Estimated emissions, concentrations, and deposition of monoterpenes from an outdoor *Cannabis* farm

Final Report

Prepared for:
Brett Vapnek
The Hacienda Company, LLC
brett@thehacienda.co

Prepared by:
Dr. William Vizuete
Chief Scientific Officer
Pacific Environmental Analytics LLC
will@pac-enviro.com

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Pacific Environmental Analytics

5142 Hollister Avenue #507 Santa Barbara, CA 93111
(805) 364-2995 info@pac-enviro.com

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Executive Summary

The purpose of this study is to determine whether or not it is feasible for cannabis monoterpenes from the proposed project ('Hacienda' 3800 Baseline Avenue Santa Ynez California) to taint grapes on a neighboring property (Appellant, 3950 Baseline Avenue).

The appellants cite a peer reviewed publication ("Capone") which identifies 1,8-cineole (eucalyptol) as having a detrimental impact on grapes. (The monoterpene 1,8-cineole is present in eucalyptus trees and some, but not all, cannabis strains.) Averaging across three years of their reported data, the study determined amounts of eucalyptol per grape material of 2.6 ug/kg. We sought to determine if it is possible for cannabis monoterpenes from the Hacienda project to reach this same threshold value of eucalytpol per grape material – 2.6 ug/kg – at the neighboring farm.

It should be noted that 1,8 cineole (eucalyptol) is the only monoterpene to be identified as potentially causing wine taint. No other monoterpenes (such as beta-myrcene, alpha-terpinene, and terpinolene) have been found in peer reviewed studies to cause taint.

To run this model, we completed the following tasks over the last several months:

1) Determination of monoterpene emission factors using measurements from five Cannabis strains.
2) Creation of monoterpene emission rates using emission factors for the proposed Cannabis farm.
3) Prediction of gas-phase concentrations using the Cannabis farm's emission rates simulated over three seasons using local meteorology.
4) Determination of deposition rates from predicted gas-phase concentrations to grape material and comparison with the assumed threshold values.

Our model was based on the size and location of the proposed project – 3800 Baseline Ave – and utilized local meteorological data from the Santa Ynez airport.

The following work describes the results of the estimation of Cannabis farm emissions, the prediction of downwind concentrations, and the deposition to grape material of four monoterpenes produced by certain cannabis strains: 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene. The modeled rates of deposition were then compared with certain assumed threshold values defined for these terpenes.

The major findings from the completion of these tasks are listed below.

- For the cannabis monoterpenes to reach threshold values (that potentially taint the grapes), they would have to emit at the highest rate, at the average predicted gas-phase concentrations, for 1,121 days straight for 1,8-cineole. Therefore, it is highly unlikely that cannabis from the Hacienda project would taint any grapes at 3950 Baseline Ave because cannabis is only grown seasonally, not year-round, and grapes are grown seasonally, not all year long. Furthermore, the cannabis is only emitting monoterpenes for 21 days prior to harvest. And if Hacienda had a maximum of 3 harvests per year, that would roughly only result in 63 days of emissions – compared to the 1,121 that would be required to taint the grapes. In other words, it would take 1,121 continual days of cannabis strains that have eucalyptol (not all strains have eucalyptol) emitting at the highest rate, without real world deposition loss (such as photochemistry) to result in grape absorption of terpenes at the threshold level, identified in the Capone study (of 2.6 ug/kg).

- Assuming mature Cannabis plants are emitting monoterpenes for 21 days prior to harvest, we estimate the fraction of the threshold values reached would be 1.9% for 1,8-cineole.
- Our model was very conservative and did not include real-world losses of gas-phase concentrations due to photochemistry and deposition during transport and thus are upper bound estimations. In reality, gas-phase concentrations of monoterpenes in the atmosphere have an average lifetime of minutes to hours in full sunlight, further reducing the possibility that the emission would travel to the nearby farm and taint the grapes. Our study did not include the real world losses due to photochemistry.
- Only 3 out of the 5 cannabis strains we evaluated had emission factors of eucalyptol. No 1,8-cineole emissions were found in two strains – Banjo, Presidential OG. The remaining strains had very small emission factors of eucalyptol ranging from 0.001-0.01 ug /g/hr.

