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SUPPLEMENTAL RESPONSES TO CEC STAFF DATA REQUEST SET 1 (11,13,14, 19-23, 31, 32, AND 34-36)

STACK SVY03A Campus (23-SPPE-01)

SUBMITTED TO: CALIFORNIA ENERGY COMMISSION
SUBMITTED BY: **STACK Infrastructure**

February 2024

DAYZEN LLC

INTRODUCTION

Attached are STACK Infrastructure's (STACK) Supplemental Responses to California Energy Commission (CEC) Staff Data Request Set No. 1 (11,13,14, 19-23, 31, 32, and 34-36) for the SVY03A Data Center Campus (SVY03A Campus) Application for Small Power Plant Exemption (SPPE) (23-SPPE-01). Staff issued Data Request Set No. 1 on November 29, 2023. STACK docketed responses to a majority of the data requests on December 15, 2023.

The Data Responses are grouped by individual discipline or topic area. Within each discipline area, the responses are presented in the same order as Staff presented them and are keyed to the Data Request numbers. Additional tables, figures, or documents submitted in response to a data request (e.g., supporting data, stand-alone documents such as plans, folding graphics, etc.) are found in Attachments at the end of the document and labeled with the Data Request Number for ease of reference.

For context, the text of the Background and Data Request precede each Data Response.

AIR QUALITY AND GREENHOUSE EMISSIONS

BACKGROUND: Additional Air Quality Analyses Schedule

On page 79 of the subject application, the applicant states that "refrigerant use was not provided at the time of this analysis and will be submitted under separate cover."

Additionally, on page 103 of the subject application, the applicant also states that "when provided by the BAAQMD, a cumulative air quality and public health risk assessment will be prepared and submitted under separate cover."

Staff would like a schedule from the applicant detailing when information on refrigerant emission information and the cumulative air quality and public health risk assessment should be expected by CEC staff.

11. Please provide a schedule detailing when the cumulative air quality and public health risk assessment would be provided to CEC staff.

SUPPLEMENTAL RESPONSE TO DATA REQUEST 11

In accordance with BAAQMD CEQA Guidelines, a project impact would be considered significant if the project would:

- Conflict with or obstruct implementation of the applicable air quality plan;
- Violate any air quality standard or contribute substantially to an existing or projected air quality violation;
- Result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non-attainment under an applicable federal or state ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors);
- Expose sensitive receptors to substantial pollutant concentrations; or
- Create objectionable odors affecting a substantial number of people

In April 2023, the BAAQMD updated the significance thresholds for agencies to use with environmental review of projects. These thresholds were designed to establish the level at which BAAQMD believed air pollutant emissions would cause significant impacts under CEQA.

A project would have a cumulative considerable impact if the aggregate total of all past, present, and foreseeable future sources within a 1,000-foot radius from the fence line of a source plus the contribution from the project, exceeds the following recommended significance thresholds at a sensitive receptor in Table 1 below.

Table 1 Cumulative Significance Thresholds

Health Risks and Hazards for Sensitive Receptors (Cumulative from All Sources within 1,000-Foot Zone of Influence) and Cumulative Thresholds for New Sources	
Excess Cancer Risk	100 per 1 million
Chronic Hazard Index	10.0
Annual Average PM25	0.8 μg/m^3
PM2.5 = fine particulate matter or particulates with an aerodynamic diameter of 2.5μm or less. Source: BAAQMD, 2018.	

The project is located within a census tract identified by the California Communities Environmental Health Screening Tool (CalEnviroScreen), Version 4.0, as having an overall CalEnviroScreen score at or above the 70^{th} percentile. Specifically, the project is located in Census Tract 6001437101 which has a CE4.0 rating of 74 percentile, which places the project in an overburdened community. These are designated communities that are overburdened by air pollution and other health disparities.

The Air District limits the excess lifetime cancer risk to 10 in one million as the maximum risk, meaning that a higher risk is deemed unacceptable on a project basis. Recent amendments to the BAAQMD Regulation 2-5 have limited the cancer risk to 6 in one million for designated overburdened communities. At this time, the BAAQMD has not proposed to change the CEQA cancer risk threshold to align with amendments made in Regulation 2-5.

Part 1 – Cumulative Assessment:

Cumulative stationary and mobile source impacts were assessed for the proposed project. As recommended by the BAAQMD (BAAQMD, 2023), in order to evaluate cumulative risks, permitted stationary sources of TACs near the project site were identified using BAAQMD's *Stationary Source Risk and Hazard Analysis Tool*. This mapping tool uses Google Earth to identify the location of stationary sources and their estimated screening level cancer risk and hazard impacts. This tool identified four sources within 1,000 feet of the project boundaries and are summarized in Table 2.

Table 2 Combined Source Listing

Source	Maximum Cancer Risk (per million)	Hazard Index	$PM_{2.5}$ concentration ($\mu g/m^3$)
#8695 Trimac Transportation Inc	0.006	0	0.02
#10991 Freund Baking Company	0.009	0	4.707 (0.62)*
#23302 Arcus Biosciences	0.747 (0.098)*	0.001	0.001
#111545 Breakwater 76 (gas station)	16.224 (2.14)*	0.07	0.0
Combined Sources[1]	2.253	0.017	0.641
BAAQMD Threshold – Combined Sources	***100***	***10.0***	***0.8***
* The BAAQMD Distance Adjustment Multiplier Tool for Generic sources was used to adjust the Cancer Risk, HI and PM2.5 impacts at the MEIR which is greater than 1,000 feet from any background source. [1]The combined source level is an overestimate because the maximum impact from each source is assumed to occur at the same location			

Cumulative health risk assessments look at all substantial sources of TACs located within 1,000 feet of a project site (i.e., influence area) that can affect sensitive receptors. These sources include rail lines, highways, busy surface streets, and stationary sources identified by BAAQMD.

A review of the project area using BAAQMD's geographic information systems (GIS) screening tools indicated that a portion of State Route 92 is within the 1,000-foot influence area could have cumulative health risk impacts at the Project MEIR (UTM 578,960m E, 4,164,700m N). Figure 1 shows the State Route 92 road segments affecting the MEIR within the influence area. Health risk impacts from State Route 92 upon the MEIR are reported in Table 1. Details of the cumulative screening and health risk calculations are included in *Attachment 1.*

An analysis of potential health impacts from vehicle traffic on State Route 92 was conducted. The analysis involved predicting emissions for the traffic volume and mix of vehicle types on the roadway near the project site and using an atmospheric dispersion model to predict exposure to TACs and $PM_{2.5}$. The associated cancer risks and $PM_{2.5}$ are then computed based on the modeled exposures.

Emission Rates

This analysis involved the development of DPM, organic TACs, and $PM_{2.5}$ emissions for traffic on the State Route 92 using the Caltrans version of the EMFAC2021 emissions model, known as CT-EMFAC2021. CT-EMFAC2021 provides emission factors for mobile source criteria pollutants and TACs, including DPM. Emission processes modeled include running exhaust for DPM, $PM_{2.5}$, total organic compounds (e.g., TOG), diesel exhaust organic gas (DEOG), running evaporative losses for TOG, tire and brake wear, and fugitive road dust for $PM_{2.5}$. All $PM_{2.5}$ emissions from all vehicles were used, rather than just the $PM_{2.5}$ fraction from diesel powered vehicles, because all vehicle types (i.e., gasoline and diesel powered) produce $PM_{2.5}$. Additionally, $PM_{2.5}$ emissions from vehicle tire and brake wear and from re-entrained roadway dust were included. DPM emissions are projected to decrease in the future and are reflected in the CT-EMFAC2021 emissions data. Inputs to the model include region (i.e., Alameda Clara County), type of road (i.e., freeway), Caltrans estimated local truck mix on State Route 92 (7.0 percent) [1], traffic mix assigned by CT-EMFAC2021 for the county, year of analysis (2026), and season (annual).

In order to estimate TAC and $PM_{2.5}$ emissions over the 30-year exposure period used for calculating the increased cancer risks for sensitive receptors at the MEIR, the CT-EMFAC2021 model was used to develop vehicle emission factors for the year 2026. Emissions associated with vehicle travel depend on the year of analysis because emission control technology requirements are phased-in over time. Therefore, the earlier the year analyzed in the model, the higher the emission rates utilized by CT-EMFAC2021. Year 2026 emissions were conservatively assumed as being representative of future conditions over the time period that cancer risks are evaluated.

The traffic information reported by Caltrans for State Route 92 in 2021was increased 1 percent per year to an annual average 105,000 vehicles per day for 2026 and includes about 7.0 percent trucks, of which 3.9 percent are considered diesel heavy duty trucks and 3.1 percent are medium duty trucks.[2] Average hourly traffic distributions for Alameda County roadways in 2026 were developed using the EMFAC model,[3] which were then applied to the average daily traffic (ADT) volumes to obtain estimated hourly traffic volumes and emissions for the roadway. For all hours

[1] Caltrans. 2022. *2021 Annual Average Daily Truck Traffic on the California State Highways.* Web: https://dot.ca.gov/programs/traffic-operations/census

[2] Caltrans. 2022. *2021 Annual Average Daily Truck Traffic on the California State Highway System.* Web: https://dot.ca.gov/programs/traffic-operations/census.

[3] The Burden output from EMFAC2007, a previous version of CARB's EMFAC model, was used for this since the current web-based version of EMFAC2021 does not include Burden type output with hour-by-hour traffic volume information.

of the day, an average speed of 50 mph was assumed for all vehicles on State Route 92, 5 mph below the posted speed limit on the roadway to account for commute congestion and the amount of access in the area.

Dispersion Modeling

Dispersion modeling of TAC and $PM_{2.5}$ emissions was conducted using the EPA AERMOD air quality dispersion model, which is recommended by the BAAQMD for this type of analysis.[4] TAC and $PM_{2.5}$ emissions from traffic on State Route 92 within 1,000 feet of the project site were evaluated. Vehicle traffic on the roadways was modeled using a series of volume sources along a line (line volume sources); with line segments used for opposing travel directions on the roadway. The same meteorological data and off-site MEIR location from the previous project impact dispersion modeling were used in the roadway modeling. Other inputs to the model included road geometry and elevations, hourly traffic emissions, and receptor location and height. Annual TAC and $PM_{2.5}$ concentrations from traffic on the roadways were calculated using the model. Concentrations were calculated at the project MEIR with receptor heights of 1.5 meters (4.9 feet) to represent the breathing height at the MEIR receptor.

Computed Cancer and Non-Cancer Health Impacts

Maximum increased lifetime cancer risks and annual $PM_{2.5}$ concentrations at the MEIR receptor was computed using modeled TAC and $PM_{2.5}$ concentrations and BAAQMD methods and exposure parameters. The traffic-related cancer risk, $PM_{2.5}$ concentration, and HI impacts on the project MEIR are 0.41 in one million with the maximum PM2.5 concentration at the MEIR would be 0.52 ug/m3. The Hazard Index would be less than 0.01. Details of the emission calculations, dispersion modeling, and cancer risk calculations for the MEIR receptor with the maximum cancer risk from State Route 92 traffic are provided in *Attachment 1.*

Summary of Cumulative Air Quality and Risk Impacts

The increased cancer risk calculations were based on guidance provided by the BAAQMD to analyze potential community health risk impacts from nearby sources of TAC emissions and applying the BAAQMD recommended age sensitivity factors to the TAC concentrations[5]. Age-sensitivity factors reflect the greater sensitivity of infants and small children to cancer causing TACs. The range of infant through adult exposures were assumed to occur at the MEIR.

As discussed above, the project site is affected by several sources of TACs. Table 3 shows the cancer and non-cancer risks associated with each source affecting the project site. The sum of impacts from combined sources (i.e., all sources within 1,000 feet of the project) would be below

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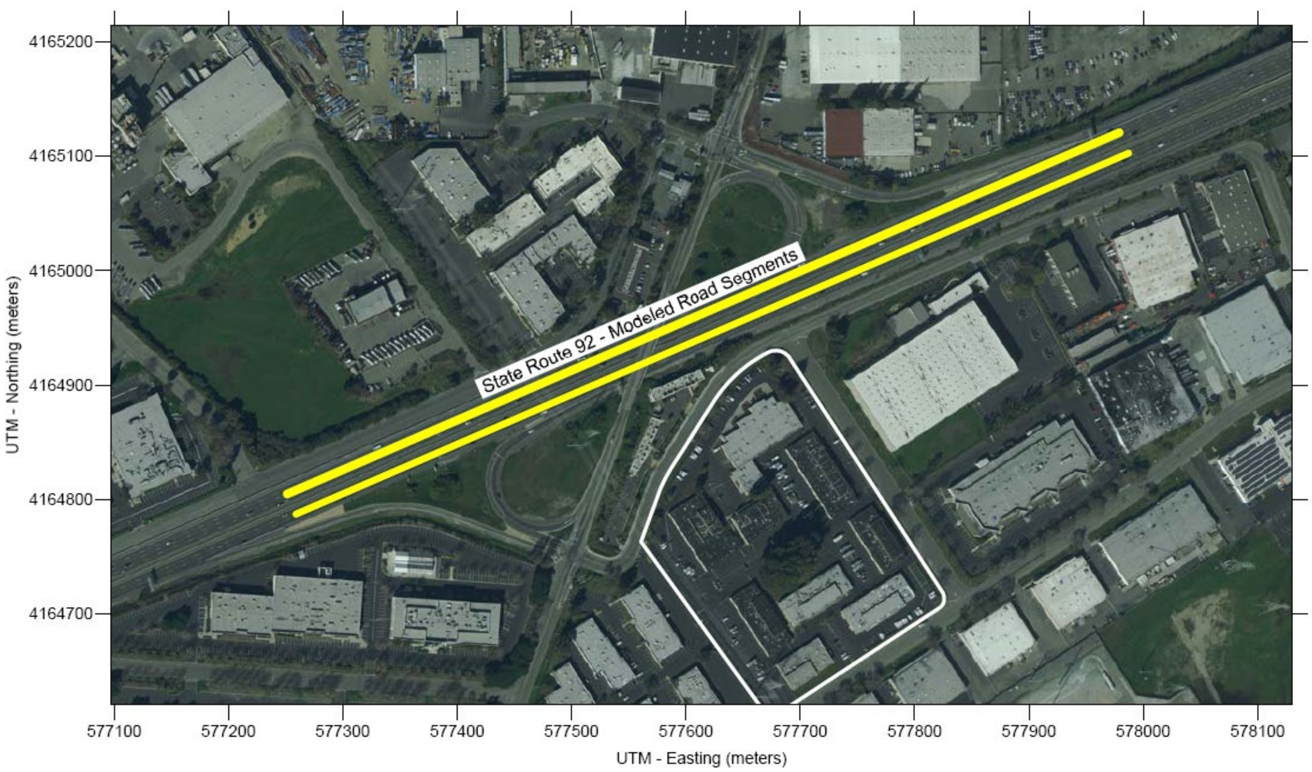
[4] BAAQMD. *Recommended Methods for Screening and Modeling Local Risks and Hazards*. May 2012
[5] BAAQMD, 2016. *BAAQMD Air Toxics NSR Program Health Risk Assessment (HRA) Guidelines*. December 2016.

the BAAQMD air quality and health risk thresholds. Therefore, the impact from combined community risk would be considered less than significant.

Table 3. Impacts from Combined Sources at the MEIR

Source	Maximum Cancer Risk (per million)	Hazard Index	PM2.5 concentration ($\mu g/m^3$)
State Route 92, ADT 105,000	0.41	0.01	0.01
Existing Background Sources.	2.253	0.017	0.641
SVY03A Project	0.0523	0.000036	0.002
Combined Sources[1]	2.715	0.027	0.653
BAAQMD Threshold – Combined Sources	***100***	***10.0***	***0.8***
Note: [1]The combined source level is an overestimate because the maximum impact from each source is assumed to occur at the same location.			

Figure 1. Project Site and Nearby TAC and $PM_{2.5}$ Sources



BIOLOGICAL RESOURCES

BACKGROUND: Special Status Plants and Wildlife

Appendix B of the SPPE Application (TN 252251) contains a discussion of sources and databases that were consulted to assess potential project impacts on special status plant and wildlife species. However, the information provided is incomplete and does not conform with the CEC's requirements for an SPPE contained in section (g)(13)(B)(i) of 20 CCR Div. 2 Ch. 5 App. B.

DATA REQUEST

13. Provide detailed maps at a scale of 1:6,000 or color aerial photographs taken at a recommended scale of 1-inch equals 500 feet (1:6,000) with a 30 percent overlap (provided under confidential cover) and 1:350,000 (for public viewing) that show the proposed project site and related facilities, biological resources including, but not limited to, those found during project-related field surveys and in records from the CNDDB, and the associated areas where biological surveys were conducted. Label the biological resources and survey areas as well as the project facilities.

SUPPLEMENTAL RESPONSE TO DATA REQUEST 13

STACK retained WRA to prepare the requested maps. The first map is provided separately under separate cover and the second map is included in Attachment BIO DR-13 to these Supplemental Data Responses.

BACKGROUND: Nitrogen Deposition

Section 4.4.2.1 (Project Impacts) on pages 110-111 of the SPPE Application (TN 252249) notes, "To assess the potential effects of nitrogen deposition from the testing and maintenance of the backup generators, the applicant has commissioned a nitrogen deposition analysis on lands contained in the Eden Landing Ecological Reserve. Excessive nitrogen deposition on low- nitrogen habitats can potentially result in adverse impacts to the habitat. The analysis was not complete at the time of the filing of this SPPE Application and will be docketed under separate cover when available."

DATA REQUEST

14. Submit a completed assessment of nitrogen deposition from the project on low-nitrogen habitats in the vicinity. The assessment must comply with the CEC's requirements for an SPPE Application contained in section (g)(13)(B)(ii) of 20 CCR Div. 2 Ch. 5 App. B, as follows:

    (ii) Provide an aerial map of the isopleth graphic depicting modeled nitrogen deposition rates. The geographical extent of the nitrogen deposition map(s) should include the entire plume and a radius of 6 (six) miles from the source, specifically identifying acres of sensitive habitat(s) within each isopleth (emphasis added). Modeling parameters and files shall be provided.

SUPPLEMENTAL RESPONSE TO DATA REQUEST 14

Air emissions from the project include nitrogen oxides (NO_x), sulfur oxides (SO_x), and particulates (PM10). Nitrogen oxide gases (NO, NO_2) convert to nitrate particulates in a form that is suitable for uptake by most plants. The effect of this nitrogen could be to promote plant growth that could potentially encourage nonnative plant species at the expense of native species.

To assess nitrogen deposition, AERMOD, which was used in the air quality permitting analysis to evaluate the project's air quality impacts, was also used in the deposition analysis. As described previously, AERMOD is a steady-state, mass-conserving, nonreactive (i.e., no chemistry) plume dispersion model. The ability of AERMOD to overestimate impacts was expanded by including several other assumptions with regards to nitrogen formation and deposition, in order to assess the potential for impacts from the SJC-04 project. These assumptions include:

- 100 percent conversion of oxides of nitrogen (NO_x) and ammonia (NH_3) into atmospherically derived nitrogen (ADN) within the engine stack(s) rather than allowing the conversion of NO_x and NH_3 to occur over distance and time within the atmosphere;
- Depositional rates and parameters were based upon nitric acid (HNO_3) which, of all the depositional species, has the most affinity for impacts to soils and vegetation and the most tendency to "stick" to what it is deposited upon;
- Maximum settling velocities to produce maximum deposition rates;
- Maximum potential emissions for the SJC-04 facility were used rather than actual emissions in the calculation of nitrogen deposition;
- And, once it leaves the engine stack, nitrogen immediately begins to deposit in the surrounding lands.

To produce conservative results (overestimates), modeling assumptions regarding the complex chemistry that occurs to produce nitrogen from NOx, ammonia, and other pollutants were not used in this modeling analysis. As one example, it was assumed that the pollutants leaving the stack(s) would already be in the form of depositional nitrogen (nitrate and ammonium ions). To do this, the emissions of NOx and ammonia were adjusted for the molecular weight of nitrogen and then summed for each individual source. Thus, all impacts would represent 100 percent conversion of combustion emissions into depositional nitrogen. This assumption leads to an exceedingly conservative estimation of nitrogen deposition, because areas with the highest nitrogen emissions do not necessarily experience the greatest deposition effects, which usually occur far from the original nitrogen source.

The AERMOD model calculates atmospheric deposition of nitrogen by calculating the wet and dry fluxes of total nitrogen. This deposition is accomplished by using a resistance model for the dry deposition part, and by assigning particle phase washout coefficients for the wet removal process from rainout. As discussed below, depositional parameters are input into the model in order to calculate the deposition of nitrogen. All depositional parameters were based on HNO3.

In order to model gaseous deposition, the model requires land use characteristics and gas deposition resistance terms based on five seasonal categories. The seasonal categories are input into AERMOD on a month by month basis, corresponding to each summer, fall, winter, and spring seasons, based on Bay Area Air Quality Management District (BAAQMD) defaults for AERMET processing, as follows:

- Late autumn/winter without snow = November, December, and January;
- Transitional spring = February and March;
- Midsummer = April, May, June, and July; and
- Autumn = August, September, and October.

The results of the analysis are presented in Figure 1.

