conference of Governmental Industrial Hygienists (ACIGH) threshold limit value (TLV) of 0.5ppm as a full-shift TWA. Personal breathing zone samples exceeded the NIOSH permissible exposure limits (PEL) and ACGIH TLV in certain cases when the workers performed tasks near point sources for benzene emissions such as tank headspaces and thief hatches. Other exposures may occur as a result of fugitive emissions from equipment throughout the flowback process, especially when performing maintenance. While all workers were observed wearing some degree of personal protective equipment (including flame-resistant clothing, safety glasses, hard hat, and occasional fall or hearing protection), none was wearing respirators, nor were they clean shaven, a requirement for proper respirator function.

Recommendations for reducing occupational exposure to benzene on hydraulic fracturing sites include developing alternative tank gauging procedures to limit exposure to vapors; limiting time spent in proximity to point sources; using appropriate respiratory protection; conducting worker exposure assessments to determine risks for benzene exposure; and using the most conservative NIOSH REL of 0.1ppm TWA for worker benzene exposures. Additional studies were recommended to characterize the risks associated with concomitant exposures to complex mixtures of VOCs, particularly in the context of long work hours, pre-existing health conditions, and use of tobacco, drugs, or alcohol.

Only one study has been published to date that characterizes the silica exposure of oil and gas workers on a hydraulic fracturing site. It was conducted by NIOSH researchers in the Field Effort to Assess Chemical Exposures in Oil and Gas Extraction Workers (Esswein et al., 2013). Workers were observed at eleven sites across five states, and respirable silica was measured in 111 personal breathing zone samples. At each of the eleven sites, full-shift samples exceeded occupational exposure criteria (Occupational Safety & Health Administration (OSHA) PEL, NIOSH REL, and ACGIH TLV), in some cases by factors of ten or more. While workers typically wore half-mask respirators, these may not have been sufficiently protective, as the observed respirable silica concentrations exceeded the maximum use concentrations for those types of respirators. Specific recommendations to control exposures include product substitution (when feasible), engineering controls or modifications to sand handling machinery, administrative controls, and use of personal protective equipment.

Exposure to respirable crystalline silica has been well established as an occupational health hazard for numerous industries, but limited data exist on the hazards to oil and gas workers (Esswein et al., 2013). Occupational exposures to respirable crystalline silica are associated with the development of silicosis, lung cancer, pulmonary tuberculosis, and airways diseases. These exposures may also be related to the development of autoimmune disorders, chronic renal disease, and other adverse health effects. The literature suggests that occupational deaths attributed to silicosis often go under-reported. Occupational deaths due to silicosis recorded on death certificates from 2000 to 2005 averaged 162 annually (Esswein et al., 2013). Oil and gas workers are exposed to respirable crystalline silica through sand dust and particulates created by the transportation, storage, and use of sand as a proppant in hydraulic fracturing (Esswein, 2013).

Although studies specific to the well stimulation industry are lacking, it is established that occupational exposure to diesel exhaust is causally related to lung cancer for occupational settings (IARC, 2013). It is well established that exposure to combustion products such as polycyclic aromatic hydrocarbons (PAHs) and their derivatives result in a higher health risk. This results from the small size and toxic composition of diesel particulate matter (dPM), as approximately 90% of the dPM mass is within the inhalable range (< 10 mm). dPM is considered as an occupational carcinogen by several government agencies, including the U.S. Environmental Protection Agency (EPA) and NIOSH.

Hydroflouric and hydrochloric acids (HF and HCl) are the acids used most often in matrix acidizing and acid fracturing in well development and stimulation and all acid-related activities in oil and gas wells. Both are powerful solvents that are used to dissolve rock formations and can damage mucous membrane and tissue through chemical contact, either in liquid or vapor form, leading to skin burns and ulcers, lung damage, and if absorbed through skin, can lead to death (ATSDR, 1993). HF has a low boiling point at atmospheric pressure of 67 degrees F (19 °C) and can form a dense vapor cloud that can be inhaled, causing respiratory distress and damage.

Hydrogen sulfide (H_2S), also known as “sour gas,” can be found in natural gas and can also result from anaerobic bacterial digestion of organic matter during the extraction process (Witter et al., 2014). It is a colorless irritant and asphyxiant gas with a noxious odor of “rotten eggs” that can cause symptoms ranging from mild mucous membrane irritation to permanent neurologic impairment and cardiopulmonary arrest (Gabbay, et al., 2001). Worker exposure to H_2S can occur during a variety of activities, including well servicing, tank gauging, and well-swabbing operations. Data on the frequency and extent of workplace exposures to hydrogen sulfide in the oil and gas industry are not available (Witter et al., 2014). One study of health outcomes in oil and gas workers found that workers with H_2S exposures in Alberta, Canada had an increased risk of respiratory symptoms and airway hyperactivity (Hessel et al., 1997). OSHA recommendations to reduce H_2S exposure in the natural gas industry include installing ground-level tank gages and continuous monitoring during servicing operations (Witter et al., 2014).

6.D.1.2. Physical Hazards

Physical hazards that are commonly associated with oil and gas development including well stimulation include motor vehicle related accidents, heavy machinery, exposure to radiation, elevated noise and working with chemicals that have hazardous properties such as inflammability, reactivity, and corrosivity.

Motor vehicle-related fatalities were reported as the leading cause of death for oil and gas workers from 2003-2011, accounting for 39.7% of all work-related fatalities over this period (Retzer et al., 2013; Mulloy, 2014). Workers and truck drivers travel between oil and gas wells located on rural highways, which often lack firm road shoulders, rumble strips, and pavement. Fatigue has been identified as an important risk factor in motor-vehicle accidents; workers are often on 8- or 12-hour shifts, 7-14 days in a row (CDC, 2013). A large proportion of oil and gas workers who were fatally injured in a motor vehicle accident were not wearing safety belts (Retzer, et al., 2013; CDC, 2013).

Workers from small companies, drilling contractors, and well-servicing companies—and those who have worked for their employer for 1 year or less—are at the greatest risk for motor vehicle-related fatality (Mulloy, 2014; Retzer, et al., 2013). In over half of the motor vehicle accidents, the decedent was the driver or passenger in a pickup truck (Retzer et al., 2013). While Federal Motor Carrier Safety Regulations (FMCSRs) regulate hours-of-service, limit consecutive hours of driving, and specify minimum numbers of off-duty hours, these FMCSRs do not apply to pickup trucks unless they are identified as carrying hazardous materials [49 CFR 383.91(a)] (Retzer et al., 2013).

Many of the hazards associated with using heavy tools and heavy machinery in the oil and gas industry were documented in the 1970s, and being struck by these items remains the second-most common event leading to an occupational fatality. From 2003 through 2011, 27.7% of the fatalities for oil and gas extraction workers resulted from contact with heavy machinery (CDC, 2013; Mulloy, 2014).

While data in California on radiation in flowback and produced water associated with well stimulation is unknown, an estimated 30 percent of oil and gas wells nationwide produce technologically enhanced naturally occurring radioactive materials in the flowback/produced water, with the amount of radioactive materials varying significantly by well and location (Garvey, 2014; Rich et al, 2013). The primary radioactive materials found in oil and gas-drilling wastes include radium and radon gas, both of which emit ionizing radiation in the form of alpha and beta particles, and gamma radiation (Rich et al., 2013; Garvey, 2014).

Dissolved radioactive compounds in wastewater can precipitate out of the water, building up inside pipes as radioactive “scale,” or remain dissolved in the waste water or pit sludge (Brown, 2014; Rich et al., 2013). Primary sources of technologically enhanced naturally occurring radioactive materials on well sites include pipe scale, recycling water, separation pits, shale shakers, filters, and pit sludge (Nicoll, 2012) Highest exposure rates are associated with areas on-site with the longest contact time, primarily at separators and choke manifolds, and where cleaning and decontamination operations are performed (Hamlat et al., 2001).

OSHA regulations (29CFR 1910.1096) require that workers not be exposed to a whole-body dose more than 1.25 rems in three months; if measured radiation levels are more than 25 percent of regulated levels the employer is required to supply radiation monitoring equipment to employees (Nicoll, 2012). Typical occupational radiation protection includes OSHA-regulated signage, periodic radiation surveys, safety training, occupational monitoring using film badges, personal protective equipment, and designated "clean" areas for eating and storage or personal items (Nicoll, 2012).

