

THESIS

COMMUNITY NOISE EXPOSURE FROM OIL AND GAS DRILLING OPERATIONS

Submitted by

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## ABSTRACT

### COMMUNITY NOISE EXPOSURE FROM NEARBY OIL AND GAS DRILLING OPERATIONS

Due to an increase in oil and gas (O&G) extraction activity near residential areas in Colorado, many community members may be at a higher risk of harmful noise exposure. The Colorado Energy and Carbon Management Commission (ECMC) has identified multiple sources of high-volume sound associated with O&G site preparation, drilling, and fracking including engines, mud circulation systems, rig top drives, and ancillary equipment. Acute and chronic exposure to elevated levels of environmental noise has been found to cause adverse health effects such as sleep disturbance, annoyance, cognitive performance decline, heart disease, and self-reported impact to overall wellbeing. While there is existing literature quantifying the extent and consequences of community noise exposure from other environmental sources (e.g., air traffic, road traffic, and railway transportation) there are limited published studies on noise exposure from proximity to O&G extraction sites. Researchers suggest, however, that oil and gas extraction operations may be producing harmful levels of noise. It also appears that the noise produced includes substantial low-frequency noise which can make it difficult to control. In addition, low frequency noise exposure may exacerbate the health effects associated with general noise exposure. To assess community noise exposure, a comprehensive environmental noise survey was performed at a new O&G extraction site in Northern Colorado during the drilling phase of operations. The research team collected noise emission data 24 hours per day over two months that included 1-second measurements of sound-pressure level, 1/3 octave bands, and triggered audio recordings. Based on the noise-monitoring results, it was determined that the noise levels from the drilling activities exceeded ECMC published noise exposure limits and noise thresholds related to adverse health effects. Distance was found to be a crucial factor in establishing compliance and reducing exposure, especially

for low frequency noise. Increasing the O&G operations setback from community residences to 2,000 feet, as compared to the previous setback distance of 350 feet, was estimated to reduce noise levels by 15dB, which, while a substantial improvement, was not entirely sufficient to eliminate the risk of health effects or establish compliance with low frequency noise limits. High noise levels were found to occur on days that the rig's hoisting mechanism and/or drill were likely in use.

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# 1. Introduction

Oil and gas extraction is a rapidly growing industry in Colorado, which has recently become one of the top producing states in the country. Tens of thousands of wells have been drilled and hundreds more are drilled every year. Due to this expansion and the growing population of the State, the number of residents living near extraction sites has been steadily rising. Whenever an industrial process encroaches on residential areas, it is only natural to wonder whether the health and wellbeing of these communities may be impacted. One concern, in particular, related to oil and gas (O&G) extraction is noise; the equipment and machinery are loud and often operate day and night. That the health of communities living near these operations is impacted is preliminarily supported by the vast number of noise complaints received by the Colorado Energy and Carbon Management Commission (ECMC) from residents living near an active well. It is also known that both acute and chronic exposure to environmental noise can and do cause adverse health effects. Unfortunately, there is little published research quantifying the degree of noise exposure from O&G activity and no research relating measured noise levels to scientifically verified noise thresholds associated with adverse health effects.

To further characterize O&G extraction noise and to help better inform the public about the risks of living near one of these sites, researchers in this study performed a comprehensive environmental noise survey near an O&G extraction site in northern Colorado. This survey was part of a larger ongoing O&G noise project and included noise monitoring during the drilling phase of operations only. Noise monitoring was performed 24 hours per day for two

consecutive months and measurements included sound pressure levels, spectral (octave band) information, low frequency noise, and audio recordings. These data were used to quantify and characterize the noise associated with drilling activities, to assess compliance with ECOM O&G extraction noise limits, and to identify the noise levels that could increase the risk of health impacts for nearby residents.

## 2. Literature Review

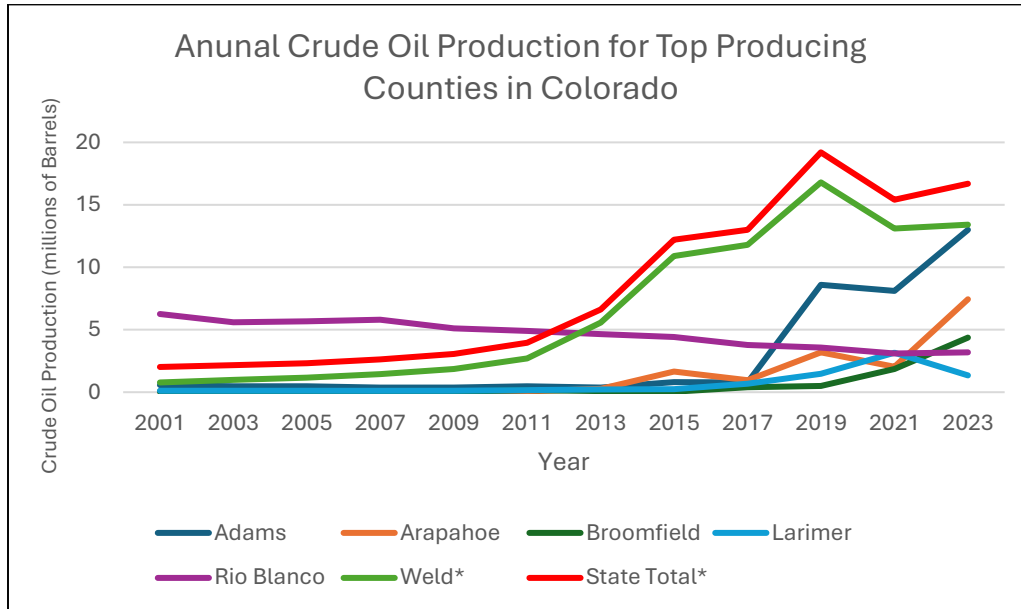
### 2.1 Oil and Gas in Colorado

Colorado is one of the largest O&G producing states in the United States, accounting for nearly 4% of both total U.S. crude oil and total U.S. natural gas output in 2022 [1]. According to the U.S. Energy Information Administration (EIA), Colorado ranked within the top six oil producers from 2018 to 2023, finishing at number four in 2023 with nearly 166 million barrels of crude oil (BBLs) [2]. The high volume of oil and gas (O&G) extraction is due primarily to the presence two large petroleum basins located within the state, the Denver-Julesburg Basin in the Northeast and, to a lesser extent, the Piceance Basin in the Western mountain region [1]. At the end of 2021, Colorado had around 5% of the nation's proved crude oil reserves available for extraction and the nation's eighth-largest oil reserve [3], [4].

Oil and gas extraction operations are steadily increasing in Colorado. To date there have been nearly 123,000 wells drilled including nearly 35,000 producing wells, with over 4,000 new wells drilled since 2020 [5]. Additionally, over the past year, the Colorado Energy and Carbon Management Commission (ECMC – formerly the Colorado Oil and Gas Conservation Committee, COGCC) approved 949 new Permits to Drill with an additional 31 permits pending and 19 under review [6].

In 2023 the top five oil producing counties in Colorado were Weld, Adams, Arapahoe, Broomfield, Rio Blanco and Larimer, making up 80.2%, 7.78%, 4.46%, 2.62%, 1.91% and 0.81% of the State's total crude oil production, respectively [2]. Historic production data collected from the ECMC website for the past 22 years (2001 – 2023) shows a dramatic increase in production in most of these counties, with Weld, Adams, Arapahoe, Broomfield, and Larimer counties experiencing between a 1,100% and 9,800% increase in oil production. The lone exception was Rio Blanco county, which experienced a 49% reduction during that period [2]. Weld County alone accounted for over eight of every ten barrels of oil produced

in Colorado in 2023 due to it being home of the Wattenberg Field, which ranks in the top ten oil and natural gas fields in the U.S. based on proved reserves [7]. Oil and gas production took a slight dip around 2020 due to the economic impacts of the Covid-19 pandemic but began to rise again by 2023 [8]. Overall, between 2001 and 2023, Colorado increased its crude oil production by over 720%. Oil production for the top five producing counties during this period is displayed in Figure 1.



**Figure 1: Annual Crude Oil Production for Top Five Producing Counties in CO, 2001-2023**

\*Weld County and State Total production displayed in 10-millions of barrels for scaling purposes

## 2.2 Population Expansion and Encroachment of Oil and Gas Operations

During the same period of expansion of O&G operations in Colorado, the state also experienced steady population growth, with all five counties listed experiencing between a 14% and 87% increase during the 2001-2023 period [9], [10]. Weld county, which was responsible for the vast majority of Colorado's oil and gas production, experienced the largest population growth (87%), growing from 192,00 to 360,000 people [2], [9], [11]. Arapahoe County, which boasted largest increase in oil production (9,820% ), also had the largest total population out of the five by 2023 housing nearly 700,00 residents. Many other

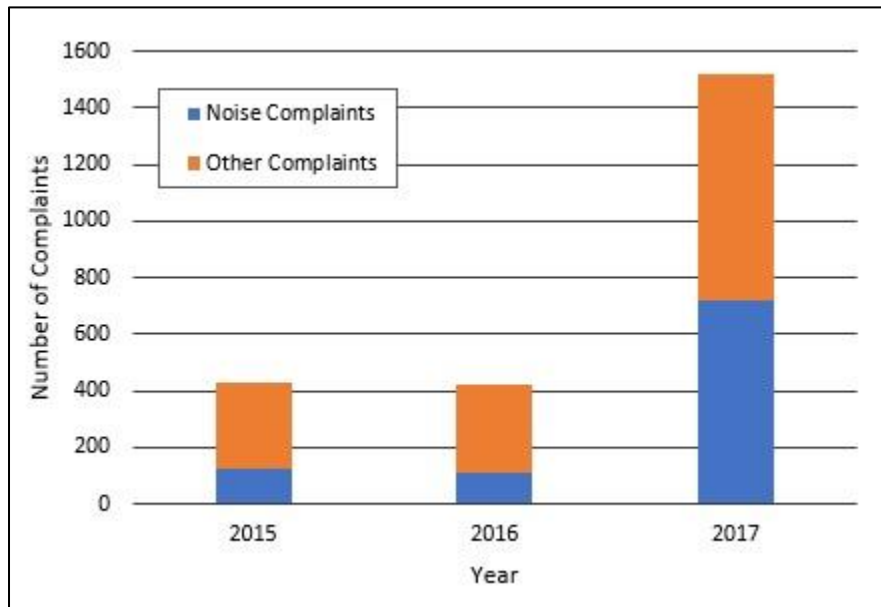
counties experienced similar growth as the overall population of Colorado grew from 4.43 to 5.88 million people between 2001 and 2023.

As both the number of citizens and the O&G industry have grown and expanded, extraction and production activities have been ever encroaching on residential areas across the state. In 2013, the (at the time) COGCC published a list of “Setback Rules” which placed restrictions on O&G facilities, drilling, and well-servicing operation locations [12]. Several exclusion zones (referred to as “setbacks”) prohibited O&G activity within 500 feet of residential structures, 1,000 feet of high-occupancy structures (buildings serving over 50 people) and childcare structures, and 350 feet from designated outside activity areas (such as a park). It should be noted that each of these setbacks had exceptions that could be petitioned for by new permit-seekers during the application process and there was no existing research at the time related to the health effects of living near O&G operations used to justify these setback distances.

There are few data quantifying the extent to which Colorado residents are living in proximity to O&G extraction operations. In 2012, however, the Wall Street Journal estimated that at least 340,000 Coloradans were living within one mile of a well drilled after the year 2000 [13]. By 2016, a study found that at least 378,000 people in Colorado lived within one mile of a well and that this population, on average, was growing faster than the overall population[14].

An additional metric by which the impact of encroaching O&G activity can be assessed is the number and type of complaints lodged by citizens through the ECMC’s website. Between 2001 and 2013, the number of annual complaints averaged around 220/year and included concerns related to noise, odors, environmental hazards, improper notifications, oil tank leaks, and permit violations, among others [15]. From 2013 to 2023, however, there was a dramatic increase in complaints, averaging over 560/year with a spike of over 1,500 complaints in 2017 alone [15], [16]. A Denver Post analysis during that year found that the predominant cause of the huge rise in complaints was due specifically to an increase in noise

complaints, with more than one noise complaint per day recorded at the time of the article’s release in July [17]. September of the same year saw 215 complaints filed, with 54% of them being related to noise, nearly four noise complaints per day [15]. By the close of the year, over 720 noise complaints related to O&G operations had been lodged, 47% of the total annual complaints, compared to just 29% of the total in 2015. This rise in complaints is visible in Figure 2.



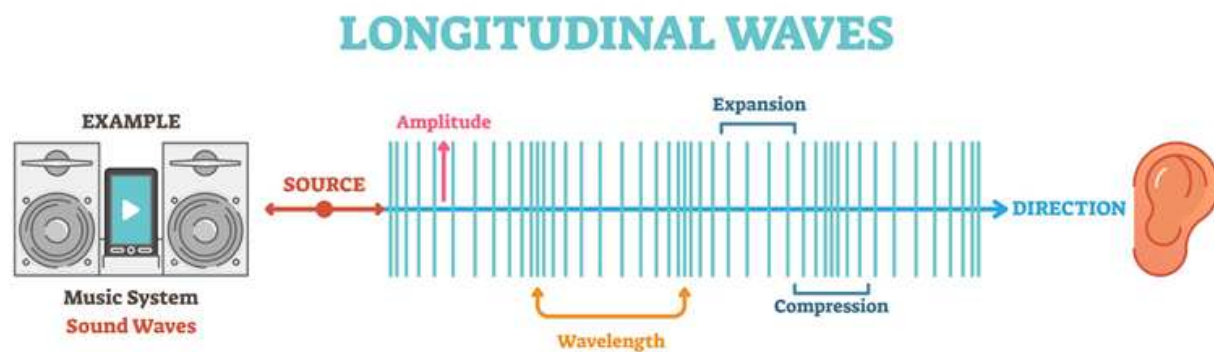
**Figure 2: ECMC Received Noise Complaints vs Total Complaints 2015-2017**  
(<https://www.noisemonitoringservices.com/a-guide-to-colorados-cogcc-oil-and-gas-noise-standards>)

Grievances included descriptions of jet-engine-like noises, loud banging, rumbling, shaking, and windows and houses vibrating. Complainants reported unrelenting noise at all hours of the day and night resulting in days or weeks of sleep loss and subjective experiences of overall degradation of quality of life [15], [17].

## 2.3 Quantifying Sound

### 2.3.1 What is Sound?

Encyclopedia Britannica defines sound as “a mechanical disturbance from a state of equilibrium that propagates through an elastic material medium” [18]. In essence, sound waves are the result of vibrations in a medium (i.e., gasses, liquids, and solids) and travel in “longitudinal waves,” consisting of alternating regions of high and low pressure created by regular intervals of compression and expansion of the molecules that make up that medium. A representation of a longitudinal wave is seen in Figure 3.



**Figure 3: Longitudinal Waves** (<https://www.inspiritvr.com/longitudinal-waves-study-guide/>)

The distance between any two consecutive points of equal compression or expansion in the wave is called the wavelength, and the number of wavelengths that pass a given point in space per second is called its *frequency* and is measured in Hertz (Hz) with 1Hz being one wavelength per second. Higher frequency sounds are perceived as higher pitched. The “height,” or *amplitude*, of the wave is a measure of the magnitude of the pressure change in the compression and expansion regions and corresponds to perceived loudness of the sound. This “sound pressure level” (SPL) is measured in decibels and is the most important measure of the risk the sound poses to human hearing and health.

### 2.3.2 Noise vs Sound

Sound and noise are technically the same physical phenomena, in that they are vibrations through the air that can be detected with the ears. The difference is that noise is considered *unwanted* or *unpleasant*

sound that causes a disturbance. Sound is an objective form of vibrational energy and is measurable and quantifiable. Noise is the subjective classification of sound as disruptive or unpleasant by those exposed to it and does not have a universal, objective basis for measurement.

### 2.3.3 Decibel Weighting

Raw noise data are an objective record of the decibel levels within each frequency range during the evaluation period and is measured in Z-weighted (or “unweighted”) decibels (dBZ or, more commonly, just dB). Since noise attenuation methods are frequency dependent, this is often useful for determining appropriate noise controls. Noise evaluations and their metrics are typically performed using and presented in A-weighted decibels (dBA). A-weighting is an adjustment of the raw noise data that is meant to conform to a notional human hearing response by reducing the contribution of low- and high-frequency noise [19]. For this reason, most noise regulations and ordinances set their limits in dBA. To evaluate low frequency noise, a weighting scale called C-Weighting (dBC), which gives much more emphasis to lower frequencies than the A-weighting scale, is used preferentially [20]

## 2.4 Noise Regulations and Guidelines

### 2.4.1 ECMC

The ECMC is the governing body responsible, in part, for regulating the development and production of O&G in Colorado. In its Operations and Reporting Rule (400 Series), rule 423 provides the maximum legally allowed noise levels with which all O&G operations, facilities, and activities must comply. Noise limits are defined for the “daytime” period (7:00 am to the next 7:00 pm) and “nighttime” period (7:00 pm to the next 7:00 am) and vary by land zone type. For residential, agricultural, and rural areas, the zones in question in this report, O&G noise may not exceed 55 dBA during the day and 50 dBA during the night. During the daytime period only, these limits may be exceeded by up to 10 dBA for no more than 15 minutes in any one-hour period. The rule also limits low frequency noise (LFN), measured using C-weighted decibels, to no more than 65 dBC during both the day- and nighttime periods. In 2021, the

ECMC updated its rules relating to noise monitoring and compliance measurements. Under the 2021 rules, if any residential structure exists within 2,000 feet of a well pad, compliance must be established according to the following:

- All dBA compliance measurements must be taken a minimum distance of 350 feet from the noise source but no closer than 25 feet from the exterior wall of the nearest residential structure.
- All dBC compliance measurements must be taken 25 feet from the exterior wall of the nearest residence or occupied structure [21].

For the remainder of this thesis, the 2,000-foot radius will be referred to as the “new setback” and the 350’ will be referred to as the “old setback”. It should be noted that the “new setback” is not a legally enforceable distance which O&G companies must maintain from a structure and does not replace the minimum 350’ setback distance listed in the original rules. However, since it is the legal distance from a residential structure inside which noise monitoring is required and compliance must be established, it is assumed to be the distance *outside* which oil and gas noise is expected to have negligible impact on residents.

#### 2.4.2 WHO

The World Health Organization (WHO) has published general guidelines for acceptable levels of community noise for daytime, evening, and nighttime [22], [23]. For outdoor living areas during the daytime and evening, the WHO recommends a 16-hour equivalent continuous sound pressure level ( $L_{eq}$ ) of no more than 55 dBA or 50 dBA to avoid serious or moderate levels of annoyance, respectively. The WHO places the ideal nighttime 8-hour  $L_{eq}$  to avoid any adverse health effects in the community at less than or equal to 30 dBA, with limited effects observed up to 40 dBA. Night noise levels over 55d BA are considered dangerous to public health (see section 1.6.2.1, *Sleep Disturbances*, for more information).

### 2.4.3 EPA

The U.S. Environmental Protection Agency (EPA) issued a protective-noise-levels guidance document which lists Day-Night Average Sound Levels (LDN) (taken over 1 year), as well as 24-hour  $L_{eq}$ , that protect public health with a margin of safety [24]. For all areas, a 24-hour  $L_{eq}$  of less than 70 dBA, averaging over one year, is recommended to avoid hearing damage. Both an LDN and an  $L_{eq}$  of less than 55 dBA is recommended for overall community health “outdoors in residential areas and farms and other outdoor areas where people spend widely varying amounts of time and other places in which quiet is a basis for use” [24].

## 2.5 Oil and Gas Drilling Noise

Extracting crude oil and natural gas from the ground is a complex and lengthy process. The terms “oil” and “natural gas” are descriptions of mixtures of hydrocarbons found naturally within the Earth’s crust. These compounds formed over millions of years as organic matter that had once settled on ancient seabeds and became compressed between Earth’s extremely hot mantle, below, and billions of tons of sediment that eventually settled on top of it, above. Different combinations of extreme heat and pressures, combined with an anoxic environment, created various combinations of hydrocarbons that ended up trapped inside the sediment deep below the surface [25]. Some of these seabeds eventually dried, exposing the rock and forming what is called a sedimentary basin, and are the primary locations of oil and gas extraction operations today [25], [26].

Extracting the hydrocarbons from the rock formations, from an average depth between 5,000 and 7,000 feet, can largely be categorized into four steps [27], [28].

1. **Site Preparation** - All above ground infrastructure and equipment are constructed, installed and/or moved to the drilling site. This can include roads, well pads and noise barriers.

2. **Drilling** - The drill is trucked in and assembled. A hole is first drilled to 100' below the deepest known aquifer and a steel casing is cemented into the drill hole to prevent groundwater contamination. The remaining distance to the oil/gas-containing shale rock is then drilled, including horizontal drilling to access multiple oil/gas reserves from one well pad. The drill is removed, and more steel casing is cemented in its place. Shaped explosives are used to perforate certain points of the casing, connecting the well to the surrounding, oil-containing rock.
3. **Hydraulic Fracturing (Fracking)** – A mixture of water, sand, and other chemicals is pumped at high pressure into the drill hole. This mixture travels through the perforations and into the shale rock, generating extensive thin cracking throughout the rock and releasing the trapped oil/gas.
4. **Production/Flowback** - The displaced oil and gas flow up the pipe and are collected at the surface. When fracking is complete, the fracking fluid is recovered from the well in a process called flowback, to be reused in future extraction operations.

Due to the extreme and difficult nature of the task, each of the phases of O&G extraction involves equipment and processes that generate noise. The focus of this thesis, however, is on noise related to the drilling phase, only.

The ECMC has identified several sources of loud noise resulting from drilling operations including truck traffic, drill rig engines, exhaust and cooling fans, mud pumps, shale shakers (which remove large solids from the drilling lubricant fluid), rig top drives, and ancillary equipment such as blowers and generators for light towers [28]. While noise complaints are common and noise sources well understood, research quantifying community noise exposure due to drilling operations is limited. The results of these studies are summarized below.