Results of the wet and dry nitrogen deposition modeling are summed by AERMOD to produce annual deposition rates in units of grams per square meter (g/m^2) for the entire 5-year meteorological period modeled, which are converted to kilograms per hectare per year (kg/ha/yr) for presentation in this report. As the critical habitats cover a variety of elevations and distances, the annual average deposition rates calculated for all receptors modeled in the critical habitat areas were used for comparison to threshold levels. The maximum project impact on nitrogen deposition rates would be 4.047 kg/ha/yr immediately adjacent to the facility. In the critical habitat area, the average deposition rates are on the order of 0.001 kg/ha-yr.

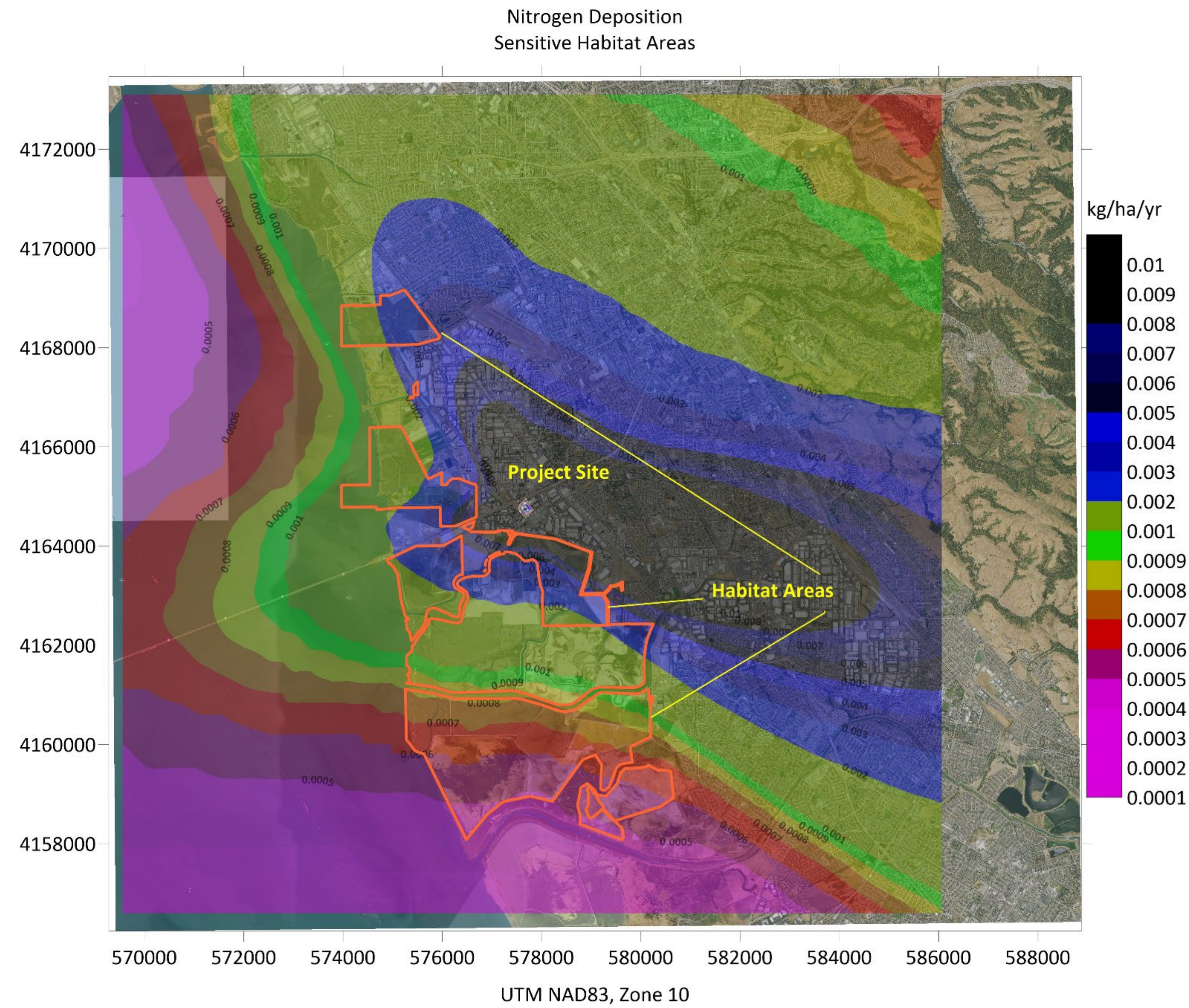
A threshold at which harmful effects from nitrogen deposition on plant communities has not been firmly established. However, a value of 5 kilograms per hectare per year (kg/ha/yr) is often used for comparing nitrogen deposition among plant communities. Research conducted in the South

San Francisco Bay Area indicates that intensified annual grass invasions can occur in areas with nitrogen deposition levels of 11–20 kg/ha/yr, with limited invasions at levels of 4–5 kg/ha/yr (Weiss 2006a and Weiss 2007, as cited in CEC 2007). The maximum and average levels of nitrogen deposition from the project in the sensitive areas are far below levels necessary to cause adverse effects.

Furthermore, the level of nitrogen deposition from the project emissions on plant-available nitrogen would actually be less than the calculated amount because the deposition will be distributed in small amounts during the year and not all of the nitrogen added to the soil during each deposition event is available for plant use because of losses associated with soil processes. Therefore, it is unlikely that there would be significant impacts to biological resources from nitrogen deposition.

The modeling files will be supplied to the CEC staff.

Figure 1


Nitrogen Deposition
Sensitive Habitat Areas
Project Site
Habitat Areas
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PROJECT DESCRIPTION-TRANSMISSION

The SPPE application indicates that the SVY03A Backup Generating Facility (SVY03ABGF) would deliver electricity to SVY03A Campus. The SVY03ABGF includes an onsite substation with two electrical supply lines that would connect to a new PG&E switchyard. Staff requires a complete description of the both the SVY03A Campus interconnection to the PG&E transmission grid and the reliability of the PG&E grid in order to understand the potential operation of the back-up generators.

DATA REQUESTS

19. Please provide a complete one-line diagram for the new PG&E switchyard. Show all equipment ratings, including bay arrangement of the breakers, disconnect switches, buses, and related equipment that would be required for interconnection of the on-site project substation. Please label the name of the transmission lines which connect the switchyard to the PG&E system.

SUPPLEMENTAL RESPONSE TO DATA REQUEST 19

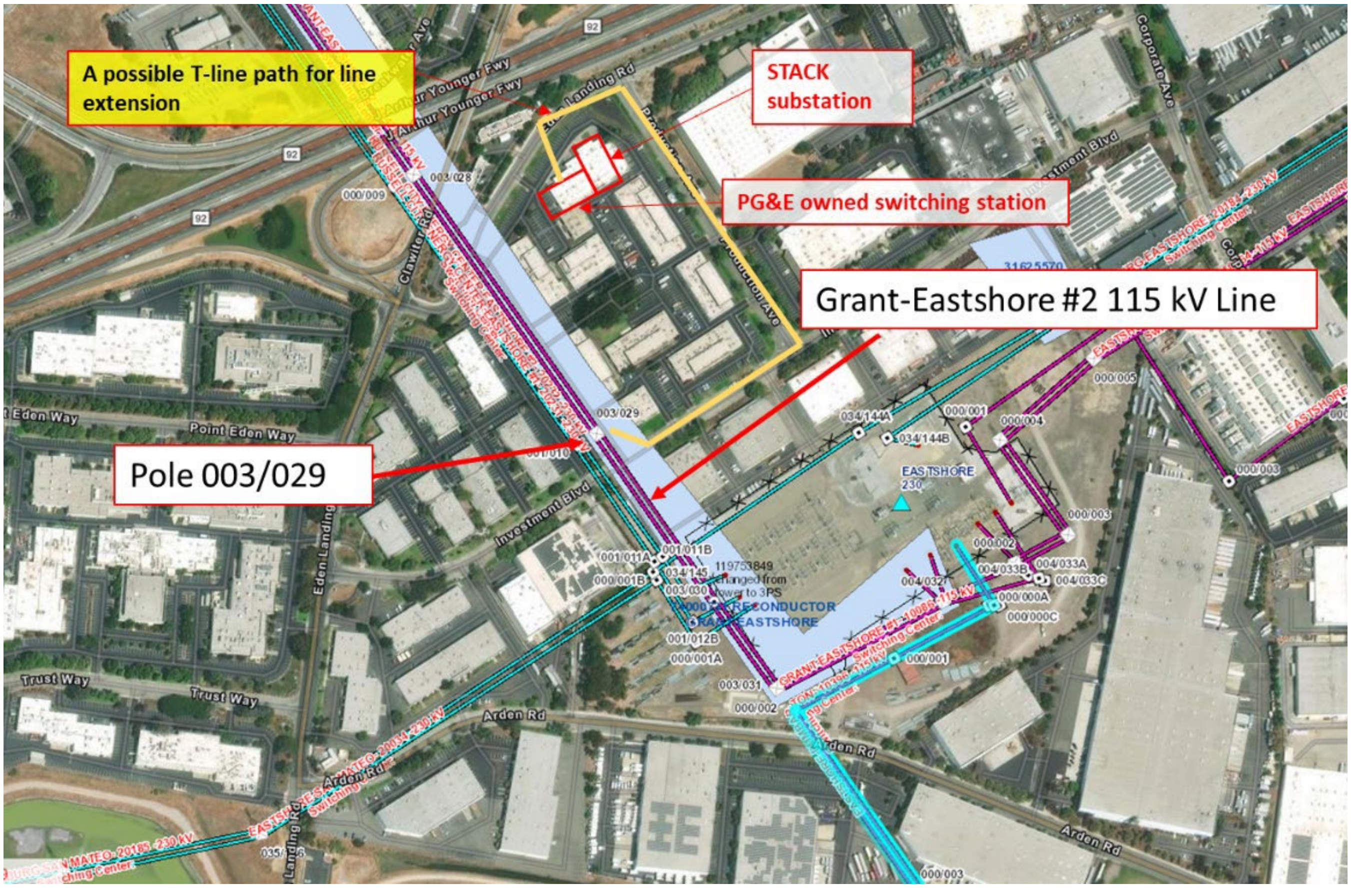
The one-line diagram was provided by PG&E and is included in Attachment PD DR-19.

20. Please provide the conductor name, type, current carrying capacity, and the overhead conductor size for the 115 kV transmission lines which connect the existing PG&E Eastshore-Grant 115 kV line to the new switchyard. Provide a map showing the route and pole locations of the extensions.

SUPPLEMENTAL RESPONSE TO DATA REQUEST 20

Transmission line will use 2-795ACSS conductor. Substation will use 2-2300AAC. The route and pole locations will be determined during preliminary design. However, for purposes of conducting a CEQA analysis, the Staff can use the following figure to further augment the written description contained in the SPPE.

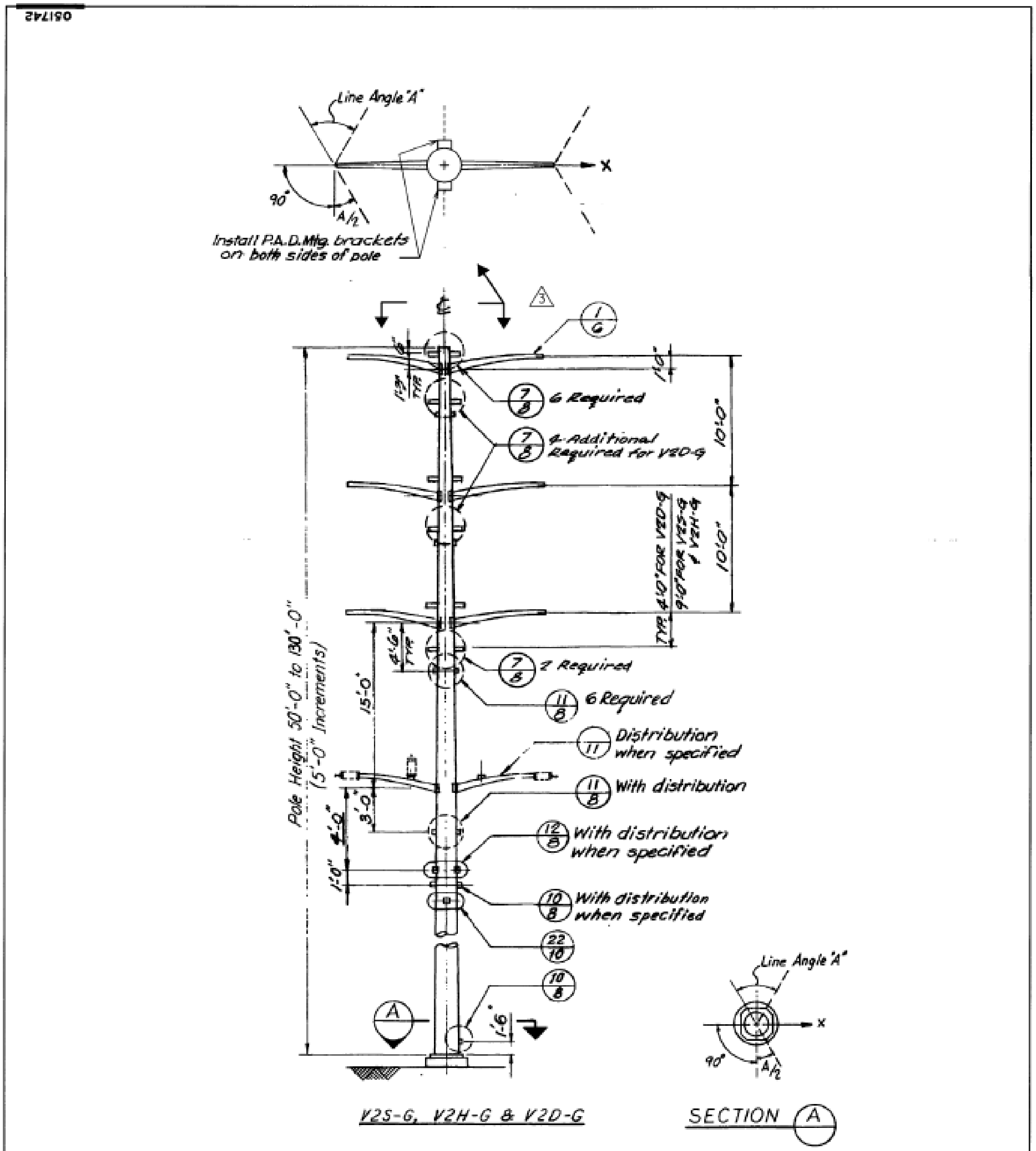
> To serve the SVY03A Campus, PG&E will be constructing a “looped” transmission interconnection involving two offsite transmission line extensions. This would involve a line on the south side of the project that comprises a two circuits of 115 kV OH (Overhead) Transmission line (T-Line) from an existing PG&E Eastshore to Grant 115 kV Line which is located on the south side of the project.



21. Please provide pole configurations that would support the 115 kV overhead line which would loop into the new switchyard and to the on-site substation.

RESPONSE TO DATA REQUEST 21

Final design of the transmission line has not been completed. However, for purposes of the CEQA analysis Staff can assume the following typical pole configuration for between 8 and 12 poles.



VERTICAL, DOUBLE CIRCUIT CONFIGURATION-GULL CROSSARMS

22. Please provide information that reviews the frequency and duration of historic outages of the Eastshore-Grant 115 kV line and related facilities that would likely trigger the loss of electric service to the proposed onsite substation and could lead to the emergency operations of the diesel-powered generators. This response should identify the reliability of service historically provided by PG&E to similar customers in this part of its service territory.

RESPONSE TO DATA REQUEST 22

PG&E provided the information responsive to this request in Attachment PD DR-22.

23. Please explain whether adding the SVY03A Campus would cause an overload to the PG&E transmission system which would require upgrades to the existing system.

RESPONSE TO DATA REQUEST 23

PG&E has conducted a preliminary study to identify potential impacts from STACK's interconnection request for service. PG&E has identified potential thermal impacts to PG&E Transmission system from STACK's interconnection and it is possible that all can potentially require upgrades and are listed in Table 3.1 included in Attachment PD DR-23. Please note some of the upgrades are needed 5 years from today or beyond, for which PG&E may not have the exact mitigation developed yet and therefore is only requiring monitoring. For the P5 mitigations that are required by 2027, Eastshore 230 kV non-redundant relay mitigation is identified in 2023 Expansion Plan and therefore would be completed by PG&E as part of its approved expansion activities.

TRANSPORTATION

BACKGROUND: Federal Aviation Administration (FAA) Form 7460-1, Notice of Proposed Construction or Alteration for SVY03A Data Center Campus

The Hayward Executive Airport is located approximately 1.75-miles (9,290-feet) north of the project site. Title 14, Part 77.9 of the Code of Federal Regulations requires FAA notification for construction or alterations within 20,000 feet of an airport with a runway more than 3,200 feet in length if the height of the construction or alteration exceeds a slope of 100 to 1 extending outward and upward from the nearest point of the nearest runway of the airport (CFR 2020). Runway 10R/28L at the Hayward Executive Airport is 5,694 feet in length.

The threshold for the FAA notification 100 to 1 surface exceedance height is approximately 92 feet at the project site. If a project's height, including any temporary equipment (such as cranes used during construction) or any ancillary structures (such as transmission poles), exceeds the 100 to 1 surface, the project applicant must submit a copy of FAA Form 7460-1, Notice of Proposed Construction or Alteration, to the FAA.

The small penthouse on the roof top of the data center building would extend to a height 116.5 feet therefore the project applicant must file FAA Form 7460-1 Notice of Proposed Construction or Alteration to comply with federal requirements. Compliance with this federal requirement is established through FAA determinations.

DATA REQUEST

31 Please prepare and submit FAA Form 7460-1, Notice of Proposed Construction or Alteration, to the FAA for the proposed project's buildings, transmission poles, and temporary construction equipment, such as cranes, which would exceed the 100 to 1 surface height of 92 feet. Submit the FAA's determinations to the project docket log once they are received.

SUPPLEMENTAL RESPONSE TO DATA REQUEST 31

FAA Form 7460-1 Notice of Proposed Construction or Alternation has been submitted to the FAA on December 6th, 2023. Emails with confirmation of the filing and the assigned Aeronautical Study Number are included in Attachment TRANS DR-31.

BACKGROUND: Thermal Plume Analysis

According to the SPPE application, the project would have emergency generators and air-cooled chillers and the project site is located 1.72 miles north of the Hayward Executive Airport.

Therefore, staff will require the following information to complete its evaluation of thermal plumes from the 28 emergency generators and server chilling units that would serve the SVY03ADC1 and SVY03ADC2 buildings to ensure air traffic safety and analyze any potentially significant impacts from such plumes.

DATA REQUESTS

32. Please perform a thermal plume modeling analysis of the project's emergency generators for the SVY03A and provide modeling files (or calculation spreadsheets) with all calculations embedded in. Please perform a thermal plume modeling analysis of the heat rejection equipment used to cool the buildings and data servers at the SVY03ADC1 and SVY03ADC2 and provide modeling files (or calculation spreadsheets) with all calculations embedded in.

SUPPLEMENTAL RESPONSE TO DATA REQUEST 32

The thermal plume analysis was completed for the diesel generators and the equipment used to cool the buildings for SVY03ADC1 and SVY03ADC2. The results of the analysis show that the maximum height of the 5.3 m/s plume averaged vertical velocity will always be less than 280 feet above ground level or essentially approximately 180 feet above the building rooftop (rooftop chillers on SVY03ADC1). Attachment TRANS DR-32 includes the calculation sheets. Working calculation sheets will be provided to the CEC staff.

34. Please provide a labeled schematic, showing all mechanical equipment on the roof of the SVY03ADC1 and SVY03ADC2 buildings.

SUPPLEMENTAL RESPONSE TO DATA REQUEST 34

Please see Attachment TRANS DR-34.

35. Please provide the following information to support the thermal plume analysis (provide equivalent data if necessary):

a. Stack Height (meters) for the data hall air handling units (DAHUs) for the SVY03ADC1 building, the computer room air conditioning (CRAC) units for the SVY03ADC2 building, and the emergency engines for both buildings.

b. Exhaust Temp (Kelvin) for the DHAUs, CRAC units, and emergency engines.

c. Exit Velocity (meter per second) for the DHAUs units, CRAC units, and the emergency engines.

d. Stack Diameter (meters) for the DHAUs, CRAC units, and the emergency engines.

e. Number of DHAU, CRAC, and emergency engine unit stacks.

f. Arrangement and distance between similar exhaust/heat rejection equipment (e.g., DHAUs, CRAC units, and emergency engine stacks) (meters).

RESPONSE TO DATA REQUEST 35

This data is provided in the working calculation data sheets as noted on the calculation sheets include in Attachment TRANS DR-32 and on the schematic drawing in Attachment TRANS DR-33.

BACKGROUND: Traffic Scoping Memorandum

According to the City of Hayward Transportation Impact Analysis Guidelines, to initiate the Transportation Impact Analysis Process, project consultants must draft a traffic scoping memorandum after completing a planning application. The traffic scoping memorandum provides project description and background information on the project and will be used by Public Works-Transportation staff to determine the various analyses to be included in the transportation impact analysis (Hayward 2020).