No comprehensive study of the radioactivity hazards and levels on well pads have been conducted or published to date (Brown, 2014; Nicoll, 2012; Hamlat et al., 2001). One study analyzing pit sludge in one site found beta particle radiation levels that exceeded regulatory guideline values by more than 800 percent (Rich et al., 2013). Technologically enhanced, naturally occurring radioactive materials wastes generated during well exploration, development, and production of oil and gas have been categorized by the EPA as "special wastes," and are currently exempt from certain federal hazardous waste regulations (Rich et al., 2013)

There are numerous sources of occupational noise exposure in the oil and gas production workplace, including diesel engines, generators, heavy equipment, mechanical brakes, draw works, radiator fans, pipe handling, and drilling (Witter et al., 2014). According to NIOSH, occupational hearing loss is the most common work-related illness in the United States. Approximately 22 million U.S. workers are exposed to hazardous noise levels at work, and an additional 9 million are exposed to ototoxic chemicals. Noise-induced hearing loss is usually the result of long-term exposure, but acoustic trauma, defined as a permanent threshold shift from a single exposure, may result from a brief exposure to extremely loud noise. From October 2010 to September 2011, OSHA inspections of the oil and gas industry resulted in two citations for noise exposure. Inspections and citations for noise exposure are limited, because companies involved in well servicing and drilling are exempt from several sections of the OSHA noise standard, including Noise-Hearing conservation 1910.95(o) (Witter et al., 2014).

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Appendix 6.E

California Division of Occupational Safety and Health (Cal/OSHA) Inspections in Oil and Gas Production[1] (January 1, 2004 – December 31, 2013)

Date of incident	**Event summary**	**Occupation**	**Incident type**	**Injury**
1/10/04	Employee Is Injured From 20 Foot Fall	N/A	Fall	Hospitalized - femur fracture
2/20/04	Employee Falls And Fractures Ankle	Mechanic	Fall	Hospitalized - ankle fracture
3/19/04	Unsecured Coring Machine Flips And Lands On Employee	Driller	Struck by	Hospitalized - multiple injuries
5/12/04	Employee Is Burned By Hot Oil During Valve Maintenance	Mechanic	Burn	Hospitalized – burns left arm, hand and both legs
5/22/04	Employee Is Injured After Being Struck By Steel Pipe	Helper	Struck by	Hospitalized - leg fracture
5/27/04	Employee Clothing And Arm Caught In Drive Shaft Of Pump	Mechanic	Caught between	Hospitalized - face and arm injuries
6/2/04	Employee Is Killed After Run Over By Forklift	Laborer	Forklift rollover	Fatality
6/28/04	Employee Is Injured When Struck By Falling Grating	Helper	Struck by	Hospitalized - face and arm injuries
7/9/04	Employee Finger Is Caught Between Trailer Hitch And Truck	Technician	Caught between	Amputation – thumb
8/31/04	Burned Oil Well Employee Is Hospitalized	Driller	Burn	Hospitalized – first and second degree burns
9/14/04	Employee Fractures Back In Fall From Elevation	N/A	Fall	Hospitalized – spinal fractures
10/28/04	Employee Injured When Struck By Boom	N/A	Struck by	Hospitalized – multiple rib fractures

Date of incident	Event summary	Occupation	Incident type	Injury
12/30/04	Employee Suffers Back Injuries In Derrick Fall	Derrickman	Fall	Hospitalized – low back injury
3/14/05	Employee Is Injured When Struck By Falling Pumping Equipment	Field hand	Struck by	Amputation - finger and thumb
3/22/05	Employee Injured When Struck By Falling Drill Rig Auger	Driller	Struck by	Hospitalized – laceration of arm
4/4/05	Employee Struck By Wrench	Well puller	Struck by	Fatality
4/8/05	One Employee Is Killed, Other Injured In Fall From Derrick	Derrickman	Fall	Fatality
4/8/05	Employee Burns Legs While Working In Well	Driller	Burn	Hospitalized – burns to lower legs
4/13/05	Electric Shock - Contact With Overhead Line Thru Boom	Crane operator	Electrical	Fatality
5/3/05	Employee’s Finger Is Crushed While Changing Pump	Well puller	Caught between	Amputation – 4th digit
5/10/05	Employee Suffers Amputation In Drilling Pipe Nip Point	Driller	Caught between	Amputation – thumb
5/12/05	Employee Is Burned At Oil Well	Well puller	Burn	Hospitalized – burns to left side
5/13/05	Employee Is Injured While Servicing Oil Well Drill Pipe	Laborer	Caught between	Hospitalized – laceration and dislocation fingers
5/19/05	Three Employees Receives Burns, One Dies, In Well Fire	Driller	Burn	Fatality
8/4/05	Employee Is Injured When Struck By Well Head	Mechanic	Struck by	Hospitalized – concussion and arm fracture
8/17/05	Employee Suffers Burns When Carburetor Backfires	Truck driver	Burn	Hospitalized – burns on face and torso
10/16/05	Employee Is Burned While Fighting Fuel Fire	Foreman	Burn	Hospitalized – burns on face and arms
10/20/05	Employee’s Skull Fractured When Struck By Falling Object	Driller	Struck by	Hospitalized – fractured skull
11/08/05	Employee’s Finger Is Amputated By Tension Plate	N/A	Caught between	Amputation – finger
12/19/05	Employee’s Leg Fractured By Flying Object	N/A	Struck by	Hospitalized – leg fracture
12/19/05	Employee Amputates Finger While Using Carbide Mill	Welder	Caught between	Amputation – finger
1/04/06	Employee Is Injured When Struck By Falling Pipe	N/A	Struck by	Hospitalized – spinal fractures
1/17/06	Employee’s Finger Is Amputated By Wire Rope	Hoist operator	Caught between	Amputation – finger

Date of incident	Event summary	Occupation	Incident type	Injury
2/13/06	Employee is injured in explosion	N/A	Explosion	Hospitalized – burns on face and hands
3/15/06	Worker Is Struck By Whipping Motion Of Unsecured Pipeline	Laborer	Struck by	Hospitalized – leg fracture
3/29/06	Employee Fractures Vertebra In Neck In Fall At Drilling Site	Laborer	Fall	Hospitalized – neck fracture
7/12/06	Employee Is Injured When Leg Is Caught Between Machine Parts	Floor hand	Struck by	Hospitalized – leg fracture
10/19/06	Employee Is Killed When Oil Rig Tips Over	Laborer	Fall	Fatality
11/25/06	Employee Is Burned In Electrical Arc Flash Repairing Breaker	Electrician	Burn	Hospitalized – flash burns
12/10/06	Employee Is Injured When Struck By Unstable Object	Motorman	Struck by	Hospitalized – multiple injuries
12/21/06	Employee's Fingers Are Crushed While Loading Pipe Onto Truck	N/A	Caught between	Amputation – fingers
12/28/06	Employee Is Killed When Struck By Counter Weight	Pumper	Struck by	Fatality
1/5/07	Employee Is Killed In Elevator Mishap On Rig	N/A	Struck by	Fatality
3/10/07	Employee's Tongue Is Amputated When Struck In Chin	N/A	Caught between	Amputation - tongue
4/28/07	Employee's Back Is Fractured In Trench Cave-In	Laborer	Struck by	Hospitalized – spine fracture
8/23/07	Employee Fractures Leg While Refurbishing Gas Well	Laborer	Caught between	Hospitalized – leg fracture and multiple injuries
10/4/07	Employee Fractures Back In Fall From Platform	Engineer	Fall	Hospitalized – lumbar fracture
10/10/07	Employee Is Injured When Struck By Lubricator	Explosives worker	Struck by	Hospitalized – pelvic fracture
10/27/07	Employee Suffers Multiple Injuries From Electric Shock	Lineman	Electrocution	Hospitalized – cardiac arrest
11/2/07	Employee Suffers Chemical Burns On Feet	Laborer	Burn	Hospitalized – burns to feet
2/28/08	Two Employees Are Injured When Struck By Block	Supervisor and rig hand	Struck by	Hospitalized - pelvic and leg fracture Amputation – ankle
3/19/08	Employee's Hand Is Struck By Object, Amputates Finger	Driller	Struck by	Amputation – finger
3/31/08	Employee Is Burned While Servicing Steam Injection Well	N/A	Burn	Hospitalized – burns to shoulder and back
4/26/08	Employee Is Injured When Pinned By Forklift	Floorhand	Caught between	Hospitalized – fractures hip and ankle