In a 2019 study, researchers performed noise monitoring at a multi-well pad in Weld County, CO over the course of three months during the drilling phase. The operation used an electric drill and had a 9.8-meter sound wall in place around the entire pad. Researchers collected continuous, 24-hour samples in both dBA and dBC at various distances, in one-minute intervals, for the duration of the monitoring period. One-minute Leqs were extrapolated from the data. The average 1-minute Leqs were found to range from 49.0 dBA to 57.3 dBA at 868 feet and 737 feet, respectively and 66.7 dBC to 77.1 dBC at 868 feet and 737 feet, respectively [29].

In 2017, Colorado State University researchers performed noise monitoring at 23 O&G extraction sites across northern Colorado during the drilling phase. Noise data were collected at a distance of 350 feet from the well pad center both with and without a sound wall in place. Multiple 20-to-45-minute samples were collected at each site in both dBA and dBC and average five second and 15-minute Leqs were extracted from those samples. The mean 5-seconds Leqs with and without the sound wall in place were 65 dBA / 78 dBC and 57 dBA / 73 dBC, respectively. The mean 15-minute Leqs with and without the sound wall in place were 65 dBA / 79 dBC and 59 dBA / 73 dBC, respectively [30].

In a 2006 study commissioned by the city of Fort Worth, Texas, researchers performed noise monitoring at four well pads during the drilling phase. Leq measurements were collected in dBA, only, from four different directions surrounding the well pad at distances ranging from 100 to 800 feet. The loudest decibel readings from the four directions at a given distance were between 84 dBA and 87 dBA, 75 dBA and 79 dBA, 70 dBA and 74 dBA, and 51 dBA and 54 dBA at 100 feet, 200 feet, 300 feet and 800 feet respectively [31].

Researchers in a 2013 study sought to assess the effectiveness of imposing a statewide 625-foot setback rule for O&G activity in West Virginia. As a small part of a much broader project, Leq measurements were taken in dBA only at a distance of 625 feet from the center of seven well pads across West Virginia

during the drilling phase for 24-hour periods at each site. Researchers reported an average Leq from the seven sites of 54 dBA over 24hours [32].

Finally, in 2017 researchers performed noise monitoring at a multi-well drill pad over the course of two months in Garfield County, CO. The drilling operation used an electric drill and had a 32-foot-tall sound wall around the entire pad. Leq measurements were recorded in one-minute intervals in dBA only over 24-hour periods. Measurements were collected at four locations whose distances from the center of the well pad ranged from 1,050 to 1,805 feet; the results, however, only list the sound levels by location description and do not include the respective distances. Two separate measurements were taken at two of the four locations for a total of six 24-hour Leqs. The resulting Leqs were 54.6 dBA, 54.2 dBA, 60.2 dBA, 51.5 dBA, 57.8 dBA, and 53.5 dBA. [33]

The noise data resulting from the five studies cited above suggest that O&G operations can generate noise levels that are not in compliance with ECMC regulations, with dBA levels reported that are higher than permissible, at distances further away than the required measurement point. In all the studies that measured in C-weighted decibels, researchers found that LFN both exceeded the ECMC 65 dBC limit and was also consistently higher than the corresponding dBA results. The researchers in the 2017 sound wall study [30] also showed an overall lesser reduction in dBC levels than in the corresponding dBA levels when a sound wall was in use. Taken together, LFN appears to not only be characteristic of O&G drilling noise, but less able to be controlled than higher frequencies. Beyond the question of compliance, the remaining question, then, is if the types and quantities of noise produced from O&G drilling poses a risk to community health for those living in proximity to these activities.

## 2.6 Noise and Health

The World Health Organization defines an adverse health as “a temporary or long-term change in the morphology and physiology of an organism that results in impairment of functional capacity, or an impairment of the capacity to compensate for additional stress, or increases the susceptibility of an organism to the harmful effects of other environmental influences” [34]. The adverse health effects of noise exposure can largely be grouped into two categories: auditory effects and non-auditory effects [35]. “Auditory” describes health effects that affect the hearing organs and ability to hear, directly. “Non-auditory” describes just the opposite, health effects that affect any part of the physical body *other* than the hearing organs or affects a person’s ability to maintain homeostasis or psychological or emotional well-being. Particular emphasis is given, in this thesis, to the non-auditory effects, as researchers suggest they are most often associated with the lower levels of noise typically observed in environmental noise exposures.

### 2.6.1 Auditory Effects

The two most common auditory effects associated with noise exposure are noise-induced hearing loss (NIHL) and tinnitus [35]. NIHL is the reduction in hearing ability typically associated with the loss of auditory sensory cells in the main hearing organ, the cochlea. NIHL can result both from acute exposure to extreme levels of sound or chronic exposure to moderate to high levels of noise over a lifetime [36]. An estimated 1.3 billion people, globally, suffer from some degree of NIHL and it is the 13<sup>th</sup> largest contributor to the global years lived with a disability (YLD) [37]. NIHL is associated with a reduced ability to understand everyday speech, increased emotional distress, declined cognitive performance, and increased accidents and falls leading to excess mortality [38], [39].

Tinnitus is a disorder affecting the hearing organs in which a change in sound perception is observed, such as a persistent buzzing or ringing noise, which cannot be attributed to an external sound source.

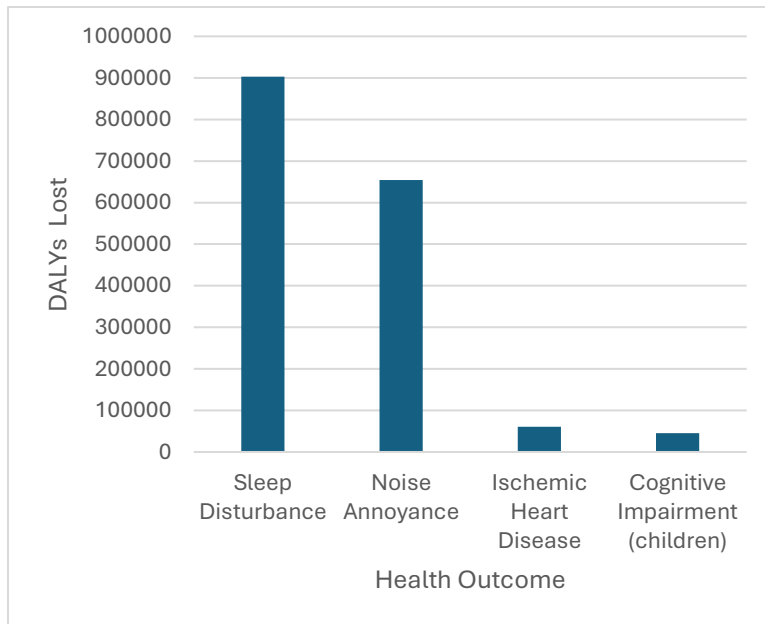
Tinnitus can be temporary, following an acute exposure to very high sound levels, or permanent, as the

result of extreme acute trauma to the hearing organs or chronic exposure to high levels of sound over long periods of time [40], [41]. Tinnitus can severely affect overall quality of life through increased anxiety and depression, a decreased sense of self-worth, sleep interruption, and an inability to sustain attention [35], [42].

As it pertains to environmental noise exposure, the EPA has found that sustained average sound levels, measured over one year, of less than 70 dBA do not pose a direct or substantial risk to human hearing.

### 2.6.2 Non-Auditory Effects

The most extensively studied health outcomes due to noise exposure are sleep disturbance, annoyance, ischemic heart disease and cognitive impairment. The WHO has estimated that, among 340 million members of high-income Western European countries, more than 1.5 million disability adjusted life-years (DALYs) are lost each year due to the non-auditory effects of environmental noise alone [41]. The distribution of the magnitude of these effects are found in Figure 4.



**Figure 4: Annual Disability Adjusted Life-Years Lost due to Non-auditory Effects of Environmental Noise (Figure Adapted from WHO)**

While there are currently no studies directly linking noise from O&G drilling operations with non-auditory health outcomes, there is an enormous body of research regarding the four health outcomes listed above and their relationship to other environmental noise sources. A review of these studies and their findings, taken together with the existing data on oil and gas noise, demonstrates a strong likelihood that environmental noise from O&G drilling could be contributing to the incidence of these health outcomes in nearby communities.

#### 2.6.2.1 Sleep Disturbance

Sleep disturbance is considered one of the most deleterious of the non-auditory health effects due to the dependence of daytime levels of performance, alertness, and overall health and quality of life on sufficient undisturbed sleep [41], [43]. Sleep restriction and/or fragmentation has been associated with acute effects such as changes in hormones regulating appetite, insulin insensitivity, and sympathetic nervous system dysfunction and chronic effects such as obesity, hypertension, cardiovascular disease, diabetes, and all-cause mortality [44], [45], [46], [47], [48], [49], [50]. Specific cardiovascular effects due to nocturnal noise exposure will be discussed in section 1.6.2.2: *Cardiovascular Effects*.

The portion of the brain called the thalamus acts as both a filter and relay system for stimulus inputs from the rest of the body; it determines which inputs from the central nervous system are relayed to the cortex and which are withheld. Information relayed to the cortex may then be distributed to other neural networks in the brain that control various body functions (e.g., the digestive system or cardiovascular system), thus allowing for bodily reactions to external stimuli [51], [52]. This relay/filter system continues to operate whether or not an individual is awake or asleep, meaning the body and brain can evaluate and react to environmental noise while it is sleeping [51]. If the thalamus decides to relay information to the cortex while asleep, it may lead to an arousal of this region which may, in turn, fragment or disturb sleep. Reactions vary in intensity from a minor “vegetative” reaction, such as increased blood pressure,

to a full regaining of consciousness [53]. Therefore, the occurrence and degree of sleep disturbance from nocturnal noise depends, in part, on whether the initial stimulus is elevated to the cortex and, if so, the degree of resulting cortical arousal.

Other factors besides the mere presence of a stimulus affect the degree to which someone will experience a cortical arousal, including the number of successive noise events, the acoustical characteristics of the sound, the noise susceptibility of the individual and the stage of sleep [54]. The specific relationship between nocturnal sound exposures and resulting physiological responses can be difficult to assess due to limitations in one's ability to definitively assign a cause to measured changes in brain activity while asleep. In a 2011 polysomnographic laboratory study, researchers evaluated the effects of various combinations of rail, airplane, and road traffic noise on sleep and recuperation [54]. Subjects were exposed to either none, one, two or all three of the different types of traffic noise, at various intervals, and their objective sleep patterns and subjective cognitive performance the following morning were measured. Researchers observed that, at the same maximum sound pressure level (SPL), road noise, followed by rail, was most likely to produce cortical arousal a vegetative response. This was explained, in part, by the characteristics of rail noise which had the lowest average duration, the second fastest SPL rise time, and the highest quantity of high frequency noise. In a 2006 polysomnographic field study, researchers investigating the effect of nocturnal aircraft noise on sleep found that, if a subject can differentiate a sound from background noise, a maximum SPLs as low as 33 dBA is sufficient to induce a physiological reaction. Researchers in a 2008 polysomnographic study relating nighttime road traffic noise to sleep disturbance found that objective measures of daytime sleepiness increased significantly with the number of noise events and the maximum SPL, and the Leq of the sounds. It has also been shown that intermittent noises with peak sound levels of greater than 45 dBA can increase the time it takes subjects to fall asleep by up to 20 minutes and that noise events more easily wake subjects and increase difficulty falling back asleep during morning hours of sleep [43].

In its report Night Noise Guidelines for Europe, the WHO correlated 8-hour nighttime  $L_{eqs}$  to community health effects, which are summarized in Table 1.

**Table 1: Effects of Different Levels of Night Noise on the Population’s Health**

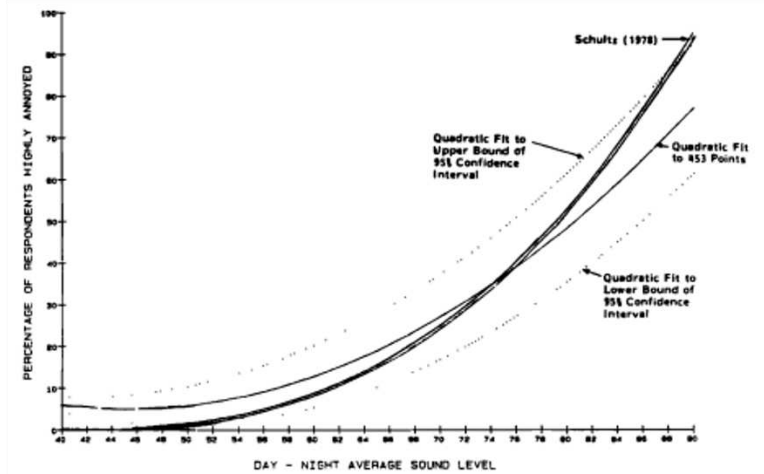
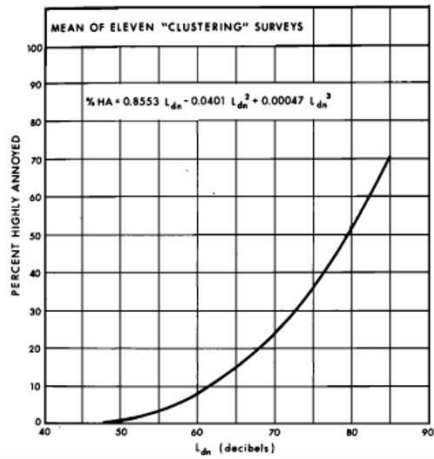
Average Night Noise Level over 1 Year (dBA)*	Health Effects Observed in the Population
≤ 30 dBA	It appears that up to this level ~ no substantial biological effects are observed. Thirty (30) dBA is equivalent to the NOEL for night noise.
30 to 40 dBA	Several effects on sleep are observed from this range: 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. Forty (40) dBA is equivalent to the LOAEL for night noise.
40 to 55 dBA	Adverse health effects are observed among the exposed population. Many people must adapt their lives to cope with the noise at night. Vulnerable groups are more severely affected.
≥ 55 dBA	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.

\*dBA = A-Weighted Decibels

### 2.6.2.2 Annoyance

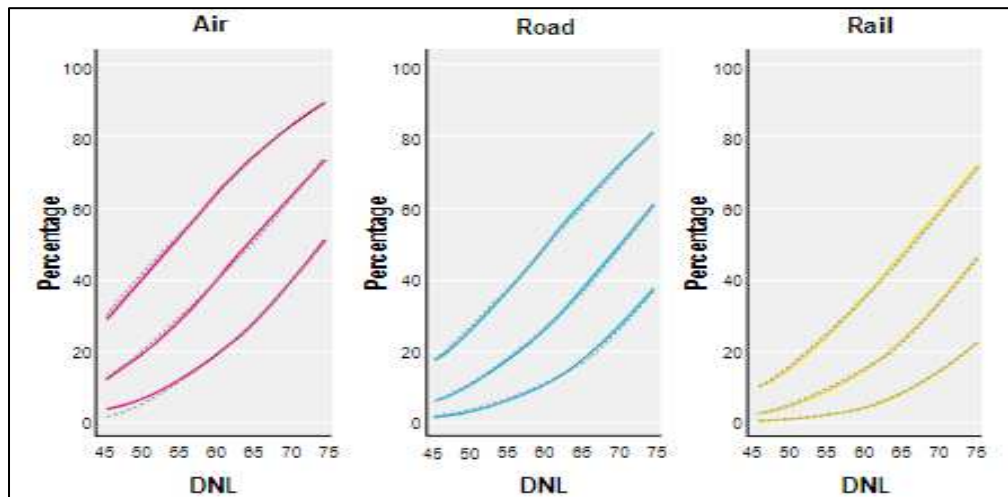
Noise annoyance is defined as a feeling of displeasure, nuisance, disturbance, or irritation caused by a specific sound, and is considered to be one of the most immediate and widespread reactions to environmental noise exposure [55]. Assessing annoyance can be difficult, due to the fact that it depends on both acoustical and non-acoustical factors [55], [56], [57]. Acoustical factors include characteristics such as the frequency spectrum, duration of exposure, levels of fluctuation, and the overall sound pressure levels [55]. However, universally linking annoyance to specific combinations of decibel levels

and noise characteristics is close to impossible; researchers have shown that it is *non-acoustical* factors that tend to have the largest effect on annoyance [56], [57], [58]. The time of day and week of exposure, activity being performed by the subject (i.e., exercising vs. watching television), predictability of the noise, personal noise sensitivity, perceived levels of control over the noise, beliefs about the importance of the noise, demographic variables (e.g., age, sex, income, education), and fear of danger from the noise all have a much more substantial impact on individual annoyance levels rather than the sound character alone [56], [57], [58], [59]. Researchers have found that as little as 10% - 14% of variance of annoyance can be accounted for by acoustical factors alone [57], [58]. Nonetheless, some general guidelines exist or can be extracted from the data. A study of the effects of road noise on a quiet street found that keeping 24-hour average sound levels (Leq) below 60 dBA reduced annoyance among the majority (80%) of people [59]. The World Health Organization (W.H.O.) places the average thresholds for moderate and serious annoyance at 50 dBA and 55 dBA, respectively, and recommends sound levels be 5-10 dBA lower at night than during the day. The most agreed-upon reliable statistic in predicting annoyance, however, is the Day Night Average Sound Level (DNL). The DNL is a derivative of the 24-hour Leq which artificially inflates nighttime (10:00 pm to 7:00 am) sound levels by 10 dBA. A 1978 team of researchers created dose response curves for DNL and self-reported annoyance for multiple data sets of transportation noise, including airplane, road traffic, and rail related noise [60]. Respondents rated their subjective annoyance levels from “not at all annoyed” to “highly annoyed” and the percentage of “highly annoyed person” was plotted against the LDN to which they were exposed. All data sets were aggregated into one dose-response curve. This research was updated by other researchers in 1990, using hundreds of new data points and found that the original 1978 relationship still provided a reasonable fit [61]. Both aggregate dose response curves are shown in Figures 5 & 6.



**Figures 5 and 6: Dose-Response Curves for Day/Night Noise Exposure and “Highly Annoyed Persons”**  
(Adapted from Shulz et al. and Sanford et al.)

In a 2001 study, researchers carried out a similar analysis, comparing the DNL from air, rail and traffic to the individual annoyance levels within exposed communities and found similar results [62]. In their study, the percentage of “highly annoyed,” “annoyed,” and “a little annoyed” were compared, and all were found to have positive correlations with increased DNL. The results of this study are summarized in Figure 7.



**Figure 7: Dose-Response Curves for Day/Night Noise Exposure and Annoyance Levels**  
(Adapted from Miedema and Oudshoorn)

Several other studies have corroborated the DNL as a statistically significant predictor of annoyance levels [55], [63], [64].

### 2.6.2.3 Cardiovascular Effects

Some of the noise-induced cardiovascular effects are due to noise-induced sleep disruption (see section 2.6.2.1: *Sleep Disruption*), so there is some overlap between the two phenomena [44], [45]. There are, however, direct effects to the cardiovascular system from both diurnal and nocturnal noise exposure unrelated to sleep disruption. Experimental, observational, and epidemiological studies have all linked environmental noise exposure to an increased risk of various cardiovascular diseases and other negative cardiovascular health outcomes including arterial hypertension, myocardial infarction, stroke, and elevated blood pressure [65]. The nature of cardiovascular disease brought on by noise exposure depends on when a person is exposed to the noise, the acoustical characteristics of the noise, and the specific physiological response triggered by the exposure [38], [39][40] [41]. Physiological reactions to noise are a symptom of a larger, more general series of psychophysiological responses the human body undergoes in response to any incurred stressor [66]. These responses can include the activation of the sympathetic portion of the autonomic nervous system (fight-or-flight response), the limbic system and endocrine system, as well as the release of stress hormones such as catecholamines and corticosteroids [66], [67], [68]. These responses, in turn, affect aspects of homeostasis including blood pressure, electrolyte and lipid concentrations in the blood, and cardiac output [69].

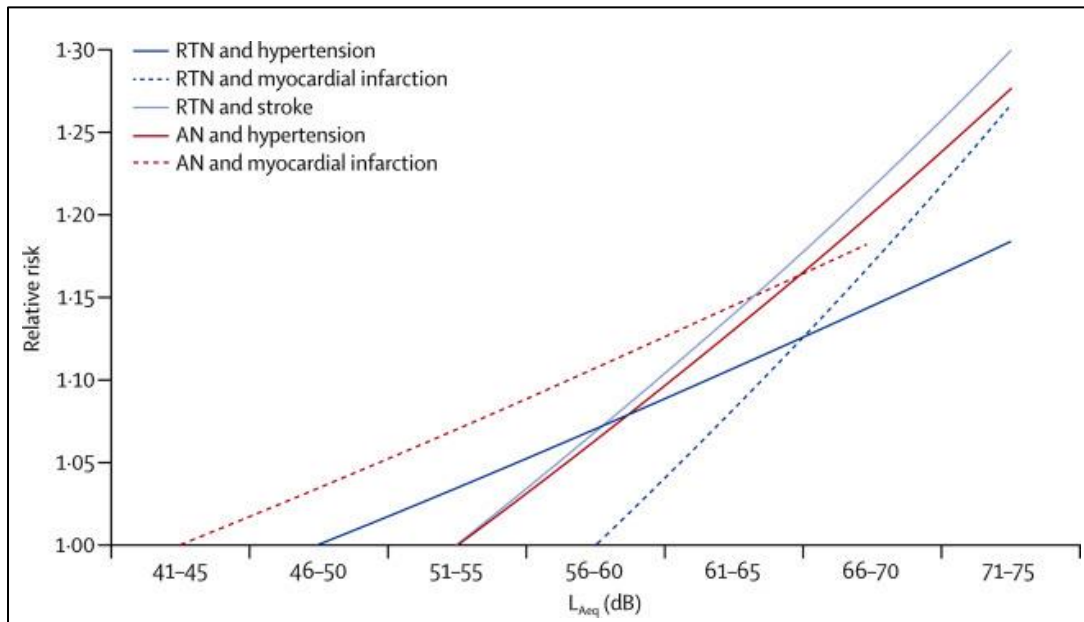
A 2013 case study was carried out in the United Kingdom examining the burden of exposure to various sources of environmental noise. Researchers estimated that within the UK population, an excess of 542 cases of hypertension-related acute myocardial infarction and 788 cases of stroke were due to daytime noise exposure levels greater than 55 dBA. A 2014 meta-analysis of 14 studies relating chronic exposure to traffic noise to incidence of coronary heart disease (including hypertension, ischemic heart diseases and stroke) confirmed a statistically significant relative risk of 1.08 per 10 dBA increase of the LDN within

the 52-77 dBA range [70]. Researchers of a large cohort study of middle-aged subjects in Denmark found an average increase of 0.26mm Hg of systolic blood pressure per 10 dBA increase of road traffic noise [71].