DATA REQUEST

36. Please provide a copy of the traffic scoping memorandum that was submitted to the City of Hayward.

SUPPLEMENTAL RESPONSE TO DATA REQUEST 36

An analysis of potential traffic impacts was prepared by Kimley Horn and was included in Appendix H. The analysis has been sent to the City of Hayward for review and comments were received. Attachment TRANS DR-36 includes the revised traffic analysis that addresses the City of Hayward comments

ATTACHMENT BIO DR-13

Biological Resources Maps

wra
Environmental
Consultants

December 20, 2023

Attn: Desiree Dei Rossi
David J. Powers & Associates
1736 Franklin, Suite 400
Oakland, CA 94612

Subject: StackSVY03 Data Center CEC Data Request

Dear Ms. Dei Rossi:

This letter and enclosed figures are in response to the California Energy Commission's (CEC) data request 13 for the StackSVY03 Data Center Project (Project) located in Hayward, Alameda County, California. The Project proposes to construct a data center within an urban area of the City of Hayward and requires CEC review. The enclosed figures pertain to sensitive biological resources as requested by the CEC and are included for your review and consideration.

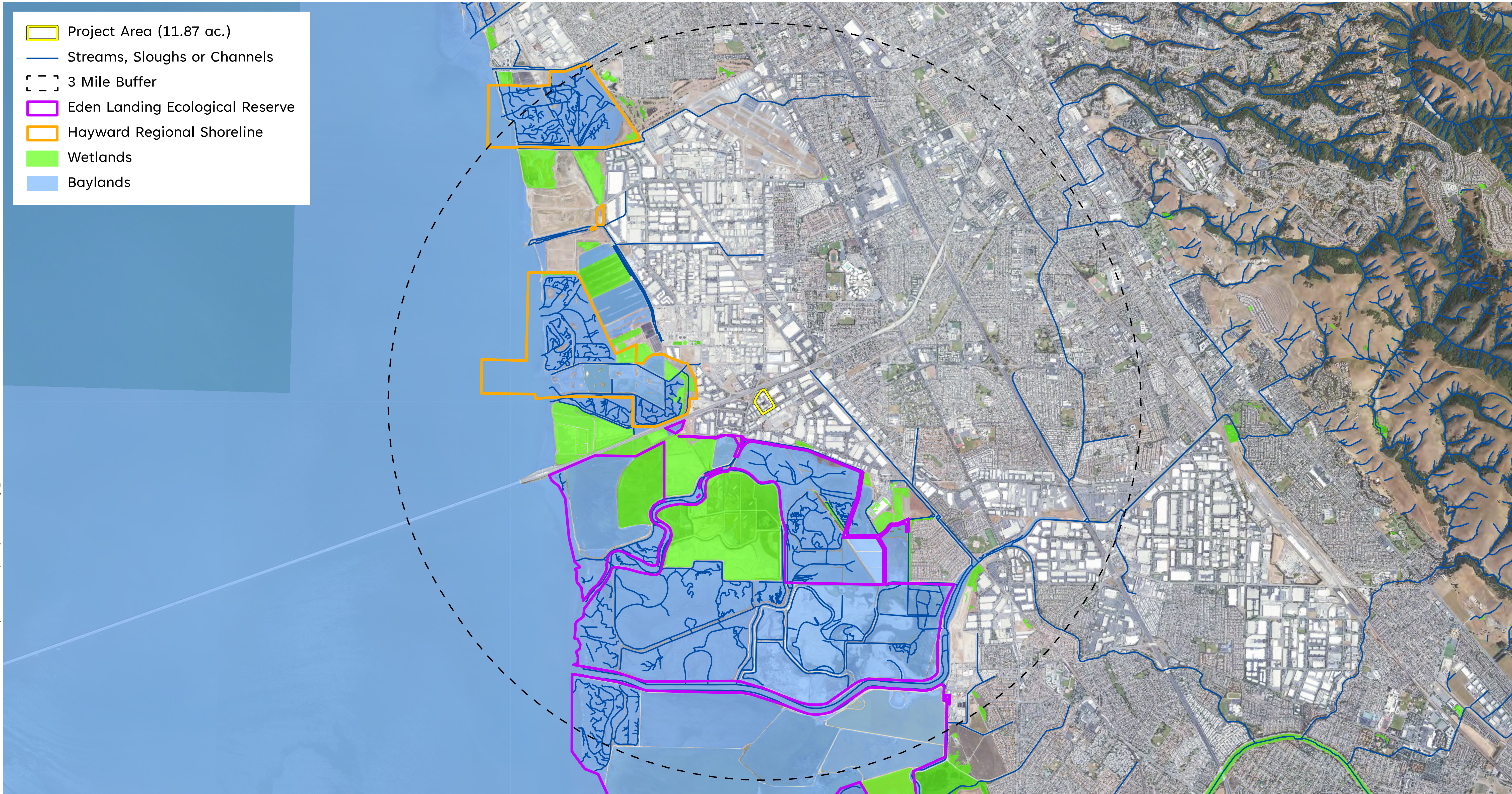
Enclosed Figure 1 details CNDDB documented occurrences of special-status plants and wildlife species within the vicinity of the proposed project area and has been scaled to the requested one inch equals 500 feet (1:6,000). Two special-status plants and four special-status wildlife species have been documented to occur in the vicinity. Given the sensitivity of these species, the data provided in California Department of Fish and Wildlife's California Natural Diversity Database (CNDDB) is confidential not for public distribution. As such, this figure has been labeled as Confidential and should not be distributed beyond the CEC's reviewing team. Figure 2 depicts known aquatic resources within the vicinity of the project site along with boundaries of known reserves and/or parks. A three-mile buffer has been included to visualize aquatic habitats within closer proximity to the project site. Eden Landing Ecological Reserve and the Hayward Regional Shoreline are both in the vicinity and situated west (north and south) of the project site and contain sensitive aquatic resources. Additional aquatic resources, such as streams, sloughs, or channels are also depicted.

Should you have any questions regarding the contents depicted in the enclosed figures, please contact me at clarke@wra-ca.com or 415-524-7255.

Sincerely,

Bianca Clarke
Senior Regulatory Permitting Specialist

Enclosures
Figure 1. CNDDB Occurrences
Figure 2. Sensitive Habitats within the Vicinity of the Project Area



Path: L:\Acad 2000 Files\320000\320464\GIS\ArcMap\320464Base.aprx Layout Name: FigX_Sensitive Habitats

Sources USDA NAIP Imagery 2022, WRA | Prepared By: njander, 12/15/2023

Figure 2. Sensitive Habitats in the Vicinity of the Project Area

TBD

0 0.5 1 Miles

N

wra Environmental Consultants

ATTACHMENT PD DR-19

PG&E Switching Station One-Line Diagram

ATTACHMENT PD DR-22

PG&E Electrical Outage Table

kV	FACILITY NAME	YEAR	Date Out	Time Out	ET Wire Down	Auto Reclose Disabled	Dur (hr:min)	Dur (mins)	Date In	Time In	Cause Category	Cause Detail	Secondary Cause	Comments	REGION	Cust Affected	Fault Type
115	GRANT-EASTSHORE #1	2019	07/09/19	7:41	No	No	3:52	232	07/09/19	11:33	External Contact	Foreign object	NONE	Relayed - 07/09/19, 0741 Grant-East Shore #1-115kV relayed, tested NG. no customers interrupted; weather clear; A-G fault 1.45 mi from Eastshore. near 002/022, +/-1 mi; 1128 Line manually tested OK after no trouble found. 1133 Line returned to service; apparent 3rd party contact, burn mark seen on its crane; CAP ER=117573629	BAY AREA	0	A-G
115	GRANT-EASTSHORE #1	2020	10/04/20	15:09	No	No	0:01	1	10/04/20	15:10	Animal	Bird	CB	Relayed - 10/04/20, 1509 Grant #2-115/12kV transformer relayed, tested OK due to avian contact on low-side; on the trouble Grant 115kV bus sections "D", "E", "F", #1-115/12kV transformer & Oakland J-Grant 115kV de-energized; Grant-East Shore #1 & #2-115kV lines open-ended at Grant; MOM Grant (CEMO=22,943); weather clear; avian contact led to catastrophic failure of CB-1108; CAP ER=119852449	BAY AREA	7,498	NA
115	GRANT-EASTSHORE #2	2020	10/04/20	15:09	No	No	0:01	1	10/04/20	15:10	Animal	Bird	CB	Relayed - 10/04/20, 1509 Grant #2-115/12kV transformer relayed, tested OK due to avian contact on low-side; on the trouble Grant 115kV bus sections "D", "E", "F", #1-115/12kV transformer & Oakland J-Grant 115kV de-energized; Grant-East Shore #1 & #2-115kV lines open-ended at Grant; MOM Grant (CEMO=22,943); weather clear; avian contact led to catastrophic failure of CB-1108; CAP ER=119852449	BAY AREA	7,497	NA
115	GRANT-EASTSHORE #2	2022	09/09/22	7:06	No	No	9:27	567	09/09/22	16:33	Other	Other-safety clearance	AUX	Forced - 09/09/22, 0706 to 1633 Grant-Eastshore #2-115kV forced to replace Grant CB-122 NG A phase CCVT; no customers interrupted	BAY AREA	0	NA

ATTACHMENT PD DR-23

Potential Impacts to PG&E System

Table 3-1: Summary of Required Capacity Upgrades

Monitored Facility	Category	Comments	T1/T2	T3	T4
Grant - East Shore 115kV Line #2 (Stack SS - East Shore 115kV Line)	P2	2032 pst-project overload, keep monitoring, mitigation TBD	no	yes	no
East Shore 230/115 kV Transformers 1 and 2	P1, P6	can be mitigated by system adjustment for short-term, long-term mitigation TBD	yes	yes	no
Moraga - Oakland J 115 kV Line	P1, P2, P3, P6, P7	2032 pst-project overload, keep monitoring, long term mitigation TBD OJ RAS can mitigate until long term mitigation can be put in place	yes	yes	yes
Moraga - San Leandro #1, #2 and E3 115 kV Lines	P3	San Leandro RAS, system adjustment for short-term, long-term mitigation TBD	yes	yes	yes
Oakland D-Oakland L 115 kV Cable	P2	pre-project issue in 2032, minor contribution from project, keep monitoring	yes	yes	yes
Pittsburg-East Shore 230 kV Line	P3	keep monitoring, 2032 OJ RAS can mitigate until long term mitigation can be put in place	yes	yes	yes
Pittsburg-San Mateo 230 kV Line (section 1)	P7	pre-project issue in 2032, minor contribution from project, keep monitoring	yes	yes	yes
San Leandro-Oakland J #1 115 kV Line	P2, P3, P6, P7	2032 pst-project overload, keep monitoring, long-term mitigation TBD OJ RAS can mitigate until long term mitigation can be put in place	yes	yes	yes
Sobrante-Moraga 115 kV Line	P2	pre-project issue in 2032, minor contribution from project, keep monitoring	yes	yes	yes
Vaca-Vacaville-Jameson-North Tower 115 kV Line (Hale Jct 1-Vacaville Jct 1)	P3	keep monitoring, 2032	no	yes	yes
P5-5A:A16:1:_EAST SHORE 230 KV BAAH (FAILURE OF NON-REDUNDENT RELAY)	P5	require mitigation in 2027, post-project issues thermal overloads and low voltage issues	yes	yes	yes only in 2032
P5-5A:A8:4:_MORAGA 230KV BUS #1 &2(FAILURE OF NON-REDUNDENT RELAY)	P5	pre-project issue in in 2032, no mitigation required from the project	yes	yes	yes
P5-5C:A10:2:_RAVENSWOOD 230-115KV BATT(FAILURE OF NON-REDUNDENT BATT)	P5	requires mitigation in 2027, post project issue for low voltage	no	yes	no
P5-5C:A16:11:_EASTSHORE 115KV BATT(FAILURE OF NON-REDUNDENT BATT)	P5	require mitigation in 2027, post-project issues thermal overloads and low voltages	no	yes	no
P5-5C:A16:5:_EASTSHORE 230KV BATT(FAILURE OF NON-REDUNDENT BATT)	P5	require mitigation in 2027, post-project issues thermal overloads and low voltages	yes	yes	yes only in 2032
P5-5C:A16:7:_NEWARK 230KV BATT(FAILURE OF NON-REDUNDENT BATT)	P5	require mitigation in 2032, post-project issues thermal overloads	yes	yes	yes
P5-5C:A16:9:_SAN LEANDRO (OAK U) 115KV BATT(FAILURE OF NON-REDUNDENT BATT)	P5	pre-project issue in in 2032, no mitigation required from the project	yes	yes	yes
P5-5C:A8:3:_PITTSBURG PP 230-115KV BATT(FAILURE OF NON-REDUNDENT BATT)	P5	require mitigation in 2032, post-project issues thermal overloads	yes	yes	yes
P5-5C:A8:8:_MORAGA 230-115KV BATT(FAILURE OF NON-REDUNDENT BATT)	P5	pre-project issue in in 2027/2032, no mitigation required from the project	yes	yes	yes

ATTACHMENT TRANS DR-31

FAA 7460 Proof of Filing

From:	Vera, Anthony
To:	Scott Galati; Alex Merritt
Cc:	mkersten@stackinfra.com; Butler, Patrick
Subject:	FW: Status of FAA Filing
Date:	Wednesday, January 3, 2024 11:10:58 AM

Here's the other confirmation as well.

Anthony Vera, PE, QSD
Kimley-Horn | 4637 Chabot Dr. #350, Pleasanton, CA 94588
Direct: 925 421 0911 | Mobile: 510 517 2714
Connect with us: Twitter | LinkedIn | Facebook | Instagram | Kimley-Horn.com

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From: Butler, Patrick <Patrick.Butler@kimley-horn.com>
Sent: Wednesday, January 3, 2024 11:05 AM
To: Vera, Anthony <Anthony.Vera@kimley-horn.com>
Subject: FW: Status of FAA Filing

Patrick Butler, P.E. (CA)
Kimley-Horn | 4637 Chabot Dr, Suite 350, Pleasanton, CA 94588
Direct: 510.350.0229

From: noreply@faa.gov <noreply@faa.gov>
Sent: Thursday, December 7, 2023 10:23 AM
To: mkersten@stackinfra.com; Butler, Patrick <Patrick.Butler@kimley-horn.com>
Subject: Status of FAA Filing

Your filing is assigned Aeronautical Study Number(s) (ASN): 2023-AWP-20464-OE, 2023-AWP-20470-OE, 2023-AWP-20474-OE, 2023-AWP-20477-OE, 2023-AWP-20473-OE, 2023-AWP-20475-OE, 2023-AWP-20476-OE, 2023-AWP-20463-OE, 2023-AWP-20467-OE, 2023-AWP-20472-OE, 2023-AWP-20465-OE, 2023-AWP-20466-OE, 2023-AWP-20468-OE, 2023-AWP-20469-OE, 2023-AWP-20471-OE.

To review your electronic record, go to our website oeaaa.faa.gov and select the Search Archives link to locate your case using the assigned Aeronautical Study Number (ASN).

The FAA verified your filing and an aeronautical study has been initiated. Please allow a minimum 45 days for the FAA to complete the study. Please refer to the assigned ASN on all future inquiries regarding this filing.

For Wind Turbine proposals only, please ensure Wind Turbine Data as described on the project summary page in your registered e-filing account has been uploaded to your filing.

To ensure e-mail notifications are delivered to your inbox please add noreply@faa.gov to your address book. Notifications sent from this address are system generated FAA e-mails and replies to this address will NOT be read or forwarded for review. Each system generated e-mail will contain specific FAA contact information in the text of the message.

From:	Vera, Anthony
To:	Scott Galati; Alex Merritt
Cc:	mkersten@stackinfra.com; Butler, Patrick; Kathryn Kafka
Subject:	FW: Status of FAA Filing
Date:	Wednesday, January 3, 2024 11:08:38 AM

Scott & Alex,

See below for the Aeronautical Study Numbers for the FAA application we submitted for our project. I think this can be included in our responses for the CEC and Planning Comments from the City of Hayward.

Thank you.

Anthony Vera, PE, QSD
Kimley-Horn | 4637 Chabot Dr. #350, Pleasanton, CA 94588
Direct: 925 421 0911 | Mobile: 510 517 2714
Connect with us: Twitter | LinkedIn | Facebook | Instagram | Kimley-Horn.com

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From: Butler, Patrick <Patrick.Butler@kimley-horn.com>
Sent: Wednesday, January 3, 2024 11:05 AM
To: Vera, Anthony <Anthony.Vera@kimley-horn.com>
Subject: FW: Status of FAA Filing

Patrick Butler, P.E. (CA)
Kimley-Horn | 4637 Chabot Dr, Suite 350, Pleasanton, CA 94588
Direct: 510.350.0229

From: noreply@faa.gov <noreply@faa.gov>
Sent: Monday, December 11, 2023 10:48 AM
To: mkersten@stackinfra.com; Butler, Patrick <Patrick.Butler@kimley-horn.com>
Subject: Status of FAA Filing

Your filing is assigned Aeronautical Study Number(s) (ASN): 2023-AWP-20636-OE, 2023-AWP-20638-OE, 2023-AWP-20637-OE, 2023-AWP-20639-OE.

To review your electronic record, go to our website oeaaa.faa.gov and select the Search Archives link to locate your case using the assigned Aeronautical Study Number (ASN).

The FAA verified your filing and an aeronautical study has been initiated. Please allow a minimum 45 days for the FAA to complete the study. Please refer to the assigned ASN on all future inquiries regarding this filing.

For Wind Turbine proposals only, please ensure Wind Turbine Data as described on the project summary page in your registered e-filing account has been uploaded to your filing.

To ensure e-mail notifications are delivered to your inbox please add noreply@faa.gov to your address book. Notifications sent from this address are system generated FAA e-mails and replies to this address will NOT be read or forwarded for review. Each system generated e-mail will contain specific FAA contact information in the text of the message.

ATTACHMENT TRANS DR-32

Thermal Plume Calculation Sheets

SINGLE/Approximated Plume Average Vertical Velocities for SVY03a Chillers using CEC Staff Methodology - Summer Max*

"***Aviation Safety and Buoyant Plumes*****," Peter Best, et. al.**

"***The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Plume from a Gas-Turbine Power Station at Oakey, Queensland, Australia*****," Dr. K.T. Spillane**

Ambient Conditions:

Constants: Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	302.21	Kelvins	84.3	°F	0.3048 meters/feet	

Plume Exit Conditions:

					Gravity g 9.81 m/s^2	
Stack Height h_s	33.03	meters	108 4/12	feet-inches	λ 1.11	
Individual Chiller Stack Diameter D	1.7374	meters	68.4	inches	λ_o ~1.0	
Stack Velocity V_{exit}	13.20	m/s	43.30	ft/sec	$4Vol/(60\pi D^2)$	
Individual Chiller Volumetric Flow	31.29	cu.m/sec	66,300	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	313.32	Kelvins	104.3	°F		
Initial Stack Buoyancy Flux F_o	3.4636	m^4/s^3	20.0	ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Number of Chillers n	24		2.213		Multiple Stack Multiplication Factor ($n^{0.25}$)	

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	10.859	meters*	35.6	feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	43.890	meters	**144.0**	feet		"
Vertical Velocity V_{jet}	6.599	m/s	21.65	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	3.475	meters	11.4	feet	$2a_{jet}$ = 2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.194	meters*	0.6	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	33.225	meters	109.0	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.9821	
Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o[(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	11.261	m^2/s			$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Single Chiller Results:

Solve for plume-averaged vertical velocity at height	**1,000.0**	**feet**	304.8		meters above ground ($z'+h_s$)	
Gives the following Height above Stack z'	271.769	meters*	891.6	feet*		
Plume Top-Hat Diameter 2a'	86.904	meters	285.1	feet	$2a'=2*0.16(z'-z_v)$	Sect.2/Eq.6
Vertical Velocity V	**0.731**	**m/s**	2.40	ft/sec	$V=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{(1/3)}/(2a'/2)$	Sect.2/Eq.6

Solve for Height of CASC critical vertical velocity V_{crit} **5.30** **m/s plume-averaged vertical velocity** **Critical VV > Top of Jet (Spillane)**

Find Height above Stack z_{crit}	13.557	meters	44.5	feet	Solve for $x=(z-z_v)$ simultaneously in both eqs. (i.e., Va and a)
Height above Ground $z_{crit}+h_s$	46.588	meters	**152.8**	feet	for $V=V_{crit}$ using the cubic equation $ax^3+bx^2+cx+d=0$, where

a=1, c=0, and $b=-(0.12F_o)/(V_{crit}^3 0.16^3)$= -0.68159

and $d=[0.12F_o(6.25D-z_v)^2-(Va)_o^3]/(V_{crit}^3 0.16^3)$= -2264.25

Interpolated Height of critical vertical velocity in Jet Phase:

Find Height above Stack z_{crit}	#N/A	meters	#N/A	feet	http://www.1728.org/cubic.htm
Height above Ground $z_{crit}+h_s$	#N/A	meters	**#N/A**	feet	gives the real solution x = z-zv = 13.3625
					or z(m/above stack) = 13.557
					z(ft/above ground) = 152.8

Table of Plume Top-Hat Diameters (2a) and Plume-Averaged Vertical Velocities starting at end of jet phase:

Height (feet) above ground	(meters) above stack	Plume Radius(m)	SingleStk VertVel(m/s)	Plume Temp(K)
Stack.Rel.Ht = 108.4	**0.00**	**0.869**	**13.20**	
110.0	0.50	0.908	12.90	
120.0	3.54	1.152	11.04	
130.0	6.59	1.396	9.19	
140.0	9.64	1.640	7.34	
Top of Single jet = 144.0	**10.86**	**1.737**	**6.60**	
152.8	13.56	2.138	5.30	306.56
160.0	15.74	2.487	4.58	305.78
170.0	18.78	2.975	3.87	305.26
180.0	21.83	3.462	3.36	304.74
190.0	24.88	3.950	2.98	304.36
200.0	27.93	4.438	2.69	304.07
210.0	30.98	4.925	2.46	303.85
250.0	43.17	6.876	1.88	303.66
300.0	58.41	9.314	1.51	303.19
350.0	73.65	11.753	1.31	302.87
400.0	88.89	14.191	1.18	302.69
450.0	104.13	16.630	1.08	302.58
500.0	119.37	19.068	1.02	302.50
550.0	134.61	21.506	0.96	302.44
600.0	149.85	23.945	0.92	302.40
700.0	180.33	28.822	0.85	302.37
800.0	210.81	33.698	0.80	302.33
900.0	241.29	38.575	0.76	302.30
1000.0	271.77	43.452	0.73	302.29
1100.0	302.25	48.329	0.70	302.27
1200.0	332.73	53.206	0.68	302.26
1300.0	363.21	58.082	0.66	302.25
1400.0	393.69	62.959	0.64	302.25
1500.0	424.17	67.836	0.62	302.24
2000.0	576.57	92.220	0.56	302.24
2500.0	728.97	116.604	0.52	302.23
3000.0	881.37	140.988	0.49	302.22
3500.0	1033.77	165.372	0.46	302.22
4000.0	1186.17	189.756	0.44	302.22
4500.0	1338.57	214.140	0.42	302.22
				302.21

Jet Phase Eqs: **10 ft Intervals**

Linearly interpolated from Stack Rel.Ht to Top of Jet

Spillane Equations:

$V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a

a = $0.16(z-z_v)$

$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$

CEC Staff Equation:

$V_{mp}=n^{0.25}V_{sp}$

Brigg's Equation:

$V_{Brigg's} = (2/3) \times 1.6^{(3/2)} \times F_{mp}^{(1/2)} \times u^{(-1/2)} \times z^{(-1/2)}$

where $F_{mp} = nF_{sp}$

50 ft Intervals

Max<5.3 m/s

100 ft Intervals

500 ft Intervals

*Winter Min = Monthly Mean of Minimum Daily Temperatures for 1971-2000 (Lowest in Dece

NOAA Sources: Climatography of the United

MERGED (along length) Plume Average Vertical Velocities for SVY03A Chillers using CEC Staff Methodology - Summer Max*

"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.