Date of incident	Event summary	Occupation	Incident type	Injury
5/6/08	Employee's Leg Is Struck By Falling Object, Later Amputated	Driller	Struck by	Amputation – leg
5/9/08	Employee Is Burned In Well Explosion	Driller	Explosion	Hospitalized – burns to leg and buttock
5/16/08	Employee Dies Of Apparent Heat-Related Illness	N/A	Heat illness	Fatality
6/6/08	Employee Is Killed When Crushed By Drill Rig	Driller	Caught between	Fatality
7/9/08	Employee Sustains Heat Illness When Exposed To Heat	Driller	Heat illness	Hospitalized – heat illness
9/4/08	Employee Is Injured When Struck By Debris	Driller	Struck by	Hospitalized – chest and arm trauma
9/16/08	Employee' Finger Is Fractured When Caught In Log Splitter	N/A	Caught between	Amputation – finger
10/4/08	Employee Is Injured In Fall Through Rat Hole	N/A	Fall	Hospitalized – multiple lacerations
10/28/08	Employee's Hand Is Injured In Winch Cable Tangle	N/A	Caught between	Amputation – finger
10/31/08	Employee Amputated Finger	N/A	Struck by	Amputation – finger
11/5/08	Employee Falls On Same Level And Fractures His Tibia And Fib	Roughneck	Fall	Hospitalized – fractures leg
11/21/08	Well Puller Is Injured When Struck By Falling Pipe	Well puller	Struck by	Hospitalized – fractures and lacerations
12/31/08	Oil Well Worker Fractures Leg Descending Stairway	N/A	Fall	Hospitalized – fracture leg
1/21/09	Oil And Gas Worker Strikes Head Against Pipes And Later Dies	Driller	Struck by	Fatality
3/2/09	Employee Amputates Finger While Working An Oil Rig	Driller	Caught between	Amputation – finger
3/12/09	Employee Slips And Falls Into Wellhead	Drill hand	Fall	Hospitalized – fractures leg
3/20/09	Employee Fractures Leg When Struck By Oil Well Hose	Machine operator	Struck by	Hospitalized – fracture leg
3/27/09	Employee' Leg Is Injured When Caught In Hoist	N/A	Caught between	Amputation - leg
6/25/09	Employee Suffers From Heat Exhaustion	Truck operator	Heat illness	Hospitalized – heat illness
7/25/09	Employee Is Killed When Crushed By Falling Pipe	N/A	Caught between	Fatality
9/4/09	Employee Is Hit By Falling Rod Elevator And Amputates Thumb	N/A	Struck by	Amputation – thumb

Date of incident	Event summary	Occupation	Incident type	Injury
11/4/09	Employee Fractures Arm When Struck By Falling Fan	N/A	Struck by	Hospitalized – fracture arm
12/7/09	Employee Steps Into Hot Liquid, Receives Burns	N/A	Burn	Hospitalized – burn to foot
1/13/10	Employee Fractures Leg While Using Monkey Wrench	N/A	Struck by	Hospitalized – fracture leg
5/26/10	Employee Dies From Head Trauma	Vehicle washer	Struck by	Fatality
8/2/10	Employee Suffers Heat Related Injuries	Floor hand	Heat illness	Hospitalized – heat illness
8/22/10	Employee amputates finger in well casing flange	Driller	Caught between	Amputation – finger
9/21/10	Employee Receives Bruises And Contusions Struck By Object	N/A	Struck by	Hospitalized – contusions
9/27/10	Plumber Is Burned By Steam From Failed Fitting	Plumber	Burn	Hospitalized – extensive burns
1/26/11	Employee Falls From Rope, Receives Injuries	Laborer	Fall	Hospitalized – multiple injuries
3/3/11	Falling Industrial Truck Parts Fracture Worker's Femur	N/A	Struck by	Hospitalized – fracture leg
3/10/11	Employee Is Burned By Hot Water And Steam Release	Truck driver	Burn	Hospitalized – burn to upper body
3/25/11	Oil Rig Worker Amputates Finger While Installing Well Flange	Mechanic	Caught between	Amputation – finger
4/6/11	Employee Finger Is Injured In Crushed Machine	Operator	Caught between	Amputation – finger
4/28/11	Employee Is Injured When Struck And Pinned By Pipe	N/A	Struck by	Hospitalized – spinal and rib fractures
5/20/11	Employee Is Struck By Unhooked Elevator And Is Paralyzed	Floorhand	Struck by	Hospitalized – multiple spinal fractures
5/28/11	Employee Fractures Finger When Struck By Joint Of Pipe	N/A	Struck by	Hospitalized – finger injuries
6/21/11	Oil Worker Dies From Burns When Falls Into Sinkhole	N/A	Fall	Fatality
7/5/11	Employee Is Crushed When Trapped By Drilling Rig	Laborer	Caught between	Hospitalized – fracture ribs and concussion
8/25/11	Employee's Finger Is Amputated By Suspended Load	N/A	Struck by	Amputation – finger
9/26/11	Employee Is Killed During Disassembly Of Drilling Rig	Driller	Caught between	Fatality
4/20/12	Employee Is Rolled Over By Ford F-250 Pick-Up Truck	N/A	Caught between	Fatality

Date of incident	Event summary	Occupation	Incident type	Injury
6/7/12	Employee's Thumb Is Crushed Under Steel Mandrel	N/A	Caught between	Hospitalized – fracture thumb
6/12/12	Employee Crushes Finger in Chain and is amputated	N/A	Caught between	Amputation – finger
7/13/12	Employee Crushes Finger In Drilling Rig	Driller	Caught between	Amputation – finger
7/16/12	Employee's Hand Is Crushed When Caught By Machinery	N/A	Caught between	Amputation – finger
12/10/12	Employee's Forehead Is Struck By Bucket And Is Fractured	Floorhand	Struck by	Hospitalized – skull fracture
1/7/13	Employee Suffers Head Concussion When Utility Truck Overturn	N/A	Struck by	Hospitalized – head injury
1/12/13	Employee's Hand Is Struck By Falling Object And Injured	N/A	Struck by	Amputation – finger

Source: (https://www.osha.gov/pls/imis/establishment.html) for NAICS 211, 213111, 213112

1. Cases where narrative of investigation is available

Appendix 6.F

Noise Pollution Associated with Well-Stimulation-Enabled Oil and Gas Development: A Review of the Literature

6.F.1. Introduction

Noise is a biological stressor that has been studied as a potential health risk for decades. Here, we review the scientific literature on environmental noise exposure to determine the potential risks unconventional oil and gas development presents to public health. The epidemiology of noise exposure has focused on both auditory and non-auditory effects. Studies have analyzed occupational noise exposure in the workplace and environmental noise from sources such as airports, road traffic, and railways. There are numerous large-scale epidemiological studies that provide evidence to link population exposure to environmental noise with adverse health outcomes.

Noise exposure modifies the function of the body's organs and systems (Munzel et al., 2014) and can be a contributing factor to the development and aggravation of conditions related to stress, (e.g., high blood pressure). Noise is classified as a nonspecific stressor that arouses both the autonomous nervous system and endocrine system (Maschke et al., 2000). It has been shown to threaten adaptable and homeostatic systems in the body (Kirschbaum and Hellhammer, 1999), which can lead to a number of poor health outcomes. For instance, noise exposure has been associated with cardiovascular diseases (Babisch, 2000; 2008; Babisch et al., 2013), birth outcomes (Gehring et al., 2014), cognitive impairment in children (Evans, et al., 1998; Evans, 1993; Lercher et al., 2002), and sleep disturbance (Hume et al., 2012; Tiesler et al., 2013). The World Health Organization (WHO) estimated that at least 1 million healthy life years (disability-adjusted life-years) are lost every year in high-income western European counties (population about 340 million people) due to environmental noise exposure (World Health Organization, 2011).