As discussed in section 2.6.2.1, *Sleep Disruption*, the body also experiences physiological responses to noise stimulus while asleep, which can disrupt sleep patterns. Sleep is important to cardiovascular health and so nocturnal disruptions from noise should be considered an important factor affecting it [72]. An example of how nocturnal noise may affect the heart is by triggering an ANS arousal reaction which, in turn, can cause an increase in blood pressure [69]. It is believed that a sustained dip in blood pressure that occurs naturally during sleep is important for long-term cardiovascular health and that repeated ANS stimulation while sleeping may prevent this sustained dip by temporarily increasing heart rate and blood pressure, increasing the risk of developing hypertension [73], [74]. Epidemiological evidence is, in fact, increasingly indicating that nocturnal noise exposure may be more impactful on cardiovascular health than daytime exposures. In a 2007 study, researchers found an excess risk of hypertension from nighttime airplane noise exposure, despite finding no such increase for similar daytime exposure [75]. The risk of hypertension was also found to be higher in those who slept with their windows open at night near loud roads, but lower in those who slept in a room facing away from a main road or with closed windows and good insulation [65].

There is no question that noise and, more specifically, environmental noise is causally correlated with increased incidence of coronary heart diseases. The extent of the effect and any correlation the specific acoustical characteristic of the noise needs further research. The WHO and U.S. Environmental Protection Agency (EPA) provide average decibel thresholds over which cardiovascular disease may be a concern, listing an Leq of 65-70 dBA or an LDEN (average day-evening-night sound level) of 60 dBA as the threshold for ischemic heart disease and an LDEN of 50 for hypertension. The relative risks for

developing hypertension, myocardial infarction, and stroke from exposures to road traffic noise (RTN) and airplane noise (AN) are shown in Figure 8.



**Figure 8: Relative Risks of Developing Heart Diseases from Road Traffic Noise Exposure** (Adapted from Basner et al.)

#### 2.6.2.4 Cognitive Performance

The adverse effects of environmental noise on cognitive performance are most notable in children aged 7 to 19 years old [41]. While the mechanism by which noise exposure can affect cognitive performance is not entirely understood, postulations include the effects of noise annoyance and sleep disturbance, frustration, physiological stress responses, communication difficulties, and impaired attention [35], [76], [77]. While the body of literature still relatively small, studies have shown strong evidence that chronic exposure to environmental noise from road traffic, airplane, and rail noise has adverse effects on children's short- and long-term memory, reading ability, and test taking performance [78], [79], [80], [81] [79]. In the largest study on the topic to date, a two-year, cross national epidemiological study called the RANCH project, researchers examined the exposure-effect relationship between noise exposure and

reading comprehension among 2,844 children aged 9-10 from 89 schools across Europe. Researchers found that aircraft noise was highly correlated with impaired reading comprehension, reporting that a five dBA increase in aircraft noise exposure was associated with between a one- and two-month delay in reading age, after adjusting for socioeconomic factors. The association was found to be linear, suggesting that there is no effect threshold and thus any reduction in noise levels should have a positive effect on a child's cognition. The WHO recommends, in its Community Noise Guidelines, that, during teaching hours, background sound levels remain below 35 dBA [41].

## 2.7 Low Frequency Noise

Low frequency noise (LFN), noise with a frequency in the 10Hz to 200Hz range, is recognized as a unique environmental stressor which warrants evaluation separate from more traditional measures of environmental noise [82], [83], [84]. Noise in this range is perceived differently by the body than in higher frequency range with sounds below 20Hz (referred to as "infrasound") more often reported as "felt" than "heard". Aural activation is still observed in response to tones in this range, however the ability to distinguish tonality is lost below 16-18Hz and the hearing threshold rises dramatically as the frequency decreases [82], [85]. Compared to exposure to mid-to-high-frequency noise at high decibels, exposure to equally high sound levels in the low range do not pose as high of a direct risk to hearing [82]. It is the non-auditory effects of LFN that are of particular concern; researchers have shown that LFN contributes to annoyance, stress levels, and cognitive performance decline [82], [86], [87], [88, p. 100]. Researchers who reviewed all of the existing research on the effects of LFN on sleep disturbance found that while there is some weak evidence of an effect, much more research is needed to draw any strong conclusions on the matter [89].

Researchers, in a study comparing annoyance levels in response to tones in the infrasound range (31.5Hz to 4Hz) to those at 1,000Hz, found that as the frequency decreased, the audible threshold increased but,

once audible, annoyance levels in response to the tones increased much more rapidly with increasing sound level [90]. This suggests that once aware of LFN, people may be more sensitive to rises in decibel levels than to a similar rise in higher frequency noise. Other studies have found that the dBA scale consistently underestimates annoyance levels for frequencies under 200Hz and that at equal dBA levels, subjects perceive broadband noise dominated by lower frequencies to be as much as 7 dBA louder and 8 “dB” more annoying than broadband noise dominated by higher frequencies [86], [91]. As with annoyance due to higher frequency noise, there are many non-acoustical factors affecting an individual’s levels of annoyance in response to LFN (see section 1.6.2.2: *Annoyance*) [82]. LFN exposure has also been linked to increased stress levels, as measured by cortisol excretion both as the result of daytime and nocturnal exposures [92], [93]. Task performance has also been shown to deteriorate while under exposure to LFN with performance decreasing with increased length of exposure and when subjects were able to perceive pressure on the eardrum. LFN had a larger impact on peripheral tasks than primary ones and performance was found to improve when pink noise that masked the LFN was played [94], [95], [96]. In a 2005 study, LFN-dominant broadband noise at 50 dBA was also found to affect visual function, attention and concentration especially in subjects with high LFN-sensitivity [87].

In 2010, researchers published an article detailing recommended criteria in residential areas for assessing LFN based on current available standards and experience with assessing community LFN exposure from open cycle gas turbines [84]. To minimize the community health of LFN exposure, the researchers recommend a daytime exposure below 65 dBC and a nighttime exposure below 60 dBC. Researchers also found that annoyance is influenced by fluctuating LFN; if the dBC levels are fluctuating by at least +/- 5 dBC, the exposure limits should be reduced by 5 dBC.

Several studies have found that a reliable predictor of annoyance and metric for assessing the existence and/or magnitude of a “LFN problem” is the C-weighted noise level minus the A-weighted noise level (dBC - dBA) [97], [98], [99]. Broadband noise, according to these researchers, is considered “unbalanced”

in favor of LFN in the dBC - dBA value exceeds 20 db. This value acts as another modifier to the above recommended exposure limits: in a particularly quiet area where A-weighted noise levels are below 40 dBA, the exposure limits should be adjusted so that the C-weighted levels do not exceed 20dB above the A-weighted levels [97].

## 3. PURPOSE, SCOPE, & HYPOTHESES

### 3.1 Purpose

The purpose of this study is to determine if O&G drilling noise poses an increased adverse health risk to community members that live near O&G extraction sites. This determination will be based on the measurement and analysis of noise data collected from an active O&G drilling site near a residential area. The results of this study can be used to inform future research and to better inform the public about potential noise-exposure related health risks associated with living near one of these sites.

### 3.2 Scope

Noise monitoring for this project occurred at one oil and gas extraction site in Northern Colorado during the drilling phase of extraction operations only. The site was a multi-well pad and used an electric drill to perform both vertical and horizontal drilling. A sound barrier was in place around the entire well pad throughout the course of the study. Noise monitoring took place 24 hours per day, every day, for two consecutive months. This study was a part of a larger on-going project funded by the Health Effects Institute to examine environmental impacts of oil and gas extraction in Colorado, including both noise and air pollution. Noise monitoring will continue to be performed at multiple sites during all phases of extraction and this study represents a contribution towards this end.

### 3.3 Hypotheses

The research team was guided by the following two hypotheses:

**H01:** Noise levels from O&G drilling activity do not exceed the ECMC published noise level limits at specified distances.

**HA1:** Noise levels from O&G drilling activity exceed the ECMC published noise level limits at specified distances.

This hypothesis was tested by comparing measured and predicted 24-hour average noise levels from this study to the day- and night-time dBA and dBC noise limits found in Rule 423 of the ECMC's Operation and Reporting Rules (400 Series).

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**H02:** Community members living near O&G extraction sites are not at increased risk of adverse health effects based on measured and predicted noise levels at specified distances.

**HA2:** Community members living near O&G extraction site are potentially at increased risk of adverse health effects based on measured and predicted noise levels at specified distances.

This hypothesis was tested by comparing various measured and predicted noise statistics (e.g.  $LA_{eq}$ ,  $L_{dn}$ ) from this study to noise thresholds identified by the World Health Organization, Environmental Protection Agency, and European Environmental Agency to be associated with adverse health outcomes. Further, distances at which noise levels were predicted to fall below these thresholds were also calculated from noise levels at known distances from the source.

## 4. METHODS

### 4.1 Noise Monitoring

Noise monitoring was performed using a Larson Davis NMS044 Portable Noise Monitoring System (PNMS) (Depew, NY). The PNMS was powered by a Larson Davis SoundAdvisor Model 831C Class 1 Sound Level Meter (SLM) (Depew, NY). All equipment was calibrated and maintained according to the manufacturer's instructions. The system was powered by batteries which were recharged with solar panels to enable 24-hour monitoring. The PNMS was placed 1,070 feet from the well pad center, 215 feet from the nearest structure, and 1,008 feet from the nearest public road. It was set up in the flat open field surrounding the well pad with a direct line of site to the pad free from obstruction with the exception of the sound barrier. While deployed the SLM was programmed to record:

- **Sound Pressure Level (SPL)** – SPL measurements in 1-second intervals in both A- and C-weighted decibels (dBA and dBC, respectively) using slow time-weighting.
- **Octave Band** – One-third octave band measurements in A-weighted decibels

In addition, the SLM was programmed to record short audio recordings triggered by one of two conditions:

- The 1-second SPL exceeded 65 dBA
- The peak (instantaneous) SPL exceeded 90 dBA

These triggered recordings are referred to as *events* and were intended to capture the sources of the triggering noises to aid in removing noise from the monitoring results that were unrelated to drilling.

The PNMS recorded data 24-hours daily from late August to the end of October 2024. Data were periodically manually downloaded from the SLM and uploaded into Google Drive. From here, files were

downloaded and analyzed using the Larson Davis G4 LD Utility Software, version 4.9.6 (G4). The data were also exported to Microsoft Excel version 2404 for further analysis.

A second PNMS was deployed on the same site, however, due to its proximity to a public road, the data were overwhelmed with road traffic noise and were not used in the analysis.

## 4.2 Data Selection

Of the 61 days for which SLM data files were available, 42 were used in the final analysis. Days were systematically qualified or disqualified for analysis based on a set of selection criteria. Grounds for disqualification included:

- **File Corruption** – Some data files were found to be ‘corrupt’ by G4 and could not be opened. No further information was provided by the software.
- **Run Time** – The SLM occasionally only recorded data for some fraction of a day, rather than the desired 24 hours. Since many of the calculated statistics are daily averages, any file with only a partial day of data was excluded.
- **Time History** – the SLM did not record a time history (TH) for several days. A TH is a complete list of second-by-second SPL data for the entire day. Data files without a TH are not able to be edited in G4, therefore the availability of a TH was a conditional disqualifier based on the need (or lack thereof) for data cleaning (see section 4.3, *Data Cleaning*). If no data cleaning was necessary, a lack of TH alone was not considered a disqualifier.
- **Wind Speed** – any day with a daily-average wind speed of  $\geq 10$  miles per hour (mph) was disqualified. For the date range included in this analysis, no days exceeded this limit.
- **Static Interference** – One day was excluded due to continuous, high-levels of static interference. Interference was assumed to be associated with the occurrence of a thunderstorm on that day.

A sample of days showing the selection process is displayed in Table 2.

**Table 2: Examples of the Selection Process**

Date	Run Time	Time History Available?	Wind Correction Needed?	Event Correction Needed?	Average Daily Wind Speed	Other Disqualifier	Selected for Analysis?
9/1/2023	24hr	Y	N	Y	2.70	n/a	Y
9/2/2023	24hr	Y	N	Y	2.30	n/a	Y
9/3/2023	24hr	Y	Y	Y	3.32	static interference	N
9/4/2023	24hr	Y	Y	Y	4.81	n/a	Y
9/5/2023	15.5hr	Y	N	Y	4.13	n/a	N
9/6/2023	n/a	n/a	n/a	n/a	n/a	corrupt file	N
9/23/2023	24hr	N	Y	N	2.22	n/a	N
9/24/2023	24hr	N	N	N	1.75	n/a	Y
9/25/2023	24hr	N	N	N	1.59	n/a	Y
9/26/2023	24hr	N	N	N	1.17	n/a	Y
10/12/2023	n/a	n/a	n/a	n/a	n/a	corrupt file	N
10/13/2023	24hr	N	Y	N	6.20	n/a	N
10/14/2023	24hr	Y	N	Y	1.81	n/a	Y
10/15/2023	24hr	Y	N	Y	1.98	n/a	Y

## 4.3 Data Cleaning

The G4 software allows for the manual selective removal of ranges of raw noise data (using the “edit band” tool) and the subsequent recalculation of daily noise statistics, excluding those data. This tool was used to remove all identifiable noise data that either were unrelated to, or would interfere with, the measured O&G noise data. These corrections to the data were guided by the *event* audio recordings and the daily wind data (see Sections 4.3.1 and 4.3.2).

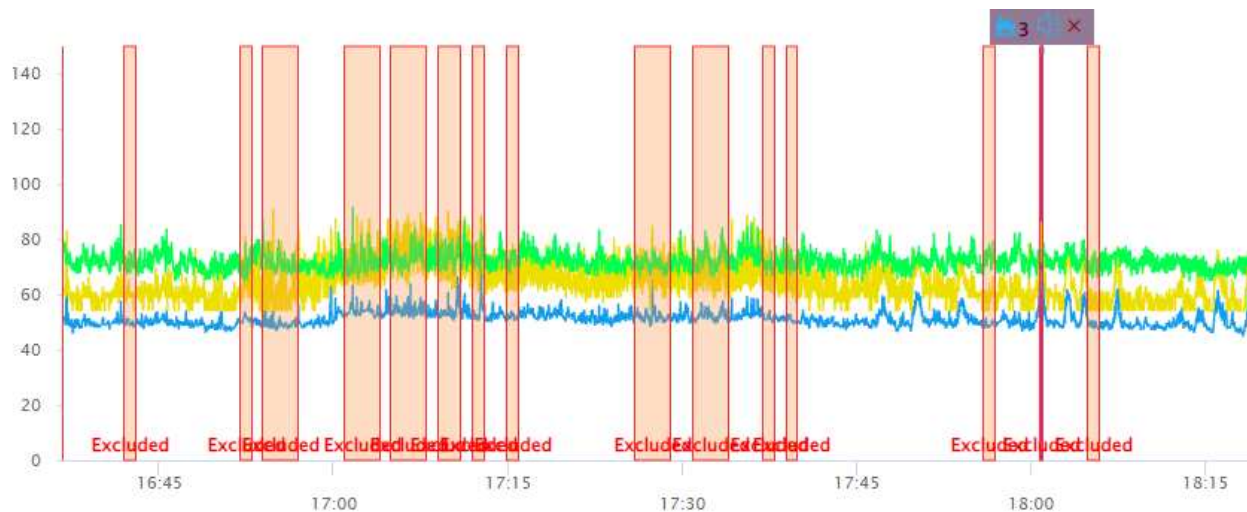
### 4.3.1 Event Data Corrections

All event audio recordings were analyzed to determine if the origin of the sound was something other than O&G activity. Common non-O&G noise sources that triggered an audio recording (i.e., whose 1-

second SPL exceeded 65 dBA or peak SPL exceeded 90 dBA) included aircraft, animals, trains, and weather. Data from any event determined to be unrelated to O&G was removed.

### 4.3.2 Wind Speed Data

A Microsoft Excel macro was used to identify any individual time stamp with a recorded wind speed of  $\geq 10$  mph. All high wind occurrences were uploaded to a table along with the date and time stamp. Since daily wind data were available in 1-minute intervals, wind speeds were assumed to be constant for the entirety of each minute recorded; thus, for any wind speed measurement exceeding 10 mph, the entire minute was removed from the data. The 10-mph limit was chosen based on best-practice methods identified in other environmental noise studies to reduce noise interference from the wind. Figure 9 shows a screen capture of the data cleaning process from G4.



**Figure 9: Example of Selective Data Removal in G4 Software**

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After all data corrections were made, new noise reports were generated in G4 containing the modified noise statistics, which were used in the final data analysis.

## 4.4 Calculated Noise Statistics

The following noise statistics were calculated by the G4 software using the edited noise data. Unless otherwise specified, all calculated values are presented in A-weighted decibels.

- **Equivalent Continuous Sound Pressure Level ( $LA_{eq} / LC_{eq}$ )** – The equivalent sound pressure level (SPL) that would produce the same total sound energy over the measurement period using a 3 dB exchange rate measured in A- and C-weighted decibels, respectively.  $L_{eq}$  accounts for fluctuating SPLs throughout the measurement period and represents the average SPL during that time.
- **( $LC_{eq} - LA_{eq}$ )** – The difference between the C- and A-weighted  $L_{eq}$ . This value is used as a tool in assessing the proportion of low frequency noise present in a broadband noise measurement.
- **Day Night Average Sound Level ( $L_{dn}$ )** – The  $L_{dn}$  represents the average sound pressure levels over a 24-hour period, calculated from the daytime  $L_{eq}$  ( $L_{Day}$ ; 7:00 a.m. - 10:00 p.m.) and nighttime  $L_{eq}$  ( $L_{Night}$ ; 10:00 p.m. - 7:00 a.m.) measurements. When calculating an LDN,  $L_{Night}$  is artificially inflated by 10dB to account for lower ambient noise levels and the lower noise levels needed to reduce sleep disturbance.
- **Daytime Equivalent Sound Pressure Level ( $L_{Day}$ )** – The  $L_{eq}$  from 7:00 a.m. to the next 10:00 p.m.
- **Nighttime Equivalent Sound Pressure Level ( $L_{Night}$ )** – The  $L_{eq}$  from 10:00 p.m. to the next 7:00 a.m.
- **Percentile Sound Levels ( $L_5 / L_{10} / L_{90}$ )** –  $L_N$  represents the sound pressure level exceeded  $N\%$  of the time. For this study, the values of interest were the SPLs exceeded 5%, 10%, and 90% of the time. The  $L_N$  can also be interpreted as the  $(100-N)^{th}$  percentile; for example, the  $L_5$  is the SPL exceeded 5% of the time or the 95<sup>th</sup> percentile SPL.
- **Maximum (Fast) Sound Level ( $LA_{fmax} / LC_{fmax}$ )** – The maximum SPL from the measurement period with fast time weighting applied, measured in A- and C-weighted decibels, respectively. Fast

time-weighting averages sound pressure levels every 125 milliseconds; this is a finer resolution than the standard slow time-weighting which averages sound pressure levels over every one second.

It should be noted that not every statistic was available for every single day since the G4 software does not preserve every originally calculated statistic when recalculating after data cleaning. On sampling days that required data corrections and a recalculation of statistics, the percentile sound levels and the maximum sound levels were not available in the modified-results report. However, on any day that did not require any data editing, the original, unmodified results were used which included all the desired statistics.

For each measured daily statistic, the arithmetic mean, standard deviation, and minimum and maximum values for all the included days were calculated in Excel.

## 4.5 Distance Extrapolations

All calculated noise statistics were based on the SLM location measurement point at 1,070 feet from the well pad. Since sound travels in a predictable manner in free field, sound pressure levels at specific distances from the measurement location were extrapolated from the measured sound pressure levels using Equation 1:

$$SPL_2 = SPL_1 - 20 \log_{10}\left(\frac{r_2}{r_1}\right) \quad \text{Equation 1}$$

where

$SPL_1$  = the measured sound pressure at a known distance

$SPL_2$  = the extrapolated sound pressure level at a specified distance

$r_1$  = the known distance at which the SPL measurement was taken

$r_2$  = the new distance at which the SPL is estimated

Each noise statistic calculated at 1,070' was extrapolated to the following three distances using Equation 1:

**The Maximum Compliance Point (1,975')** – In rule 423 of its Operations and Reporting Rules [100], the ECMC specifies that compliance, at its maximum, must be established at least 25 feet from the nearest structure. Since compliance must be established if a residential structure is within 2,000', the maximum compliance distance for the closest possible well would be 1,975' from the well pad center (2,000' to the structure, minus 25' as per regulation).

**The Current Setback (2,000')** – The current ECMC specified distance within which compliance must be established if there exists a residential structure.

**The Minimum Compliance Point/Old Setback (350')** – The ECMC specifies that 350' is the minimum distance from a well pad center at which compliance can be assessed. This is also the original minimum setback distance established by the ECMC.

At each of the extrapolated distances, the arithmetic mean, standard deviation, and minimum and maximum values were recalculated for each statistic for all the included days.

## 4.6 Compliance and Health Effects Thresholds

The measured and extrapolated noise data were used to assess compliance with ECMC regulations and the potential risk of adverse health effects in potentially exposed communities. A list of decibel thresholds for each health effect endpoint being assessed was compiled from sources including the ECMC for compliance and the WHO, EEA, and EPA for health effects [22], [24], [41], [100]. For compliance, the noise thresholds are the noise limits set by the ECMC; they are the maximum permissible noise levels during the specified time periods using the specified decibel weighting scheme. For the health effects, each threshold is, in essence, a Lowest Adverse Effect Level and represents the lowest sound pressure level at which the corresponding health effect is observed.