"*The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Merged Plume from Two Gas-Turbine Power Station at Oakey, Queensland, Australia*," Dr. K.T. Spillane

Ambient Conditions: | **Constants:** Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	302.21	Kelvins	84.3	°F	0.3048 meters/feet	
Plume Exit Conditions:					Gravity g 9.81 m/s^2	
Stack Height h_s	33.03	meters	108 4/12	feet-inches	λ 1.11	
Individual Stack Diameter D	1.73736	meters	68.4	inches	λ_o ~1.0	
Stack Velocity V_{exit}	13.20	m/s	43.30	ft/sec	$4Vol/(60\pi D^2)$	
Individual Volumetric Flow	31.29	cu.m/sec	66,300	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	313.32	Kelvins	104.3	°F		
Initial Stack Buoyancy Flux F_o	3.46	m^4/s^3	20.0	ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Total Number of Stacks n	24					
Average Adjacent Stack Separation d	2.80	meters	9.2	feet	**Calcs based on multiple plume treatment in Peter Best Paper:**	
Number of Stacks along Orientation N	12				**plume velocities increased by $N^{0.25}$ at the height where plumes fully merged (interp. below ht, single merged stack above ht)**	

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	10.859	meters*	35.6	feet*	$z_{jet} = 6.25D$, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	43.890	meters	**144.0**	feet		"
Vertical Velocity V_{jet}	**6.599**	m/s	21.65	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	3.475	meters	11.4	feet	$2a_{jet} = 2D$ Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet and Merging Phases

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Single Plume Values: Plume Top-Hat Radius a	**Used in Plume Merging Only**				$a = 0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.194	meters*	0.6	feet*	$z_v = 6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	33.225	meters	109.0	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.9821	
Single Plume Values: Vertical Velocity V	**Used in Plume Merging Only**				$\{(Va)_o^3 + 0.12F_o[(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a$	Sect.2.1(6)
Product $(Va)_o$	11.261	m^2/s			$V_{exit}(D/2)(\theta_e/\theta_s)^{1/2}$	

Plume Merging - Based on Single Plume Calculations where: Sect.3/¶3

Begin Merging Plume Top-Hat Diameter $2a_{touch}$	2.800	meters	9.2	feet	$2a_{touch}=d$, (or $a_{touch}=d/2$)
Height above Stack z_{touch}	8.944	meters*	29.3	feet*	$z_{touch} = z_v+d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{touch}+h_s$	41.975	meters	**137.7**	feet	
Vertical Velocity V_{touch}	**8.014**	m/s	26.3	ft/sec	$V_{touch} = \{(Va)_o^3 + 0.12F_o[(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a$
Total Merging Plume Top-Hat **Diameter** $2a_{full}$	**30.800**	meters	101.0	feet	$2a_{full}=2d(N-1)/2$, (or $a_{full}=d(N-1)/2$) **FOR 2 STACKS, $2a_{full}=2d$**
Height above Stack z_{full}	96.444	meters*	316.4	feet*	$z_{full} = z_v+2d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{full}+h_s$	129.475	meters	**424.8**	feet	
Vertical Velocity V_{full}	1.127	m/s	3.7	ft/sec	$V_{full} = \{(Va)_o^3 + 0.12F_o[(z_{full}-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a_{full}$
Product $(V^3a)_{full}$	22	m^4/s^3			

Conditions at End (Top) of Merging Phase - Define new values for V_{full} and a_{full} in Merged Plume calculations (based on TOTAL number of stacks):

Merged Plume Values: Plume Diameter 2a	**Solutions in Table Below**				$2a = 2 \times (a_m + 0.16(z-z_{full}))$, or linear increase with height
Revised Merged Plume **Radius** a_m	34.086	meters	111.8	feet	where $a_m = n^{0.25}a_{full}$ where Total Merging Occurs
Revised Merged Plume Velocity V_m	**2.495**	m/s	8.19	ft/sec	and $V_m = n^{0.25}V_{full}$ where Total Merging Occurs
Revised Virtual Source Height z_{full}	96.444	meters*	316.4	feet*	Height above stack where Total Merging Occurs (shown above)
Revised Vertical Velocity V	**Solutions in Tables Below**				$V=\{n(V^3a)_{full}/a\}^{1/3}$ for heights above total merging elevation $V=V_{touch}+(V_m-V_{touch})*(z-z_{touch})/(z_{full}-z_{touch})$ for heights below total merging elevation

Multiple Plume Calculations

Solve for plume-averaged vertical velocity at height	**1,000.0**	**feet**	304.8		meters above ground $(z+h_s)$
Gives the following Height above Stack z	271.769	meters*	891.6	feet*	REGULAR EQNS
Plume Top-Hat Radius a	62.138	meters	203.9	feet	$a=a_m+0.16(z-z_{full})$ **if $z>z_{full}$**
Vertical Velocity V	**2.042**	**m/s**	6.70	ft/sec	$V=\{n(V^3a)_{full}/a\}^{1/3}$ **if $z>z_{full}$** $V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$ **if $z_{touch}<z<z_{full}$** V'=single plume values **if $z<z_{touch}$**
Solve for Height of CASC critical vertical velocity V_{crit}	**5.30**	**m/s**			LESS THAN TOP OF MERGING PHASE-INTERPOL
Find Height above Stack z_{crit}	51.976	meters	170.5	feet	$z_{crit} = z_{full} + \{[n(V^3a)_{full}/(V_{crit})^3]-a_m\}/0.16$ **if $V_{crit}<V_m$**
Height above Ground $z_{crit}+h_s$	85.007	meters	**278.9**	**feet**	$z_{crit}=z_{touch}+(z_{full}-z_{touch})*(V_{crit}-V_{touch})/(V_m-V_{touch})$ **if $V_{crit}>V_m$**

Table of MERGED Plume-Averaged Vertical Velocities starting at Touching Height:

Single Plume Eqns (see Single Plume spreadsheet)

$V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3} / a$

$a = 0.16(z-z_v)$

$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$

Height (feet) above ground	(meters) above stack	Plume Radius(m)	Vert. Vel(m/s)		
Begin Merging (touch) = 137.7	***8.94***	***1.400***	***8.01***		
140.0	9.64	#N/A	7.97	*Interpolated Layer Eqns*	**20 ft Intervals**
160.0	15.74	#N/A	7.59	$V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$	
180.0	21.83	#N/A	7.20		
200.0	27.93	#N/A	6.82		
220.0	34.02	#N/A	6.43		
240.0	40.12	#N/A	6.05		
260.0	46.22	#N/A	5.66		
280.0	52.31	#N/A	5.28		
300.0	*58.41*	#N/A	4.89	*Merged Plume Eqns*	
320.0	64.50	#N/A	4.51	$V=\{n(V^3a)_{full}/a\}^{1/3}$	**20 ft Intervals**
340.0	70.60	#N/A	4.13	$a=a_m+0.16(z-z_{full})$	
360.0	76.70	#N/A	3.74		
380.0	82.79	#N/A	3.36		
End Merging (full/mp) = 424.8	***96.45***	***34.086***	***2.49***		
500.0	119.37	37.754	2.41		**100 ft Intervals**
600.0	149.85	42.631	2.32		
700.0	180.33	47.507	2.23		
800.0	210.81	52.384	2.16		
900.0	241.29	57.261	2.10		
1000.0	271.77	62.138	2.04		
1100.0	302.25	67.015	1.99		
1200.0	332.73	71.891	1.95		
1300.0	363.21	76.768	1.90		**500 ft Intervals**
1500.0	424.17	86.522	1.83		
2000.0	576.57	110.906	1.68		
2500.0	728.97	135.290	1.58		
3000.0	881.37	159.674	1.49		
3500.0	1033.77	184.058	1.42		
4000.0	1186.17	208.442	1.36		
4500.0	1338.57	232.826	1.31		

MERGED (along width) Plume Average Vertical Velocities for SVY03A Chillers using CEC Staff Methodology - Summer Max*

"***Aviation Safety and Buoyant Plumes***," Peter Best, et. al.

"***The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Merged Plume from Two Gas-Turbine Power Station at Oakey, Queensland, Australia***," Dr. K.T. Spillane

Ambient Conditions: | **Constants:** Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	302.21 Kelvins	84.3 °F		0.3048 meters/feet

Plume Exit Conditions:

			Gravity g	9.81 m/s^2
Stack Height h_s	33.03 meters	108 4/12 feet-inches	λ	1.11
Individual Stack Diameter D	1.73736 meters	68.4 inches	λ_o	~1.0
Stack Velocity V_{exit}	13.20 m/s	43.30 ft/sec	$4Vol/(60\pi D^2)$	
Individual Volumetric Flow	31.29 cu.m/sec	66,300 ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	313.32 Kelvins	104.3 °F		
Initial Stack Buoyancy Flux F_o	3.46 m^4/s^3	20.0 ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A m^4/s^3		$\lambda^2gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Total Number of Stacks n	24			
Average Adjacent Stack Separation d	4.36 meters	14.3 feet	**Calcs based on multiple plume treatment in Peter Best Paper: plume velocities increased by $N^{0.25}$ at the height where plumes fully merged (interp. below ht, single merged stack above ht)**	
Number of Stacks along Orientation N	8			

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	10.859 meters*	35.6 feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	43.890 meters	**144.0** feet		"
Vertical Velocity V_{jet}	**6.599** m/s	21.65 ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	3.475 meters	11.4 feet	$2a_{jet}$ = 2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet and Merging Phases

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Single Plume Values: Plume Top-Hat Radius a	**Used in Plume Merging Only**		a = $0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.194 meters*	0.6 feet*	$z_v = 6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	33.225 meters	109.0 feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.9821	
Single Plume Values: Vertical Velocity V	**Used in Plume Merging Only**		$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	11.261 m^2/s		$V_{exit}(D/2)(\theta_e/\theta_s)^{1/2}$	

Plume Merging - Based on Single Plume Calculations where: Sect.3/¶3

Begin Merging Plume Top-Hat Diameter $2a_{touch}$	4.360 meters	14.3 feet	$2a_{touch}$=d, (or a_{touch}=d/2)
Height above Stack z_{touch}	13.819 meters*	45.3 feet*	$z_{touch} = z_v+d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{touch}+h_s$	46.850 meters	**153.7** feet	
Vertical Velocity V_{touch}	**5.201** m/s	17.1 ft/sec	$V_{touch} = \{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a
Total Merging Plume Top-Hat **Diameter** $2a_{full}$	30.520 meters	100.1 feet	$2a_{full}$=2d(N-1)/2, (or a_{full}=d(N-1)/2) **FOR 2 STACKS, $2a_{full}$=2d**
Height above Stack z_{full}	95.569 meters*	313.5 feet*	$z_{full} = z_v+2d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{full}+h_s$	128.600 meters	**421.9** feet	
Vertical Velocity V_{full}	1.132 m/s	3.7 ft/sec	$V_{full} = \{(Va)_o^3 + 0.12F_o [(z_{full}-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a_{full}$
Product $(V^3a)_{full}$	22 m^4/s^3		

Conditions at End (Top) of Merging Phase - Define new values for V_{full} and a_{full} in Merged Plume calculations (based on TOTAL number of stacks):

Merged Plume Values: Plume Diameter 2a	**Solutions in Table Below**		2a = 2 x ($a_m + 0.16(z-z_{full})$), or linear increase with height
Revised Merged Plume **Radius** a_m	33.776 meters	110.8 feet	where $a_m = n^{0.25}a_{full}$ where Total Merging Occurs
Revised Merged Plume Velocity V_m	**2.507** m/s	8.22 ft/sec	and $V_m = n^{0.25}V_{full}$ where Total Merging Occurs
Revised Virtual Source Height z_{full}	95.569 meters*	313.5 feet*	Height above stack where Total Merging Occurs (shown above)
Revised Vertical Velocity V	**Solutions in Tables Below**		$V=\{n(V^3a)_{full}/a\}^{1/3}$ for heights above total merging elevation $V=V_{touch}+(V_m-V_{touch})*(z-z_{touch})/(z_{full}-z_{touch})$ for heights below total merging elevation

Multiple Plume Calculations

Solve for plume-averaged vertical velocity at height	**1,000.0 feet**	304.8	meters above ground $(z+h_s)$
Gives the following Height above Stack z	271.769 meters*	891.6 feet*	REGULAR EQNS
Plume Top-Hat Radius a	61.968 meters	203.3 feet	$a=a_m+0.16(z-z_{full})$ **if $z>z_{full}$**
Vertical Velocity V	**2.048 m/s**	6.72 ft/sec	$V=\{n(V^3a)_{full}/a\}^{1/3}$ **if $z>z_{full}$** $V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$ **if $z_{touch}<z<z_{full}$** V'=single plume values **if $z<z_{touch}$**
Solve for Height of CASC critical vertical velocity V_{crit}	**5.30 m/s**		BEFORE TOUCHING **Critical VV < Top of Jet**
Find Height above Stack z_{crit}	JET meters	JET feet	$z_{crit} = z_{full} + \{[n(V^3a)_{full}/(V_{crit})^3]-a_m\}/0.16$ **if $V_{crit}<V_m$**
Height above Ground $z_{crit}+h_s$	JET meters	**JET feet**	$z_{crit}=z_{touch}+(z_{full}-z_{touch})*(V_{crit}-V_{touch})/(V_m-V_{touch})$ **if $V_{crit}>V_m$**

Table of MERGED Plume-Averaged Vertical Velocities starting at Touching Height:

Height (feet) above ground	(meters) above stack	Plume Radius(m)	Vert. Vel(m/s)	
				Single Plume Eqns (see Single Plume spreadsheet) $V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a a = $0.16(z-z_v)$
Begin Merging (touch) = 153.7	***13.82***	***2.180***	***5.20***	$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$
160.0	15.74	#N/A	5.14	*Interpolated Layer Eqns* **20 ft Intervals**
180.0	21.83	#N/A	4.94	$V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$
200.0	27.93	#N/A	4.74	
220.0	34.02	#N/A	4.54	
240.0	40.12	#N/A	4.33	
260.0	46.22	#N/A	4.13	
280.0	52.31	#N/A	3.93	**50 ft Intervals**
300.0	58.41	#N/A	3.73	
320.0	64.50	#N/A	3.53	
340.0	70.60	#N/A	3.33	
360.0	76.70	#N/A	3.13	
380.0	82.79	#N/A	2.93	
400.0	88.89	#N/A	2.73	
End Merging (full/mp) = 421.9	***95.56***	***33.776***	***2.51***	
450.0	104.13	35.145	2.47	
500.0	119.37	37.584	2.42	**100 ft Intervals**
600.0	149.85	42.461	2.32	
700.0	180.33	47.337	2.24	
800.0	210.81	52.214	2.17	
900.0	241.29	57.091	2.10	
1000.0	271.77	61.968	2.05	*Merged Plume Eqns*
1000.0	271.77	61.968	2.05	$V=\{n(V^3a)_{full}/a\}^{1/3}$
1100.0	302.25	66.845	2.00	$a=a_m+0.16(z-z_{full})$
1500.0	424.17	86.352	1.83	
2000.0	576.57	110.736	1.69	
2500.0	728.97	135.120	1.58	**500 ft Intervals**
3000.0	881.37	159.504	1.49	
3500.0	1033.77	183.888	1.42	
4000.0	1186.17	208.272	1.37	
4500.0	1338.57	232.656	1.32	
5000.0	1490.97	257.040	1.27	

SINGLE/Approximated Plume Average Vertical Velocities for SVY03A Chillers using CEC Staff Methodology - Winter Min*

"***Aviation Safety and Buoyant Plumes***," **Peter Best, et. al.**

"***The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Plume from a Gas-Turbine Power Station at Oakey, Queensland, Australia***," **Dr. K.T. Spillane**

Ambient Conditions: | **Constants:** Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	278.15	Kelvins	41.0	°F	0.3048 meters/feet	
Plume Exit Conditions:					Gravity g 9.81 m/s^2	
Stack Height h_s	33.03	meters	108 4/12	feet-inches	λ 1.11	
Individual Chiller Stack Diameter D	1.7374	meters	68.4	inches	λ_o ~1.0	
Stack Velocity V_{exit}	13.20	m/s	43.30	ft/sec	$4Vol/(60\pi D^2)$	
Individual Chiller Volumetric Flow	31.29	cu.m/sec	66,300	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	289.26	Kelvins	61.0	°F		
Initial Stack Buoyancy Flux F_o	3.7531	m^4/s^3	20.0	ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Number of Chillers n	24		2.213		Multiple Stack Multiplication Factor ($n^{0.25}$)	

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	10.859	meters*	35.6	feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	43.890	meters	**144.0**	feet		"
Vertical Velocity V_{jet}	6.599	m/s	21.65	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	3.475	meters	11.4	feet	$2a_{jet}$ = 2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.211	meters*	0.7	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	33.242	meters	109.1	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.9806	
Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	11.243	m^2/s			$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Single Chiller Results:

Solve for plume-averaged vertical velocity at height	**1,000.0**	**feet**	304.8		meters above ground ($z'+h_s$)	
Gives the following Height above Stack z'	271.769	meters*	891.6	feet*		
Plume Top-Hat Diameter 2a'	86.899	meters	285.1	feet	$2a'=2*0.16(z'-z_v)$	Sect.2/Eq.6
Vertical Velocity V	**0.750**	**m/s**	2.46	ft/sec	$V=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{(1/3)}/(2a'/2)$	Sect.2/Eq.6

Solve for Height of CASC critical vertical velocity V_{crit} **5.30** **m/s plume-averaged vertical velocity** | **Critical VV > Top of Jet (Spillane)**

Find Height above Stack z_{crit}	13.559	meters	44.5	feet	Solve for $x=(z-z_v)$ simultaneously in both eqs. (i.e., Va and a)
Height above Ground $z_{crit}+h_s$	46.590	meters	**152.9**	feet	for $V=V_{crit}$ using the cubic equation $ax^3+bx^2+cx+d=0$, where

a=1, c=0, and $b=-(0.12F_o)/(V_{crit}^3 0.16^3)$= -0.73856

and $d=[0.12F_o(6.25D-z_v)^2-(Va)_o^3]/(V_{crit}^3 0.16^3)$= -2246.82

Interpolated Height of critical vertical velocity in Jet Phase:

Find Height above Stack z_{crit}	#N/A	meters	#N/A	feet	http://www.1728.org/cubic.htm
Height above Ground $z_{crit}+h_s$	#N/A	meters	**#N/A**	feet	gives the real solution x = z-zv = 13.3484

or z(m/above stack) = 13.559

z(ft/above ground) = 152.9

Table of Plume Top-Hat Diameters (2a) and Plume-Averaged Vertical Velocities starting at end of jet phase:

Height (feet) above ground	(meters) above stack	Plume Radius(m)	SingleStk VertVel(m/s)	Plume Temp(K)
Stack.Rel.Ht = 108.4	**0.00**	**0.869**	**13.20**	
110.0	0.50	0.908	12.90	
120.0	3.54	1.152	11.04	
130.0	6.59	1.396	9.19	
140.0	9.64	1.640	7.34	
Top of Single jet = 144.0	**10.86**	**1.737**	**6.60**	
152.9	13.56	2.136	5.30	282.49
160.0	15.74	2.484	4.59	281.72
170.0	18.78	2.972	3.87	281.20
180.0	21.83	3.460	3.37	280.67
190.0	24.88	3.947	2.99	280.29
200.0	27.93	4.435	2.70	280.00
210.0	30.98	4.923	2.47	279.78
250.0	43.17	6.873	1.89	279.59
300.0	58.41	9.312	1.53	279.12
350.0	73.65	11.750	1.33	278.80
400.0	88.89	14.189	1.20	278.62
450.0	104.13	16.627	1.11	278.51
500.0	119.37	19.065	1.04	278.43
550.0	134.61	21.504	0.99	278.38
600.0	149.85	23.942	0.94	278.34
700.0	180.33	28.819	0.87	278.31
800.0	210.81	33.696	0.82	278.27
900.0	241.29	38.573	0.78	278.24
1000.0	271.77	43.449	0.75	278.22
1100.0	302.25	48.326	0.72	278.21
1200.0	332.73	53.203	0.70	278.20
1300.0	363.21	58.080	0.68	278.19
1400.0	393.69	62.957	0.66	278.19
1500.0	424.17	67.833	0.64	278.18
2000.0	576.57	92.217	0.58	278.18
2500.0	728.97	116.601	0.53	278.17
3000.0	881.37	140.985	0.50	278.16
3500.0	1033.77	165.369	0.47	278.16
4000.0	1186.17	189.753	0.45	278.16
4500.0	1338.57	214.137	0.43	278.16
				278.15

Jet Phase Eqs: **10 ft Intervals**

Linearly interpolated from Stack Rel.Ht to Top of Jet

Spillane Equations:

$V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a

a = $0.16(z-z_v)$

$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$

CEC Staff Equation:

$V_{mp}=n^{0.25}V_{sp}$

Brigg's Equation:

$V_{Brigg's} = (2/3) \times 1.6^{(3/2)} \times F_{mp}^{(1/2)} \times u^{(-1/2)} \times z^{(-1/2)}$

where $F_{mp} = nF_{sp}$

50 ft Intervals

Max<5.3 m/s

100 ft Intervals

500 ft Intervals

*Winter Min = Monthly Mean of Minimum Daily Temperatures for 1971-2000 (Lowest in Dece

NOAA Sources: Climatography of the United

MERGED (along width) Plume Average Vertical Velocities for SVY03A Chillers using CEC Staff Methodology - Winter Min*

"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.