Unconventional oil and gas development is an industrial activity that sometimes occurs in close proximity to human populations. The types of noise associated with oil and gas operational activities can be complex in nature, owing to a wide variety of sources. Some of these noises are spontaneous, some are continuous, and many vary in their intensity. Further, because noise exposure involves a psychological dimension, the effects of noise from oil and gas development is highly related to the specific relationship between the operations and the exposed individual.

Most of the noises for unconventional oil and gas development are similar to those associated with conventional oil and gas development; however, some aspects can differ in important ways. For instance, drilling a horizontal well can take 4 to 5 weeks of 24 hours per day drilling to complete whereas a traditional vertical well usually takes less than a week (Nagle, 2009). Also, high volume hydraulic fracturing requires a greater volume of water and higher pressure to frac a horizontal well, resulting in more pump and fluid handling noise than traditional oil and gas development (Nagle, 2009). Some of these differences may or may not be relevant to California unconventional oil and gas development.

Our review of the existent body of health literature on noise exposure considered with decibel (dB) levels associated with oil and gas operations suggests that noise from oil and gas development presents potential adverse health outcomes.

6.F.2. Methods

This review draws upon literature pertinent to the public health implications of noise resulting from oil and gas development. There is a substantial body of science pertaining to both the auditory and non-auditory effects of noise. Nearly all of the literature on environmental noise exposure examines non-auditory health outcomes and does not consider hearing impairment. While there are no peer-reviewed studies that directly assess the health effects of noise from oil and gas development, there are some environmental impact reports/statements (EIR/EIS) and health impact assessments (HIA) that provide specific dB (unit of noise measurement) readings for oil and gas operational activities. These readings can then be matched with the body of literature that focuses on the health effects of environmental exposure to noise.

Research on the health effects of noise exposure is extensive, and the studies provided in this review do not represent an exhaustive collection of the available literature.

For this review, we adopted a search strategy comprised of the following:

- Systematic searches in PubMed (National Center for Biotechnology, U.S. National Library of Medicine) complimented by Google and Google Scholar

- Manual searches (hand-searches) of references included in review articles published within the past ten years, as well as references included in EIS/HIA and other reports directly relevant to noise and oil and gas development

For bibliographic databases, we used a combination of Medical Subject Headings (MeSH)-based and keyword strategies, which included the following combinations of terms: noise AND health; noise AND epidemiology; noise AND non-auditory health effects; noise AND industry; noise AND natural gas; noise AND oil; noise AND hypertension; noise AND traffic; noise AND sleep disturbance; noise AND cardiovascular disease; noise AND myocardial ischemia; noise AND myocardial infarction; noise AND annoyance; noise AND congenital abnormalities; noise AND birth defects; noise AND immune system; noise AND tinnitus; noise AND stress; noise AND occupational health; noise exposure; noise pollution; environmental noise pollution; environmental noise pollution AND health; noise pollution AND psychological health; construction noise AND health; chronic noise exposure.

6.F.2.1. Noise and Health

The health effects of noise can be categorized as (1) auditory (e.g., temporary and permanent deafness); (2) extra-auditory (e.g., annoyance, fatigue); (3) biological (e.g., sleep disturbances, autonomic functions (cardiovascular, endocrine)); and (4) behavioral (e.g., medication intake, psychiatric symptoms). Figure 6.F-1 shows the severity of health effects due to noise exposure and the number of people affected. The top three levels of the triangle refer to physiological outcomes and include stress indicators (e.g., stress hormones), risk factors (e.g., blood pressure), and manifest diseases (e.g., hypertension, ischaemic heart disease).

Health outcomes associated with noise exposure have been studied for some time and were originally recognized in occupational settings with hearing loss (e.g., factories, mills). However, there has been an increasing body of literature on the non-auditory health effects of environmental noise exposure. Most of these studies have analyzed associations between adverse health outcomes and noise from airports, road traffic, and railways. Some of the more commonly identified non-auditory health endpoints for noise exposure have been annoyance/perceived disturbance, sleep disturbance, and cardiovascular health (Basner et al., 2014).

Noise is a stressor that activates the sympathetic nervous and endocrine systems. Acute noise effects are not limited to high sound levels such as those found in occupational settings, but also at relatively low environmental sound levels when other activities are disturbed (e.g., sleep, concentration, etc.) (Babisch, 2002). Both the sound level of the noise (objective noise exposure) and its subjective perception can influence the impact of noise on neuroendocrine homeostasis (Munzel et al., 2014). In other words, noise exposure can lead to adverse health outcomes through direct and indirect pathways. Figure 6.F-2 depicts the relationships between exposure to noise and primary and secondary health effects. Non-physical effects of noise are mediated by psychological and psychophysiological processes (Shepherd et al., 2010).

Certain levels of noise exposure have been shown to produce both auditory and non-auditory adverse health outcomes. Here, we consider some of the more common non-auditory health outcomes associated with environmental noise exposure. These have been summarized by the European Environment Agency with corresponding thresholds (see Table 6.F-1). We briefly discuss potential mechanisms and some relevant epidemiological evidence that has considered threshold calculations and exposure-response relationships.

6.F.2.1.1. Annoyance

Annoyance appears to be one of the more common responses to environmental noise exposure among communities. Noise annoyance may produce a host of negative responses, such as feeling of anger, displeasure, anxiety, helplessness, distraction, and exhaustion (Babisch, 2002; Babisch et al., 2013; World Health Organization, 2011). It is important to keep in mind that most definitions of health encompass not only disease and infirmity, but also wellbeing (World Health Organization, 1946). Annoyance affects both the wellbeing and quality of life among populations exposed to environmental noise.

Noise sensitivity is a strong predictor of noise annoyance (Paunovié et al., 2009; Stansfeld, 1992). Sensitivity is a personality trait that varies among individuals depending on the attention one pays to a sound, its evaluation, and the emotional response. There are a number of stress-related psychosocial symptoms that have been associated with noise annoyance, such as tiredness and stomach discomfort (Öhrström et al., 2006).

It has been difficult to develop an exposure-response relationship for annoyance because it varies significantly among individuals due to noise sensitivity. Nonetheless, efforts have been made to synthesize existing data from community annoyance surveys to develop exposure-response relationships (Fidell et al., 1991; Miedema and Oudshoorn, 2001; Schultz, 1978). Annoyance is also source dependent, meaning that dBA readings alone are not always sufficient to gauge annoyance thresholds. However, for transport noises the thresholds are generally taken to be the same (42 Lden) (European Environment Agency (EEA), 2010). Still, a number of uncertainties and limitations remain, and there have been significant differences among study results.

In a 2002 position paper, the EU Commission considered dose response relationships between transportation noise and annoyance for aircraft, road traffic, and rail traffic noise (see Table 6.F-1). These data are based on a Netherlands Organization for Applied Scientific Research (TNO) report in Leiden, which compiled an archive of original datasets from studies in Europe, North America, and Australia on annoyance caused by environmental noise (European Commission, 2002).

6.F.2.1.2. Sleep Disturbance

Sleep disturbance is another common response among populations exposed to environmental noise. It is associated with significant impacts on both health and quality of life and is often considered the most severe non-auditory effect of environmental noise exposure (Muzet, 2007). Depending on the severity and frequency of sleep disturbance, noise can cause meaningful levels of sleep fragmentation and deprivation, which in turn can adversely affect both physical and mental health (Hume et al., 2012).

Sleep is a physiological state that enables us to recuperate. Noise can impact sleep in a number of ways and can have immediate effects (e.g., arousal, sleep stage changes), after-effects (e.g., drowsiness, cognitive impairment), and long-term effects (e.g., chronic sleep disturbance) (World Health Organization, 2011). The body still responds to stimuli coming from the environment during sleep. Similar to annoyance, noise sensitivity plays a significant role in sleep disturbance as well, and is influenced by both noise dependent factors (e.g., noise type, intensity, frequency) and other subjective factors (e.g., age, personality, self-estimated sensitivity) (Muzet, 2007). Some evidence also suggests a genetic component in determining noise sensitivity (Heinonen-Guzejev et al., 2005).