For each health effect, the associated acoustic indicator (i.e. noise statistic) used to predict its onset was identified in the study from which the threshold was sourced (e.g.,  $LA_{eq}$ ,  $L_{dn}$ ,  $L_{max}$ ). The corresponding noise statistic calculated in this study was used for comparison to each threshold (i.e.,  $L_{dn}$  to  $L_{dn}$ ,  $LA_{eq}$  to  $LA_{eq}$ ). A well substantiated threshold for cognitive effect could not be located in the literature and was not included in this analysis. All assessment endpoints and their thresholds and acoustic indicators are listed in Table 3.

**Table 3: Decibel Limits and Thresholds for EMC Compliance and Adverse Health Effects**

Category	Effect	Time Domain	Acoustic Indicator	Threshold	Source
Compliance (residential)	Day	Chronic	LA <sub>Day</sub>	<b>55 dBA</b>	ECMC [100]
		Chronic	LC <sub>Day</sub>	<b>60 dBC</b>	ECMC [100]
	Night	Chronic	LA <sub>Night</sub>	<b>50 dBA</b>	ECMC [100]
		Chronic	LC <sub>Night</sub>	<b>60 dBC</b>	ECMC [100]
Auditory	NIHL, Tinnitus	Chronic	LA <sub>eq</sub>	<b>70 dBA</b>	EPA [24]
Sleep	Sleep Disturbance (Observed)	Chronic	LA <sub>night</sub>	<b>30 dBA</b>	WHO [41]
	Sleep Disturbance (Observed)	Acute	LA <sub>max, night</sub>	<b>45 dBA</b>	WHO [41]
	Sleep Disturbance (Polysomnographic)	Acute, Chronic	L <sub>max, night (indoors)</sub>	<b>32 dBA</b>	EEA [22]
	Sleep Disturbance (Self-Reported)	Chronic	L <sub>night(A)</sub>	<b>42 dBA</b>	EEA [22]
Annoyance	Unspecified	Chronic	L <sub>dn</sub>	<b>42 dBA</b>	EEA [22]
		Chronic	LC <sub>eq</sub> - LA <sub>eq</sub>	<b>20 dB</b>	Hessler (2005) [97]
	Outdoor Activity Interference	Chronic	L <sub>dn</sub>	<b>55 dBA</b>	EPA [24]
	Moderate	Chronic	LA <sub>Day</sub>	<b>50 dBA</b>	WHO [41]
		Chronic	LA <sub>Night</sub>	<b>40 dBA</b>	WHO [41]
	Severe	Chronic	LA <sub>Day</sub>	<b>55 dBA</b>	WHO [41]
		Chronic	LA <sub>Night</sub>	<b>45 dBA</b>	WHO [41]
Cardiovascular	Hypertension	Chronic	L <sub>dn</sub>	<b>50 dBA</b>	EEA [22]
	Ischemic Heart Disease	Chronic	L <sub>dn</sub>	<b>60 dBA</b>	EEA [22]
		Chronic	LA <sub>eq</sub>	<b>65 dBA</b>	WHO [41]
General	Reported Health/Wellbeing	Chronic	L <sub>dn</sub>	<b>50 dBA</b>	EEA [22]
		Chronic	LC <sub>Day</sub> * (LC <sub>eq</sub> )	<b>65 dBC</b>	Hessler (2005) [97]

		Chronic	LC <sub>Day</sub> * (LC <sub>eq</sub> )	60 dBC	Hessler (2005) [97]
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For the original measurement data and for each of the distance-extrapolated data sets, each individual day from the measurement period was compared to each threshold and the percentage of days exceeding that threshold was calculated.

## 4.7 Distance-Effect Thresholds

Equation 1 was rearranged and used to extrapolate the distance from the source at which the SPL would be equal to a target SPL (Equation 2).

$$r_2 = 10^{-\frac{SPL_2 - SPL_1}{20} + \log_{10}(r_1)} \quad \text{Equation 2}$$

where

SPL<sub>1</sub> = the measured sound pressure at a known distance

SPL<sub>2</sub> = the target sound pressure level

r<sub>1</sub> = the known distance at which the SPL measurement was taken

r<sub>2</sub> = the extrapolated distance at which SPL<sub>2</sub> = the desired SPL

In applying Equation 2, the target SPLs (SPL<sub>2</sub>) were the compliance/health effects thresholds. For each of the SPL endpoints, Equation 2 was used to predict the distance from the well pad center at which compliance would be established and/or the health-effect threshold would be reached. For each calculation, the arithmetic mean (of the appropriate noise data statistic) for the entire two-month measurement period was used for SPL<sub>1</sub>.

### Select High Noise Days

The five loudest days by LA<sub>eq</sub> and the five loudest days by LC<sub>eq</sub> were selected for further analysis including octave band and noise-source analyses. Two of these days, however, (10/27 and 10/28) were both in the top five LA<sub>eq</sub> and top five LC<sub>eq</sub> days; this overlap resulted in a total of eight *different* days being selected for analysis.

### **Octave Band**

One third octave band analyses (OBA) were performed for the five loudest days by LA<sub>eq</sub> only, since octave band information was available in dBA only. In a traditional OBA, the full frequency spectrum being monitored during the measurement period (in this case, 6.3 Hz to 20 kHz) is divided into smaller, consecutive ranges of frequencies called “bands”. Each band spans one octave, where a one-octave increase from a given frequency is represented mathematically by a doubling of that frequency. Bands are denoted by their center frequency ( $f_{center}$ ) which is defined in relation to the upper and lower bounds of the band ( $f_{upper}$  and  $f_{lower}$ ) by  $f_{center} = \sqrt{f_{lower} \times f_{upper}}$ . In a one third OBA, the full spectrum is broken into bands spanning 1/3 of an octave. These bands are still denoted by their center frequency, and the upper and lower bounds are defined as  $f_{upper} = f_{center} \times 2^{1/6}$  and  $f_{lower} = f_{center} \times 2^{-1/6}$ . The SPL for each band is the average SPL for that range of frequencies; the logarithmic sum of the SPLs from all bands is equal to the total SPL for the measurement period.

## **4.8 Noise Source Analysis**

Potential sources of noise that occurred on all eight select high-noise days were identified where possible. A daily activity log provided by the O&G company performing the drilling was used to aid in the identification of loud noise sources. The activity log included technical O&G-industry specific jargon to describe daily activities and did not include a description of the actual equipment used to perform the activities. Open AI’s™ ChatGPT (version 4) natural language processor was used to help decipher the activity log and identify potential sources of noise within each activity. The text from the activity log was

uploaded into the ChatGPT software and asked to explain each line in plain English. For example, the software was provided the following text from the activity log and asked to interpret it:

1. *NIPPLE UP BOP*
2. *LOWER KELLY, FLOOR VALVE AND DART VALVE*
3. *DRILL SHOE TRACK/ FLOAT COLLAR*

The response from ChatGPT was:

1. *NIPPLE UP BOP:*

- *"BOP" stands for Blowout Preventer, a critical safety device used in drilling operations to prevent uncontrolled release of oil or gas. "Nipple up" refers to the process of connecting the BOP to the wellhead.*

2. *LOWER KELLY, FLOOR VALVE AND DART VALVE:*

- *Refers to the process of lowering the kelly (a part of the drilling string used to transmit rotary motion to the drill bit), floor valve (a valve located on the rig floor), and dart valve (a valve used to control fluid flow) into position.*

3. *DRILL SHOE TRACK/ FLOAT COLLAR:*

- *Refers to drilling the casing shoe track and float collar sections of the well. The casing shoe track is the hole section drilled just below the casing shoe, and the float collar is a device installed on the casing string to prevent backflow of fluids.*

Subsequently, the ChatGPT software was asked to identify any potential noise sources associated with each of the listed steps. A sample response to this inquiry was:

1. *NIPPLE UP BOP:*

- *Noise from hydraulic systems operating the blowout preventer (BOP).*
- *Noise from rig crew activities, including handling and connecting heavy equipment.*

The complete ChatGPT responses explaining the daily activities and identifying associated noise sources are found in **Appendix B**.

## 5. RESULTS

### 5.1 Average Daily Statistics

At the noise measurement location, the  $LA_{eq}$  ranged from 45 dBA to 52 dBA, averaging just over 49 dBA.

Maximum noise levels reached as high as 91 dBA and 97 dBC and noise levels, on average, exceeded 52.2 dBA 5% of the time. The average  $LC_{eq}$  was approximately 20 dB higher than the average  $LA_{eq}$  and noise levels were similar during the day and night, with daytime levels averaging less than 2 dBA more than nighttime levels. Extrapolating to the minimum (350') and maximum (1,975') compliance points increased and decreased all decibel levels by approximately 10 dB and 5 dB, respectively, resulting in a 15 dB difference in noise levels between the minimum and maximum distance points. Due to the logarithmic nature of decibel decay with distance, the 25' difference in distance between the maximum compliance point (1,975') and the current setback (2,000') was negligible; decibel levels only decreased an additional 0.1 dB between the two distances and were considered the same, given the accuracy of the SLM of +/- 1dB.

The arithmetic mean, standard deviation and minimum and maximum values of each calculated statistic are summarized in Table 4. Individual daily averages can be found in Appendix A.

**Table 4: Average Calculated Noise Statistics by Distance from Well Pad Center**

Location / (Distance from Well Pad Center)	Analytic Statistic	Calculated Noise Statistic										
		LA <sub>eq</sub> (dBA)	LC <sub>eq</sub> (dBC)	LC <sub>eq</sub> - LA <sub>eq</sub> (dB)	L <sub>dn</sub> (dBA)	L <sub>day</sub> (dBA)	L <sub>Night</sub> (dBA)	L <sub>5</sub> (dBA)	L <sub>10</sub> (dBA)	L <sub>90</sub> (dBA)	LA <sub>fmax</sub> (dBA)	LC <sub>fmax</sub> (dBC)
<b>Measurement Location (1,070')</b>	<b>Mean</b>	49.1	69.3	20.2	54.6	49.6	47.8	52.2	50.9	42.5	76.7	85.1
	<b>SD</b>	1.3	3.2	3.1	1.4	1.6	1.7	1.5	1.5	1.8	6.1	4.7
	<b>Min</b>	45.8	60.2	9.6	50.8	45.6	43.1	49.4	48.0	38.5	68.5	80.8
	<b>Max</b>	51.7	74.9	25.8	57.7	52.9	51.7	54.8	53.1	46.9	91.9	97.9
<b>Maximum Compliance Point (1,975')*</b>	<b>Mean</b>	43.8	64.0	20.2	49.3	44.3	42.5	46.7	45.5	37.2	71.6	79.9
	<b>SD</b>	1.3	3.2	3.1	1.4	1.6	1.7	1.4	1.5	1.9	6.2	4.7
	<b>Min</b>	40.5	54.9	9.6	45.5	40.3	37.8	44.1	42.7	33.2	63.2	75.5
	<b>Max</b>	46.4	69.6	25.7	52.4	47.6	46.4	49.0	47.8	41.6	86.6	92.6
<b>Current Setback (2,000')*</b>	<b>Mean</b>	43.7	63.9	20.2	49.2	44.2	42.4	46.7	45.5	37.1	71.2	79.7
	<b>SD</b>	1.3	3.2	3.1	1.4	1.6	1.7	1.5	1.5	1.8	6.1	4.7
	<b>Min</b>	40.4	54.8	9.6	45.4	40.2	37.7	44.0	42.6	33.1	63.1	75.4
	<b>Max</b>	46.3	69.5	25.7	52.3	47.5	46.3	49.4	47.7	41.5	86.5	92.5
<b>Minimum Compliance / Old Setback Point (350')*</b>	<b>Mean</b>	58.8	79.0	20.2	64.3	59.3	57.5	61.9	60.6	52.2	86.4	94.8
	<b>SD</b>	1.3	3.2	3.1	1.4	1.6	1.7	1.5	1.5	1.8	6.1	4.7
	<b>Min</b>	55.5	69.9	9.6	60.5	55.3	52.8	59.1	57.7	48.2	78.2	90.5
	<b>Max</b>	61.4	84.6	25.7	67.4	62.6	61.4	64.5	62.8	56.6	101.6	107.6

\*Values at distance are extrapolated from values at measurement location;

dB = Decibel

dBA = A-Weighted Decibel

dBC = C-Weighted Decibel

LA<sub>eq</sub> = Equivalent Continuous Sound Pressure Level (A-Weighted Decibels)

LC<sub>eq</sub> = Equivalent Continuous Sound Pressure Level (C-Weighted Decibels)

[LC<sub>eq</sub> - LA<sub>eq</sub>] = Difference between LC<sub>eq</sub> and LA<sub>eq</sub>

L<sub>dn</sub> = Day Night Average Sound Level

L<sub>day</sub> = LA<sub>eq</sub> for Daytime Period (7:00 a.m. to 10:00 p.m.)

L<sub>Night</sub> = LA<sub>eq</sub> for Daytime Period (7:00 a.m. to 10:00 p.m.)

L<sub>5/10/90p</sub> = 95<sup>th</sup>, 90<sup>th</sup>, and 10<sup>th</sup> percentile SPL

LA<sub>fmax</sub> = Maximum SPL with fast time-weighting in dBA

LC<sub>fmax</sub> = Maximum SPL with fast time-weighting in dBC

SD = Standard Deviation

## 5.2 Compliance

Compliance was assessed using both A- and C- weighted decibels for both the daytime (7:00 a.m. – 10:00 p.m.) and nighttime (10:00 p.m. – 7:00 a.m.) period. The acoustic indicators are the  $L_{day}$ , in dBA and dBC, and  $L_{night}$  in dBA and dBC. The ECMC limits O&G noise to 55 and 50 dBA during the day- and nighttime, respectively, and 60 dBC during both periods. Daily average values (Appendix A) for the respective acoustic indicators were compared to the ECMC limits, and the % of days exceeding the limits were calculated. It should be noted that separate  $L_{day}$  and  $L_{night}$  values were available from the data in A-weighted decibels only. A 24-hour  $L_{eq}$ , only, was available in C-weighted decibels ( $LC_{eq}$ ); since the day- and nighttime dBC limit is the same, the  $LC_{eq}$  was used as a proxy for both  $L_{day}$  (dBC) and  $L_{night}$  (dBC) in this analysis. Of the days included in the analysis, none exceeded the threshold for daytime (55 dBA) or nighttime (50 dBA) noise limits at the measurement location. All the days exceeded the threshold for C-weighted threshold (60 dBC) however, for both daytime and nighttime at the measurement location, with more than 90% of the days continuing to do so at the maximum compliance point (1,975'). At the minimum compliance point (350') extrapolated values exceeded all daytime and nighttime limits on 100% of the days. Using Equation 2, it was calculated that predicted A-weighted noise levels would decrease to the compliance limit (55 dBA and 50 dBA) at distances of 575' and 831' from the well pad center for the daytime and nighttime periods, respectively. Predicted C-weighted noise levels were calculated to decrease to the compliance level (60 dBC) at a distance of 3,122' from the well pad center. The percentage of days exceeding the ECMC thresholds and the extrapolated distances at which compliance is established are summarized in Table 5.

**Table 5: Percentage of Days Exceeding ECMC Limits**

Time Period	Acoustic Indicator	Limit	Source	% Days Exceeding Limit by Distance				Distance from Source Compliance Met
				1,070'	1,975'*	2,000'*	350'*	
Daytime (7:00 a.m. – 10:00 p.m.)	LA <sub>Day</sub>	<b>55 dBA</b>	ECMC	0.0%	0.0%	0.0%	100.0%	575'
	LC <sub>Day</sub> ** (LC <sub>eq</sub> )	<b>60 dBC</b>	ECMC	100.0%	90.7%	90.7%	100.0%	3122'
Nighttime (10:00 p.m. – 7:00 a.m.)	LA <sub>Night</sub>	<b>50 dBA</b>	ECMC	0.0%	0.0%	0.0%	100.0%	831'
	LC <sub>Night</sub> ** (LC <sub>eq</sub> )	<b>60 dBC</b>	ECMC	100.0%	90.7%	90.7%	100.0%	3122'

\* Extrapolated values

\*\* Statistic not available from measured data; statistic in parenthesis used as proxy for comparison

dBA = A-weighted decibels

dBC = C-weighted decibels

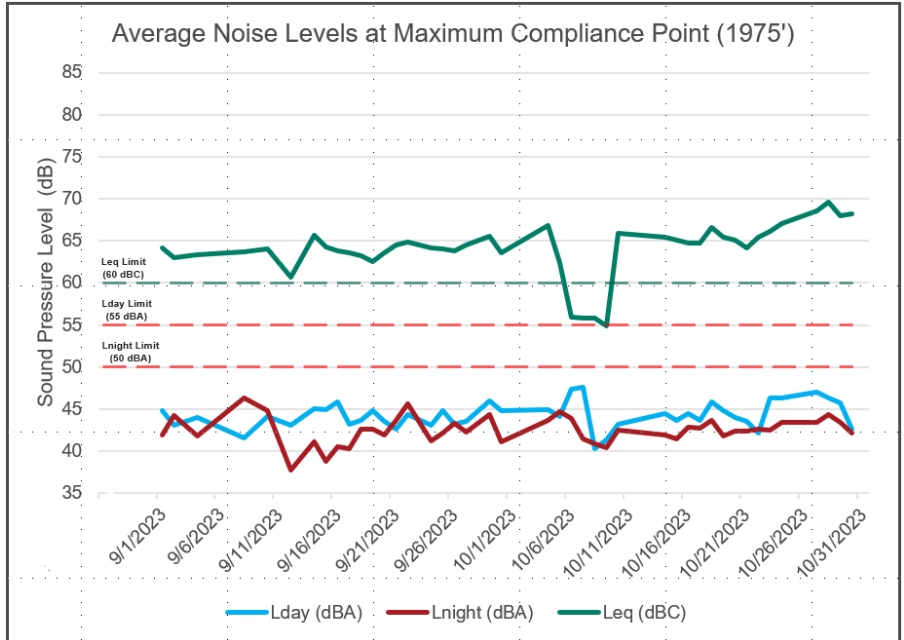
LA<sub>Day</sub> = Equivalent Continuous Sound (L<sub>eq</sub>) Pressure Level during the daytime period in dBA

LA<sub>Night</sub> = L<sub>eq</sub> during the nighttime period in dBA

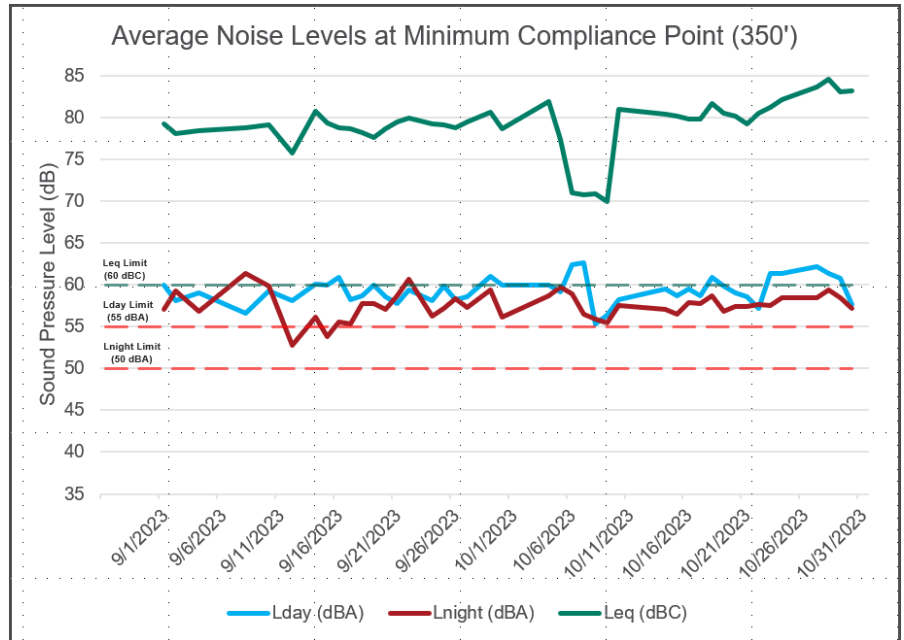
LC<sub>Day</sub> = L<sub>eq</sub> during the daytime period in dBC

LC<sub>Night</sub> = L<sub>eq</sub> during the nighttime period in dBC

To aid in the visualization of the effect of distance on noise levels and maintaining compliance, daily average values for L<sub>day</sub> (dBA) , L<sub>night</sub> (dBA), and the L<sub>eq</sub> (dBC) were plotted for both the minimum (350') and maximum (1,975') compliance points. Between the two plots, the average increase of 15 dB for all averages is clearly visible, and the average 20 dB difference between dBC levels and dBA levels is also apparent. In addition to the daily noise statistic averages, dashed lines representing the compliance limits are shown. Figure 10B clearly shows all extrapolated measurements over their respective limits at the minimum compliance point and both figures show the C-weighted measurements exceeding their limit as well.



(A)



(B)

Figures 10A and 10B: Noise Levels at Minimum and Maximum Compliance Points

### 5.3 Health Effects Thresholds

The risk of various noise-exposure-related health effects from O&G drilling activity was assessed in a similar manner to compliance. For each health effect, thresholds at which the effect has been observed in studies are listed along with the corresponding acoustic indicators. Again, the percentage of days that met or exceeded the threshold was calculated using noise levels from the measurement site as well as extrapolated noise levels at three other distances from the well pad center. It should be noted that the acoustic indicator used for polysomnographic sleep disturbance and acute observed sleep disturbance ( $L_{\max, \text{night}}$ ) was not calculated during this study. The  $L_{\max, \text{night}}$  represents the loudest 1-second interval during the nighttime period (10:00 p.m. – 7:00 a.m.). Since this statistic was not available,  $L_{\text{night}}$  was used as a proxy statistic for the analysis in those cases. At the maximum compliance point (1,975'), extrapolated noise levels exceeded the threshold for at least one specific health effect per category on at least 30% of, and up to 100% of the days. Notably, at the minimum compliance point (350'), extrapolated noise levels exceeded all but three thresholds on 100% of the days. The threshold for adverse auditory effects, however, was not theoretically exceeded at any distance included in this study. Extrapolated noise levels were calculated to exceed thresholds at a wide range of distances from the noise source (the well pad), ranging from 575' to 8,306'. The sole exception was the threshold for auditory effects, which is not expected to be exceeded until within 96' of the source. Sleep disturbance and annoyance had the highest percentages of days exceeding thresholds overall, with the thresholds for 6 of 11 effects exceeded by more than 60% of days at the maximum compliance point. Thresholds with an acoustic indicator that incorporated nighttime noise levels (i.e.,  $L_{\text{night}}$  or  $L_{\text{dn}}$ ) were generally found to have more days in exceedance than thresholds with acoustic indicators that only incorporated daytime noise levels. Due to thresholds associated with nighttime noise exposure being generally lower than those associated with daytime exposure, the distances at which those thresholds were expected to be exceeded were

generally much larger. The percentage of days exceeding the thresholds and the extrapolated distances at which they are exceeded are summarized in Table 6.