"*The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Merged Plume from Two Gas-Turbine Power Station at Oakey, Queensland, Australia*," Dr. K.T. Spillane

Ambient Conditions: | **Constants:** Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	278.15 Kelvins	41.0 °F	0.3048 meters/feet	
Plume Exit Conditions:			Gravity g 9.81 m/s^2	
Stack Height h_s	33.03 meters	108 4/12 feet-inches	λ 1.11	
Individual Stack Diameter D	1.73736 meters	68.4 inches	λ_o ~1.0	
Stack Velocity V_{exit}	13.20 m/s	43.30 ft/sec	$4Vol/(60\pi D^2)$	
Individual Volumetric Flow	31.29 cu.m/sec	66,300 ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	289.26 Kelvins	61.0 °F		
Initial Stack Buoyancy Flux F_o	3.75 m^4/s^3	20.0 ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A m^4/s^3		$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Total Number of Stacks n	24			
Average Adjacent Stack Separation d	4.36 meters	14.3 feet	**Calcs based on multiple plume treatment in Peter Best Paper: plume velocities increased by $N^{0.25}$ at the height where plumes fully merged (interp. below ht, single merged stack above ht)**	
Number of Stacks along Orientation N	8			

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	10.859 meters*	35.6 feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	43.890 meters	**144.0** feet		"
Vertical Velocity V_{jet}	**6.599** m/s	21.65 ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	3.475 meters	11.4 feet	$2a_{jet}$ = 2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet and Merging Phases

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Single Plume Values: Plume Top-Hat Radius a	**Used in Plume Merging Only**		a = 0.16($z-z_v$), or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.211 meters*	0.7 feet*	$z_v = 6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	33.242 meters	109.1 feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.9806	
Single Plume Values: Vertical Velocity V	**Used in Plume Merging Only**		$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	11.243 m^2/s		$V_{exit}(D/2)(\theta_e/\theta_s)^{1/2}$	

Plume Merging - Based on Single Plume Calculations where: Sect.3/¶3

Begin Merging Plume Top-Hat Diameter $2a_{touch}$	4.360 meters	14.3 feet	$2a_{touch}$=d, (or a_{touch}=d/2)
Height above Stack z_{touch}	13.836 meters*	45.4 feet*	$z_{touch} = z_v$+d/(2*0.16), meters*=meters above stack top
Height above Ground $z_{touch}+h_s$	46.867 meters	**153.8** feet	
Vertical Velocity V_{touch}	**5.196** m/s	17.1 ft/sec	$V_{touch} = \{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a
Total Merging Plume Top-Hat **Diameter** $2a_{full}$	**30.520** meters	100.1 feet	$2a_{full}$=2d(N-1)/2, (or a_{full}=d(N-1)/2) **FOR 2 STACKS, $2a_{full}$=2d**
Height above Stack z_{full}	95.586 meters*	313.6 feet*	$z_{full} = z_v$+2d/(2*0.16), meters*=meters above stack top
Height above Ground $z_{full}+h_s$	128.617 meters	**422.0** feet	
Vertical Velocity V_{full}	1.154 m/s	3.8 ft/sec	$V_{full} = \{(Va)_o^3 + 0.12F_o [(z_{full}-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a_{full}$
Product $(V^3a)_{full}$	23 m^4/s^3		

Conditions at End (Top) of Merging Phase - Define new values for V_{full} and a_{full} in Merged Plume calculations (based on TOTAL number of stacks):

Merged Plume Values: Plume Diameter 2a	**Solutions in Table Below**		2a = 2 x (a_m + 0.16($z-z_{full}$)), or linear increase with height
Revised Merged Plume **Radius** a_m	33.776 meters	110.8 feet	where $a_m = n^{0.25}a_{full}$ where Total Merging Occurs
Revised Merged Plume Velocity V_m	**2.555** m/s	8.38 ft/sec	and $V_m = n^{0.25}V_{full}$ where Total Merging Occurs
Revised Virtual Source Height z_{full}	95.586 meters*	313.6 feet*	Height above stack where Total Merging Occurs (shown above)
Revised Vertical Velocity V	**Solutions in Tables Below**		$V=\{n(V^3a)_{full}/a\}^{1/3}$ for heights above total merging elevation
			$V=V_{touch}+(V_m-V_{touch})*(z-z_{touch})/(z_{full}-z_{touch})$

Multiple Plume Calculations | for heights below total merging elevation

Solve for plume-averaged vertical velocity at height	**200.0 feet**	60.96	meters above ground ($z+h_s$)
Gives the following Height above Stack z	27.929 meters*	91.6 feet*	LESS THAN TOP OF MERGING PHASE-INTERPOLATE
Plume Top-Hat Radius a	#N/A meters	#N/A feet	$a=a_m+0.16(z-z_{full})$ **if $z>z_{full}$**
Vertical Velocity V	**4.741 m/s**	15.55 ft/sec	$V=\{n(V^3a)_{full}/a\}^{1/3}$ **if $z>z_{full}$**
			$V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$ **if $z_{touch}<z<z_{full}$**
			V'=single plume values **if $z<z_{touch}$**
Solve for Height of CASC critical vertical velocity V_{crit}	**5.30 m/s**		BEFORE TOUCHING **Critical VV < Top of Jet**
Find Height above Stack z_{crit}	JET meters	JET feet	$z_{crit} = z_{full} + \{[n(V^3a)_{full}/(V_{crit})^3]-a_m\}/0.16$ **if $V_{crit}<V_m$**
Height above Ground $z_{crit}+h_s$	JET meters	**JET feet**	$z_{crit}=z_{touch}+(z_{full}-z_{touch})*(V_{crit}-V_{touch})/(V_m-V_{touch})$ **if $V_{crit}>V_m$**

Table of MERGED Plume-Averaged Vertical Velocities starting at Touching Height:

Height (feet) above ground	(meters) above stack	Plume Radius(m)	Vert. Vel(m/s)	
Begin Merging (touch) = 153.8	***13.85***	***2.180***	***5.20***	
160.0	15.74	#N/A	5.13	**20 ft Intervals**
180.0	21.83	#N/A	4.94	
200.0	27.93	#N/A	4.74	
220.0	34.02	#N/A	4.54	
240.0	40.12	#N/A	4.35	
260.0	46.22	#N/A	4.15	
280.0	52.31	#N/A	3.95	**50 ft Intervals**
300.0	58.41	#N/A	3.76	
320.0	64.50	#N/A	3.56	
340.0	70.60	#N/A	3.36	
360.0	76.70	#N/A	3.17	
380.0	82.79	#N/A	2.97	
400.0	88.89	#N/A	2.77	
End Merging (full/mp) = 422.0	***95.59***	***33.776***	***2.56***	
450.0	104.13	35.143	2.52	
500.0	119.37	37.581	2.47	**100 ft Intervals**
600.0	149.85	42.458	2.37	
700.0	180.33	47.335	2.28	
800.0	210.81	52.212	2.21	
900.0	241.29	57.088	2.15	
1000.0	271.77	61.965	2.09	
1000.0	271.77	61.965	2.09	
1100.0	302.25	66.842	2.04	
1500.0	424.17	86.349	1.87	
2000.0	576.57	110.733	1.72	
2500.0	728.97	135.117	1.61	**500 ft Intervals**
3000.0	881.37	159.501	1.52	
3500.0	1033.77	183.885	1.45	
4000.0	1186.17	208.269	1.39	
4500.0	1338.57	232.653	1.34	
5000.0	1490.97	257.037	1.30	

Single Plume Eqns (see Single Plume spreadsheet)

$V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a

a = 0.16($z-z_v$)

$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$

Interpolated Layer Eqns

$V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$

Merged Plume Eqns

$V=\{n(V^3a)_{full}/a\}^{1/3}$

$a=a_m+0.16(z-z_{full})$

MERGED (along length) Plume Average Vertical Velocities for SVY03AChillers using CEC Staff Methodology - Winter Min*

"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.

"*The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Merged Plume from Two Gas-Turbine Power Station at Oakey, Queensland, Australia*," Dr. K.T. Spillane

Ambient Conditions: | **Constants:** Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	278.15	Kelvins	41.0	°F	0.3048 meters/feet	
Plume Exit Conditions:					Gravity g 9.81 m/s^2	
Stack Height h_s	33.03	meters	108 4/12	feet-inches	λ 1.11	
Individual Stack Diameter D	1.73736	meters	68.4	inches	λ_o ~1.0	
Stack Velocity V_{exit}	13.20	m/s	43.30	ft/sec	$4Vol/(60\pi D^2)$	
Individual Volumetric Flow	31.29	cu.m/sec	66,300	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	289.26	Kelvins	61.0	°F		
Initial Stack Buoyancy Flux F_o	3.75	m^4/s^3	20.0	ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Total Number of Stacks n	24					
Average Adjacent Stack Separation d	2.80	meters	9.2	feet	**Calcs based on multiple plume treatment in Peter Best Paper: plume velocities increased by $N^{0.25}$ at the height where plumes fully merged (interp. below ht, single merged stack above ht)**	
Number of Stacks along Orientation N	12					

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	10.859	meters*	35.6	feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	43.890	meters	**144.0**	feet		"
Vertical Velocity V_{jet}	**6.599**	m/s	21.65	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	3.475	meters	11.4	feet	$2a_{jet}$ = 2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet and Merging Phases

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Single Plume Values: Plume Top-Hat Radius a	**Used in Plume Merging Only**				$a = 0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.211	meters*	0.7	feet*	$z_v = 6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	33.242	meters	109.1	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.9806	
Single Plume Values: Vertical Velocity V	**Used in Plume Merging Only**				$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	11.243	m^2/s			$V_{exit}(D/2)(\theta_e/\theta_s)^{1/2}$	

Plume Merging - Based on Single Plume Calculations where: Sect.3/¶3

Begin Merging Plume Top-Hat Diameter $2a_{touch}$	2.800	meters	9.2	feet	$2a_{touch}$=d, (or a_{touch}=d/2)
Height above Stack z_{touch}	8.961	meters*	29.4	feet*	$z_{touch} = z_v+d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{touch}+h_s$	41.992	meters	**137.8**	feet	
Vertical Velocity V_{touch}	**7.999**	m/s	26.2	ft/sec	$V_{touch} = \{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a
Total Merging Plume Top-Hat **Diameter** $2a_{full}$	**30.800**	meters	101.0	feet	$2a_{full}$=2d(N-1)/2, (or a_{full}=d(N-1)/2) **FOR 2 STACKS, $2a_{full}$=2d**
Height above Stack z_{full}	96.461	meters*	316.5	feet*	$z_{full} = z_v+2d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{full}+h_s$	129.492	meters	**424.8**	feet	
Vertical Velocity V_{full}	1.149	m/s	3.8	ft/sec	$V_{full} = \{(Va)_o^3 + 0.12F_o [(z_{full}-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a_{full}$
Product $(V^3a)_{full}$	23	m^4/s^3			

Conditions at End (Top) of Merging Phase - Define new values for V_{full} and a_{full} in Merged Plume calculations (based on TOTAL number of stacks):

Merged Plume Values: Plume Diameter 2a	**Solutions in Table Below**				$2a = 2 \times (a_m + 0.16(z-z_{full}))$, or linear increase with height
Revised Merged Plume **Radius** a_m	34.086	meters	111.8	feet	where $a_m = n^{0.25}a_{full}$ where Total Merging Occurs
Revised Merged Plume Velocity V_m	**2.544**	m/s	8.34	ft/sec	and $V_m = n^{0.25}V_{full}$ where Total Merging Occurs
Revised Virtual Source Height z_{full}	96.461	meters*	316.5	feet*	Height above stack where Total Merging Occurs (shown above)
Revised Vertical Velocity V	**Solutions in Tables Below**				$V=\{n(V^3a)_{full}/a\}^{1/3}$ for heights above total merging elevation $V=V_{touch}+(V_m-V_{touch})*(z-z_{touch})/(z_{full}-z_{touch})$ for heights below total merging elevation

Multiple Plume Calculations

Solve for plume-averaged vertical velocity at height	**1,000.0**	**feet**	304.8		meters above ground ($z+h_s$)
Gives the following Height above Stack z	271.769	meters*	891.6	feet*	REGULAR EQNS
Plume Top-Hat Radius a	62.135	meters	203.9	feet	$a=a_m+0.16(z-z_{full})$ **if $z>z_{full}$**
Vertical Velocity V	**2.082**	**m/s**	6.83	ft/sec	$V=\{n(V^3a)_{full}/a\}^{1/3}$ **if $z>z_{full}$** $V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$ **if $z_{touch}<z<z_{full}$** V'=single plume values **if $z<z_{touch}$**
Solve for Height of CASC critical vertical velocity V_{crit}	**5.30**	**m/s**			LESS THAN TOP OF MERGING PHASE-INTERPOL
Find Height above Stack z_{crit}	52.252	meters	171.4	feet	$z_{crit} = z_{full} + \{[n(V^3a)_{full}/(V_{crit})^3]-a_m\}/0.16$ **if $V_{crit}<V_m$**
Height above Ground $z_{crit}+h_s$	85.284	meters	**279.8**	**feet**	$z_{crit}=z_{touch}+(z_{full}-z_{touch})*(V_{crit}-V_{touch})/(V_m-V_{touch})$ **if $V_{crit}>V_m$**

Table of MERGED Plume-Averaged Vertical Velocities starting at Touching Height:

Single Plume Eqns (see Single Plume spreadsheet)

$V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a

$a = 0.16(z-z_v)$

$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$

Height (feet) above ground	(meters) above stack	Plume Radius(m)	Vert. Vel(m/s)	
Begin Merging (touch) = 137.8	***8.97***	***1.400***	***8.00***	
140.0	9.64	#N/A	7.96	**20 ft Intervals** — *Interpolated Layer Eqns* $V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$
160.0	15.74	#N/A	7.58	
180.0	21.83	#N/A	7.20	
200.0	27.93	#N/A	6.82	
220.0	34.02	#N/A	6.44	
240.0	40.12	#N/A	6.06	
260.0	46.22	#N/A	5.68	
280.0	52.31	#N/A	5.30	
300.0	*58.41*	#N/A	4.92	*Merged Plume Eqns*
320.0	64.50	#N/A	4.54	**20 ft Intervals** — $V=\{n(V^3a)_{full}/a\}^{1/3}$
340.0	70.60	#N/A	4.16	$a=a_m+0.16(z-z_{full})$
360.0	76.70	#N/A	3.78	
380.0	82.79	#N/A	3.40	
End Merging (full/mp) = 424.8	***96.45***	***34.086***	***2.54***	
500.0	119.37	37.751	2.46	**100 ft Intervals**
600.0	149.85	42.628	2.36	
700.0	180.33	47.505	2.28	
800.0	210.81	52.382	2.20	
900.0	241.29	57.258	2.14	
1000.0	271.77	62.135	2.08	
1100.0	302.25	67.012	2.03	
1200.0	332.73	71.889	1.98	
1300.0	363.21	76.766	1.94	**500 ft Intervals**
1500.0	424.17	86.519	1.86	
2000.0	576.57	110.903	1.72	
2500.0	728.97	135.287	1.61	
3000.0	881.37	159.671	1.52	
3500.0	1033.77	184.055	1.45	
4000.0	1186.17	208.439	1.39	
4500.0	1338.57	232.823	1.34	

SINGLE/Approximated Plume Average Vertical Velocities for SVY03A CRACs using CEC Staff Methodology - Summer Max*

Based on 9 chillers w/ 6 cells/chiller. Calc' eff.diam for each chiller wiith each cell at 33" ID (69,000 ACFM total for each chiller).

"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.
"*The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Plume from a Gas-Turbine Power Station at Oakey, Queensland, Australia*," Dr. K.T. Spillane

Ambient Conditions: | **Constants:** Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	302.21	Kelvins	84.3	°F	0.3048 meters/feet	
Plume Exit Conditions:					Gravity g 9.81 m/s^2	
Stack Height h_s	10.83	meters	35 6/12	feet-inches	λ 1.11	
Individual Chiller Stack Diameter D	2.0404	meters	80.3	inches	λ_o ~1.0	
Stack Velocity V_{exit}	9.96	m/s	32.67	ft/sec	$4Vol/(60\pi D^2)$	
Individual Chiller Volumetric Flow	32.56	cu.m/sec	69,000	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	322.21	Kelvins	120.3	°F		
Initial Stack Buoyancy Flux F_o	6.3105	m^4/s^3	36.0	ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Number of Chillers n	9		1.732		Multiple Stack Multiplication Factor ($n^{0.25}$)	

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	12.752	meters*	41.8	feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	23.585	meters	**77.4**	feet		"
Vertical Velocity V_{jet}	4.980	m/s	16.34	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	4.081	meters	13.4	feet	$2a_{jet}$ = 2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.402	meters*	1.3	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	11.235	meters	36.9	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.9685	
Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o[(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	9.840	m^2/s			$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Single Chiller Results:

Solve for plume-averaged vertical velocity at height	**500.0**	**feet**	152.4	meters above ground (z'+h_s)		
Gives the following Height above Stack z'	141.567	meters*	464.5	feet*		
Plume Top-Hat Diameter 2a'	45.173	meters	148.2	feet	2a'=2*0.16(z'-z_v)	Sect.2/Eq.6
Vertical Velocity V	**1.114**	**m/s**	3.65	ft/sec	$V=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{(1/3)}/(2a'/2)$	Sect.2/Eq.6

Solve for Height of CASC critical vertical velocity V_{crit} **5.30** **m/s plume-averaged vertical velocity** — **Critical VV < Top of Jet**

Find Height above Stack z_{crit}	#N/A	meters	#N/A	feet	Solve for $x=(z-z_v)$ simultaneously in both eqs. (i.e., Va and a)
Height above Ground $z_{crit}+h_s$	#N/A	meters	**#N/A**	feet	for $V=V_{crit}$ using the cubic equation $ax^3+bx^2+cx+d=0$, where

a=1, c=0, and $b=-(0.12F_o)/(V_{crit}^3 0.16^3)$= -1.24181
and $d=[0.12F_o(6.25D-z_v)^2-(Va)_o^3]/(V_{crit}^3 0.16^3)$= -1373.00
http://www.1728.org/cubic.htm

Interpolated Height of critical vertical velocity in Jet Phase:

Find Height above Stack z_{crit}	11.932	meters	39.1	feet
Height above Ground $z_{crit}+h_s$	22.765	meters	**74.7**	feet

gives the real solution x = z-zv = 11.5442
or z(m/above stack) = 11.946
z(ft/above ground) = 74.7

Table of Plume Top-Hat Diameters (2a) and Plume-Averaged Vertical Velocities starting at end of jet phase:

Height (feet) above ground	**(meters) above stack**	**Plume Radius(m)**	**SingleStk VertVel(m/s)**	**Plume Temp(K)**
Stack.Rel.Ht = 35.5	**0.00**	**1.020**	**9.96**	
40.0	1.36	1.122	9.43	
50.0	4.41	1.351	8.24	
60.0	7.46	1.579	7.05	
70.0	10.50	1.807	5.86	
Single Jet 5.3 m/s Height = 74.7	**11.93**	**1.915**	**5.30**	
Top of Single jet = 77.4	12.75	1.976	4.98	310.33
80.0	13.55	2.104	4.70	310.32
90.0	16.60	2.592	3.90	309.79
100.0	19.65	3.079	3.37	308.23
110.0	22.70	3.567	2.99	307.15
120.0	25.74	4.055	2.71	306.36
130.0	28.79	4.542	2.49	305.75
150.0	34.89	5.518	2.18	305.28
200.0	50.13	7.956	1.75	304.59
250.0	65.37	10.394	1.53	303.63
300.0	80.61	12.833	1.39	303.16
350.0	95.85	15.271	1.30	302.90
400.0	111.09	17.710	1.22	302.73
450.0	126.33	20.148	1.16	302.62
500.0	141.57	22.586	1.11	302.54
600.0	172.05	27.463	1.04	302.49
700.0	202.53	32.340	0.98	302.41
800.0	233.01	37.217	0.93	302.36
900.0	263.49	42.094	0.89	302.33
1000.0	293.97	46.970	0.86	302.31
1100.0	324.45	51.847	0.83	302.29
1200.0	354.93	56.724	0.81	302.28
1300.0	385.41	61.601	0.79	302.27
1500.0	446.37	71.354	0.75	302.26
2000.0	598.77	95.738	0.68	302.25
2500.0	751.17	120.122	0.63	302.24
3000.0	903.57	144.506	0.59	302.23
3500.0	1055.97	168.890	0.56	302.22
4000.0	1208.37	193.274	0.54	302.22
4500.0	1360.77	217.658	0.51	302.22
				302.22

Jet Phase Eqs: **10 ft Intervals**
Linearly interpolated from Stack Rel.Ht to Top of Jet

Spillane Equations:
$V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a
$a = 0.16(z-z_v)$
$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$

CEC Staff Equation:
$V_{mp}=n^{0.25}V_{sp}$

Brigg's Equation:
$V_{Brigg's} = (2/3) \times 1.6^{(3/2)} \times F_{mp}^{(1/2)} \times u^{(-1/2)} \times z^{(-1/2)}$
where $F_{mp} = nF_{sp}$

50 ft Intervals
Max<5.3 m/s
100 ft Intervals
500 ft Intervals

*Winter Min = Monthly Mean of Minimum Daily Temperatures for 1971-2000 (Lowest in Dece
NOAA Sources: Climatography of the United

MERGED (along length) Plume Average Vertical Velocities for SVY03A CRACs using CEC Staff Methodology - Winter Min*

"***Aviation Safety and Buoyant Plumes***," Peter Best, et. al.