There has been a large amount of research on sleep and health that has led to both variable and controversial results. Because the effects of noise exposure on sleep are dependent on a number of objective and subjective factors, it has been difficult to determine a clear dose-effect relationship. However, reviews of evidence produced by epidemiological and experimental studies have been able to develop a relationship between night noise exposure and adverse health effects (see Table 6.F-3) (Ristovska and Lekaviciute, 2013). It is generally accepted that no effects on sleep tend to be observed below the level of 30 dB L_{night}, and no sufficient evidence that the biological effects that have been observed below 40 dB (A) L_{night} are harmful to health. Adverse health effects such as self-reported sleep disturbance, insomnia, and increased use of drugs are observed at levels above 40 dB (A) L_{night} and levels above 55 dB (A) present a major public health concern (see Table 6.F-3).

6.F.2.1.3. Cardiovascular Health

The generalized stress model can be used to explain reactions to noise exposure, where reactions can be caused at both a conscious and non-conscious level. Specifically, noise can trigger emotional stress reactions from perceived discomfort, as well as physiological stress from interactions between the auditory system and other regions of the central nervous system (Basner et al., 2014). Exposure to noise can increase systolic and diastolic blood pressure, create changes in heart rate, and cause the release of stress hormones (e.g., catecholamines and glucocorticoids) (Basner et al., 2014). Studies on chronic noise exposure have shown relationships with elevated blood pressure, hyptertension, and ischaemic heart disease (Munzel et al., 2014).

The epidemiology linking environmental noise exposure continues to grow. A number of studies have indicated an increased risk of high blood pressure and myocardial infarction (MI) in populations exposed to environmental noise (Babisch et al., 1993; Babisch et al., 2005; de Kluizenaar et al., 2007; Selander et al., 2009). Systematic and quantitative reviews provide evidence of a relationship between noise exposure and cardiovascular disease as well (Babisch, 2000; Babisch, 2006; Stansfeld and Matheson, 2003; van Kempen et al., 2002). Some meta-analyses have developed exposure-response curves that can be used for quantitative health impact assessments (Argalášová-Sobotová et al., 2013).

Notably, Babisch (2000) performed a numerical meta-analysis of two descriptive and five analytical studies and assessed an exposure-response relationship between environmental noise and cardiovascular risk in order to derive a common dose-effect curve (Babisch, 2008). This meta-analysis looked specifically at the association between road traffic noise levels and the risk of myocardial infarction. An increase in cardiovascular risk was found in noise levels above 60 dB(A), but not below, indicating a dose-response relationship between environmental noise and cardiovascular risk. According to a subsequent follow-up review, Babisch (2006) found that the evidence for a causal relationship between environmental noise exposure and cardiovascular risk increased after additional research was published (Babisch, 2006).

6.F.3. Vulnerable Populations

Noise exposure, like other health risks, may disproportionately impact vulnerable populations, such as children, the elderly, and the chronically ill. In addition to these groups, the literature also considers those who are hearing impaired, sensitive to noise, of a low social economic status, suffering from tinnitus, shift workers, mentally ill, and fetus or neonates (van Kamp and Davies, 2013). Overall, there is a dearth of epidemiological literature on the effects of environmental noise exposure on vulnerable groups, and so determining dose-response curves and setting specific limit values is difficult. Most of the literature has focused on environmental noise and cognitive impairment in children, so we include this in our discussion.

Children can be more or less vulnerable for certain health effects associated with noise exposure than adults. For instance, evidence suggests that they are actually less vulnerable for annoyance, but more vulnerable for cognitive effects (van Kamp and Davies, 2013). This may be due to children's sensitive development period and less developed coping mechanisms (van Kamp and Davies, 2013). Noise can impact children's cognition in a number of ways and can be detrimental to comprehension, memory, and attention/perception (Haines et al., 2001a; Haines et al., 2001b). Children who are chronically exposed to noise may have their development impaired and suffer lifelong effects on educational attainment (World Health Organization, 2011).

There have been a number of studies that have shown an association between environmental noise exposure and a negative impact on children's cognitive performance (Basner et al., 2014; Evans, 1993). For instance, Clark et al. (2006) examined exposure around three major European airports and found that aircraft noise exposure was associated with impaired reading comprehension (Clark et al., 2006). Kaltenbach et al. (2008) found an association between learning difficulties in school children and exposure to aircraft daytime noise of 50 dBA (Kaltenbach et al. 2008). Another study by Ljung et al. (2009) found that road traffic noise impaired reading speed and basic mathematics, although no effect on reading comprehension or mathematical reasoning was observed (Ljung et al., 2009).

6.F.4. Oil & Gas Operational Noise Sources and Levels

The main sources of noise from oil and natural gas operational activities can be grouped into the following categories (1) the construction phase (road and well pad construction machinery); (2) drilling and completion phases (flaring operations, drilling rig, compressor station, injection well complex); (3) production phase and (4) truck traffic (all phases). There is currently no peer-reviewed literature on the noise levels and potential health impacts from noise exposure related to oil and gas development. However, measurements and estimates for noise dB levels for oil and gas development can be found in a number of environmental impact reports. These sources are subject to a number of limitations and can vary significantly in terms of methodology and the type of oil or gas development for which the measurements were taken.

In what follows, we summarize some of the more recent and relevant findings, estimates, and predictions from environmental impacts statements, reviews, and health impact assessments. Because the reports often use different methods (e.g., source, distance, etc.), their findings are not necessarily commensurate. Furthermore, some of the data contained in these reports are industry/consultant predictions and do not necessarily reflect actual field monitoring results. Nonetheless, they are useful in providing a rough estimate of the noise levels from various sources that might be expected from the development of shale in California.

In a report prepared for the West Virginia Department of Environmental Protection, McCawley (2013) monitored noise levels associated with various stages of natural gas development from 2-4 sampling sites located 190.5 m (625 ft) from the center of five different well pads (see Table 6.F-4). McCawley (2013) provided actual monitoring results from a number of different sites and for a variety of stages in the development process, including site preparation, drilling, hydraulic fracturing, and truck traffic. This report frequently recorded noise levels above 55 dBA for natural gas operations in West Virginia (see Table 6.F-4). According to the report, noise exceeded 85 dBA a number of times from 190.5 m (625 ft) (Mccawley, 2013).

A 2006 Bureau of Land Management Environmental Impact Statement for the Jonah Infill Drilling Project in Sublette County, Wyoming suggested that drilling and well testing operations such as fracturing and flaring create noise levels up to 115 (dBA), with a noise level of 55 dBA at 1,067 m (3,500 ft; 0.66 mi) from the source (Bureau of Land Management, 2006). Noise levels from one compressor station were recorded between 58-75 dBA about 1.6 km (1 mi) and 54 dBA about 2 km (1.25 mi) to the southeast, while another station provided readings of about 65 dBA about 1.6 km (1 mi) east (Bureau of Land Management, 2006). Readings from construction activities ranged from 70 dBA to 90 dBA about 15 m (50 ft from the source. The measurements provided in this report came from sources with no residences in or immediately adjacent to the area.

In a more recent report prepared for the Wyoming Game and Fish Department, Ambrose and Florian (2014) recorded sound levels at the Pinedale Anticline Project Area (PAPA) in Wyoming. The purpose of this project was to measure the potential threat caused by this type of anthropogenic noise to greater sage grouse, a species reliant on vocal communication for its propagation. Ambrose and Florian (2014) measured sound level at 100 meters (~ 328 feet) for a number of common PAPA gas field activities. There were a number of sources that produced median sound levels at least 50 dBA at 100 meters (~328 feet), including an active drill rig (62 dBA), an injection well complex (56 dBA), a drill rig being disassembled (54 dBA), a compressor station (54 dBA), a gathering facility with generator (52 dBA) and a well pad with 21 well heads and generator (50 dBA) (Ambrose and Florian, 2014).

The New York State Department of Environmental Conservation's Revised Draft Supplemental Environmental Impact Statement On The Oil, Gas and Solution Mining Regulatory Program provided a number of estimates for noise levels associated with specific construction equipment used for well pad preparation at a number of distances (see Table 6.F-6). Composite noise levels exceeded 50 dBA for all measured distances (52 dBA at 610 m or 2,000 ft, 55 dBA at 457 or 1,500 ft, 58 dBA at 305 m or 1,000 ft, 64 dBA at 152 m or 500 ft, and 84 dBA at 15 m or 50 ft) (New York State Department of Environmental Conservation, 2011).