**Table 6: Percentage of Days Exceeding Published Thresholds for Adverse Health Effects**

Category	Effect	Time Domain	Acoustic Indicator	Threshold	Source	% Days Exceeding Threshold by Distance				Distance from Source Threshold Exceeded
						1,070'	1,975'*	2,000'*	350'*	
Auditory	NIHL, Tinnitus	Chronic	LA <sub>eq</sub>	70 dBA	EPA [24]	0.0%	0.0%	0.0%	0.0%	96'
Sleep	Sleep Disturbance (Observed)	Chronic	LA <sub>night</sub>	30 dBA	WHO [41]	100.0%	100.0%	100.0%	100.0%	8306'
	Sleep Disturbance (Observed)	Acute	LA <sub>max, night</sub> ** (L <sub>night</sub> )	45 dBA	WHO [41]	95.3%	4.7%	4.7%	100.0%	1477'
	Sleep Disturbance (Polysomnographic)	Acute, Chronic	L <sub>max, night indoors</sub> ** (L <sub>night</sub> )	32 dBA	EEA [22]	100.0%	100.0%	100.0%	100.0%	6598'
	Sleep Disturbance (Self-Reported)	Chronic	L <sub>night(A)</sub>	42 dBA	EEA [22]	100.0%	62.8%	62.8%	100.0%	2086'
Annoyance	Unspecified	Chronic	L <sub>dn</sub>	42 dBA	EEA [22]	100.0%	100.0%	100.0%	100.0%	4564'
		Chronic	LC <sub>eq</sub> - LA <sub>eq</sub>	20 dB	Hessler (2005) [97]	65.1%	65.1%	65.1%	65.1%	n/a
	Outdoor Activity Interference	Chronic	L <sub>dn</sub>	55 dBA	EPA [24]	32.6%	0.0%	0.0%	100.0%	1022'
	Moderate	Chronic	LA <sub>Day</sub>	50 dBA	WHO [41]	41.9%	0.0%	0.0%	100.0%	1022'
		Chronic	LA <sub>Night</sub>	40 dBA	WHO [41]	100.0%	95.3%	95.3%	100.0%	2627'

	Severe	Chronic	LA <sub>Day</sub>	55 dBA	WHO [41]	0.0%	0.0%	0.0%	100.0%	575'
		Chronic	LA <sub>Night</sub>	45 dBA	WHO [41]	95.3%	4.7%	4.7%	100.0%	1477'
Cardiovascular	Hypertension	Chronic	L <sub>dn</sub>	50 dBA	EEA [22]	100.0%	30.2%	30.2%	100.0%	1817'
	Ischemic Heart Disease	Chronic	L <sub>dn</sub>	60 dBA	EEA [22]	0.0%	0.0%	0.0%	100.0%	575'
		Chronic	LA <sub>eq</sub>	65 dBA	WHO [41]	0.0%	0.0%	0.0%	0.0%	172'
General	Reported Health/Wellbeing	Chronic	L <sub>dn</sub>	50 dBA	EEA [22]	100.0%	30.2%	30.2%	100.0%	1817'
		Chronic	LC <sub>Day</sub> * (LC <sub>eq</sub> )	65 dBC	Hessler (2005) [97]	90.7%	37.2%	32.6%	100.0%	1755'
		Chronic	LC <sub>Day</sub> * (LC <sub>eq</sub> )	60 dBC	Hessler (2005) [97]	100.0%	90.7%	90.7%	100.0%	3122'

\* Extrapolated values

\*\* Statistic not available from measured data; statistic in parenthesis used as proxy for comparison

dBA /dBC = A-weighted decibels / C-weighted decibels

LA<sub>eq</sub> = Equivalent Continuous Sound Pressure Level (Leq) in dBA

LC<sub>eq</sub> = Leq in dBC

LA<sub>Day</sub> = during the daytime period in dBA

LA<sub>Night</sub> = Leq during the nighttime period in dBA

LC<sub>Day</sub> = Leq during the daytime period in dBC

LC<sub>Night</sub> = Leq during the nighttime period in dBC

L<sub>dn</sub> = Average Day Night Sound Levels

L<sub>max, night</sub> = Maximum 1-Second Sound Pressure Level during the nighttime period

The distances at which the noise thresholds for various health effects were expected to be exceeded during drilling (from Table 6) are presented in Figure 11. Figure 11 is a top-down point-of-view with each concentric circle representing a distance from the well pad center. Each distance is labeled with the specific health effect and the distance the threshold is expected to be exceeded. An American football field is used for scale (120 yards). Not every health effect listed in **Table 6** is included in **Figure 11**.

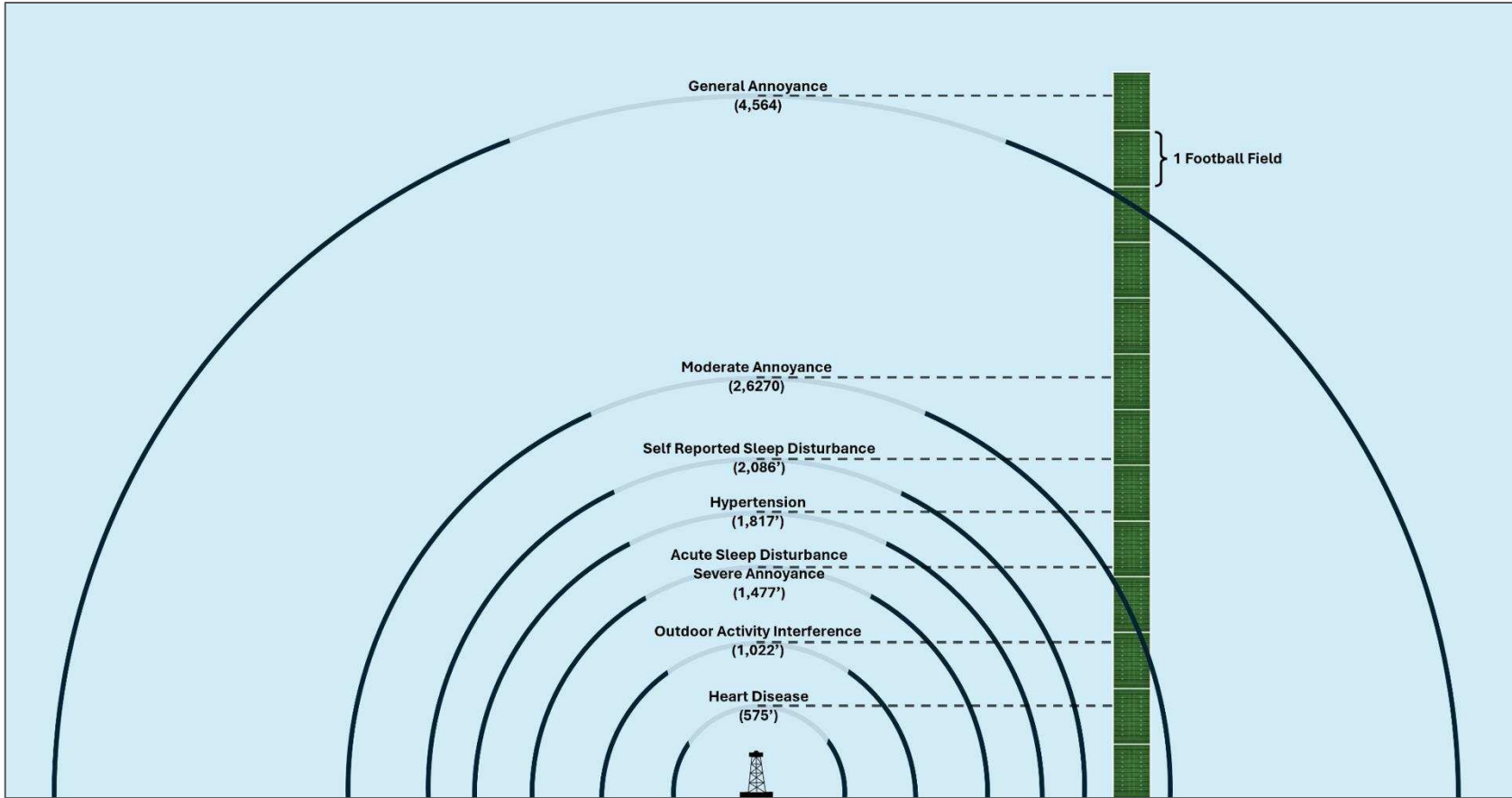


Figure 11: Health Effects Distances Graph

## 5.4 Select High-Noise Days

The daily noise statistics for the eight high-noise days selected for further analysis are presented in Table

6. Results in bold indicate which  $L_{eq}$  (dBA or dBC) was used as the inclusion criteria. As described in section 4, *Methods*, after data cleaning, not all original statistics were recalculated by the G4 software.

This is reflected in the missing data in Table 6.

**Table 6: Daily Statistics for Select High Noise Days**

Date	Calculated Noise Statistic										
	LA <sub>eq</sub> (dBA)	LC <sub>eq</sub> (dBC)	LC <sub>eq</sub> - LA <sub>eq</sub> (dB)	L <sub>dn</sub> (dBA)	L <sub>day</sub> (dBA)	L <sub>Night</sub> (dBA)	L <sub>5</sub> (dBA)	L <sub>10</sub> (dBA)	L <sub>90</sub> (dBA)	LA <sub>fmax</sub> (dBA)	LC <sub>fmax</sub> (dBC)
10/6/23	51.7	61.3	9.6	56.3	52.7	49.2	53	52	44.1	91.9	91.6
10/27/23	51.2	73.9	22.7	55.8	52.4	48.7	-	-	-	-	-
10/28/23	51.1	74.9	23.8	56.4	51.7	49.7	-	-	-	-	-
9/22/23	51	70.2	19.3	57.3	49.7	51	-	-	-	-	-
9/29/23	50.7	70.9	20.2	56.4	51.3	49.7	54	53.1	46.9	72.7	90.3
10/30/23	47.8	73.5	25.8	54	47.9	47.5	-	-	-	-	-
10/29/23	50.3	73.3	23	55.6	51.1	48.8	-	-	-	-	-
10/24/23	50.4	72.4	22	55.8	51.6	48.8	-	-	-	-	-

dB = Decibel

dBA – A-Weighted Decibel

dBC – C-Weighted Decibel

LA<sub>eq</sub> – Equivalent Continuous Sound Pressure Level (A-Weighted Decibels)

LC<sub>eq</sub> – Equivalent Continuous Sound Pressure Level (C-Weighted Decibels)

[LC<sub>eq</sub> – LA<sub>eq</sub>] – Difference between LC<sub>eq</sub> and LA<sub>eq</sub>

L<sub>day</sub> – LA<sub>eq</sub> for Daytime Period (7:00 a.m. to 10:00 p.m.)

L<sub>Night</sub> – LA<sub>eq</sub> for Daytime Period (7:00 a.m. to 10:00 p.m.)

L<sub>5/10/90p</sub> – 95<sup>th</sup>, 90<sup>th</sup>, and 10<sup>th</sup> percentile SPL

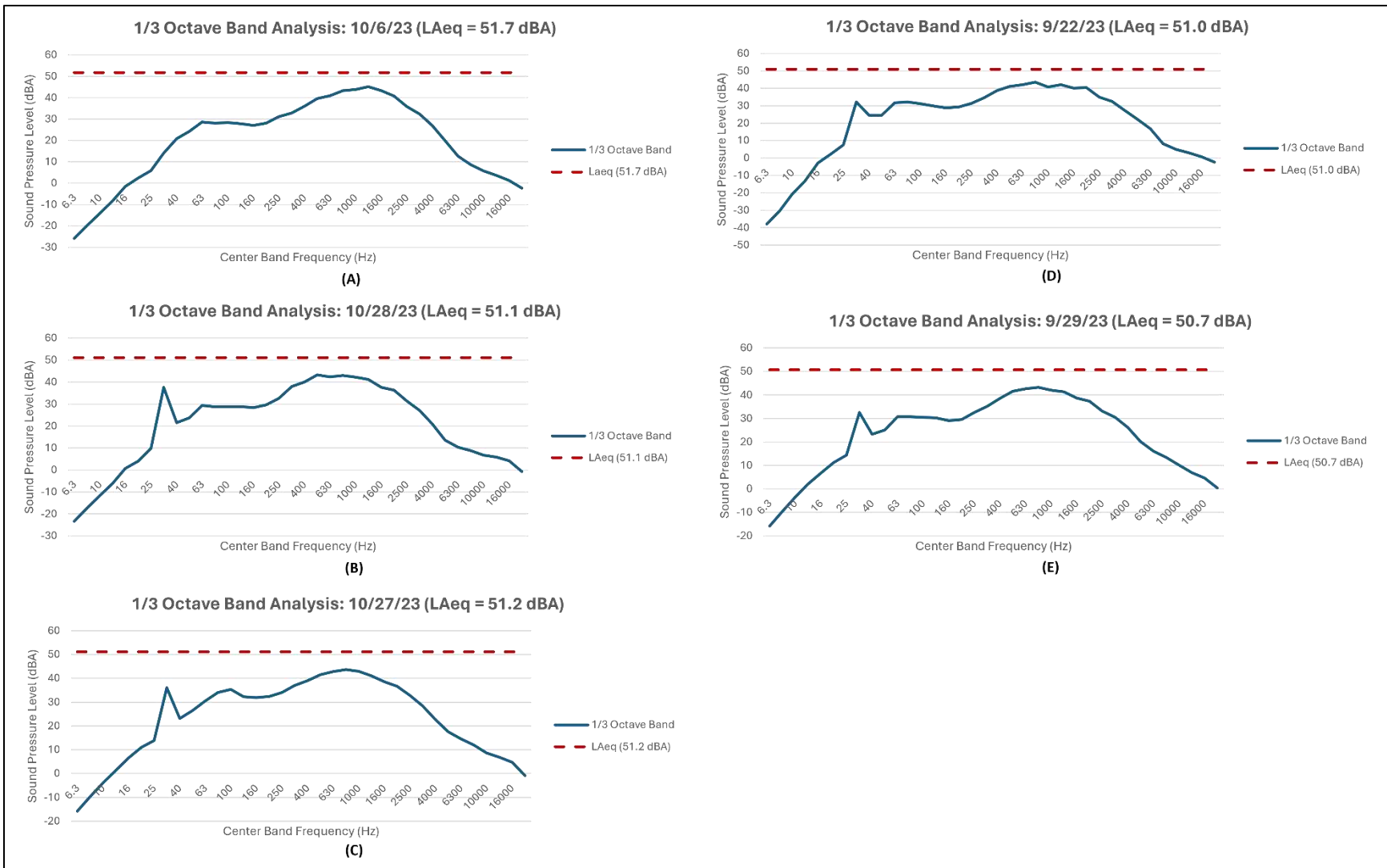
LA<sub>fmax</sub> – Maximum SPL with fast time-weighting in dBA

LC<sub>fmax</sub> – Maximum SPL with fast time-weighting in dBC

L<sub>dn</sub> – Day Night Average Sound Level

### 5.4.1 Octave Band Analyses

The 1/3 octave band analysis results for the 5 loudest days by  $LA_{eq}$  are displayed in Figures 11A-11E. The center band frequency is displayed along the x-axis and the average SPL is displayed on the y-axis. The  $LA_{eq}$  for the day is shown as a dashed red line across the top of the graph. Each day followed a similar trend, showing two distinct “humps” in the lower and mid-range frequencies and dropping into the very-high frequencies. All days except for 10/6/23 featured a large spike in SPL in the very-low frequencies just below 40Hz.



**Figures 12A – 12E: 1/3 Octave Band Analyses for Select High Noise Days**

dBA = A-Weighted Decibels

Hz = Hertz

LAeq = Equivalent Continuous Sound Pressure Level in dBA

### 5.4.2 Noise Source Analysis

The activities performed on each of the eight loudest days and the potential sources of loud noise identified by the ChatGPT software are summarized in Tables 7 and 8. See the section 6.6, *A Word on ChatGPT*, for a discussion of trends in the activities and information on the limitations from the use of ChatGPT.

**Table 7: Activities and Potential Noise Sources on Select High Noise Days (by LA<sub>eq</sub>)**

Date	LA <sub>eq</sub> (dBA) by Distance			Daily Activities	Potential Noise Sources
	1070'	1975'	350'		
10/6/23	51.7	46.4	61.4	<ol style="list-style-type: none"> <li>1. Cleaned drilling rig (drill floor, derrick, tanks, equipment, etc.)</li> <li>2. Removed inside blowout preventer (IBOP) from drill string and replace it with new one</li> <li>3. Assembled 4 sections of drill pipe</li> <li>4. Hoisted the bottom hole assembly (BHA) to the surface and racked it in the derrick's storage area</li> </ol>	<ol style="list-style-type: none"> <li>1. Cleaning equipment (pressure washers)</li> <li>2. Tool noise during IBOP change</li> <li>3. Hoisting system equipment/operations (picking up/setting down pipe, moving drill pieces, lifting IBOP, raising BHA)</li> <li>4. Iron roughnecks (automated pipe handling systems)</li> <li>5. Drill assembly equipment (top drive, draw works)</li> </ol>
10/27/23	51.2	45.9	60.9	<ol style="list-style-type: none"> <li>1. Moved the drill rig 15' to new location</li> <li>2. Assembled the blowout preventer (BOP), drilling mud circulation equipment, and positioned the catwalk</li> <li>3. Tested various BOP system components and well control equipment</li> <li>4. Tensioned/adjusted the drill line cable</li> <li>5. Calibrated hoisting system</li> <li>6. Picked up the BHA and lowered it into the wellbore</li> <li>7. Drilled through the shoe track (seal at bottom of casing)</li> </ol>	<ol style="list-style-type: none"> <li>1. Hoisting system equipment/operations (picking up/setting down pipe, moving/raising drill pieces, lifting/positioning BHA)</li> <li>2. Tool noise during BOP/mud equipment assembly</li> <li>3. Testing BOP systems (pumps, valves, high-pressure lines)</li> <li>4. Drill line adjusting equipment (power tongs, elevators, power tools)</li> <li>5. Drilling equipment (Top drive/draw works system, mud pumps, shale shakers, drill bit impact)</li> </ol>

10/28/23	51.1	45.8	60.8	<ol style="list-style-type: none"> <li>1. Finished drilling through the shoe track</li> <li>2. Finished vertical portion of drilling</li> <li>3. Began horizontal drilling</li> </ol>	<ol style="list-style-type: none"> <li>1. Drilling equipment (top drive, draw works system)</li> <li>2. Drilling mud circulation (mud pumps, flow lines, shale shakers)</li> <li>3. Drill bit impact (especially during transition from vertical to horizontal)</li> <li>4. Pipe handling (moving/inserting/connecting drill pipe sections)</li> <li>5. Drilling fluid discharge</li> </ol>
9/22/23	51	45.7	60.7	<ol style="list-style-type: none"> <li>1. Finished horizontal drilling</li> <li>2. Cleaned out the wellbore</li> <li>3. Prepared for inserting casing including assessing wellbore integrity and displacing drilling mud with a water solution</li> <li>4. Removed the drill string from the wellbore</li> <li>5. Lowered casing into the wellbore</li> </ol>	<ol style="list-style-type: none"> <li>1. Drilling equipment (top drive, draw works system)</li> <li>2. Drilling mud circulation (mud pumps, flow lines, shale shakers)</li> <li>3. Drill bit impact</li> <li>4. Pumps for circulating / displacing drilling mud</li> <li>6. Hoisting system equipment/operations (picking up/setting down pipe, moving/raising/lowering drill &amp; casing pieces)</li> </ol>
9/29/23	50.7	45.4	60.4	<ol style="list-style-type: none"> <li>1. Finished horizontal drilling</li> <li>2. Cleaned hole by circulating drilling mud</li> <li>4. Removed the drill string and BHA from the wellbore</li> </ol>	<ol style="list-style-type: none"> <li>1. Drilling equipment (top drive, draw works system)</li> <li>2. Drilling mud circulation (mud pumps, flow lines, shale shakers)</li> <li>3. Drill bit impact</li> <li>4. Pumps for circulating / displacing drilling mud</li> <li>6. Hoisting system equipment/operations (picking up/setting down pipe, moving/raising/lowering drill pieces)</li> </ol>

dBA – A-weighted Decibels

LA<sub>eq</sub> – Equivalent Continuous Sound Pressure Level in dBA

**Table 8: Activities and Potential Noise Sources on Select High Noise Days (by LC<sub>eq</sub>)**

Date	LC <sub>eq</sub> (dBC) by Distance			Daily Activities	Potential Noise Sources
	1070'	1975'	350'		
10/28/23	74.9	69.6	84.6	<ol style="list-style-type: none"> <li>1. Finished drilling through the shoe track</li> <li>2. Finished vertical portion of drilling</li> <li>3. Began horizontal drilling</li> </ol>	<ol style="list-style-type: none"> <li>1. Drilling equipment (top drive, draw works system)</li> <li>2. Drilling mud circulation (mud pumps, flow lines, shale shakers)</li> <li>3. Drill bit impact (especially during transition from vertical to horizontal)</li> <li>4. Pipe handling (moving/inserting/connecting drill pipe sections)</li> <li>5. Drilling fluid discharge</li> </ol>
10/27/23	73.9	68.6	83.6	<ol style="list-style-type: none"> <li>1. Moved the drill rig 15' to new location</li> <li>2. Assembled the blowout preventer (BOP), drilling mud circulation equipment, and positioned the catwalk</li> <li>3. Tested various BOP system components and well control equipment</li> <li>4. Tensioned/adjusted the drill line cable</li> <li>5. Calibrated hoisting system</li> <li>6. Picked up the BHA and lowered it into the wellbore</li> <li>7. Drilled through the shoe track (seal at bottom of casing)</li> </ol>	<ol style="list-style-type: none"> <li>1. Hoisting system equipment/operations (picking up/setting down pipe, moving/raising drill pieces, lifting/positioning BHA)</li> <li>2. Tool noise during BOP/mud equipment assembly</li> <li>3. Testing BOP systems (pumps, valves, high-pressure lines)</li> <li>4. Drill line adjusting equipment (power tongs, elevators, power tools)</li> <li>5. Drilling equipment (Top drive/draw works system, mud pumps, shale shakers, drill bit impact)</li> </ol>