"***The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Merged Plume from Two Gas-Turbine Power Station at Oakey, Queensland, Australia***," Dr. K.T. Spillane

Ambient Conditions:

Constants: Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	302.21	Kelvins	84.3	°F	0.3048 meters/feet	
Plume Exit Conditions:					Gravity g: 9.81 m/s^2	
Stack Height h_s	10.83	meters	35 6/12	feet-inches	λ: 1.11	
Individual Stack Diameter D	2.040382	meters	80.3	inches	λ_o: ~1.0	
Stack Velocity V_{exit}	9.96	m/s	32.67	ft/sec	$4Vol/(60\pi D^2)$	
Individual Volumetric Flow	32.56	cu.m/sec	69,000	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	322.21	Kelvins	120.3	°F		
Initial Stack Buoyancy Flux F_o	6.31	m^4/s^3	36.0	ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Total Number of Stacks n	9					
Average Adjacent Stack Separation d	2.13	meters	7.0	feet	**Calcs based on multiple plume treatment in Peter Best Paper:**	
Number of Stacks along Orientation N	9				**plume velocities increased by $N^{0.25}$ at the height where plumes**	
					fully merged (interp. below ht, single merged stack above ht)	

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	12.752	meters*	41.8	feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	23.585	meters	**77.4**	feet		"
Vertical Velocity V_{jet}	**4.980**	m/s	16.34	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	4.081	meters	13.4	feet	$2a_{jet}$ = 2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet and Merging Phases

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Single Plume Values: Plume Top-Hat Radius a	**Used in Plume Merging Only**				$a = 0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.402	meters*	1.3	feet*	$z_v = 6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	11.235	meters	36.9	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$ = 0.9685	
Single Plume Values: Vertical Velocity V	**Used in Plume Merging Only**				$\{(Va)_o^3 + 0.12F_o[(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a$	Sect.2.1(6)
Product $(Va)_o$	9.840	m^2/s			$V_{exit}(D/2)(\theta_e/\theta_s)^{1/2}$	

Plume Merging - Based on Single Plume Calculations where: Sect.3/¶3

Begin Merging Plume Top-Hat Diameter $2a_{touch}$	2.130	meters	7.0	feet	$2a_{touch}$=d, (or a_{touch}=d/2)
Height above Stack z_{touch}	7.058	meters*	23.2	feet*	$z_{touch} = z_v+d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{touch}+h_s$	17.891	meters	**58.7**	feet	
Vertical Velocity V_{touch}	**8.967**	m/s	29.4	ft/sec	$V_{touch} = \{(Va)_o^3 + 0.12F_o[(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a$
Total Merging Plume Top-Hat **Diameter** $2a_{full}$	17.040	meters	55.9	feet	$2a_{full}$=2d(N-1)/2, (or a_{full}=d(N-1)/2) **FOR 2 STACKS, $2a_{full}$=2d**
Height above Stack z_{full}	53.652	meters*	176.0	feet*	$z_{full} = z_v+2d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{full}+h_s$	64.485	meters	**211.6**	feet	
Vertical Velocity V_{full}	1.690	m/s	5.5	ft/sec	$V_{full} = \{(Va)_o^3 + 0.12F_o[(z_{full}-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a_{full}$
Product $(V^3a)_{full}$	41	m^4/s^3			

Conditions at End (Top) of Merging Phase - Define new values for V_{full} and a_{full} in Merged Plume calculations (based on TOTAL number of stacks):

Merged Plume Values: Plume Diameter 2a	**Solutions in Table Below**				$2a = 2 \times (a_m + 0.16(z-z_{full}))$, or linear increase with height
Revised Merged Plume **Radius** a_m	14.757	meters	48.4	feet	where $a_m = n^{0.25}a_{full}$ where Total Merging Occurs
Revised Merged Plume Velocity V_m	**2.927**	m/s	9.60	ft/sec	and $V_m = n^{0.25}V_{full}$ where Total Merging Occurs
Revised Virtual Source Height z_{full}	53.652	meters*	176.0	feet*	Height above stack where Total Merging Occurs (shown above)
Revised Vertical Velocity V	**Solutions in Tables Below**				$V=\{n(V^3a)_{full}/a\}^{1/3}$ for heights above total merging elevation
					$V=V_{touch}+(V_m-V_{touch})*(z-z_{touch})/(z_{full}-z_{touch})$ for heights below total merging elevation

Multiple Plume Calculations

Solve for plume-averaged vertical velocity at height	**500.0**	**feet**	152.4		meters above ground $(z+h_s)$
Gives the following Height above Stack z	141.567	meters*	464.5	feet*	REGULAR EQNS
Plume Top-Hat Radius a	28.824	meters	94.6	feet	$a=a_m+0.16(z-z_{full})$ **if $z>z_{full}$**
Vertical Velocity V	**2.342**	**m/s**	7.68	ft/sec	$V=\{n(V^3a)_{full}/a\}^{1/3}$ **if $z>z_{full}$**
					$V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$ **if $z_{touch}<z<z_{full}$**
					V'=single plume values **if $z<z_{touch}$**
Solve for Height of CASC critical vertical velocity V_{crit}	**5.30**	**m/s**			LESS THAN TOP OF MERGING PHASE-INTERPOL
Find Height above Stack z_{crit}	35.345	meters	116.0	feet	$z_{crit} = z_{full} + \{[n(V^3a)_{full}/(V_{crit})^3]-a_m\}/0.16$ **if $V_{crit}<V_m$**
Height above Ground $z_{crit}+h_s$	46.177	meters	**151.5**	**feet**	$z_{crit}=z_{touch}+(z_{full}-z_{touch})*(V_{crit}-V_{touch})/(V_m-V_{touch})$ **if $V_{crit}>V_m$**

Table of MERGED Plume-Averaged Vertical Velocities starting at Touching Height:

Height (feet) above ground	(meters) above stack	Plume Radius(m)	Vert. Vel(m/s)		
Begin Merging (touch) = 58.7	***7.06***	***1.065***	***8.97***	*Single Plume Eqns (see Single Plume spreadsheet)* $V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3} / a$ $a = 0.16(z-z_v)$ $\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$	
60.0	7.46	#N/A	8.92	*Interpolated Layer Eqns*	**20 ft Intervals**
80.0	13.55	#N/A	8.12	$V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$	
100.0	19.65	#N/A	7.33		
120.0	25.74	#N/A	6.54		
140.0	31.84	#N/A	5.75		
160.0	37.94	#N/A	4.96		
180.0	44.03	#N/A	4.17		
200.0	50.13	#N/A	3.38		
End Merging (full/mp) = 211.6	***53.66***	***14.757***	***2.93***	*Merged Plume Eqns*	
300.0	80.61	19.070	2.69	$V=\{n(V^3a)_{full}/a\}^{1/3}$	**20 ft Intervals**
400.0	111.09	23.947	2.49	$a=a_m+0.16(z-z_{full})$	
500.0	141.57	28.824	2.34		
600.0	172.05	33.700	2.22		
700.0	202.53	38.577	2.12		
800.0	233.01	43.454	2.04		**100 ft Intervals**
900.0	263.49	48.331	1.97		
1000.0	293.97	53.208	1.91		
1100.0	324.45	58.084	1.85		
1200.0	354.93	62.961	1.80		
1300.0	385.41	67.838	1.76		
1400.0	415.89	72.715	1.72		
1500.0	446.37	77.592	1.68		
1600.0	476.85	82.468	1.65		**500 ft Intervals**
2000.0	598.77	101.976	1.54		
2500.0	751.17	126.360	1.43		
3000.0	903.57	150.744	1.35		
3500.0	1055.97	175.128	1.28		
4000.0	1208.37	199.512	1.23		
4500.0	1360.77	223.896	1.18		
5000.0	1513.17	248.280	1.14		

SINGLE/Approximated Plume Average Vertical Velocities for SVY03A CRACs using CEC Staff Methodology - Winter Min*

Based on 9 chillers w/ 6 cells/chiller. Calc' eff.diam for each chiller wiith each cell at 33" ID (69,000 ACFM total for each chiller).

"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.

"*The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Plume from a Gas-Turbine Power Station at Oakey, Queensland, Australia*," Dr. K.T. Spillane

Ambient Conditions:

Ambient Potential Temp θ_a 278.15 Kelvins 41.0 °F

Constants: Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

0.3048 meters/feet

Gravity g 9.81 m/s^2

λ 1.11

λ_o ~1.0

Plume Exit Conditions:

Stack Height h_s	10.83	meters	35 6/12	feet-inches		
Individual Chiller Stack Diameter D	2.0404	meters	80.3	inches		
Stack Velocity V_{exit}	9.96	m/s	32.67	ft/sec	$4Vol/(60\pi D^2)$	
Individual Chiller Volumetric Flow	32.56	cu.m/sec	69,000	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	289.26	Kelvins	61.0	°F		
Initial Stack Buoyancy Flux F_o	3.9060	m^4/s^3	20.0	ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Number of Chillers n	9		1.732		Multiple Stack Multiplication Factor ($n^{0.25}$)	

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	12.752	meters*	41.8	feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	23.585	meters	**77.4**	feet		"
Vertical Velocity V_{jet}	4.980	m/s	16.34	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	4.081	meters	13.4	feet	$2a_{jet}$ = 2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.247	meters*	0.8	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	11.080	meters	36.4	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.9806	
Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	9.963	m^2/s			$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Single Chiller Results:

Solve for plume-averaged vertical velocity at height **500.0** **feet** 152.4 meters above ground ($z'+h_s$)

Gives the following Height above Stack z'	141.567	meters*	464.5	feet*		
Plume Top-Hat Diameter 2a'	45.222	meters	148.4	feet	$2a'=2*0.16(z'-z_v)$	Sect.2/Eq.6
Vertical Velocity V	**0.962**	**m/s**	3.15	ft/sec	$V=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{(1/3)}/(2a'/2)$	Sect.2/Eq.6

Solve for Height of CASC critical vertical velocity V_{crit} **5.30** **m/s plume-averaged vertical velocity** **Critical VV < Top of Jet**

Find Height above Stack z_{crit}	#N/A	meters	#N/A	feet	Solve for $x=(z-z_v)$ simultaneously in both eqs. (i.e., Va and a)
Height above Ground $z_{crit}+h_s$	#N/A	meters	**#N/A**	feet	for $V=V_{crit}$ using the cubic equation $ax^3+bx^2+cx+d=0$, where

a=1, c=0, and $b=-(0.12F_o)/(V_{crit}^3 0.16^3)$= -0.76864

and $d=[0.12F_o(6.25D-z_v)^2-(Va)_o^3]/(V_{crit}^3 0.16^3)$= -1501.55

Interpolated Height of critical vertical velocity in Jet Phase:

Find Height above Stack z_{crit}	11.932	meters	39.1	feet
Height above Ground $z_{crit}+h_s$	22.765	meters	**74.7**	feet

http://www.1728.org/cubic.htm

gives the real solution x = z-zv = 11.7131

or z(m/above stack) = 11.960

z(ft/above ground) = 74.8

Table of Plume Top-Hat Diameters (2a) and Plume-Averaged Vertical Velocities starting at end of jet phase:

Height (feet) above ground	(meters) above stack	Plume Radius(m)	SingleStk VertVel(m/s)	Plume Temp(K)
Stack.Rel.Ht = 35.5	**0.00**	**1.020**	**9.96**	
40.0	1.36	1.125	9.43	
50.0	4.41	1.359	8.24	
60.0	7.46	1.593	7.05	
70.0	10.50	1.828	5.86	
Single Jet 5.3 m/s Height = 74.7	**11.93**	**1.938**	**5.30**	
Top of Single jet = 77.4	12.75	2.001	4.98	282.67
80.0	13.55	2.129	4.70	282.66
90.0	16.60	2.616	3.87	282.37
100.0	19.65	3.104	3.32	281.54
110.0	22.70	3.592	2.92	280.96
120.0	25.74	4.079	2.62	280.54
130.0	28.79	4.567	2.39	280.21
150.0	34.89	5.542	2.06	279.95
200.0	50.13	7.981	1.60	279.57
250.0	65.37	10.419	1.37	279.03
300.0	80.61	12.858	1.23	278.75
350.0	95.85	15.296	1.13	278.59
400.0	111.09	17.734	1.06	278.49
450.0	126.33	20.173	1.01	278.42
500.0	141.57	22.611	0.96	278.37
600.0	172.05	27.488	0.89	278.33
700.0	202.53	32.365	0.84	278.28
800.0	233.01	37.242	0.80	278.25
900.0	263.49	42.118	0.76	278.23
1000.0	293.97	46.995	0.74	278.22
1100.0	324.45	51.872	0.71	278.21
1200.0	354.93	56.749	0.69	278.20
1300.0	385.41	61.626	0.67	278.19
1500.0	446.37	71.379	0.64	278.19
2000.0	598.77	95.763	0.58	278.18
2500.0	751.17	120.147	0.53	278.17
3000.0	903.57	144.531	0.50	278.16
3500.0	1055.97	168.915	0.48	278.16
4000.0	1208.37	193.299	0.46	278.16
4500.0	1360.77	217.683	0.44	278.16
				278.15

Jet Phase Eqs: **10 ft Intervals**

Linearly interpolated from Stack Rel.Ht to Top of Jet

Spillane Equations:

$V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a

$a = 0.16(z-z_v)$

$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$

CEC Staff Equation:

$V_{mp}=n^{0.25}V_{sp}$

Brigg's Equation:

$V_{Brigg's} = (2/3) \times 1.6^{(3/2)} \times F_{mp}^{(1/2)} \times u^{(-1/2)} \times z^{(-1/2)}$

where $F_{mp} = nF_{sp}$

50 ft Intervals

Max<5.3 m/s

100 ft Intervals

500 ft Intervals

*Winter Min = Monthly Mean of Minimum Daily Temperatures for 1971-2000 (Lowest in Dece

NOAA Sources: Climatography of the United

MERGED (along length) Plume Average Vertical Velocities for SVY03A CRACs using CEC Staff Methodology - Winter Min*

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Ambient Conditions:

Constants: Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	278.15	Kelvins	41.0	°F	0.3048 meters/feet	
Plume Exit Conditions:					Gravity g: 9.81 m/s^2	
Stack Height h_s	10.83	meters	35 6/12	feet-inches	λ: 1.11	
Individual Stack Diameter D	2.040382	meters	80.3	inches	λ_o: ~1.0	
Stack Velocity V_{exit}	9.96	m/s	32.67	ft/sec	$4Vol/(60\pi D^2)$	
Individual Volumetric Flow	32.56	cu.m/sec	69,000	ACFM	$\pi V_{exit}D^2/4$	Sect.2/¶1
Stack Potential Temp θ_s	289.26	Kelvins	61.0	°F		
Initial Stack Buoyancy Flux F_o	3.91	m^4/s^3	20.0	ΔT(°F)	$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$	Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)	
Total Number of Stacks n	9					
Average Adjacent Stack Separation d	2.13	meters	7.0	feet	**Calcs based on multiple plume treatment in Peter Best Paper:**	
Number of Stacks along Orientation N	9				**plume velocities increased by $N^{0.25}$ at the height where plumes**	
					fully merged (interp. below ht, single merged stack above ht)	

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	12.752	meters*	41.8	feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	23.585	meters	**77.4**	feet		"
Vertical Velocity V_{jet}	**4.980**	m/s	16.34	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	4.081	meters	13.4	feet	$2a_{jet}$ = 2D Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet and Merging Phases

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Single Plume Values: Plume Top-Hat Radius a	**Used in Plume Merging Only**				a = $0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	0.247	meters*	0.8	feet*	$z_v = 6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	11.080	meters	36.4	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.9806	
Single Plume Values: Vertical Velocity V	**Used in Plume Merging Only**				$\{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	9.963	m^2/s			$V_{exit}(D/2)(\theta_e/\theta_s)^{1/2}$	

Plume Merging - Based on Single Plume Calculations where: Sect.3/¶3

Begin Merging Plume Top-Hat Diameter $2a_{touch}$	2.130	meters	7.0	feet	$2a_{touch}$=d, (or a_{touch}=d/2)
Height above Stack z_{touch}	6.904	meters*	22.6	feet*	$z_{touch} = z_v+d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{touch}+h_s$	17.736	meters	**58.2**	feet	
Vertical Velocity V_{touch}	**9.186**	m/s	30.1	ft/sec	$V_{touch} = \{(Va)_o^3 + 0.12F_o [(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a
Total Merging Plume Top-Hat **Diameter** $2a_{full}$	**17.040**	meters	55.9	feet	$2a_{full}$=2d(N-1)/2, (or a_{full}=d(N-1)/2) **FOR 2 STACKS, $2a_{full}$=2d**
Height above Stack z_{full}	53.497	meters*	175.5	feet*	$z_{full} = z_v+2d/(2*0.16)$, meters*=meters above stack top
Height above Ground $z_{full}+h_s$	64.330	meters	**211.1**	feet	
Vertical Velocity V_{full}	1.537	m/s	5.0	ft/sec	$V_{full} = \{(Va)_o^3 + 0.12F_o [(z_{full}-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)} / a_{full}$
Product $(V^3a)_{full}$	31	m^4/s^3			

Conditions at End (Top) of Merging Phase - Define new values for V_{full} and a_{full} in Merged Plume calculations (based on TOTAL number of stacks):

Merged Plume Values: Plume Diameter 2a	**Solutions in Table Below**				2a = 2 x (a_m + $0.16(z-z_{full})$), or linear increase with height
Revised Merged Plume **Radius** a_m	14.757	meters	48.4	feet	where $a_m = n^{0.25}a_{full}$ where Total Merging Occurs
Revised Merged Plume Velocity V_m	**2.662**	m/s	8.73	ft/sec	and $V_m = n^{0.25}V_{full}$ where Total Merging Occurs
Revised Virtual Source Height z_{full}	53.497	meters*	175.5	feet*	Height above stack where Total Merging Occurs (shown above)
Revised Vertical Velocity V	**Solutions in Tables Below**				$V=\{n(V^3a)_{full}/a\}^{1/3}$ for heights above total merging elevation
					$V=V_{touch}+(V_m-V_{touch})*(z-z_{touch})/(z_{full}-z_{touch})$

Multiple Plume Calculations   for heights below total merging elevation

Solve for plume-averaged vertical velocity at height	**500.0**	**feet**	152.4		meters above ground $(z+h_s)$
Gives the following Height above Stack z	141.567	meters*	464.5	feet*	REGULAR EQNS
Plume Top-Hat Radius a	28.848	meters	94.6	feet	$a=a_m+0.16(z-z_{full})$ **if $z>z_{full}$**
Vertical Velocity V	**2.129**	**m/s**	6.98	ft/sec	$V=\{n(V^3a)_{full}/a\}^{1/3}$ **if $z>z_{full}$**
					$V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$ **if $z_{touch}<z<z_{full}$**
					V'=single plume values **if $z<z_{touch}$**
Solve for Height of CASC critical vertical velocity V_{crit}	**5.30**	**m/s**			LESS THAN TOP OF MERGING PHASE-INTERPOL
Find Height above Stack z_{crit}	34.657	meters	113.7	feet	$z_{crit} = z_{full} + \{[n(V^3a)_{full}/(V_{crit})^3]-a_m\}/0.16$ **if $V_{crit}<V_m$**
Height above Ground $z_{crit}+h_s$	45.490	meters	**149.2**	**feet**	$z_{crit}=z_{touch}+(z_{full}-z_{touch})*(V_{crit}-V_{touch})/(V_m-V_{touch})$ **if $V_{crit}>V_m$**

Table of MERGED Plume-Averaged Vertical Velocities starting at Touching Height:

Height (feet) above ground	(meters) above stack	Plume Radius(m)	Vert. Vel(m/s)		
Begin Merging (touch) = 58.2	***6.91***	***1.065***	***9.19***	*Single Plume Eqns (see Single Plume spreadsheet)* $V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a; a = $0.16(z-z_v)$; $\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$	
60.0	7.46	#N/A	9.11	*Interpolated Layer Eqns*	**20 ft Intervals**
80.0	13.55	#N/A	8.26	$V'=V_{touch}+(V_m-V_{touch})*(z'-z_{touch})/(z_{full}-z_{touch})$	
100.0	19.65	#N/A	7.40		
120.0	25.74	#N/A	6.55		
140.0	31.84	#N/A	5.69		
160.0	37.94	#N/A	4.84		
180.0	44.03	#N/A	3.99		
200.0	50.13	#N/A	3.13		
End Merging (full/mp) = 211.1	***53.51***	***14.757***	***2.66***	*Merged Plume Eqns*	
300.0	80.61	19.095	2.44	$V=\{n(V^3a)_{full}/a\}^{1/3}$	**20 ft Intervals**
400.0	111.09	23.971	2.26	$a=a_m+0.16(z-z_{full})$	
500.0	141.57	28.848	2.13		
600.0	172.05	33.725	2.02		
700.0	202.53	38.602	1.93		
800.0	233.01	43.479	1.86		**100 ft Intervals**
900.0	263.49	48.355	1.79		
1000.0	293.97	53.232	1.74		
1100.0	324.45	58.109	1.69		
1200.0	354.93	62.986	1.64		
1300.0	385.41	67.863	1.60		
1400.0	415.89	72.739	1.56		
1500.0	446.37	77.616	1.53		
1600.0	476.85	82.493	1.50		**500 ft Intervals**
2000.0	598.77	102.000	1.40		
2500.0	751.17	126.384	1.30		
3000.0	903.57	150.768	1.23		
3500.0	1055.97	175.152	1.17		
4000.0	1208.37	199.536	1.12		
4500.0	1360.77	223.920	1.08		
5000.0	1513.17	248.304	1.04		

SINGLE Plume Average Vertical Velocities for SVY03A Large Emer.Gen Engine, 100% Load, and Maximum Stack Height - Winter Min*

"***Aviation Safety and Buoyant Plumes***," Peter Best, et. al.