A 2011 Health Impact Assessment (HIA) conducted by the Colorado School of Public Health (CSPH) considered the health impacts of noise, vibration, and light pollution on health in the Battlement Mesa community in Garfield County, Colorado. CSPH obtained documentation of noise monitoring from an operator (Antero) conducted at a well pad from 8/29/10 through 9/2/10. Noise levels during drilling operations were measured below industrial noise limits at 191 m (625 ft) to the northwest and 165 m (540 ft) to the southeast (75 and 80 dBA during night and day, respectively), but they varied as much as 25 dBA and were measured at levels that the data suggest may cause health impacts (Garfield County, Colorado, 2011).

6.F.5. Well Stimulation-Enabled Oil and Gas Development in California

In response to concerns about environmental noise exposure from oil and gas activities, many cities and counties in California have enacted regulations and noise ordinances that require operators to meet specific decibel levels (e.g., Table 6.F-8a). The primary method used by local governments to promote noise and land use compatibility involve form of a nuisance noise control, zoning, or grading ordinance. Additionally, noise abatement companies offer a variety of mitigation techniques to help operators meet these levels, such as sounds walls, temporary and permanent acoustical barriers, engine exhaust silencers, acoustical equipment enclosures, sound-absorbing blankets/panels, and acoustically treated buildings (e.g., sound-dampening flooring and siding materials).

6.F.6. Discussion

When considering the health impacts of noise from a given source, the volume and intensity of the noise, whether it is prolonged and continuous, how it contrasts with the ambient noise levels, and the time of day must be taken into account. Noise levels depend not only on the source, but also on other factors such as distance from the source, air temperature, humidity, wind gradient, and the topography. A loss of 6 dB per doubling of distance is generally used to estimate sound attenuation, but this can be influenced by the aforementioned factors. The specific environment should also be taken into account, such as whether or not the dB level is indoor/outdoor or whether it is heard in a hospital, school, or other facility. The World Health Organization published guidelines for community noise in specific environments that also considers associated health effects with particular readings in a variety of environments (see Table 6.F-7).

Due to the psychological dimension of noise exposure, the relationship between the source and the exposed individual can vary dramatically. Thus, while most of the epidemiology on noise exposure involves aircraft, road traffic, and railways, the dBA associated with these sources are not necessarily transferable to oil and gas development for all health outcomes. For instance, levels of annoyance from noise exposure to oil and gas activities may be greater or less than levels of annoyance associated with road traffic, depending on the individual.

Our review of the health literature on noise exposure considered with dB levels associated with oil and gas operations suggest that noise from oil and gas development in California presents a number of potential adverse health outcomes. This finding is consistent with the few other studies and reports that consider the health impacts of noise exposure in the context of oil and gas development (Garfield County, Colorado, 2011; Mccawley, 2013; Witter et al., 2013). Although measurements and results of health studies differ, the literature indicates that oil and gas activities frequently produce noise at levels that may adversely impact human health.

To determine the potential for health outcomes, thresholds from Tables 6.F-1, 6.F-2, 6.F-3, and 6.F-7 can be compared with data from Tables 6.F-4 through 6.F-6. Generally, an increase in cardiovascular risk was found in noise levels above 60 dB(A), and many oil and gas operations produce noise at or above that sound level (see Tables 6.F-4 through 6.F-6). Other health impacts that occur at lower noise levels such as annoyance and sleep disturbance are even more probable (see Tables 6.F-2 and 6.F-3). Flaring operations are generally regarded as one of the activities with the highest noise level and BLM estimates for 0.1 mile distance (528 ft) were 66.3 dB(A). Noise levels associated with well pad preparation (trucks, construction, and sit prep) were measured around 64-65 dB on average from two different sites located 191 m (625 ft) from the center of the well pad (see Table 6.F-4) and estimated in separate environmental impact statements at around 64-65 dB from 152 m (500 ft) (see Table 6.F-6).

There are also a number of other significant noise events associated with oil and gas development that aren't accounted for in environmental impact reports. For instance, blow-down events, which vent natural gas in order to reduce pressure in the pipeline system, have generated some complaints among citizens. This review, however, could not find any dB readings associated with blow-down events.

There are a number of factors that need to be taken into account when assessing the health impacts of noise exposure, such as the distance of populations to oil and gas operations, mitigation techniques used by the industry, and differences in noise sensitivity among individuals. Not all of the dB readings and estimates contained in Tables 6.F-4 through 6.F-6 would be experienced by the majority of the population, and some readings come from locations in much closer proximity than setback distances from oil and gas operations. Nonetheless, there is strong evidence that oil and gas operations can, and often do, produce noise levels that may adversely impact population and community health in relatively close proximity to these operations.

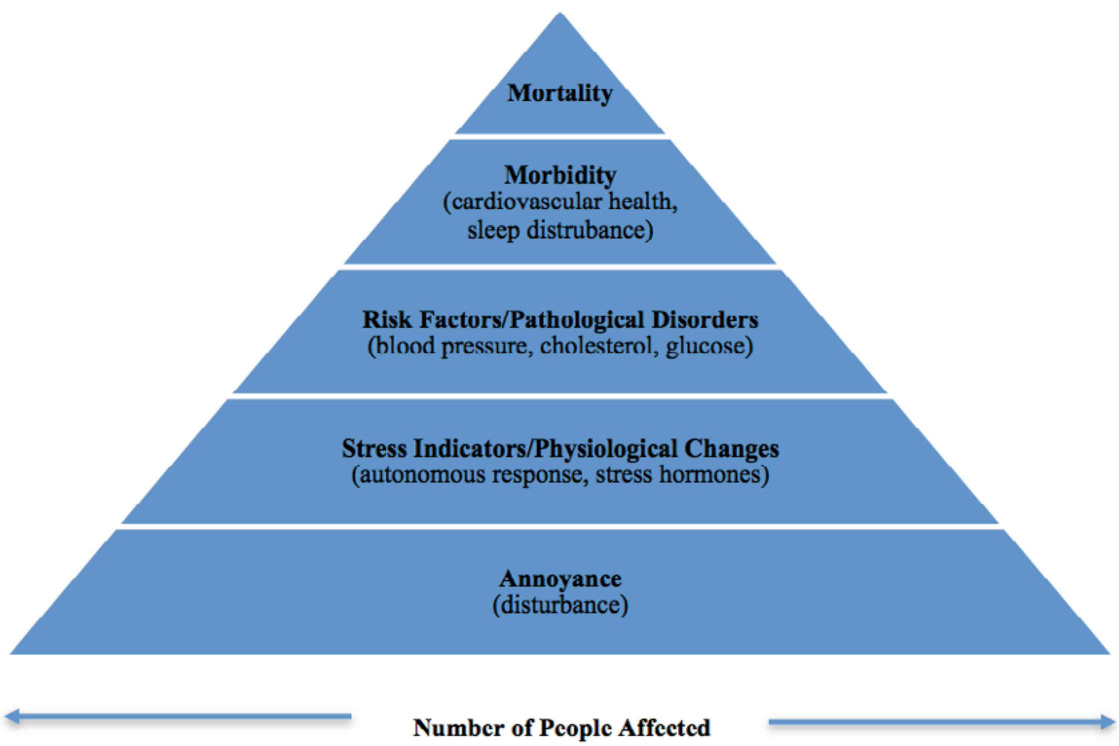

Figure 6.F-1. Severity of noise effects and number of people affected.*
** adapted from Babisch (2002) and WHO (2011) (Babisch, 2002; World Health Organization, 2011)*