10/30/23	73.5	68.2	83.2	<ol style="list-style-type: none"> <li>1. Finished horizontal drilling, reaching final depth</li> <li>2. Cleaned wellbore by circulating drilling mud</li> <li>4. Removed the drill string from the wellbore and returned the BHA drill steering system to the storage rack</li> <li>5. Began lowering casing into the wellbore</li> </ol>	<ol style="list-style-type: none"> <li>1. Drilling equipment (top drive, draw works system)</li> <li>2. Drilling mud circulation (mud pumps, flow lines, shale shakers)</li> <li>3. Drill bit impact</li> <li>4. Pumps for circulating / displacing drilling mud</li> <li>6. Hoisting system equipment/operations (picking up/setting down pipe, racking BHA, moving/raising/lowering drill &amp; casing pieces)</li> </ol>
10/29/23	73.3	68.0	83.0	<ol style="list-style-type: none"> <li>1. Continued horizontal drilling</li> <li>2. Troubleshooted slowing in drill rate</li> <li>3. Removed entire drill string to replace drill head</li> <li>4. Returned drill string to wellbore with new drill head, continued drilling horizontal</li> </ol>	<ol style="list-style-type: none"> <li>1. Drilling equipment (top drive, draw works system)</li> <li>2. Drilling mud circulation (mud pumps, flow lines, shale shakers)</li> <li>3. Drill bit impact.</li> <li>4. Hoisting system equipment/operations (picking up/setting down pipe, moving/raising/lowering drill pieces)</li> <li>5. Tool noise while replacing drill head</li> </ol>
10/24/23	72.4	67.1	82.1	<ol style="list-style-type: none"> <li>1. Lowered the drill string back into the wellbore</li> <li>2. Displaced the drilling mud with an oil-based mud</li> <li>3. Drilled through the bottom components of the existing casing (the show track and float collar)</li> <li>4. Finished vertical drilling, continued with horizontal drilling</li> </ol>	<ol style="list-style-type: none"> <li>1. Hoisting system equipment/operations (picking up/setting down pipe, moving/raising/lowering drill pieces)</li> <li>2. Drilling equipment (top drive, draw works system)</li> <li>3. Drilling mud circulation (mud pumps, flow lines, shale shakers)</li> <li>4. Drill bit impact (especially during transition from vertical to horizontal)</li> </ol>

dBC – A-weighted Decibels

LC<sub>eq</sub> – Equivalent Continuous Sound Pressure Level in dBC

## 6. DISUCSSSION

### 6.1 Comparison to the Literature on Oil and Gas Noise

A major strength of this study, and one that makes it unique relating to oil and gas noise studies, was the removal of non-oil and gas related noise from the dataset using the G4 software. This data cleaning dramatically increased confidence that the calculated noise levels were, in fact, due to the drilling operations. The location of the drilling site in a rural location in a flat open field and the placement of the sound level meter several feet above the ground, away from major roads, with an unobstructed line-of-site to the oil rig also reduced the chances of interference from other noise sources or from the surrounding terrain. The noise monitoring performed in this study was also more data intensive as compared to other published oil and gas noise studies, incorporating more than 40 days into the calculated noise averages, which can help account for potential anomalies in the data and fluctuating noise levels from different drilling activities. Given these study parameters, some general comparisons can be made between the results of this study and published noise levels found at other oil and gas sites.

A summary of some select results from five studies on oil and gas noise is displayed in Table 9. Noise levels in the current study were found to be comparable to noise levels found in previous studies, if not a slightly quieter. At similar distances, previously measured noise levels from Allshouse et al. (2019), Radke et al. (2017), and McCawley et al. (2013) generally fell within the ranges (minimum to maximum) found in this study for the noise metric in question. Noise levels measured in Behrens and Associates (2006) and Blair et al. (2017) were found to be higher, however. For ease of comparison with the results from McCawley et al. (2013), the distance was artificially halved; halving the distance from a sound source mathematically results in a 6 dB increase in SPL, which is reflected in the 'result'. Radtke et al. (2017) appear to have include the most data in their analysis, having taken multiple samples at over 20

locations on multiple days. Many of the other studies only included a few measurements from one site. Due to the differences in measurement strategies and timeframes, it is difficult to make any conclusive statements about the similarities and differences in the data. Both the similar and higher noise levels observed in the data, though seem to support the conclusions and opinions of the authors of this study.

**Table 9: Comparison to Select Results from Previous Studies**

Study of Interest				Current Study	
Study/Description	Metric	Distance	Result	Metric Range	Distance
Allshouse et al., 2019 [29]	1 min L <sub>eq</sub>	868'	49.6 dBA 66.7 dBC	45.8 – 51.7 dBA 60.2 – 74.9 dBC	1,070'
Radtke et al., 2017 [30]	5 sec / 15 min L <sub>eq</sub>	350'	57 / 59 dBA 73 / 73 dBC	55.5 – 61.4 dBA 69.9 – 84.6 dBC	350'
Behrens and Associates, 2006	L <sub>eq</sub>	300'	70 – 74 dBA	55.5 – 61.4 dBA	350'
McCawley et al., 2013	24 hr. L <sub>eq</sub>	625' (312.5')*	54 dBA (60 dBA)*	55.5 – 61.4 dBA	350'
Blair et al., 2017	L <sub>eq</sub>	1,050' – 1,805'	51.5 – 60.2 dBA	40.5 – 51.7 dBA	1,070' – 1,975'

\*Values extrapolated by halving distance and increasing dB level by 6 for comparison purposes

dBA = A-Weighted Decibels

dBC = C-Weighted Decibels

L<sub>eq</sub> = Equivalent Continuous Sound Pressure Level

## 6.2 Distance and Setbacks

One of the most substantial observations based on the results of the current study is the clear importance of distance in minimizing the impact of drilling noise on community members. One immediate takeaway is that a 350' buffer is almost entirely ineffective at protecting residents living at that distance or maintaining compliance with noise regulations. The recent change of the ECMC rule, mandating noise compliance within 2,000' if a residential structure exists within that distance, does not ban new extraction operations within that distance. Hence the authors' decision to extrapolate noise levels back to the minimum distance; there are still Colorado residents living well within 2,000' of an

O&G well. For these residents, noise levels from drilling may not only be out of compliance with the ECMC noise limits but may also pose a risk for the evaluated health effects except for direct damage to the auditory organs. According to the distance extrapolated noise levels from the current study, those living at the border of the new setback (2,000') could expect an average 15 dB reduction in noise levels compared to those living at 350'. Though a substantial reduction, it is still not clear that residents are adequately protected, even at the 2000' distance. Noise levels extrapolated to 2,000' were still found to exceed the thresholds for sleep disturbance and annoyance as well as the ECMC LC<sub>eq</sub> day- and nighttime limit. Naturally, this begs the question: is the current setback sufficient to protect the community?

In January 2023, the California Senate passed a bill establishing a 3,200' setback distance between oil and gas drilling sites and sensitive receptors including residential structures and schools. This is the largest setback implemented by any state in the U.S. to date and has been challenged by O&G lobby groups as being "without scientific basis." The results of the noise monitoring performed in the current study, however, support a setback distance greater than the 2,000' currently in place in Colorado. Noise levels in the current study were estimated to exceed five thresholds across sleep disturbance, annoyance, and impact to self-reported well-being at distances of greater than 2,000 feet, and three thresholds across the same categories at distances greater than 3,000 feet. When considering the measured and predicted noise data from the current study in the context of the other oil and gas noise studies referenced in Table 9, other sites appear to be at least as loud, if not louder, than the noise levels reported in the current study. Based on the results from the current study, it can reasonably be inferred that extending the setback distance to 3,200' would reduce the risk of potential adverse health outcomes and that any setback beyond 2,000' would be beneficial to future residents living near an O&G well.

## 6.3 High Noise Days

Since the activity log only listed tasks completed and not a comprehensive list of task-specific equipment, identified noise sources are *possible* contributors, not definitive sources. Across all eight high-noise days, some common activities included operating/testing the blowout preventer, drilling, and activities involved in using the hoisting system such as raising/lowering/moving equipment, and inserting or removing the drill string, casing, or blowout preventer into and out of the well bore. The consistency of these activities across the different days points to the various components of the hoisting system, the drill rig, and the drilling mud circulation as possible loud-noise sources. Further, comparing noise levels from the next few highest-noise days (after the eight already included in the formal analysis in section 5.4.2) to the activity log shows similar trends in activities, supporting the assertion that the noise sources listed above may be major noise contributors. In reference to the highest  $LC_{eq}$  days only, the loudest days seem to be those on which horizontal drilling occurred and the hoisting equipment was used, especially to raise and lower the drill string; suggesting that these activities and the associated ancillary equipment may be sources of low frequency noise. The assertion that low-frequency noise emanates from horizontal drilling is further evidenced by the noise levels on 10/6; there was primarily cleaning being performed on that day and it was the only day included in the high noise days with no drilling activity. While the  $LA_{eq}$  was quite high (possibly due to noise from the high-pressure water used for cleaning), the  $LC_{eq}$  was approximately 10 dB lower than on those days that included drilling. Review of the activity log also reveals that on the 10 *lowest*  $LC_{eq}$  days (not included in the formal analysis in section 5.4.2), there was no drilling activity on seven of them. The  $LC_{eq}$  was also almost 10 dB below the average from 10/6 to 10/9 (a dip that is easily seen in Section 5.2, Figures 10A/10B). The activity log, again, reveals no drilling activities on these days. Together, these findings further strengthen the observational association between low frequency noise and activity. Further, it was observed from the octave band measurements for the five high- $LA_{eq}$  days that on the days drilling was performed there was

a large characteristic spike in the relatively low frequency SPLs near 40 Hz; the only day the low-frequency spike did not occur was on 10/6, the day with no drilling activity. It is clear from the substantial differences in measured dBA and dBC noise levels that low frequency noise is characteristic of drilling activities. However, a more detailed account of the equipment used during the activities listed in the activity log would be beneficial in making a more conclusive association between low-frequency noise and drilling site equipment.

## 6.4 Octave Band Comparisons

The octave band measurements taken in the current study were compared to the results of octave band measurements in environmental noise studies that had similar low-frequency noise spectra that could cause negative health impacts. In addition, studies that included the influence of noise frequency on noise annoyance was reviewed to determine if any related inferences could be drawn from the octave band results in the current study.

Three studies were identified that included octave band measurements for different types of road noise [101], [102], [103]. Octave band information was available from all three studies including the frequency range of 63 Hz to 8 kHz, varying in frequency intensity based on the vehicle and road type. Generally, the SPL octave band levels for road traffic had similar trends across the frequency range as compared to the SPL octave band levels found in the current study [101], [102], [103]. Similar to the octave band frequency measurements in the current study, elevated noise levels were reported at the very low end of the frequency spectrum (near 63 Hz), followed by a slight dip and then an increase in noise levels to a peak around 800 Hz – 1.5 kHz; and then a continuous decline in noise levels with little contribution to the overall SPL from frequencies greater than 8 kHz.

Researchers in several studies have associated higher levels of noise annoyance to lower frequency sounds [83], [98], [99], [104]. The high dBC noise levels and the 20 dB difference in average dBC and dBA

noise levels found in the current study were indicative of oil and gas noise being low-frequency heavy. The octave band SPLs were measured in A-weighted decibels (i.e., the low frequencies are intentionally depressed). Even with A-weighting applied to the octave band measurements, low frequencies below 250 Hz contributed a substantial amount of noise to the overall SPL, with a large spike around 40 Hz on days when drilling occurred. This low-frequency exposure, in consideration with the similarities to road traffic noise (a known contributor to nuisance environmental noise) lends further credibility to the proposition that oil and gas noise may have a negative impact on the overall health and wellbeing of nearby communities.

## 6.5 Missing Data

Of the 62 days on which noise levels were measured, twenty were not included in the final analysis (the selection criteria for days *included* are listed in section 4.2). Of these twenty, six were due to a corrupt file yielding no noise data for the day at all, leaving fourteen days of actual data excluded. An analysis of the noise data from these days reveals no patterns, abnormalities, outliers, or any other anomalies that would have significantly affected the overall results had those days been included in the analysis. The mean, minimum, maximum, and standard deviation of the  $LA_{eq}$  for the fourteen days *not* included were 50 dBA, 48.3 dBA, 52.2 dBA, and 1.2 dBA, respectively. Compared to the same statistics for the 42 days included in the final analysis, 49.1 dBA, 45.8 dBA, 51.7 dBA, and 1.3 dBA, respectively, all four statistics are slightly higher than but within 3 dBA of these values; including the fourteen days would have very slightly *increased* the reported values by a very small percentage. Additionally, there were no patterns in the timing of the days excluded (they were spaced out randomly over the measurement period) or activities performed on the days excluded.

## 6.5 Limitations

### 6.5.1 Generalizability

This generalizability of the current study results is limited to the use of an electric drill, specific equipment used on site, and the flat, unobstructed terrain that can affect the propagation of sound. The electric drill is intended to reduce noise levels as compared to conventional drilling rigs. The current study site was located in a flat, open field with no geographical or manufactured obstacles (other than the sound wall) between the sound level meter and the well pad. Large objects and terrain features (e.g., hills, buildings, forest, and bodies of water) can affect how sound propagates, either limiting or facilitating its travel. All extrapolated noise levels in this study were done under the assumption of uninterrupted propagation through open space and did not account for any environmental features that could affect sound propagation.

### 6.5.2 Non-Oil and Gas Operation noise sources

The influence of non-O&G noise sources was controlled by audio recording instances of noise greater than 65 dBA and then manually removing the specified noise if it was identified as unrelated to O&G activities. However, non-O&G related noise may have contributed to the measured noise in the current study if the noise did not exceed 65 dBA, triggering an audio recording and identification of the noise source. The impact of the non-O&G noise less than 65 dB, however, was assumed to be minimal. Further, only noise sources greater than 65 dB that were *definitively* and *obviously* not related to O&G were removed (e.g., animal noises, airplanes, train horns). Unidentified noises (e.g., rumblings and machine noise) were assumed to be from O&G operations and were included in the analysis.

### 6.5.3 Data Extrapolation

Conclusions in this study were, in part, based off extrapolated noise levels. Measurements were made at one distance in one direction from the noise source. Extrapolation was explicit when calculating projected noise levels at different distances, and implicit in the assumption that noise levels would be

the same at a given distance in all directions from the source. Extrapolating noise data from measured values introduces new factors that have the potential to affect the accuracy of the results. For example, atmospheric conditions such as temperature and relative humidity and environmental factors such as the type of ground (e.g., grass vs. rocky soil) affect the way sound propagates, either facilitating or limiting its travel. Attenuation of sound is also frequency dependent, meaning different frequencies will be absorbed at different rates by the air and surroundings. This can introduce error when extrapolating averages of broadband noise (which assumes equal propagation of all frequencies) depending on the relative frequency composition of the noise being measured. Any of these factors may cause values extrapolated to different distances to either over- or underestimate actual conditions at those locations. Noise sources can also have variation in directivity, meaning that they may not emit sound uniformly in all directions. Since measurements were only made in one direction from the source, it is possible that noise levels in other directions may be different at the same distance. Again, this may over- or underestimate noise levels at different locations. While extrapolated data are likely close approximations to actual values at different locations, it is important to note that factors affecting its accuracy have the potential to skew results in *either* direction. This can lead to conclusions being either more protective or insufficiently protective to potentially affected community members; without detailed information concerning all the factors listed, it is difficult to predict in which direction, if any, extrapolated values deviate from actual values.

#### 6.5.4 Indoor Noise Attenuation

Measured and extrapolated noise levels in this study represent those expected on the *exterior* of a residence at the specified distance. The walls of the structures themselves will provide further noise attenuation and so the results may not be representative of noise levels a resident inside a structure would be exposed to. While compliance is measured and established from outside a structure, certain health effects (e.g., sleep and cardiovascular effects) are based on noise exposure levels experienced by

the individual [53], [67], [72], [74], [89]. There are two primary factors that may affect the level of noise inside a residence: the noise attenuating properties of different building materials and the amount of people spend time during the day and night with windows and/or doors open/closed. Total individual noise exposure can also be affected by the amounts of time spent outside the home. The results of this study likely overestimate personal noise exposure inside the home, which may affect the potential for related adverse health effects.

#### 6.5.5 Baseline

Baseline noise levels were not measured at the site before or after drilling activities as a point of comparison. The lack of baseline noise measurements reduces the certainty that the noise measured was from drilling activities specifically and not attributable to some other source present in the absence of drilling. However, the location of the drilling site reduces some uncertainty since the well pad was located in a rural location away from busy roads, industrial structures, commercial buildings, and transportation hubs. In a 2013 environmental noise impact assessment, the California Public Utilities Commission found that baseline noise levels were approximately 30 dBA in rural and agricultural areas [105]. Noise levels measured in this study over 1,000 feet away from the well pad exceeded this level, on average, by more than 20 dBA. Given the lack of other prominent noise sources and the rural location, it can be assumed with some level of certainty that most, if not all, of the elevated noise levels were attributable to the drilling activity.

#### 6.5.6 Low thresholds

Some of the health effect noise thresholds were extremely low, resulting in the distances from the drilling site at which the thresholds would be exceeded being extremely high. An example was observed in two of the thresholds for sleep disturbance; the WHO [41] and EEA [22] reported the thresholds for observed and polysomnographic sleep disturbances to be 30 and 32 dBA, respectively. Based on the

noise levels measured at 1,070', the extrapolated distances at which those thresholds would be met were 8,306' and 6,598', respectively. Since baseline noise levels were not established for this area, it is uncertain whether these levels are achievable in this area. Externally, with typical rural noise levels being around 30 dBA, it is also unclear whether noise levels could fall below these thresholds in other locations. The large distances derived from extremely low thresholds, then, carry some uncertainty with them.

## 6.6 A Word on ChatGPT

OpenAI's™ ChatGPT is a natural language processor artificial intelligence software. It consists of a complex neural network with millions of parameters that have been trained on vast amounts of text data using machine learning algorithms. It uses this information to perform a wide variety of tasks including generating text, answering questions, summarizing documents, translating languages, and generating computer code. The information sources used to train the model include books, articles, websites, research papers, technical documentation, educational material, legal documents, and multimedia transcripts. This includes both peer-reviewed and non-peer-reviewed sources, and any information provided by the software should be understood as such. For this reason, the use of the software was limited to translating technical terminology and making conjectures as to sources of noise within common oil and gas drilling activity. Although pulling from an enormous body of literature, ChatGPT is not an infallible software and therefore the results in section 5.4.2, *Noise Source Analysis*, are taken as reasonable conjecture, not as definitive fact. At most, they should be viewed as areas of interest, possibly ones warranting further investigation.

## 7. CONCLUSION

Results from this study support the rejection of both null hypotheses (section 3.3) and concluding that

1. noise levels from O&G drilling activity exceed the ECMC published noise level limits at specified distances and
2. community members living near O&G extraction site are potentially at increased risk of adverse health effects based on measured and predicted noise levels.

Noise levels due to oil and gas drilling activities using an electric drill were found to exceed noise limits set by the ECMC and noise levels that are potentially harmful to community residents living nearby. Low frequency noise was highly characteristic of the measured drilling activities, with average C-weighted decibel levels exceeding average A-weighted decibel levels by more than 20 decibels. Activities involving operating the drilling rig's hoisting mechanisms and ancillary equipment associated with operating the drill appear to have been two significant contributors to the noise levels during the measurement period. The measured noise was spectrally similar to traffic noise which is a known harmful environmental noise, and the dominant frequencies measured in the current study were similar to those frequencies known to cause noise annoyance.

This study was limited to the drilling phase of O&G extraction only. However, researchers suggest that other phases of extraction (site preparation, hydraulic fracturing, flowback, tear-down, etc.) also generate elevated levels of noise. A similar collection and analysis of noise data from those additional O&G extraction phases is suggested to determine the degree of community noise exposure from all phases of oil and gas extraction operations. It is possible that the risks of various health effects, the distances at which those risks arise, and the degree to which compliance limits are violated may be underestimated for the entire extraction process by considering drilling noise data alone. Additionally,

for the purposes of assessing options for noise abatement and control, having data from all O&G extraction phases will help prioritize and allocate resources.

The results from the current study support the hypothesis that those living near extraction operations are at increased risk of adverse health effects but do not establish a causal link to any specific outcome.

As discussed in section 2.6, *Noise and Health*, Epidemiological studies *have* established causal links to these health effects with other sources of environmental noise; further research is warranted to examine the health impacts from oil and gas noise.

Radtke et al (2017) demonstrated that the use of the sound wall was effective in reducing dBA levels, but much less effective in reducing dBC levels. Given the relatively high levels of dBA reported in this study with the sound wall in place, sound walls should continue to be a standard part of all drilling activities to protect community members. Additional efforts, however, need to be made to control the low frequency noise produced during drilling. To further inform noise control development, equipment-specific area monitoring is necessary to conclusively identify high-noise sources during the various activities.

Well pad setback distances in all states should be sufficient to protect community members. The 3,200' recommended in California is likely adequate to eliminate the risk of most, and possibly all, adverse health effects. Until more data are available regarding the actual incidence rates of these effects in those living near extractions sites and noise levels generated during the other phases of extraction, setback distances that err on the side of caution should be implemented in areas with high oil and gas activity.