Background

There currently exists only one peer-reviewed study that has linked the influence of 1,8-cineole in vineyards to taint in corresponding red wines [1]. This study (Capone) examined the effects that eucalyptus trees had on nearby vineyard operations. The study found the largest concentrations of 1,8-cineole in samples closest to eucalyptus trees. The study results were used to determine a threshold value for 1,8-cineole against which modeled deposition rates from predicted gas-phase concentrations could be compared.

Data from this study in Figure 1 shows 1,8-cineole concentrations in grape tissue from four grapevine rows over three vintages. Triplicate sampling was conducted at each of the three positions within each row. Using the highest measured values closest to the eucalyptus trees, a three year average was calculated of 2.6 ug/kg of 1,8-cineole per grape material. This average concentration was used as the threshold value for 1,8-cineole in the present modeling analysis.

Similarly, at the County of Santa Barbara Board of Supervisors meeting on August 20, 2019, data was publicly presented as shown in Figure 2. The figure shows terpene concentrations in grape material from two farms, one near a cannabis farm, and the second without a cannabis farm. There are three monoterpenes highlighted in yellow that were only found in the grape tissue near the cannabis farm. The data suggests the source of the monoterpenes was from the cannabis farm. The data does not suggest these monoterpenes had a deleterious effect on the quality of grape tissue, or the resulting wine produced. Nevertheless, for purposes of the present modeling analysis, the data presented was used to determine threshold values for the three monoterpenes identified: (i) 0.3801 mg/kg for beta-myrcene, (ii) 0.1931 mg/kg for alpha-terpinene, and (iii) 0.5632 mg/kg for terpinolene.

The goal of this work was to determine the amount of deposition of gas-phase concentrations of 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene that could occur on grape material located approximately 700 feet downwind, and then compare those concentrations with the assumed threshold values previously discussed. This goal was achieved by accomplishing the following tasks:

1) Determine emission factors using leaf enclosure measurements for five different strains of Cannabis;
2) Estimate emission rates for the proposed Cannabis farm based on the anticipated canopy size;
3) Predict gas-phase concentrations using EPA-approved dispersion modeling; and
4) Estimate deposition rates onto grape material located approximately 700 feet downwind.

Details on the methodology used in these tasks and results are described below.

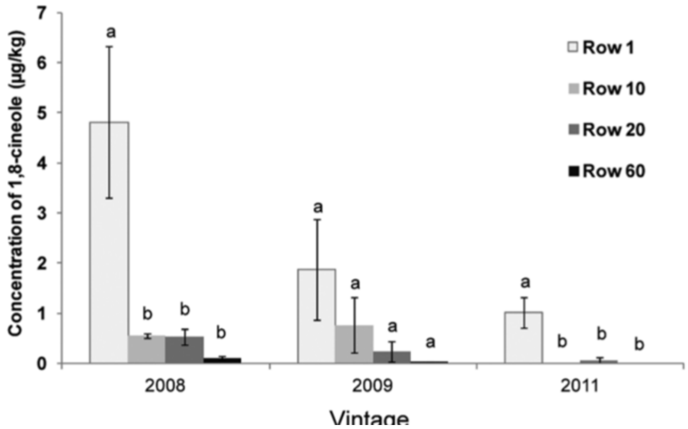

Figure 1. Concentration of 1,8-cineole (ug/kg) in grapes from different rows at set distances from the Eucalyptus trees over three vintages. Error bars represent the standard error of the mean for three replicates. Different letters indicate significant differences between the means ($p < 0.05$).

Round 1, Terpene Analysis on Grapevine Tissue near Hoop House Grow 9/3/2019

Date	Sample name	beta-Caryophyllene	alpha-Humulene	beta-Myrcene	alpha-Terpinene	Terpinolene	Values in PPM
6/8/2019	Site 1 SB	12.4066	12.9406	0.3801	0.1931	0.5632	mg/kg
6/8/2019	SL SB Control	7.5387	14.0317	0	0	0	mg/kg
				Found in Cannabis but not in grapes.			
	Lliterature Defined Terp Armoa Thresholds	3-250+	3-10	0-0.009	0.006-0.035	0.4-0.5	

NOTES: higher value in one VOC does not necessarily signify it is more likely to be perecieved.