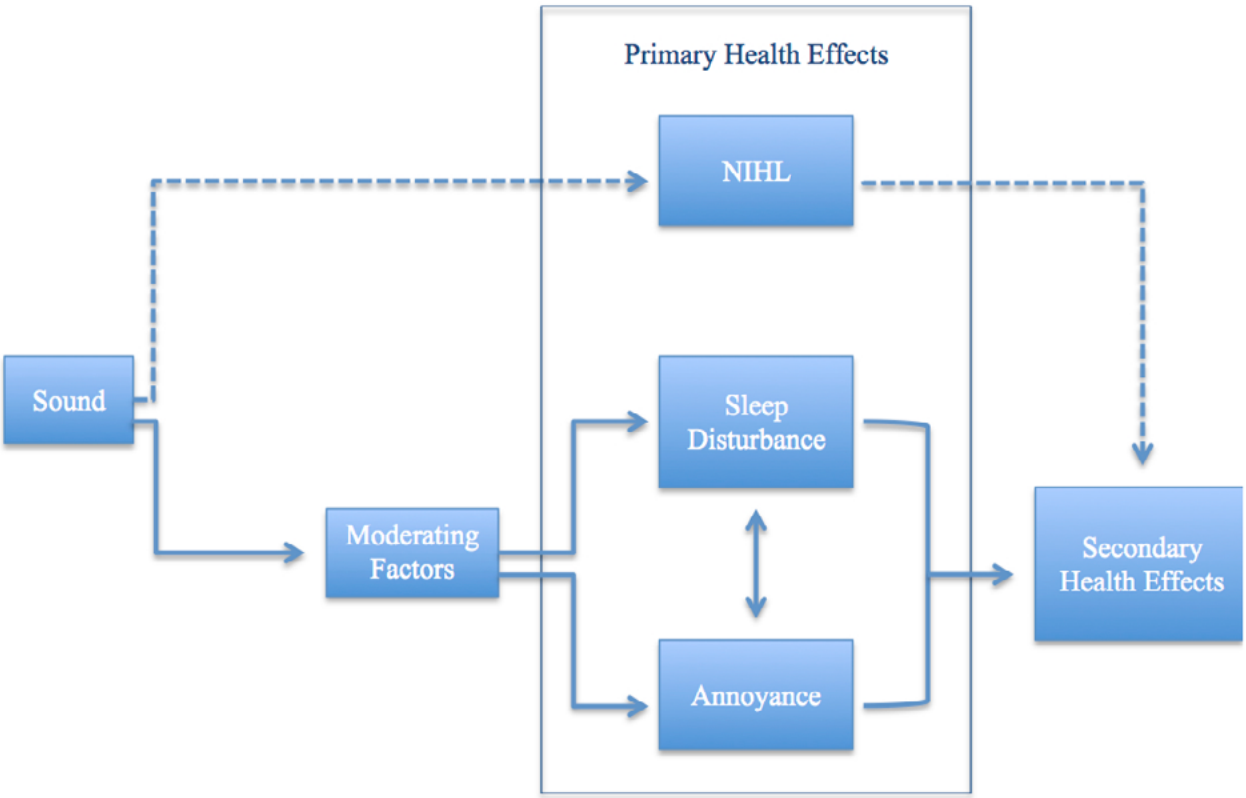

Figure 6.F-2. The impact of noise on health.*
** adapted from Figure 1 in Sheperd et al. (2010) (Shepherd et al., 2010) (model detailing how noise might compromise health). NIHL refers to Noise Induced Hearing Loss. The dashed lines indicate the physical effects of noise and the solid lines indicate the non-physical effects. Annoyance and sleep disturbance act as mediators between predisposing factors and secondary health effects, such as quality of life or cardiovascular disease.*

Table 6.F-1. Effects of noise on health and wellbeing with sufficient evidence.*

Effect	**Dimension**	**Acoustic indicator†**	**Threshold**	**Time domain**
Annoyance disturbance	Psychosocial, quality of life	L_{den}	42	Chronic
Self-reported sleep disturbance	Quality of life, somatic health	L_{night}	42	Chronic
Learning, memory	Performance	L_{eq}	50	Acute, chronic
Stress hormones	Stress indicator	L_{max} L_{eq}	N/A	Acute, chronic
Sleep (polysomnographic)	Arousal, motility, sleep quality	$L_{max, indoors}$	32	Acute, chronic
Reported awakening	Sleep	$SEL_{indoors}$	53	Acute
Reported health	Wellbeing clinical health	L_{den}	50	Chronic
Hypertension	Physiology somatic health	L_{den}	50	Chronic
Ischaemic heart diseases	Clinical health	L_{den}	60	Chronic

** adapted from Table 1.1 in European Environment Agency (EEA, 2010)*

† refer to glossary for acoustic indicator definitions

Table 6.F-2. %A and %HA at various noise exposure levels (Lden) for aircraft, road traffic, and rail traffic†.*

Lden	**Aircraft**		**Road Traffic**		**Rail Traffic**	
	%A	%HA	%A	%HA	%A	%HA
45	11	1	6	1	3	0
50	19	5	11	4	5	1
55	28	10	18	6	10	2
60	38	17	26	10	15	5
65	48	26	35	16	23	9
70	60	37	47	25	34	14
75	73	49	61	37	47	23

** adapted from Table 1 from EU position paper on dose response relationships between transportation and annoyance.*

† % A = percent annoyed; % HA = percent highly annoyed; Lden = average noise level during daytime, evening, and night-time, applying a 5 dB penalty to noise in the evening and a 10 dB penalty to noise in the night (10 lg [(12/24).10LD/10 + (4/24).10(LE+5)/10 + (8/24).10(LN+10)/10]).

Table 6.F-3. WHO definitions for the effects of different levels of night noise on the population's health.*

Average night noise level over a year $L_{night,outside}$	**Health effects observed in the population**
Up to 30 dB	Although individual sensitivities and circumstances may differ, it appears that up to this level no substantial biological effects are observed. $L_{night,outside}$ of 30 dB is equivalent to the NOEL for night noise.
30 to 40 dB	A number of effects on sleep are observed from this range: body movements, awakening, self-reported sleep disturbance, arousals. The intensity of the effect depends on the nature of the source and the number of events. Vulnerable groups (for example children, the chronically ill and the elderly) are more susceptible. However, even in the worst cases the effects seem modest. $L_{night,outside}$ of 40 dB is equivalent to the LOAEL for night noise.
40 to 55 dB	Adverse health effects are observed among the exposed population. Many people have to adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
Above 55 dB	The situation is considered increasingly dangerous for public health. Adverse health effects occur frequently, a sizeable proportion of the population is highly annoyed and sleep-disturbed. There is evidence that the risk of cardiovascular disease increases.

** adapted from the WHO night noise guidelines for Europe (World Health Organization, 2009b)*

*Table 6.F-4. Collective sampling site results from natural gas well operations in West Virginia *†.*

Well Pad	**Development Stage**	**Sampling Site and Average dBA (625 foot setbacks)**				
		A	B	C	D	**Avg**
Donna Pad	Hydraulic Fracturing	49	-	60	47	**52**
Mill Wetzel Pad 2	Trucks/Construction	56	-	73	-	**65**
Mill Wetzel Pad 3	Site Preparation	58	-	69	-	**64**
Maury Pad	Hyd Frac/Flowback	-	55	-	61	**58**
Lemons Pad	Vertical Drilling	-	-	54	-	**-**

** adapted from data contained in McCawley (2013). The readings were taken at a 625-foot setback distance from the center of each well pad.*

†Key: dBA = A-weighted decibels

Table 6.F-5a. Typical noise levels near gas field operations†.*

Source	Noise Level (dBA)	Description
Flaring Operations (on-site)	97.9	Loud
Flaring Operations (0.1-mile distant)	66.3	Moderate
Flowback Separator (on-site)	63.7	Moderate
Drilling Rig (on-site)	77.5	Moderate
Drilling Rig (0.25-mile distant)	50.1	Quiet
Compressor Station (on-site)	63.8	Moderate
Compressor Station (0.25-mile distant)	39.5	Very Quiet

adapted from Figure 3.13 from the Final Environmental Impact Statement, Jonah Infill Drilling Project (Bureau of Land Management, 2006).

†Key: dBA = A-weighted decibels

Table 6.F-5b. Comparison of measure noise levels with common sounds†.*

Source	Noise Level (dBA)	Description
Normal breathing	10	Barely audible
Rustling leaves	20	
Soft whisper (at 16 feet)	30	Very quiet
Library	40	
Quiet office	50	Quiet
Normal conversation (at 3 feet)	60	
Busy traffic	70	Moderately noisy
Factory	80	
Heavy truck (at 49 feet)	90	Loud

adapted from Table 3.16 from the Final Environmental Impact Statement, Jonah Infill Drilling Project (Bureau of Land Management, 2006).