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## Appendix A

Daily Average Noise Statistics and Select High Noise Days Octave Band Results

**Table 10: Daily Average Statistics at the Measurement Location (1,070')**

Date	At Measurement Location (1070')										
	LA <sub>eq</sub> (dBA)	LC <sub>eq</sub> (dBC)	LC <sub>eq</sub> - LA <sub>eq</sub> (dB)	L <sub>dn</sub> (dBA)	L <sub>day</sub> (dBA)	L <sub>Night</sub> (dBA)	L <sub>5</sub> (dBA)	L <sub>10</sub> (dBA)	L <sub>90</sub> (dBA)	LA <sub>fmax</sub> (dBA)	LC <sub>fmax</sub> (dBC)
9/1/2023	49.8	69.5	19.7	54.3	50.2	47.3	-	-	-	-	-
9/2/2023	49.1	68.3	19.2	55.8	48.4	49.6	-	-	-	-	-
9/4/2023	48.6	68.7	20.2	53.9	49.3	47.1	-	-	-	-	-
9/8/2023	49.4	69	19.6	57.7	46.9	51.7	54.8	53.1	42.7	72.9	82.5
9/10/2023	49.7	69.4	19.7	56.4	49.5	50.1	-	-	-	-	-
9/12/2023	46.8	66	19.2	50.8	48.4	43.1	-	-	-	-	-
9/14/2023	49.1	71	21.9	53.6	50.4	46.4	-	-	-	-	-
9/15/2023	48.9	69.6	20.8	52.2	50.3	44.1	-	-	-	-	-
9/16/2023	49.9	69.1	19.2	53.6	51.2	45.9	51.8	50.2	40.8	82.7	81.7
9/17/2023	47.6	68.9	21.3	52.5	48.5	45.6	51.7	50.4	42.7	69.6	84
9/18/2023	48.7	68.5	19.8	54.6	49	48	-	-	-	-	-
9/19/2023	49.3	67.9	18.6	54.8	50.2	48	-	-	-	-	-
9/20/2023	48.4	68.9	20.6	54	48.9	47.3	-	-	-	-	-
9/21/2023	48.6	69.8	21.2	55.2	48	49	-	-	-	-	-
9/22/2023	51	70.2	19.3	57.3	49.7	51	-	-	-	-	-
9/24/2023	47.8	69.5	21.7	53.3	48.4	46.5	51	50	43.3	78.8	84
9/25/2023	49.3	69.4	20.1	54.4	50.1	47.5	53	51.7	42.2	80.8	80.9
9/26/2023	48.5	69.1	20.6	55	48.5	48.6	52	51	43.5	72.5	82.6
9/27/2023	48.5	69.8	21.3	54.2	48.9	47.6	51.7	50.8	42.3	75.5	83.8
9/29/2023	50.7	70.9	20.2	56.4	51.3	49.7	54	53.1	46.9	72.7	90.3
9/30/2023	49.1	68.9	19.8	53.6	50.2	46.4	50.5	49.4	42.9	79.7	97.9
10/4/2023	49.9	72.2	22.3	55.6	50.3	49	53.8	52.9	43.6	76.2	86

10/5/2023	49.6	67.7	18.1	56.3	49.4	50	54.3	53	42.2	73.2	82.3
10/6/2023	51.7	61.3	9.6	56.3	52.7	49.2	53	52	44.1	91.9	91.6
10/7/2023	51.5	61.1	9.6	54.8	52.9	46.8	50.5	49.4	41.1	88	91.4
10/8/2023	45.8	61.2	15.4	52.5	45.6	46.2	49.4	48	39.8	74	83.5
10/9/2023	46.3	60.2	13.9	52.3	46.7	45.7	51	49.5	38.5	68.5	81.8
10/10/2023	48.3	71.2	22.9	54.3	48.5	47.8	52.5	50.9	41.9	76	84.6
10/14/2023	49	70.7	21.6	54.2	49.8	47.3	-	-	-	-	-
10/15/2023	48.3	70.4	22.1	53.6	49	46.8	-	-	-	-	-
10/16/2023	49.3	70.1	20.8	54.9	49.8	48.2	-	-	-	-	-
10/17/2023	48.6	70.1	21.5	54.7	49	48.1	-	-	-	-	-
10/18/2023	50.4	71.9	21.5	55.8	51.2	49	-	-	-	-	-
10/19/2023	49.2	70.8	21.6	54.1	50.1	47.1	53.4	51.8	42.7	74.2	82.3
10/20/2023	48.8	70.4	21.6	54.4	49.3	47.7	-	-	-	-	-
10/21/2023	48.6	69.5	20.9	54.3	48.9	47.7	-	-	-	-	-
10/22/2023	47.6	70.8	23.2	54.2	47.5	47.9	50.4	49.7	43.9	73	80.8
10/23/2023	50.6	71.5	20.9	55	51.7	47.8	-	-	-	-	-
10/24/2023	50.4	72.4	22	55.8	51.6	48.8	-	-	-	-	-
10/27/2023	51.2	73.9	22.7	55.8	52.4	48.7	-	-	-	-	-
10/28/2023	51.1	74.9	23.8	56.4	51.7	49.7	-	-	-	-	-
10/29/2023	50.3	73.3	23	55.6	51.1	48.8	-	-	-	-	-
10/30/2023	47.8	73.5	25.8	54	47.9	47.5	-	-	-	-	-

dB – Decibel  $L_{day} - LA_{eq}$  for Daytime Period (7:00 a.m. to 10:00 p.m.)

dBA – A-Weighted Decibel  $L_{Night} - LA_{eq}$  for Daytime Period (7:00 a.m. to 10:00 p.m.)

dBc – C-Weighted Decibel  $L_{5/10/90p} - 95^{th}, 90^{th}, \text{ and } 10^{th}$  percentile SPL

$LA_{eq}$  – Equivalent Continuous Sound Pressure Level (A-Weighted Decibels)

$LA_{fmax}$  – Maximum SPL with fast time-weighting in dBA

$LC_{eq}$  – Equivalent Continuous Sound Pressure Level (C-Weighted Decibels)

$LC_{fmax}$  – Maximum SPL with fast time-weighting in dBc

$[LC_{eq} - LA_{eq}]$  – Difference between  $LC_{eq}$  and  $LA_{eq}$

**Table 11: Daily Average Statistics Distance Extrapolated to Maximum Compliance Point (1,975')**

Date	Distance Extrapolated to Maximum Compliance Point (1,975')										
	LA <sub>eq</sub> (dBA)	LC <sub>eq</sub> (dBC)	LC <sub>eq</sub> - LA <sub>eq</sub> (dB)	L <sub>dn</sub> (dBA)	L <sub>day</sub> (dBA)	L <sub>Night</sub> (dBA)	L <sub>5</sub> (dBA)	L <sub>10</sub> (dBA)	L <sub>90</sub> (dBA)	LA <sub>fmax</sub> (dBA)	LC <sub>fmax</sub> (dBC)
9/1/2023	44.5	64.2	19.7	49.0	44.9	42.0	-	-	-	-	-
9/2/2023	43.8	63.0	19.2	50.5	43.1	44.3	-	-	-	-	-
9/4/2023	43.3	63.4	20.1	48.6	44.0	41.8	-	-	-	-	-
9/8/2023	44.1	63.7	19.6	52.4	41.6	46.4	49.5	47.8	37.4	67.6	77.2
9/10/2023	44.4	64.1	19.7	51.1	44.2	44.8	-	-	-	-	-
9/12/2023	41.5	60.7	19.2	45.5	43.1	37.8	-	-	-	-	-
9/14/2023	43.8	65.7	21.9	48.3	45.1	41.1	-	-	-	-	-
9/15/2023	43.6	64.3	20.7	46.9	45.0	38.8	-	-	-	-	-
9/16/2023	44.6	63.8	19.2	48.3	45.9	40.6	46.5	44.9	35.5	77.4	76.4
9/17/2023	42.3	63.6	21.3	47.2	43.2	40.3	46.4	45.1	37.4	64.3	78.7
9/18/2023	43.4	63.2	19.8	49.3	43.7	42.7	-	-	-	-	-
9/19/2023	44.0	62.6	18.6	49.5	44.9	42.7	-	-	-	-	-
9/20/2023	43.1	63.6	20.5	48.7	43.6	42.0	-	-	-	-	-
9/21/2023	43.3	64.5	21.2	49.9	42.7	43.7	-	-	-	-	-
9/22/2023	45.7	64.9	19.2	52.0	44.4	45.7	-	-	-	-	-
9/24/2023	42.5	64.2	21.7	48.0	43.1	41.2	45.7	44.7	38.0	73.5	78.7
9/25/2023	44.0	64.1	20.1	49.1	44.8	42.2	47.7	46.4	36.9	75.5	75.6
9/26/2023	43.2	63.8	20.6	49.7	43.2	43.3	46.7	45.7	38.2	67.2	77.3
9/27/2023	43.2	64.5	21.3	48.9	43.6	42.3	46.4	45.5	37.0	70.2	78.5
9/29/2023	45.4	65.6	20.2	51.1	46.0	44.4	48.7	47.8	41.6	67.4	85.0
9/30/2023	43.8	63.6	19.8	48.3	44.9	41.1	45.2	44.1	37.6	74.4	92.6
10/4/2023	44.6	66.9	22.3	50.3	45.0	43.7	48.5	47.6	38.3	70.9	80.7

10/5/2023	44.3	62.4	18.1	51.0	44.1	44.7	49.0	47.7	36.9	67.9	77.0
10/6/2023	46.4	56.0	9.6	51.0	47.4	43.9	47.7	46.7	38.8	86.6	86.3
10/7/2023	46.2	55.8	9.6	49.5	47.6	41.5	45.2	44.1	35.8	82.7	86.1
10/8/2023	40.5	55.9	15.4	47.2	40.3	40.9	44.1	42.7	34.5	68.7	78.2
10/9/2023	41.0	54.9	13.9	47.0	41.4	40.4	45.7	44.2	33.2	63.2	76.5
10/10/2023	43.0	65.9	22.9	49.0	43.2	42.5	47.2	45.6	36.6	70.7	79.3
10/14/2023	43.7	65.4	21.7	48.9	44.5	42.0	-	-	-	-	-
10/15/2023	43.0	65.1	22.1	48.3	43.7	41.5	-	-	-	-	-
10/16/2023	44.0	64.8	20.8	49.6	44.5	42.9	-	-	-	-	-
10/17/2023	43.3	64.8	21.5	49.4	43.7	42.8	-	-	-	-	-
10/18/2023	45.1	66.6	21.5	50.5	45.9	43.7	-	-	-	-	-
10/19/2023	43.9	65.5	21.6	48.8	44.8	41.8	48.1	46.5	37.4	68.9	77.0
10/20/2023	43.5	65.1	21.6	49.1	44.0	42.4	-	-	-	-	-
10/21/2023	43.3	64.2	20.9	49.0	43.6	42.4	-	-	-	-	-
10/22/2023	42.3	65.5	23.2	48.9	42.2	42.6	45.1	44.4	38.6	67.7	75.5
10/23/2023	45.3	66.2	20.9	49.7	46.4	42.5	-	-	-	-	-
10/24/2023	45.1	67.1	22.0	50.5	46.3	43.5	-	-	-	-	-
10/27/2023	45.9	68.6	22.7	50.5	47.1	43.4	-	-	-	-	-
10/28/2023	45.8	69.6	23.8	51.1	46.4	44.4	-	-	-	-	-
10/29/2023	45.0	68.0	23.0	50.3	45.8	43.5	-	-	-	-	-
10/30/2023	42.5	68.2	25.7	48.7	42.6	42.2	-	-	-	-	-

dB – Decibel                      L<sub>day</sub> – LA<sub>eq</sub> for Daytime Period (7:00 a.m. to 10:00 p.m.)

dBA – A-Weighted Decibel                      L<sub>Night</sub> – LA<sub>eq</sub> for Daytime Period (7:00 a.m. to 10:00 p.m.)

dBc – C-Weighted Decibel                      L<sub>5/10/90p</sub> – 95<sup>th</sup>, 90<sup>th</sup>, and 10<sup>th</sup> percentile SPL

LA<sub>eq</sub> – Equivalent Continuous Sound Pressure Level (A-Weighted Decibels)

LA<sub>fmax</sub> – Maximum SPL with fast time-weighting in dBA

LC<sub>eq</sub> – Equivalent Continuous Sound Pressure Level (C-Weighted Decibels)

LC<sub>fmax</sub> – Maximum SPL with fast time-weighting in dBc

[LC<sub>eq</sub> – LA<sub>eq</sub>] – Difference between LC<sub>eq</sub> and LA<sub>eq</sub>

**Table 12: Daily Average Statistics Distance Extrapolated to Current Setback Point (2,000')**

Date	Distance Extrapolated to Current Setback (2,000')										
	LA <sub>eq</sub> (dBA)	LC <sub>eq</sub> (dBC)	LC <sub>eq</sub> - LA <sub>eq</sub> (dB)	L <sub>dn</sub> (dBA)	L <sub>day</sub> (dBA)	L <sub>Night</sub> (dBA)	L <sub>5</sub> (dBA)	L <sub>10</sub> (dBA)	L <sub>90</sub> (dBA)	LA <sub>fmax</sub> (dBA)	LC <sub>fmax</sub> (dBC)
9/1/2023	44.4	64.1	19.7	48.9	44.8	41.9	-	-	-	-	-
9/2/2023	43.7	62.9	19.2	50.4	43.0	44.2	-	-	-	-	-
9/4/2023	43.2	63.3	20.1	48.5	43.9	41.7	-	-	-	-	-
9/8/2023	44.0	63.6	19.6	52.3	41.5	46.3	49.4	47.7	37.3	67.5	77.1
9/10/2023	44.3	64.0	19.7	51.0	44.1	44.7	-	-	-	-	-
9/12/2023	41.4	60.6	19.2	45.4	43.0	37.7	-	-	-	-	-
9/14/2023	43.7	65.6	21.9	48.2	45.0	41.0	-	-	-	-	-
9/15/2023	43.5	64.2	20.7	46.8	44.9	38.7	-	-	-	-	-
9/16/2023	44.5	63.7	19.2	48.2	45.8	40.5	46.4	44.8	35.4	77.3	76.3
9/17/2023	42.2	63.5	21.3	47.1	43.1	40.2	46.3	45.0	37.3	64.2	78.6
9/18/2023	43.3	63.1	19.8	49.2	43.6	42.6	-	-	-	-	-
9/19/2023	43.9	62.5	18.6	49.4	44.8	42.6	-	-	-	-	-
9/20/2023	43.0	63.5	20.5	48.6	43.5	41.9	-	-	-	-	-
9/21/2023	43.2	64.4	21.2	49.8	42.6	43.6	-	-	-	-	-
9/22/2023	45.6	64.8	19.2	51.9	44.3	45.6	-	-	-	-	-
9/24/2023	42.4	64.1	21.7	47.9	43.0	41.1	45.6	44.6	37.9	73.4	78.6
9/25/2023	43.9	64.0	20.1	49.0	44.7	42.1	47.6	46.3	36.8	75.4	75.5
9/26/2023	43.1	63.7	20.6	49.6	43.1	43.2	46.6	45.6	38.1	67.1	77.2
9/27/2023	43.1	64.4	21.3	48.8	43.5	42.2	46.3	45.4	36.9	70.1	78.4
9/29/2023	45.3	65.5	20.2	51.0	45.9	44.3	48.6	47.7	41.5	67.3	84.9
9/30/2023	43.7	63.5	19.8	48.2	44.8	41.0	45.1	44.0	37.5	74.3	92.5
10/4/2023	44.5	66.8	22.3	50.2	44.9	43.6	48.4	47.5	38.2	70.8	80.6

10/5/2023	44.2	62.3	18.1	50.9	44.0	44.6	48.9	47.6	36.8	67.8	76.9
10/6/2023	46.3	55.9	9.6	50.9	47.3	43.8	47.6	46.6	38.7	86.5	86.2
10/7/2023	46.1	55.7	9.6	49.4	47.5	41.4	45.1	44.0	35.7	82.6	86.0
10/8/2023	40.4	55.8	15.4	47.1	40.2	40.8	44.0	42.6	34.4	68.6	78.1
10/9/2023	40.9	54.8	13.9	46.9	41.3	40.3	45.6	44.1	33.1	63.1	76.4
10/10/2023	42.9	65.8	22.9	48.9	43.1	42.4	47.1	45.5	36.5	70.6	79.2
10/14/2023	43.6	65.3	21.7	48.8	44.4	41.9	-	-	-	-	-
10/15/2023	42.9	65.0	22.1	48.2	43.6	41.4	-	-	-	-	-
10/16/2023	43.9	64.7	20.8	49.5	44.4	42.8	-	-	-	-	-
10/17/2023	43.2	64.7	21.5	49.3	43.6	42.7	-	-	-	-	-
10/18/2023	45.0	66.5	21.5	50.4	45.8	43.6	-	-	-	-	-
10/19/2023	43.8	65.4	21.6	48.7	44.7	41.7	48.0	46.4	37.3	68.8	76.9
10/20/2023	43.4	65.0	21.6	49.0	43.9	42.3	-	-	-	-	-
10/21/2023	43.2	64.1	20.9	48.9	43.5	42.3	-	-	-	-	-
10/22/2023	42.2	65.4	23.2	48.8	42.1	42.5	45.0	44.3	38.5	67.6	75.4
10/23/2023	45.2	66.1	20.9	49.6	46.3	42.4	-	-	-	-	-
10/24/2023	45.0	67.0	22	50.4	46.2	43.4	-	-	-	-	-
10/27/2023	45.8	68.5	22.7	50.4	47.0	43.3	-	-	-	-	-
10/28/2023	45.7	69.5	23.8	51.0	46.3	44.3	-	-	-	-	-
10/29/2023	44.9	67.9	23	50.2	45.7	43.4	-	-	-	-	-
10/30/2023	42.4	68.1	25.7	48.6	42.5	42.1	-	-	-	-	-

dB – Decibel  $L_{day} - LA_{eq}$  for Daytime Period (7:00 a.m. to 10:00 p.m.)

dBA – A-Weighted Decibel  $L_{Night} - LA_{eq}$  for Daytime Period (7:00 a.m. to 10:00 p.m.)

dBc – C-Weighted Decibel  $L_{5/10/90p} - 95^{th}, 90^{th}, \text{ and } 10^{th}$  percentile SPL

$LA_{eq}$  – Equivalent Continuous Sound Pressure Level (A-Weighted Decibels)

$LA_{fmax}$  – Maximum SPL with fast time-weighting in dBA

$LC_{eq}$  – Equivalent Continuous Sound Pressure Level (C-Weighted Decibels)

$LC_{fmax}$  – Maximum SPL with fast time-weighting in dBc

$[LC_{eq} - LA_{eq}]$  – Difference between  $LC_{eq}$  and  $LA_{eq}$

**Table 13: Daily Average Statistics Distance Extrapolated to Minimum Compliance Point / Old Setback (350')**

Date	Distance Extrapolated to Minimum Compliance Point / Old Setback (350')										
	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)	LA <sub>eq</sub> (dBA)
9/1/2023	59.5	79.2	19.7	64.0	59.9	57.0	-	-	-	-	-
9/2/2023	58.8	78.0	19.2	65.5	58.1	59.3	-	-	-	-	-
9/4/2023	58.3	78.4	20.1	63.6	59.0	56.8	-	-	-	-	-
9/8/2023	59.1	78.7	19.6	67.4	56.6	61.4	64.5	62.8	52.4	82.6	92.2
9/10/2023	59.4	79.1	19.7	66.1	59.2	59.8	-	-	-	-	-
9/12/2023	56.5	75.7	19.2	60.5	58.1	52.8	-	-	-	-	-
9/14/2023	58.8	80.7	21.9	63.3	60.1	56.1	-	-	-	-	-
9/15/2023	58.6	79.3	20.7	61.9	60.0	53.8	-	-	-	-	-
9/16/2023	59.6	78.8	19.2	63.3	60.9	55.6	61.5	59.9	50.5	92.4	91.4
9/17/2023	57.3	78.6	21.3	62.2	58.2	55.3	61.4	60.1	52.4	79.3	93.7
9/18/2023	58.4	78.2	19.8	64.3	58.7	57.7	-	-	-	-	-
9/19/2023	59.0	77.6	18.6	64.5	59.9	57.7	-	-	-	-	-
9/20/2023	58.1	78.6	20.5	63.7	58.6	57.0	-	-	-	-	-
9/21/2023	58.3	79.5	21.2	64.9	57.7	58.7	-	-	-	-	-
9/22/2023	60.7	79.9	19.2	67.0	59.4	60.7	-	-	-	-	-
9/24/2023	57.5	79.2	21.7	63.0	58.1	56.2	60.7	59.7	53.0	88.5	93.7
9/25/2023	59.0	79.1	20.1	64.1	59.8	57.2	62.7	61.4	51.9	90.5	90.6
9/26/2023	58.2	78.8	20.6	64.7	58.2	58.3	61.7	60.7	53.2	82.2	92.3
9/27/2023	58.2	79.5	21.3	63.9	58.6	57.3	61.4	60.5	52.0	85.2	93.5
9/29/2023	60.4	80.6	20.2	66.1	61.0	59.4	63.7	62.8	56.6	82.4	100.0
9/30/2023	58.8	78.6	19.8	63.3	59.9	56.1	60.2	59.1	52.6	89.4	107.6
10/4/2023	59.6	81.9	22.3	65.3	60.0	58.7	63.5	62.6	53.3	85.9	95.7
10/5/2023	59.3	77.4	18.1	66.0	59.1	59.7	64.0	62.7	51.9	82.9	92.0