Figure 2. Monoterpene analysis on grapevine tissue at two vineyards near a hoop house grow (Site 1 SB) and a second away from a Cannabis grow (SL SB Control).

1: Emission Factors Using Leaf Enclosure Measurements

The efforts to accomplish this task were completed by Synergy Environmental Solutions (SES) and led by Dr. Alex Guenther. Dr. Guenther is an international leader in atmospheric and terrestrial ecosystem research who has published more than 280 peer-reviewed journal articles. He has led more than 40 integrative field studies on six continents in tropical, temperate, and boreal ecosystems to provide observations to advance understanding of biogenic emissions and their role in air quality and climate. Dr. Guenther led Pacific Northwest National Laboratory's Environmental Molecular Science Laboratory and was Senior Scientist and Section Head at the National Center for Atmospheric Research (NCAR). The overall goal for SES was to quantify the emission capacities of five Cannabis strains at the mature growth stage to investigate their potential impact on atmospheric distributions of specific biogenic volatile organic compounds (BVOCs). Although there are existing models available for estimating BVOC emissions from plants generally, the lack of emission factors for specific Cannabis strains limits accurate estimation of their emission rates. Therefore, the quantification of speciated emission factors is required to know the impact of a specific strain of Cannabis.

Figure 3. Example of leaf enclosure system used to develop emission factors.

To determine emission factors for 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene we conducted enclosure measurements from five (5) different Cannabis strains growing in a greenhouse environment (Forbidden Fruit, Banjo, Wedding Cake, Presidential OG, and Gorilla Glue), and calculated emission factors in μg/g/h (at leaf conditions of temperature= 30^{o} C and light = 1000 μmol visible light m^{-1} s^{-1}). An example of the leaf enclosure used in this study is shown in Figure 3. The primary output is a dataset of terpenoid emission factors that is suitable for use in biogenic emission models that drive air quality simulations. We found that a bag enclosure system with TD-GC-MS/FID analysis is a suitable approach for characterizing Cannabis terpenoid emission factors and leaf cuvette measurements generally agree with bag measurements. However, there are uncertainties associated with potential emission perturbations that should be further investigated. Our results found ninety-seven terpenoid compounds including: 1 homoterpene, 30 monoterpenes, 5 aromatic monoterpenes, 21 oxygenated monoterpenes, and 40 sesquiterpenes. On average, monoterpenes contributed 69% and sesquiterpenes 31% of the total terpenoid emission.

Based on measurement data emission factors were developed for 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene. It is important to note that there was a complete lack of 1,8-cineole emissions from two strains: Banjo, Presidential OG. The other strains had relatively small emission factors ranging from 0.001-0.01 ug /g/hr.

2: Emission rates for *Cannabis* Farm

Hacienda reported 20,000 plants based on 2,000 plants per acre and a total canopy acreage of 10 (or 15 acres of cultivation area as defined by the County). The farm also reported that the 20,000 plants were evenly distributed (4,000 plants) among five strains: Forbidden Fruit, Banjo, Wedding Cake, Presidential OG, and Gorilla Glue. We were also provided, based on grower provided information, the dry plant weight of a mature plant in the outdoor grow for each strain. Using these data, and measured emission factors, emission rates of 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene were determined from the proposed *Cannabis* farm.

3: Predicted Gas-Phase Concentrations

Air dispersion modeling was completed using AERMOD version 19191 to determine the 1-hour gas-phase concentration of 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene using the emission rates described above. AERMOD is a U.S. EPA approved steady-state plume model that incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain [2].

It was assumed that 10 acres of canopy will be spread over roughly 15 acres as shown in red shade in Figure 4. All model predictions were completed for August through October in 2016, 2017, and 2018 using observed meteorological data derived from Santa Ynez airport monitoring station resulting in 2,160 simulated hours. September and October are also the days with the lowest wind speed, and the highest chance for deposition. Figure 4 provides the location of the farm at 3800 Baseline Avenue Santa Ynez, CA 93460 that was modeled as an area source denoted in a red shade. The receptor location where 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene concentrations were predicted is at 34°37'57.4"N 120°04'09.8"W (located approximately 700 feet downwind) and is shown in Figure 4 as a red cross.