†Key: dBA = A-weighted decibels

Table 6.F-6. Estimated construction noise levels at various distances for well pad preparation†.*

Construction Equipment	**Distance in Feet/SPL (dBA)**				
	50	**500**	**1000**	**1500**	**2000**
Excavator	77	57	51	47	45
Bulldozer	78-89	58-69	52-63	48-59	46-57
Water Truck	72-88	52-68	46-62	42-58	40-56
Dump Truck	75-88	55-68	49-62	45-58	43-56
Pickup Truck	74	54	48	44	42
Crane	88	68	62	58	56
Backhoe	85	65	59	55	53
Tractor	80	60	54	50	48
Concrete Pump	82	62	56	52	50
Front End Loader	83	63	57	53	51
Road Scraper	87	67	61	57	55
Air Compressor	82	62	56	52	50
Composite Noise Level (Construction Site Avg.)	**84-85**	**64-65**	**58-59**	**55**	**52-53**

**adapted from Table 6.55 from the NYS DEC Revised Draft SGEIS 2011 (New York State Department of Environmental Conservation, 2011) and Table 3-47 from the La Plata County Oil and Gas Impact Report (La Plata County, CO, 2002). Where findings were available from both reports a range is provided. The high end of the range corresponds to the La Plata County Oil and Gas Impact Report. The NYS SGEIS only provided estimates for the first five type of equipment listed above.*

†Key: dBA = A-weighted decibels; SPL = Sound Pressure Level

Table 6.F-7. WHO guideline values for community noise in specific environments.*

Environment	**Critical health effect(s)**	**LAeq [dB]** †	**Time base [hours]**	**LAmax, fast [dB]** ††
Outdoor living area	Serious annoyance, daytime and evening Moderate annoyance, daytime and evening	55 50	16 16	- -
Dwelling, indoors Inside bedrooms	Speech intelligibility and moderate annoyance, daytime and evening Sleep disturbance, night-time	35 40	16 8	 45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
School classrooms and pre-schools, indoors	Speech intelligibility, disturbance of information extraction, message communication	35	During class	-
Preschool bedrooms, indoors	Sleep disturbance	30	Sleep time	45
School, outdoor playground	Annoyance (external source)	55	During play	-
Hospital, ward rooms	Sleep disturbance, night-time Sleep disturbance, daytime and evenings	30 30	8 16	40 -

Environment	Critical health effect(s)	LAeq [dB] †	Time base [hours]	LAmax, fast [dB] ††
Hospital, treatment rooms	Interference with rest and recovery	#1		
Industrial, commercial, shopping and traffic areas, indoors and outdoors	Hearing impairment	70	24	110
Ceremonies, festivals and entertainment events	Hearing impairment (for patrons, < 5 times/year)	100	4	110
Public addresses, indoors and outdoors	Hearing impairment	85	1	110
Music through headphones/ earphones	Hearing impairment (free-field value)	85 #2	1	110
Impulse sounds from toys, fireworks and firearms	Hearing impairment (adults) Hearing impairment (children)	- -	- -	140 #3 120 #3
Outdoors in parkland and conservation areas	Disruption of tranquility	#4		

#1: as low as possible;

#2: under headphones, adapted to free-field values;

#3: peak sound pressure (not LAmax, fast), measured 100 mm from the ear;

#4: existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low

** adapted from Table 4.1 from WHO Guidelines for Community Noise (2009) (World Health Organization, 2009a)*

† LAeq[dB] = lowest decibel level, measured as the average of continuous noise level, where noisy events have a significant influence

†† LAmax, fast [dB] = maximum decibel level, measured as the maximum A-weighted level of a single sound

Table 6.F-8a. State of California Model Noise Ordinance Recommended Standards*.

Receiving Land Use	Duration of Intrusive Sound	Daytime Standard (7 a.m. – 10 p.m.)	Nighttime Standard (10 p.m. – 7 a.m.)
One & Two Family Residential	30-60 min/hour	55	45
	15-30 min/hour	60	50
	5-15 min/hour	65	55
	1-5 min/hour	70	60
	< 1 min/hour	75	65

** these recommended standards are not adopted State standards and are merely guidelines intended to assist cities and counties develop noise standards for their jurisdictions. They are based on the California Department of Health/ California Office of Noise Control Model Community Noise Ordinance of 1977.*

Table 6.F-8b. City of Hermosa Beach Noise Level Standards†.

Cumulative Number of Minutes In Any 1 Hour Time Period	Noise Level Standards, dBA*	
	Daytime (8 a.m. – 7 p.m.)	Nighttime (7 p.m. – 8 a.m.)
30	50	45
15	55	50
5	60	55
1	65	60
0	70	65

† adapted from City of Hermosa Environmental Impact Report for the Proposed E&B Drilling and Oil Production Project (City of Hermosa Beach, 2014) and based on Article VI of the City of Hermosa Beach Oil Code (established by Ordinance No. 85-803 and added to the Municipal Code as Chapter 21A), defining noise level standards for oil drilling and re-drilling operations
** measured at property lines*

Table 6.F-9. Equipment noise levels for drilling and production.*

Work Stage	Equipment	Sound Power Level† (dBA)
Drilling (30 month scheduled duration)	Hydraulic Power Unit	110.7
	Mud Pump	105.4
	Drill Rig	93.3
	Shaker	75.3
	Pipe Handling (Quiet Mode)	107.5
Production (at rate of 800 barrels per day)	Well Pumps	97.7
	Produced Oil Pump	77.7
	Produced Water Pump	86.7
	Shipping Pump	92.8
	Water Booster Pump	86.7
	Water Injection Pumps (2)	102.8
	Vapor Recovery Compressor	88.6
	Vapor Recovery Unit Cooler	90.2
	1st Stage Compressor (2)	96.2
	2nd Stage Compressor (2)	96.2
	Compressor Cooler	102.0
	Amine Cooler	102.1
	DEA Charge Pump	77.7
	Regenerator Reflux Pump	77.7
	Chiller	85.0
	Glycol Regenerator	92.4
	Micro-turbines (5)	92.9
	Variable Frequency Drives	83.3

** adapted from Hermosa Beach E&B Oil Drilling and Production Project (Final Environmental Impact Report) (City of Hermosa Beach, 2014). Measurements reflect the source noise level and do not include noise control design features, where proposed, such as acoustical barriers, etc.*

Table 6.F-10. Glossary of terms.

Sound	Rapid fluctuations in air pressure processed by the human auditory system
Noise	Unwanted sound that may be disturbing
Decibel, dB	A unit for measuring sound pressure level or the intensity of sound. It is equal to 10 times the logarithm to the base 10 of the ratio of the measure sound pressure squared to a reference pressure, which is 20 micropascals.
dBA	A-weighted decibel. This is a frequency dependent correction that is applied to a measured to mimic the varying sensitivity of the ear to sound for different frequencies. The A-weighted decibel scale (dBA) is most common and correlates well with human perceptions of the annoying aspects of noise.
Sound Pressure Level	The magnitude of the sound. It is a ratio between the actual sound pressure and a fixed reference pressure. Sound pressure level takes into account surroundings.
Sound Power Level	The amount of acoustical energy produced by a sound source. Sound power level does not take into account a specific object's surroundings.
Frequency	The rate at which sound pressure changes
Pure Tone	Noise in which a single frequency stands out
Ambient noise level	Noise level before a noise of concern is added
L_{max}	Maximum sound pressure occurring in an interval
SEL	Sound exposure level (sound pressure level over an interval normalized to 1 second)
L_{day}	Average sound pressure level over 1 day
L_{night}	Average sound pressure level over 1 night
L_{24h}	Average sound pressure level of a whole day
L_{dn}	Average sound pressure level of a whole day (compound indicator where the night value gets a penalty of 10 dB)
L_{den}	Average sound pressure level over all days, evenings, and night in a year (compound indicator where evening gets penalty of 5 dB and night 10 dB)
L_{eq}	Equivalent continuous sound pressure level

6.F.7. References

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