10/6/2023	61.4	71.0	9.6	66.0	62.4	58.9	62.7	61.7	53.8	101.6	101.3
10/7/2023	61.2	70.8	9.6	64.5	62.6	56.5	60.2	59.1	50.8	97.7	101.1
10/8/2023	55.5	70.9	15.4	62.2	55.3	55.9	59.1	57.7	49.5	83.7	93.2
10/9/2023	56.0	69.9	13.9	62.0	56.4	55.4	60.7	59.2	48.2	78.2	91.5
10/10/2023	58.0	80.9	22.9	64.0	58.2	57.5	62.2	60.6	51.6	85.7	94.3
10/14/2023	58.7	80.4	21.7	63.9	59.5	57.0	-	-	-	-	-
10/15/2023	58.0	80.1	22.1	63.3	58.7	56.5	-	-	-	-	-
10/16/2023	59.0	79.8	20.8	64.6	59.5	57.9	-	-	-	-	-
10/17/2023	58.3	79.8	21.5	64.4	58.7	57.8	-	-	-	-	-
10/18/2023	60.1	81.6	21.5	65.5	60.9	58.7	-	-	-	-	-
10/19/2023	58.9	80.5	21.6	63.8	59.8	56.8	63.1	61.5	52.4	83.9	92.0
10/20/2023	58.5	80.1	21.6	64.1	59.0	57.4	-	-	-	-	-
10/21/2023	58.3	79.2	20.9	64.0	58.6	57.4	-	-	-	-	-
10/22/2023	57.3	80.5	23.2	63.9	57.2	57.6	60.1	59.4	53.6	82.7	90.5
10/23/2023	60.3	81.2	20.9	64.7	61.4	57.5	-	-	-	-	-
10/24/2023	60.1	82.1	22.0	65.5	61.3	58.5	-	-	-	-	-
10/27/2023	60.9	83.6	22.7	65.5	62.1	58.4	-	-	-	-	-
10/28/2023	60.8	84.6	23.8	66.1	61.4	59.4	-	-	-	-	-
10/29/2023	60.0	83.0	23.0	65.3	60.8	58.5	-	-	-	-	-
10/30/2023	57.5	83.2	25.7	63.7	57.6	57.2	-	-	-	-	-

dB – Decibel                      L<sub>day</sub> – LA<sub>eq</sub> for Daytime Period (7:00 a.m. to 10:00 p.m.)

dBA – A-Weighted Decibel                      L<sub>Night</sub> – LA<sub>eq</sub> for Daytime Period (7:00 a.m. to 10:00 p.m.)

dBC – C-Weighted Decibel                      L<sub>5/10/90p</sub> – 95<sup>th</sup>, 90<sup>th</sup>, and 10<sup>th</sup> percentile SPL

LA<sub>eq</sub> – Equivalent Continuous Sound Pressure Level (A-Weighted Decibels)

LA<sub>fmax</sub> – Maximum SPL with fast time-weighting in dBA

LC<sub>eq</sub> – Equivalent Continuous Sound Pressure Level (C-Weighted Decibels)

LC<sub>fmax</sub> – Maximum SPL with fast time-weighting in dBC

[LC<sub>eq</sub> – LA<sub>eq</sub>] – Difference between LC<sub>eq</sub> and LA<sub>eq</sub>

**Table 14: 1/3 Octave Band Results for Select High Noise Days**

Date	Sound Pressure Level (dBA) by Frequency Band Center (Hz)																	
	6.3	8	10	12.5	16	20	25	31.5	40	50	63	80	100	125	160	200	250	315
9/29/23	-15.8	-9.5	-3.4	2.1	6.8	11.2	14.4	32.5	23.3	25.1	30.7	30.7	30.5	30.3	29.1	29.5	32.5	35.2
9/22/23	-37.9	-30.4	-20.7	-13.2	-2.8	2.1	7.6	32.1	24.6	24.6	31.7	32.2	31.2	29.9	28.7	29.2	31.3	34.6
10/23/23	-23.3	-17	-10.9	-4.9	1.2	5.4	8.9	33.7	22	25.1	29.3	29.4	30.3	28.7	28.5	29.9	32.9	35.8
10/27/23	-15.8	-9.7	-3.9	1.3	6.5	11	13.9	36.1	23.1	26.5	30.5	34.1	35.3	32.3	31.9	32.4	34.1	37
10/28/23	-23.4	-17.3	-11.7	-6.1	0.7	4.1	9.8	37.6	21.5	23.7	29.4	28.7	28.8	28.9	28.3	29.6	32.6	38

Sound Pressure Level (dBA) by Frequency Band Center (Hz) [cont.]																	
400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10000	12500	16000	20000
38.6	41.5	42.6	43.2	42	41.3	38.7	37.3	33.1	30.5	26.2	20.1	16	13.4	10.2	6.9	4.6	0.4
38.7	41.1	42	43.6	40.8	42	40.1	40.5	34.9	32.5	27.3	22.1	16.8	8.2	4.9	3	0.7	-2.3
39.9	41.9	42.7	42.8	41.4	40.9	38.9	36.8	31.9	30.1	24.8	17	10.9	8.9	6.7	5.1	3	-1.6
39	41.5	42.8	43.7	43	41.1	38.6	36.7	32.8	28.5	22.7	17.5	14.6	12	8.7	6.9	4.7	-0.8
40.1	43.3	42.4	43	42.2	41.2	37.6	36.3	31.4	27	20.9	13.6	10.3	8.8	6.8	5.9	4.2	-0.7

dBA – A-Weighted Decibels

Hz – Hertz

## Appendix B

ChatGPT Response Printouts

## Activity Log Entry 10/6/2023

1. CLEAN RIG/CHANGE OUT IBOP/BUILD FOUR STANDS OF DP/PICK UP BHA AND RACK IN DERRICK

### ChatGPT Interpretation

1. Clean rig:	<ul style="list-style-type: none"><li>• This involves cleaning the drilling rig and its components, including the drill floor, derrick, mud tanks, mud pumps, and other equipment. Cleaning the rig helps maintain a safe and efficient working environment, removes debris and mud buildup, and prevents corrosion and equipment damage.</li></ul>
2. Change out IBOP:	<ul style="list-style-type: none"><li>• IBOP stands for Inside Blowout Preventer, which is a critical safety device used in drilling operations to control wellbore pressure. Changing out the IBOP involves removing the existing IBOP from the drill string and replacing it with a new one. This may be done as part of routine maintenance or in response to equipment failure or damage.</li></ul>
3. Build four stands of DP:	<ul style="list-style-type: none"><li>• DP stands for Drill Pipe, which is a hollow steel pipe used to transmit drilling fluid and torque from the surface to the drill bit at the bottom of the wellbore. Building four stands of DP involves assembling or connecting sections of drill pipe to create four complete stands, each consisting of multiple joints of drill pipe. These assembled stands are then prepared for deployment in the wellbore during drilling operations.</li></ul>
4. Pick up BHA and rack in derrick:	<ul style="list-style-type: none"><li>• BHA stands for Bottom Hole Assembly, which refers to the components of the drill string located near the bottom of the wellbore, including the drill bit, drill collars, stabilizers, and other tools.</li><li>• Picking up the BHA involves using the rig's hoisting equipment (such as the traveling block and hook) to lift the BHA from the wellbore to the surface.</li><li>• Racking in the derrick refers to placing the lifted BHA components in the derrick's storage area, known as the "fingerboards" or "racking board," for safekeeping and easy access. The components are typically arranged in a specific order and secured to prevent movement during rig operations.</li></ul>

### ChatGPT Conjectured Noise Sources

1. Equipment Operation:	<ul style="list-style-type: none"><li>• The operation of drilling equipment such as mud pumps, drawworks, top drive systems, and rotary tables can generate significant noise levels. These machines are essential for drilling operations but can produce loud and continuous noise.</li></ul>
2. Hoisting Operations:	<ul style="list-style-type: none"><li>• Activities such as picking up and setting down drill pipe, Bottom Hole Assembly (BHA), and other tubulars using the rig's hoisting equipment (traveling block, crown block, and drawworks) can produce loud noise, particularly when engaging or disengaging the rig's braking systems.</li></ul>
3. Pipe Handling:	

	<ul style="list-style-type: none"> <li>The movement of drill pipe, casing, and other tubulars on the drill floor can create noise, especially when handling heavy components or when using power tongs, elevators, or other handling tools.</li> </ul>
4.	<b>Iron Roughnecks:</b> <ul style="list-style-type: none"> <li>Iron roughnecks are automated pipe-handling systems used to make up and break out threaded connections on drill pipe and casing. The operation of iron roughnecks can generate noise as they grip, rotate, and torque pipe sections.</li> </ul>
5.	<b>Cementing Operations:</b> <ul style="list-style-type: none"> <li>Cementing activities, including mixing and pumping cement slurries down the casing string, can produce noise from the operation of cement pumps, mixers, and associated equipment.</li> </ul>
6.	<b>Crew Communication:</b> <ul style="list-style-type: none"> <li>Shouting and communication among rig crew members, especially during noisy operations or when working in different areas of the rig, can contribute to overall noise levels.</li> </ul>
7.	<b>Rig-Up and Rig-Down:</b> <ul style="list-style-type: none"> <li>Activities involved in rigging up (assembling) and rigging down (disassembling) the drilling rig, including moving heavy equipment, erecting and dismantling structures, and securing loads, can generate noise from machinery, metal-on-metal contact, and hydraulic systems.</li> </ul>
8.	<b>Environment:</b> <ul style="list-style-type: none"> <li>Environmental factors such as wind, rain, and sea conditions can affect noise levels on a drilling rig. Wind can amplify noise, while rain can create additional background noise. In offshore environments, the sound of waves and ocean currents may also contribute to overall noise levels.</li> </ul>

## Activity Log Entry 10/27/2023

1. WALK RIG 15' TO THE [REDACTED] 22C
2. NIPPLE UP BOP/ RIG UP MUD LINES/ POSITION CATWALK
3. TEST PIPE RAMS, BLIND RAMS, CHOKE MANIFOLD, CHOKE LINE, HCR'S AND KILL LINE VALVES, LOWER KELLY, FLOOR VALVE AND DART VALVE, TEST WELLHEAD.
4. SLIP N' CUT DRILL LINE/ CALIBRATE BLOCKS
5. P/U BHA AS PER DIRECTIONAL/ TRIP IN HOLE
6. DRILL OUT SHOE TRACK

## ChatGPT Interpretation

1. Walk rig 15' to the Ottesen 22C:
  - This involves physically moving (walking) the drilling rig a distance of 15 feet to a specific location known as the [REDACTED] 22C. The reason for moving the rig may vary and could include positioning the rig for a particular wellbore trajectory or optimizing the rig's location on the drilling pad.
2. Nipple up BOP / Rig up mud lines / Position catwalk:
  - These are standard procedures for preparing the drilling rig's equipment for drilling operations:
    - Nipple up BOP: Assembling or connecting various components of the Blowout Preventer (BOP) stack, a critical safety device used in drilling operations.
    - Rig up mud lines: Setting up the piping and equipment to circulate drilling mud during drilling operations.
    - Position catwalk: Placing the catwalk (a raised platform or walkway) in a specific location on the rig's deck to facilitate the safe and efficient handling of equipment.
3. Test pipe rams, blind rams, choke manifold, choke line, HCR's and kill line valves, lower kelly, floor valve and dart valve, test wellhead:
  - This involves testing various components of the Blowout Preventer (BOP) system and other well control equipment to ensure they are functioning correctly and are ready for use during drilling operations. Testing typically includes pressure testing and functional checks.
4. Slip n' cut drill line / Calibrate blocks:
  - Slip n' cut drill line: This involves adjusting or cutting the drill line (the cable used to raise and lower the drill string) using slips (mechanical devices) to ensure proper tension and alignment.
  - Calibrate blocks: Checking and adjusting the calibration (measurement accuracy) of the blocks or sheaves used in the rig's hoisting system.
5. P/U BHA as per directional / Trip in hole:
  - P/U BHA as per directional: Picking up the Bottom Hole Assembly (BHA) according to the directional drilling plan, which may involve specific configurations of tools and equipment.
  - Trip in hole: Lowering the BHA and drill string into the wellbore as part of the drilling process.

6. Drill out shoe track:

- This involves drilling through the shoe track, which is the bottom portion of the casing shoe assembly that provides a seal at the bottom of the casing string. Drilling out the shoe track allows drilling to continue into the formation below.

### ChatGPT Conjectured Noise Sources

1. Equipment Operation:

- The operation of drilling equipment such as mud pumps, drawworks, top drive systems, and rotary tables can generate significant noise levels. These machines are essential for drilling operations but can produce loud and continuous noise.

2. Hoisting Operations:

- Activities such as moving the rig, picking up and setting down drill pipe, Bottom Hole Assembly (BHA), and other tubulars using the rig's hoisting equipment (traveling block, crown block, and drawworks) can produce loud noise, particularly when engaging or disengaging the rig's braking systems.

3. BOP Testing:

- Testing various components of the Blowout Preventer (BOP) system and other well control equipment involves pressurizing the system to check for leaks and ensure functionality. This process can generate noise from the operation of pumps, valves, and high-pressure lines.

4. Drill Line Operations:

- Adjusting or cutting the drill line and calibrating blocks involves handling heavy equipment and using power tongs, elevators, or other tools, which can create noise from machinery and metal-on-metal contact.

5. BHA Pickup and Tripping:

- Picking up the Bottom Hole Assembly (BHA) and tripping it into the hole requires the operation of the rig's hoisting equipment and handling of heavy tubulars, which can generate noise from machinery and equipment.

6. Drilling Operations:

- Drilling out the shoe track involves the use of the drill bit and other drilling tools to penetrate through the casing shoe and into the formation below. This process can create noise from the rotation and impact of the drill bit against the formation.

## Activity Log Entry 10/28/2023

1. DRILL SHOE TRACK
2. FINISHED DRILLING VERTICAL
3. DRILLED AHEAD - HORIZONTAL

### ChatGPT Response

1. Drill Shoe Track:	<ul style="list-style-type: none"><li>• This involves drilling through the shoe track, which is the bottom portion of the casing shoe assembly that provides a seal at the bottom of the casing string. Drilling out the shoe track allows drilling to continue into the formation below.</li></ul>
2. Finished Drilling Vertical:	<ul style="list-style-type: none"><li>• This indicates that the vertical section of the wellbore has been drilled to the desired depth. In vertical drilling, the wellbore follows a straight path perpendicular to the surface.</li></ul>
3. Drilled Ahead - Horizontal:	<ul style="list-style-type: none"><li>• This means that drilling operations have progressed beyond the vertical section, and the wellbore is now being drilled horizontally or at an angle. Horizontal drilling involves deviating the wellbore from vertical to reach a specific target zone within the reservoir. This allows for increased exposure to the reservoir and can enhance production rates.</li></ul>

### ChatGPT Conjectured Noise Sources

1. Drilling Equipment Operation:	<ul style="list-style-type: none"><li>• The operation of drilling equipment such as the rotary table, top drive system, mud pumps, and drawworks can generate significant noise levels. These machines are essential for drilling operations but can produce loud and continuous noise.</li></ul>
2. Drill Bit Impact and Rotation:	<ul style="list-style-type: none"><li>• The rotation and impact of the drill bit against the formation can create noise, especially during the drilling of the shoe track and the transition from vertical to horizontal drilling. This noise is generated as the drill bit cuts through rock and other formations.</li></ul>
3. Mud Circulation System:	<ul style="list-style-type: none"><li>• The circulation of drilling mud (fluid) through the wellbore, including the mud pumps, mud pits, and flow lines, can produce noise from the operation of pumps and the movement of fluid. The mud circulation system is essential for cooling and lubricating the drill bit, carrying drill cuttings to the surface, and maintaining wellbore stability.</li></ul>
4. Pipe Handling:	<ul style="list-style-type: none"><li>• Handling and manipulating drill pipe, casing, and other tubulars on the drill floor can create noise, especially during operations such as tripping in or out of the hole, making connections, and running or pulling pipe.</li></ul>
5. Drilling Fluid Discharge:	<ul style="list-style-type: none"><li>• Discharging drilling fluid from the wellbore can produce noise as the fluid exits the well and interacts with the surrounding environment, particularly during flowback or well control operations.</li></ul>

## Activity Log Entry 9/22/2023

1. DRILLED AHEAD – HORIZONTAL
2. CIRCULATE WELLBORE CLEAN/ FLOW CHECK/ PUMP DRY JOB
3. TOO H TO RUN 5.5" PRODUCTION CASING
4. RUN 5 1/2" CASING

### ChatGPT Response

1. Drilled Ahead - Horizontal:	<ul style="list-style-type: none"><li>• This indicates that drilling operations have progressed beyond the vertical section, and the wellbore is now being drilled horizontally or at an angle. Horizontal drilling involves deviating the wellbore from vertical to reach a specific target zone within the reservoir.</li></ul>
2. Circulate Wellbore Clean / Flow Check / Pump Dry Job:	<ul style="list-style-type: none"><li>• After drilling ahead horizontally, the wellbore is circulated clean to remove any debris or cuttings generated during drilling. Flow checks may be performed to assess wellbore integrity and fluid circulation. Pumping a dry job involves displacing the drilling fluid (mud) from the wellbore, typically using a displacement fluid such as water or brine, to prepare for casing installation.</li></ul>
3. TOO H to Run 5.5" Production Casing:	<ul style="list-style-type: none"><li>• TOO H stands for "Tripping Out Of Hole," which means removing the drill string (drill pipe, BHA, and drill bit) from the wellbore. The purpose of tripping out is to prepare the wellbore for casing installation. In this case, the 5.5" production casing is being prepared for installation.</li></ul>
4. Run 5 1/2" Casing:	<ul style="list-style-type: none"><li>• This involves running (lowering) the 5 1/2" production casing into the wellbore. Production casing is installed to provide structural integrity to the wellbore and to isolate the production zone from other formations. Running casing typically involves using casing running tools and equipment to lower the casing string into the wellbore to the desired depth.</li></ul>

### ChatGPT Conjectured Noise Sources

1. Drilling Equipment Operation:	<ul style="list-style-type: none"><li>• During drilling ahead horizontally, the operation of drilling equipment such as the rotary table, top drive system, and mud pumps continues. These machines generate noise due to their mechanical operation and the movement of components. The noise intensity may vary depending on the size and power of the equipment.</li></ul>
2. Drill Bit Impact and Rotation:	<ul style="list-style-type: none"><li>• As drilling progresses horizontally, the rotation and impact of the drill bit against the formation continue to generate noise. The drill bit cuts through rock and other formations, creating vibrations and sound waves. This noise is particularly noticeable during the drilling of hard formations.</li></ul>
3. Mud Circulation System:	

- Circulating the wellbore clean involves operating mud pumps to circulate drilling fluid (mud) through the wellbore. The pumps generate noise as they move the fluid, especially if they are located near the drilling rig's deck or living quarters. Additionally, noise may come from the flow of mud through the wellbore and associated flow lines.

#### 4. Pipe Handling:

- During tripping out of the hole (TOOH) and running casing operations, the handling and manipulation of drill pipe and casing on the drill floor can create noise. This includes the use of hoisting equipment, power tongs, elevators, and other handling tools. The noise intensity depends on the size and weight of the tubulars being handled and the speed of the operation.

#### 5. Pumping Dry Job:

- Pumping a dry job involves displacing the drilling fluid from the wellbore, which may include pumping a displacement fluid such as water or brine. The operation of pumps and associated equipment can generate noise, especially during high-pressure pumping activities.

#### 6. Wellbore Cleaning:

- During the circulation of the wellbore clean, noise may come from the flow of drilling fluid, the movement of equipment on the drill floor, and the operation of valves and chokes. Cleaning the wellbore involves removing debris and cuttings, which can create additional noise as they are circulated to the surface.

## Activity Log Entry 9/29/2023

1. DRILLED AHEAD – HORIZONTAL
2. CIRCULATE HOLE CLEAN, TRIP OUT OF HOLE

### ChatGPT Response

1. Drilled Ahead - Horizontal:	<ul style="list-style-type: none"><li>• This indicates that drilling operations have progressed beyond the vertical section, and the wellbore is now being drilled horizontally or at an angle. Horizontal drilling involves deviating the wellbore from vertical to reach a specific target zone within the reservoir.</li></ul>
2. Circulate Hole Clean:	<ul style="list-style-type: none"><li>• After drilling ahead horizontally, the wellbore is circulated clean to remove any debris or cuttings generated during drilling. Circulating the hole clean involves pumping drilling fluid (mud) down the drill string and up the annulus to carry cuttings to the surface. This helps maintain wellbore stability and ensures efficient drilling operations.</li></ul>
3. Trip Out of Hole:	<ul style="list-style-type: none"><li>• Tripping out of the hole (TOOH) means removing the entire drill string (drill pipe, Bottom Hole Assembly, and drill bit) from the wellbore. Tripping out is typically done to perform maintenance, make equipment changes, or prepare for casing installation. It involves using the rig's hoisting equipment to lift the drill string to the surface.</li></ul>

### ChatGPT Conjectured Noise Sources

1. Drilling Equipment Operation:	<ul style="list-style-type: none"><li>• The operation of drilling equipment such as the rotary table, top drive system, mud pumps, and drawworks can generate significant noise levels. These machines are essential for drilling operations but can produce loud and continuous noise.</li></ul>
2. Drill Bit Impact and Rotation:	<ul style="list-style-type: none"><li>• The rotation and impact of the drill bit against the formation can create noise, especially during drilling ahead horizontally and circulating the hole clean. The drill bit cuts through rock and other formations, creating vibrations and sound waves.</li></ul>
3. Mud Circulation System:	<ul style="list-style-type: none"><li>• Circulating the hole clean involves operating mud pumps to circulate drilling fluid (mud) through the wellbore. The pumps generate noise as they move the fluid, especially if they are located near the drilling rig's deck or living quarters. Additionally, noise may come from the flow of mud through the wellbore and associated flow lines.</li></ul>
4. Pipe Handling:	<ul style="list-style-type: none"><li>• Tripping out of the hole (TOOH) requires handling and manipulating drill pipe and other tubulars on the drill floor. This includes using hoisting equipment, power tongs, elevators, and other handling tools, which can create noise from machinery and metal-on-metal contact.</li></ul>
5. Equipment Movement:	<ul style="list-style-type: none"><li>• The movement of equipment on the drill floor, such as the operation of rig hoisting equipment and the positioning of tools and components, can generate noise. This</li></ul>

includes the movement of drill pipe, casing, and other tubulars, as well as the operation of rig machinery.

6. Flowback and Displacement:

- During circulation of the hole clean and displacement of drilling fluid from the wellbore, noise may come from the flow of fluid and the operation of pumps and associated equipment. This includes noise generated by fluid flow through pipes and valves.