Figure 4. The location of the farm, modeled as an area source, shown as a red shade. Also shown the receptor where model predictions were made denoted by a red cross.

The model predicted 2,160 hourly averaged model predictions of concentrations at the receptor location for 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene. Table 1 shows the average concentrations for the entire modeling period. Beta-myrcene is the strongest emitter and thus had the largest predicted downwind concentrations. Given the relatively small emissions of 1,8-cineole, the predicted concentrations of this monoterpene were three orders of magnitude smaller than beta-myrcene.

Table 1. Identified monoterpenes and their fraction of total monoterpene emissions from the Cannabis farm and the AERMOD predicted concentrations averaged over 2,160 hours.

Monoterpene	Fraction of total Emissions	Concentration (ug/m3)
1,8-cineole	1.0E-04	2.7E-04
Beta-myrcene	2.2E-01	5.8E-01
Alpha-terpinene	1.7E-02	4.4E-02
Terpinolene	1.6E-02	4.2E-02

4: Deposition Rates

Comparison with threshold values requires estimation of deposition rates of the gas-phase molecules into the grape tissue. Deposition from the gas-phase is an important process that has to be addressed in all air-quality models. Wesely (1989) developed a parameterization scheme for estimating gaseous dry deposition velocities, which has been widely used in a number of models [3]. A review of available dry deposition models has been reported by Wesely and Hicks (2000) [4]. Most existing dry deposition models utilize the multiple resistance analogy approach when parameterizing the deposition velocity to vegetation and other surfaces.

This analysis relied on the deposition velocities estimated in the Comprehensive Air Quality Model with Extensions, CAMx6.10 [5, 6] for this location. The model and protocols used in this study are based on the Western Air Quality Modeling Study (WAQS) for 2011 [6, 7]. The WAQS 2011b baseline model simulation period runs from June 15th to September 15th, 2011. All data and supporting documentation are publicly available via the Intermountain West Data Warehouse (IWDW) website [8]. At the location of the receptor this study predicted an average deposition velocity for the terpene (TERP) species of 6.7 e-5 m/s [6, 7]. Using this velocity, and predicted gas-phase concentrations, a flux of 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene can be determined. Assuming a yield of 3 tons of grapes per acre [9] the rate of 1,8-cineole, beta-myrcene, alpha-terpinene, and terpinolene per mass of grape tissue was calculated. These results were then used to determine how long it would take to reach the threshold values and results are shown in Table 2.

It should be noted that although terpenes, once released, are highly reactive to sunlight and other environmental factors, the modeling did not account for photochemical or other types of degradation and loss that can often occur during transport. In addition, the modeling assumed a smaller plume rise than one would normally expect from a cannabis farm of this size, and for these reasons the modeling results should be considered very conservative.

As shown in Table 2 to reach threshold values would require, at the predicted average gas-phase concentrations, 1,121 days for 1,8-cineole, 75.9 days for beta-myrcene, 1,005 days for alpha-terpinene, and 1,486 days for terpinolene. Assuming that mature *Cannabis* plants are emitting for 21 days prior to harvest, the fraction of the threshold values reached would be 1.9% for 1,8-cineole, 27.7% for beta-myrcene, 4.1% for alpha-terpinene, and 1.4% for terpinolene.

Table 2. The identified monoterpenes and their reported threshold values (THV) used in this study. Also shown are the number of days to achieve the THV at average gas-phase concentrations. Assuming a 21-day growing season for emissions of a mature Cannabis plant, data is shown as the percentage of THV values that are achieved in that time period.

Monoterpene	Threshold Value (ug/kg)	Time to reach THV (days)	Season fraction of THV (%)
1,8-cineole	2.6	1121	1.9
Beta-myrcene	381	75.9	27.7
Alpha-terpinene	193	1005	4.1
Terpinolene	563	1486	1.4

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