"***The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Plume from a Gas-Turbine Power Station at Oakey, Queensland, Australia***," Dr. K.T. Spillane

Ambient Conditions:

Constants: Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	278.15	Kelvins	41.0	°F		0.3048	meters/feet
Plume Exit Conditions:					Gravity g	9.81	m/s^2
Maximum Stack Height h_s	30.48	meters	100	feet-inches	λ	1.11	
Stack Diameter D	0.5080	meters	20	inches	λ_o	~1.0	
Stack Velocity V_{exit}	51.34	m/s	168.45	ft/sec			
Volumetric Flow	10.41	cu.m/sec	22,050	ACFM	$\pi V_{exit}D^2/4$		Sect.2/¶1
Stack Potential Temp θ_s	753.15	Kelvins	896	°F			
Initial Stack Buoyancy Flux F_o	20.4929	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$		Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)		
No.of Stacks N	1			1.000	Multiple Stack Multiplication Factor ($N^{0.25}$)		

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	3.175	meters*	10.4	feet*	z_{jet} = 6.25D, meters*=meters above stack top	Sect.3/¶1
Height above Ground $z_{jet}+h_s$	33.655	meters	**110.4**	feet		"
Vertical Velocity V_{jet}	25.670	m/s	84.22	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$	"
Plume Top-Hat Diameter $2a_{jet}$	1.016	meters	3.3	feet	$2a_{jet}$ = 2D — Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	1.246	meters*	4.1	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	31.726	meters	104.1	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.6077	
Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o[(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	7.925	m^2/s			$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Solve for plume-averaged vertical velocity at height	**200.0**	**feet**	60.96		meters above ground $(z'+h_s)$	
Gives the following Height above Stack z'	30.480	meters*	100.0	feet*		
Plume Top-Hat Diameter 2a'	9.355	meters	30.7	feet	$2a'=2*0.16(z'-z_v)$	Sect.2/Eq.6
Vertical Velocity V	**2.936**	**m/s**	9.63	ft/sec	$V=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{(1/3)}/(2a'/2)$	Sect.2/Eq.6

Solve for Height of CASC critical vertical velocity V_{crit} **5.30** **m/s plume-averaged vertical velocity** — **Critical VV > Top of Jet (Spillane)**

Find Height above Stack z_{crit}	12.090	meters	39.7	feet	Solve for $x=(z-z_v)$ simultaneously in both eqs. (i.e., Va and a)	
Height above Ground $z_{crit}+h_s$	42.570	meters	**139.7**	feet	for V=4.3 m/s using the cubic equation $ax^3+bx^2+cx+d=0$, where	
					a=1, c=0, and $b=-(0.12F_o)/(4.3^3 0.16^3)$=	-4.0327
Interpolated Height of critical vertical velocity in Jet Phase:					and $d=[0.12F_o(6.25D-z_v)^2-(Va)_o^3]/(4.3^3 0.16^3)$=	-801.21
Find Height above Stack z_{crit}	#N/A	meters	#N/A	feet	http://www.1728.org/cubic.htm	
Height above Ground $z_{crit}+h_s$	#N/A	meters	**#N/A**	feet	gives the real solution x = z-zv =	10.8450
					or z(m/above stack) =	12.090
					z(ft/above ground) =	139.7

Table of Plume Top-Hat Diameters (2a) and Plume-Averaged Vertical Velocities starting at end of jet phase:

Height (feet) above ground	(meters) above stack	Plume Radius(m)	SingleStk VertVel(m/s)	Plume Temp(K)
Stack.Rel.Ht = 100.0	**0.00**	**0.254**	**51.34**	
105.0	1.52	0.376	39.00	
110.0	3.05	0.498	26.66	
Top of jet = 110.4	**3.17**	**0.508**	**25.67**	
120.0	6.10	0.776	10.53	352.48
130.0	9.14	1.264	6.83	321.41
140.0	12.19	1.751	5.26	307.36
Spillane 5.3 m/s Height = 139.7	**12.09**	**1.735**	**5.30**	307.70
150.0	15.24	2.239	4.42	299.43
160.0	18.29	2.727	3.90	294.41
170.0	21.34	3.214	3.55	291.02
180.0	24.38	3.702	3.29	288.61
190.0	27.43	4.190	3.09	286.84
200.0	30.48	4.678	2.94	285.49
250.0	45.72	7.116	2.46	281.94
300.0	60.96	9.554	2.20	280.50
350.0	76.20	11.993	2.02	279.77
400.0	91.44	14.431	1.90	279.34
450.0	106.68	16.870	1.80	279.07
500.0	121.92	19.308	1.71	278.89
550.0	137.16	21.746	1.65	278.76
650.0	167.64	26.623	1.54	278.58
750.0	198.12	31.500	1.45	278.48
850.0	228.60	36.377	1.38	278.41
950.0	259.08	41.254	1.33	278.36
1050.0	289.56	46.130	1.28	278.32
1150.0	320.04	51.007	1.24	278.30
1250.0	350.52	55.884	1.20	278.28
1350.0	381.00	60.761	1.17	278.26
1450.0	411.48	65.638	1.14	278.25
1550.0	441.96	70.514	1.11	278.24
1650.0	472.44	75.391	1.08	278.23
1750.0	502.92	80.268	1.06	278.22
1850.0	533.40	85.145	1.04	278.21
1950.0	563.88	90.022	1.02	278.21
2050.0	594.36	94.898	1.00	278.20

Jet Phase Eqs: — **5 foot Intervals**

Linearly interpolated from Stack Rel.Ht to Top of Jet

Spillane Equations:

$V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a

a = $0.16(z-z_v)$ — **10 foot Intervals**

$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$

Max<5.30 m/s

50 foot Intervals

100 foot Intervals

*Winter Min = Monthly Mean of Minimum Daily Temperatures for 1971-2000 (Lowest in December)

NOAA Sources: Climatography of the United States No.81 *"Monthly Station Normals of Temperatures, Precipitation, and Heating and Cooling Degree Days, 1971-2000 California"* and Climatography of the United States No. 20 *"Monthly Station Climate Summaries, 1971-2000 California"*

SINGLE Plume Average Vertical Velocities for Single SVY03A Large Emer.Gen Engine, 100% Load, and Maximum Stack Height - Summer Max*

"*Aviation Safety and Buoyant Plumes*," Peter Best, et. al.

"*The Evaluation of Maximum Updraft Speeds for Calm Conditions at Various Heights in the Plume from a Gas-Turbine Power Station at Oakey, Queensland, Australia*," Dr. K.T. Spillane

Ambient Conditions:

Constants: Assume neutral conditions ($d\theta/dz=0$ or $\theta_a=\theta_e$)

Ambient Potential Temp θ_a	302.21	Kelvins	84.3	°F		0.3048 meters/feet	
Plume Exit Conditions:					Gravity g	9.81 m/s^2	
Maximum Stack Height h_s	30.48	meters	100	feet-inches	λ	1.11	
Stack Diameter D	0.5080	meters	20	inches	λ_o	~1.0	
Stack Velocity V_{exit}	51.34	m/s	168.45	ft/sec			
Volumetric Flow	10.41	cu.m/sec	22,050	ACFM	$\pi V_{exit}D^2/4$		Sect.2/¶1
Stack Potential Temp θ_s	753.15	Kelvins	896	°F			
Initial Stack Buoyancy Flux F_o	19.4549	m^4/s^3			$gV_{exit}D^2(1-\theta_a/\theta_s)/4$ = Vol.Flow$(g/\pi)(1-\theta_a/\theta_s)$		Sect.2/¶1
Plume Buoyancy Flux F	N/A	m^4/s^3			$\lambda^2 gVa^2(1-\theta_a/\theta_p)$ for a,V,θ_p at plume height (see below)		
No.of Stacks N	1			1.000	Multiple Stack Multiplication Factor ($N^{0.25}$)		

Conditions at End (Top) of Jet Phase:

Height above Stack z_{jet}	3.175	meters*	10.4	feet*	z_{jet} = 6.25D, meters*=meters above stack top		Sect.3/¶1
Height above Ground $z_{jet}+h_s$	33.655	meters	**110.4**	feet			"
Vertical Velocity V_{jet}	25.670	m/s	84.22	ft/sec	$V_{jet} = 0.5V_{exit} = V_{exit}/2$		"
Plume Top-Hat Diameter $2a_{jet}$	1.016	meters	3.3	feet	$2a_{jet}$ = 2D	Conservation of momentum	"

Spillane Methodology - Analytical Solutions for Calm Conditions for Plume Heights above Jet Phase

Single Plume-averaged Vertical Velocity V given by Analytical Solution in Paper where Product Va given by equations below:

Plume Top-Hat Radius a	**Solutions in Table Below**				$0.16(z-z_v)$, or linear increase with height	Sect.2/Eq.6
Virtual Source Height z_v	1.164	meters*	3.8	feet*	$6.25D[1-(\theta_e/\theta_s)^{1/2}]$, meters*=meters above stack top	Sect.2/Eq.6
Height above Ground z_v+h_s	31.644	meters	103.8	feet	where $(\theta_a/\theta_s)^{1/2} = (\theta_e/\theta_s)^{1/2}$= 0.6335	
Vertical Velocity V	**Solutions in Table Below**				$\{(Va)_o^3 + 0.12F_o\,[\,(z-z_v)^2 - (6.25D-z_v)^2]\}^{(1/3)}$ / a	Sect.2.1(6)
Product $(Va)_o$	8.260	m^2/s			$V_{exit}D/2(\theta_e/\theta_s)^{1/2}$	

Solve for plume-averaged vertical velocity at height	**200.0**	**feet**		60.96	meters above ground ($z'+h_s$)	
Gives the following Height above Stack z'	30.480	meters*	100.0	feet*		
Plume Top-Hat Diameter 2a'	9.381	meters	30.8	feet	$2a'=2{*}0.16(z'-z_v)$	Sect.2/Eq.6
Vertical Velocity V	**2.917**	**m/s**	9.57	ft/sec	$V=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{(1/3)}/(2a'/2)$	Sect.2/Eq.6

Solve for Height of CASC critical vertical velocity V_{crit}	**5.30**	**m/s plume-averaged vertical velocity**				**Critical VV > Top of Jet (Spillane)**
Find Height above Stack z_{crit}	12.308	meters	40.4	feet	Solve for $x=(z-z_v)$ simultaneously in both eqs. (i.e., Va and a)	
Height above Ground $z_{crit}+h_s$	42.788	meters	**140.4**	feet	for V=4.3 m/s using the cubic equation $ax^3+bx^2+cx+d=0$, where	
					a=1, c=0, and $b=-(0.12F_o)/(4.3^3 0.16^3)$=	-3.8284
Interpolated Height of critical vertical velocity in Jet Phase:					and $d=[0.12F_o(6.25D-z_v)^2-(Va)_o^3]/(4.3^3 0.16^3)$=	-908.69
Find Height above Stack z_{crit}	#N/A	meters	#N/A	feet		http://www.1728.org/cubic.htm
Height above Ground $z_{crit}+h_s$	#N/A	meters	**#N/A**	feet	gives the real solution x = z-zv =	11.1446
					or z(m/above stack) =	12.308
					z(ft/above ground) =	140.4

Table of Plume Top-Hat Diameters (2a) and Plume-Averaged Vertical Velocities starting at end of jet phase:

Height (feet) above ground	(meters) above stack	Plume Radius(m)	SingleStk VertVel(m/s)	Plume Temp(K)
Stack.Rel.Ht = 100.0	***0.00***	**0.254**	**51.34**	
105.0	1.52	0.376	39.00	
110.0	3.05	0.498	26.66	
Top of jet = 110.4	***3.17***	***0.508***	***25.67***	
120.0	6.10	0.789	10.75	374.85
130.0	9.14	1.277	6.96	345.06
140.0	12.19	1.765	5.34	331.45
Spillane 5.3 m/s Height = 140.4	**12.31**	**1.783**	**5.30**	331.08
150.0	15.24	2.252	4.46	323.69
160.0	18.29	2.740	3.92	318.74
170.0	21.34	3.228	3.55	315.36
180.0	24.38	3.715	3.28	312.95
190.0	27.43	4.203	3.08	311.16
200.0	30.48	4.691	2.92	309.79
250.0	45.72	7.129	2.43	306.15
300.0	60.96	9.567	2.17	304.66
350.0	76.20	12.006	1.99	303.90
400.0	91.44	14.444	1.87	303.46
450.0	106.68	16.883	1.77	303.18
500.0	121.92	19.321	1.69	302.98
550.0	137.16	21.759	1.62	302.84
650.0	167.64	26.636	1.51	302.66
750.0	198.12	31.513	1.43	302.55
850.0	228.60	36.390	1.36	302.48
950.0	259.08	41.267	1.30	302.43
1050.0	289.56	46.143	1.26	302.39
1150.0	320.04	51.020	1.21	302.36
1250.0	350.52	55.897	1.18	302.34
1350.0	381.00	60.774	1.15	302.32
1450.0	411.48	65.651	1.12	302.31
1550.0	441.96	70.527	1.09	302.30
1650.0	472.44	75.404	1.07	302.29
1750.0	502.92	80.281	1.04	302.28
1850.0	533.40	85.158	1.02	302.28
1950.0	563.88	90.035	1.00	302.27
2050.0	594.36	94.911	0.99	302.26

Jet Phase Eqs: **5 foot Intervals**

Linearly interpolated from Stack Rel.Ht to Top of Jet

Spillane Equations:

$V_{plume}=\{(Va)_o^3+0.12F_o[(z-z_v)^2-(6.25D-z_v)^2]\}^{1/3}$ / a

a = $0.16(z-z_v)$ **10 foot Intervals**

$\theta_p=\theta_s(1+(1-(\theta_e/\theta_s))*(V_{exit}D^2/(4V_{plume}*a^2*\lambda^2)))$

Max<5.30 m/s

50 foot Intervals

100 foot Intervals

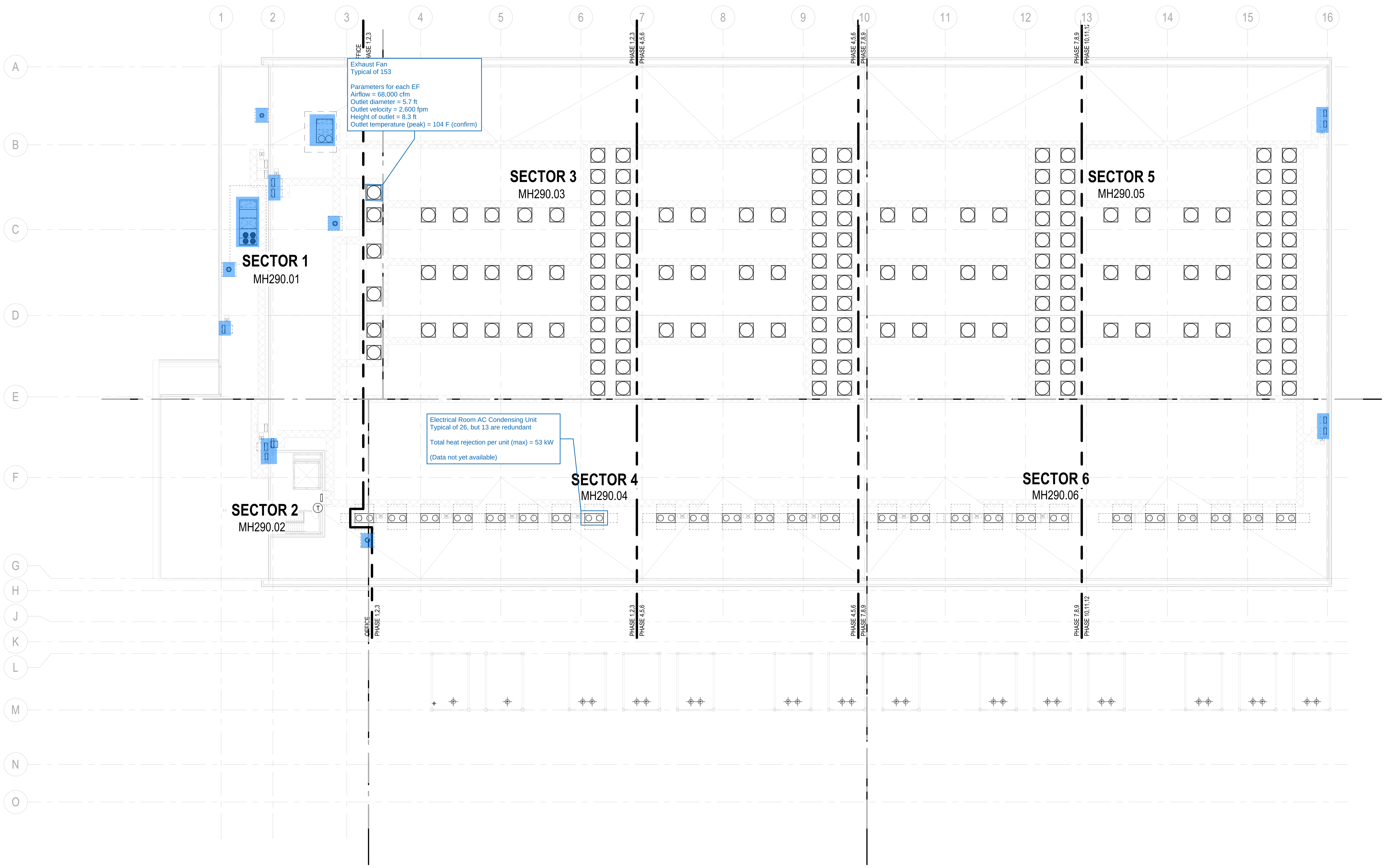
*Summer Max = Monthly Mean of Maximum Daily Temperatures for 1971-2000 (Highest in July)

NOAA Sources: Climatography of the United States No.81 *"Monthly Station Normals of Temperatures, Precipitation, and Heating and Cooling Degree Days, 1971-2000 California"* and Climatography of the United States No. 20 *"Monthly Station Climate Summaries, 1971-2000 California"*

ATTACHMENT TRANS DR-34

Thermal Plume Schematic of Room Mounted Equipment

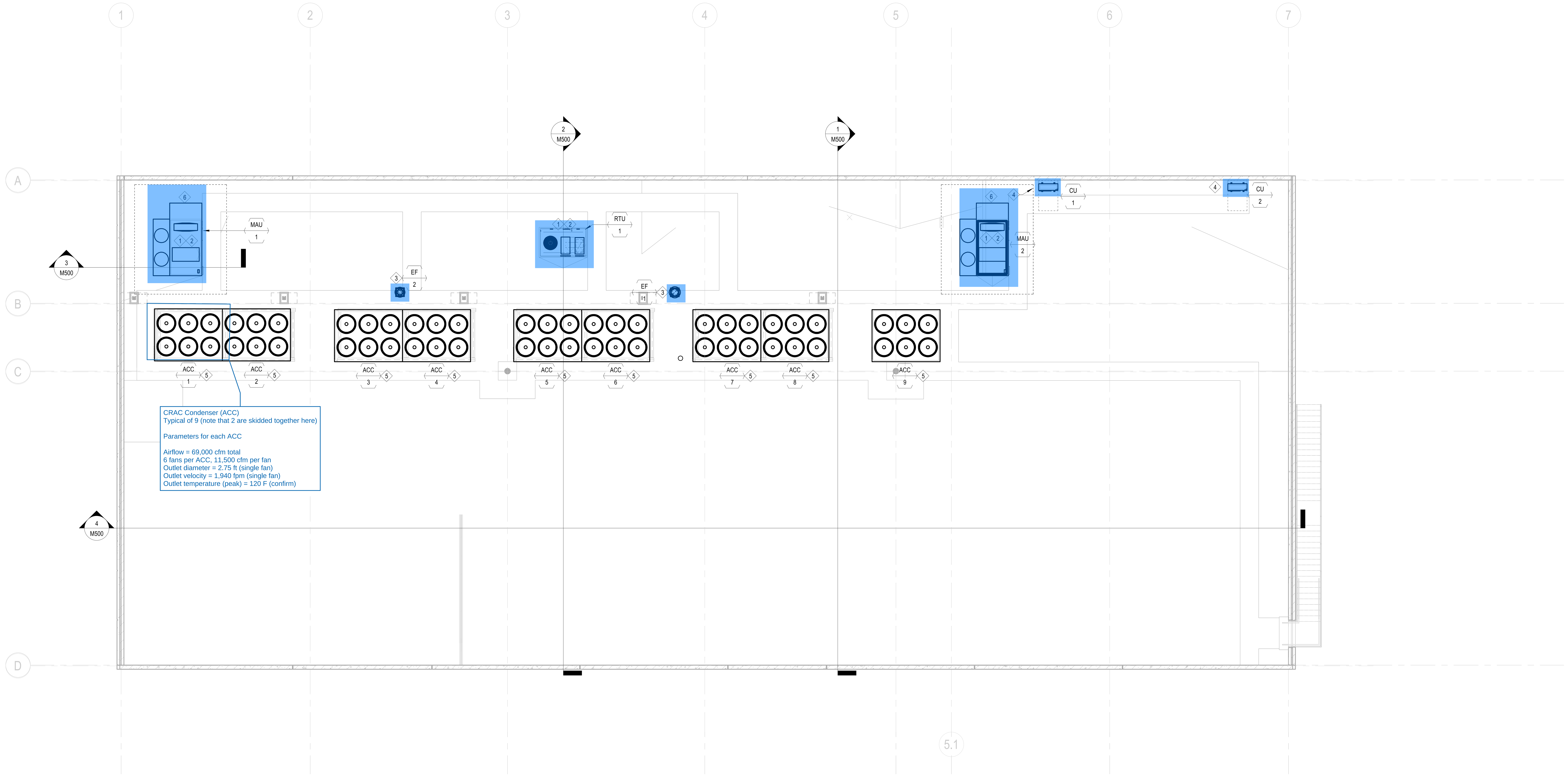
Mechanical with minimal heat rejection to atmosphere



1 MH290.00 MECHANICAL ROOF HVAC OVERALL PLAN

1" = 20'-0"

Mechanical with minimal heat rejection to atmosphere



1 MH203.00 MECHANICAL ROOF HVAC OVERALL PLAN

1/8" = 1'-0"

ATTACHMENT TRANS DR-36

Revised Traffic Analysis

MEMORANDUM

To: Transportation Division
City of Hayward

From: Anthony Vera, P.E. and Elizabeth Chau, P.E.
Kimley-Horn and Associates, Inc.

Date: January 26, 2024

Subject: Traffic Evaluation Assumptions Memo for STACK Hayward Data Center

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The purpose of this memorandum is to state the assumptions for project understanding and methodology in the analysis to identify potential traffic impacts for the proposed STACK Hayward data center (Project) in the City of Hayward (City).

Project Description

The Project is located at 3401-3475 Investment Boulevard in Hayward, California. The project consists of redeveloping the existing 205,556 square feet of industrial uses and constructing 336,164 square feet of data center use. Note that the proposed use consists of 318,700 square feet of data center with two supporting office buildings (14,500 square feet and 2,964 square feet). A site plan, dated August 2023, for the Project is included as **Attachment A**.

Similar to other data centers, the data center will be operational 24-hours, 7-days a week. **Table 1** summarizes the anticipated headcount of personnel and visitors that would be on-site throughout a typical day. It is anticipated that on an average day there will be approximately 45 people at the building throughout the day, with 7-38 people in the building at the same time.

Table 1: Anticipated Average Daily Headcount

Type	Daily Persons	Persons Per Shift
Employees	25	3-22[1]
Security	8	4
Visitors	12	0-12
Total	**45**	**7-38**

[1] Operational staff work in two shifts: day (22 employees) and graveyard (3 employees)

TRIP GENERATION

A trip generation analysis was conducted to determine the number of trips the Project would generate. The trip generation was determined based on average rates from Institute of Transportation Engineer's (ITE) publication, *Trip Generation, 11th Edition.*

For the existing land uses, ITE Land Use 130: Industrial Park was used to estimate the trip generation for the existing buildings part of the Eden Landing Business Park. Building sizes for the existing buildings part of the Eden Landing Business Park are provided in **Attachment B**. Note, **Attachment B** provides the size of the ground level floor area, whereas many existing buildings have a second level, therefore the sizes of the second level were estimated based on measurements made from aerial imagery.

For the proposed land use, ITE Land Use 160: Data Center for the data center building was used to estimate the trip generation. It is anticipated that the two on-site office spaces will have the same trip generation characteristics as the data center building and are included in the data center land use. **Table 2** presents the trip generation for the project. The project is expected to generate net -360 daily trips, net -33 trips in the AM peak hour, and net -40 trips in the PM peak hour.

Table 2: Project Trip Generation

ITE Land Use Code		Land Use	Size		Daily Trips	AM Peak			PM Peak		
						Rate	In%	Out%	Rate	In%	Out%
130		Industrial Park	1,000 Sq Ft		3.37	0.34	0.81	0.19	0.34	0.22	0.78
160		Data Center	1,000 Sq Ft		0.99	0.11	0.55	0.45	0.09	0.30	0.70
Scenario	**ITE Land Use Code**	**Land Use**	**Size**	**Units**	**Daily Trips**	**AM Peak**			**PM Peak**		
						Total	**In**	**Out**	**Total**	**In**	**Out**
Existing	130	Industrial Park	205.556	1,000 Sq Ft	693	70	57	13	70	15	55
Proposed	160	Data Center	336.164	1,000 Sq Ft	333	37	20	17	30	9	21
Total Net New Trips (Proposed – Existing)					**-360**	**-33**	**-37**	**4**	**-40**	**-6**	**-34**

Source: ITE Trip Generation, 11th Edition

Note:

Existing square footage is based on combination of ground floor areas from existing plans and second level estimates from existing aerials.
Proposed land use includes two (2) on-site office buildings.

Level of Transportation Analysis

As of July 1, 2020, the State of California has fully adopted a change in the California Environmental Quality Act (CEQA) significant impact methodology for transportation impacts to use vehicle miles traveled (VMT) as opposed to level of service (LOS) via State Bill 743 (SB 743). To address this change, the City developed and adopted the *City of Hayward Transportation Impact Analysis Guidelines* (TIA Guidelines) to provide screening criteria for determining the level of transportation analysis and requirements for a transportation impact analysis (TIA).

The TIA may consist of CEQA transportation analysis (CTA) and/or supplemental non-CEQA Local Transportation Analysis (LTA). The City's TIA Guidelines outlines criteria for determining the level of transportation analysis for a given project. **Table 3** shows that both CTA and LTA are not required for the Project based on City's TIA Guidelines thresholds. The follow sections describe the details of the screening process.

Table 3: Transportation Analysis Requirement Summary

Analysis	Required?
CEQA Transportation Analysis (CTA)	No
Local Transportation Analysis (LTA)	No

CEQA Transportation Analysis (CTA)

VMT SCREENING

The City's *Transportation Impact Analysis Guidelines* provides guidance on when a project may be exempt from performing CTA VMT analysis if the project meets at least one screening criteria based on:

- Small Infill Projects
- Local Serving Retail
- Local Serving Public Facilities
- Location-Based Screening for Residential Projects
- Location-Based Screening for Office Projects
- Location-Based Screening for Industrial Projects
- Location-Based Screening for Affordable Housing Projects

Project information was evaluated to determine if the Project would be exempt from a VMT analysis and is summarized in **Table 4**. Based on current project information given for this analysis, a VMT analysis **is not required** for the data center use. Detailed evaluation for each criterion is discussed in the following sections.

Table 4: Project CEQA Screening

CEQA Land Use Screening Criteria	Project Exempt?
Small Infill Projects	No
Local Serving Retail	N/A
Local Serving Public Facilities	N/A
Location-Based Screening for Residential Projects	N/A
Location-Based Screening for Office Projects	N/A
Location-Based Screening for Industrial Projects	Yes
Location-Based Screening for Affordable Housing Projects	N/A

Small Project

Small projects are defined as:

- New construction or conversion of small structures up to 10,000 square feet of office
- 15 single-family homes
- 25 multi-family homes
- Projects that generate fewer than 110 average daily trips for other land use.

The Project does not qualify as small project as the Project is converting more than 10,000 square feet of existing building and proposed use exceeds the 110 daily trips threshold.

Local Serving Retail Project

Local Serving Retail Projects are defined as projects that are of 50,000 square feet or less of retail land use. The project does not include any retail land uses; therefore, this criterion does not apply.

Local Serving Public Project

Local Serving Public Projects are projects such as fire stations, passive parks, public utilities, and other similar facilities. The project does not include any of these uses; therefore, this criterion does not apply.

Location-Based Screening for Residential, Office, Industrial, and Affordable Housing Projects

These four screening criteria assume projects in areas of low VMT and/or within a half mile of a major transit stop or corridor and includes low VMT-supporting features that will produce low VMT per capita or per employee. This screening may apply for the following project characteristics:

- Project located either:
  - Within ½-mile of an existing major transit stop
  - Residential or office projects in an area with low (below the threshold) VMT per capita or per employee and in an area with planned growth
  - Industrial projects in an area with below average VMT per employee and in an area with planned growth
- Density/FAR
  - Office projects with a minimum gross floor area ratio (FAR) of 0.75
  - Residential projects with a minimum density of 35 units/acre

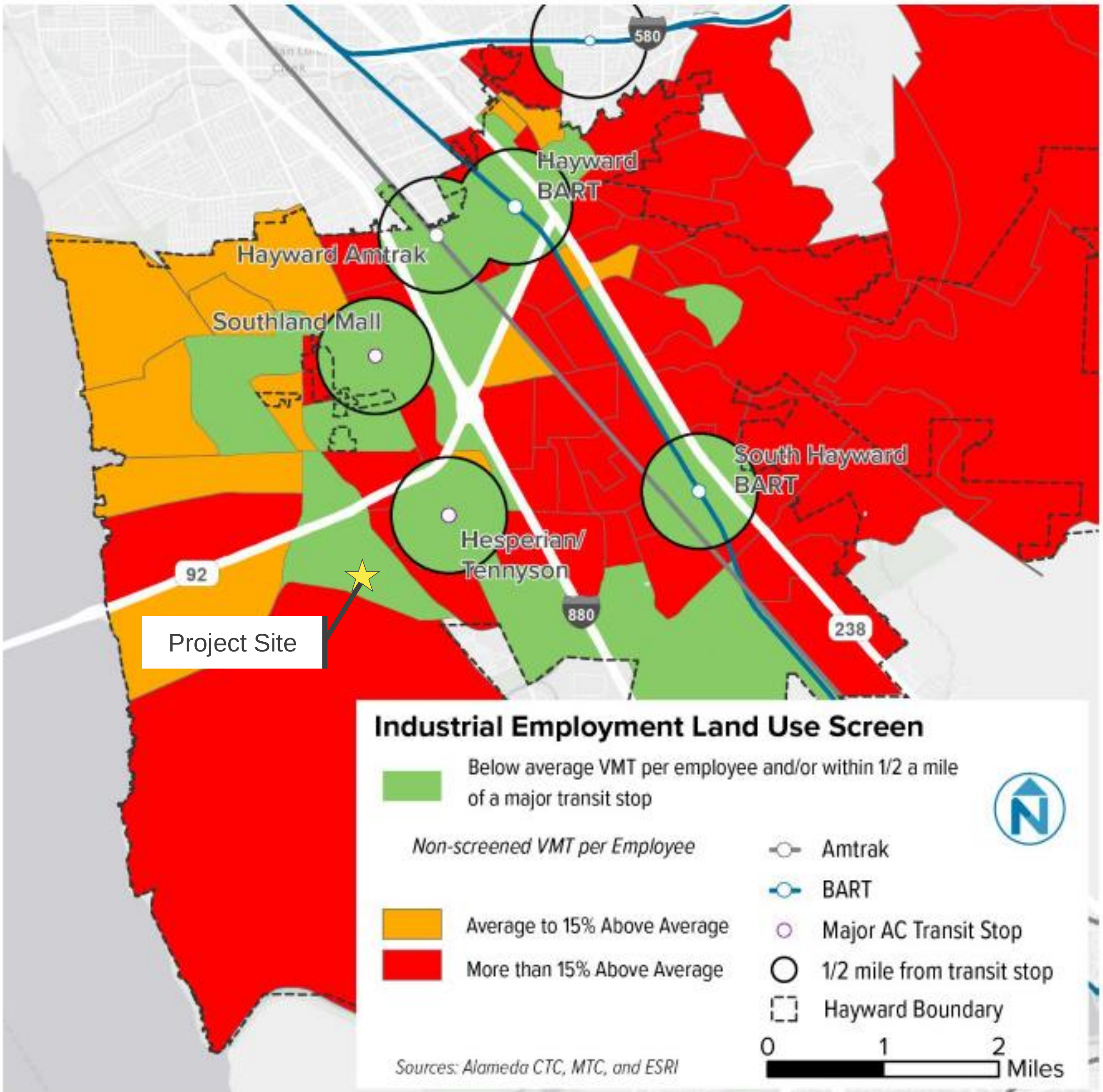


Figure 1: CEQA Transportation Screening Map for Industrial Projects (Figure 6 from City of Hayward Transportation Impact Analysis Guidelines)

Local Transportation Analysis

If deemed necessary, the City may require a local transportation analysis (LTA), to evaluate additional operational or site access analysis. The LTA may include the following analysis:

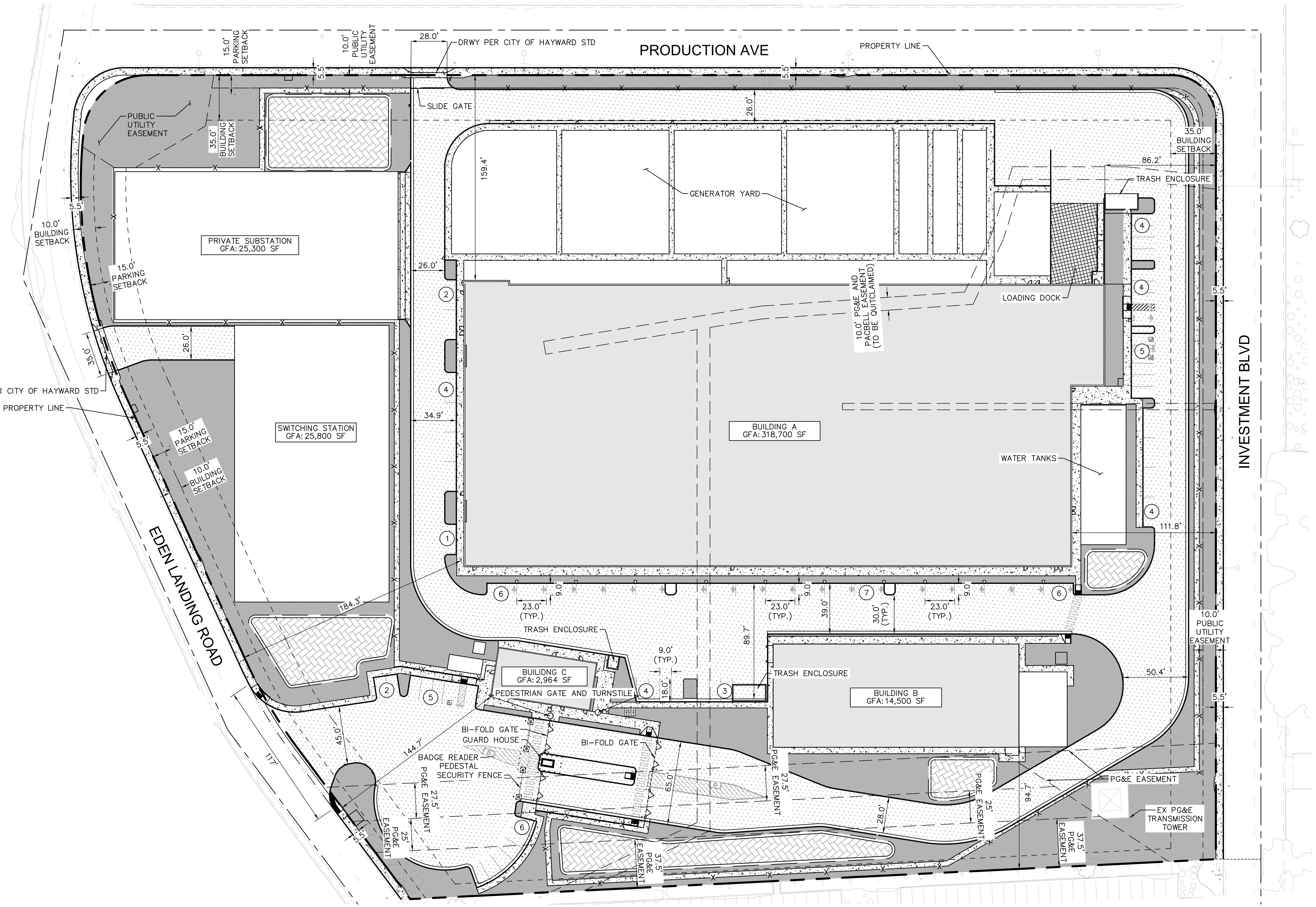
- Vehicle Operations
- Multimodal Operations
- Site Plan Access and Design Review

City staff reviewed Project trip generation, entitlement application, and site plan and determined that that an LTA is not required[1].

Attachment A – Site Plan
Attachment B – Site Plan for Existing Building
Attachment C – VMT Map

[1] Correspondence with City staff dated January 24, 2024.

Attachment A – Site Plan



LEGEND

- PROPERTY LINE
- RIGHT OF WAY LINE
- BUILDING SETBACK LINE
- PROPOSED CHAIN LINK FENCE
- FLOW LINE
- HEAVY DUTY ASPHALT PAVING
- CONCRETE SIDEWALK
- HEAVY DUTY CONCRETE FOR LOADING DOCK
- LANDSCAPE/PLANTER AREA
- BIORETENTION AREA
- (X) PARKING COUNT

PARKING SUMMARY

REQUIRED PARKING - BUILDING A

USE	REQUIRED	PROVIDED
DATA CENTER 318,700 SF	1 STALL PER 250 SF (1275 STALLS)	44
ADA	23	2 TOTAL (1 VAN)

REQUIRED PARKING - BUILDING B

USE	REQUIRED	PROVIDED
OFFICE 14,500 SF	1 STALL PER 250 SF (58 STALLS)	6
ADA	3	2 TOTAL

REQUIRED PARKING - BUILDING C

USE	REQUIRED	PROVIDED
OFFICE 2,964 SF	1 STALL PER 250 SF (12 STALLS)	13
ADA	1	1 VAN

CAL GREEN PARKING REQUIREMENTS (OVERALL CAMPUS)

STALL TYPE	REQUIRED	PROVIDED
EV ADA STALL	2 TOTAL (1 VAN)	2 TOTAL (1 VAN)
EV STALL	13	16
EVCS STALL	3	3
SHORT TERM BIKE PARKING	2	2
LONG TERM BIKE PARKING	3	3

OVERALL CAMPUS PARKING SUMMARY

STALL TYPE	REQUIRED	PROVISION
STANDARD PARKING STALL (9'X18')	1318	58
ADA PARKING	27	5 TOTAL (2 VAN)
TOTAL	1345	63

NORTH

GRAPHIC SCALE IN FEET
0 20 40 80

811. Know what's below. Call before you dig.

CONFIDENTIAL

PROJECT ADDRESS
26203 PRODUCTION AVE
HAYWARD, CA 94545

PROJECT DELIVERY PACKAGE
30% DESIGN REVIEW

SEAL/SIGNATURE

PRELIMINARY
THESE DOCUMENTS ARE INCOMPLETE AND NOT FOR REGULATORY APPROVAL, PERMIT OR CONSTRUCTION

ISSUE DATE: 14 AUG 2023 | PROJECT NO: 25993.000
DESIGNED: HKS | ARCHITECT: HKS

MARK	DATE	DESCRIPTION

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ELECTRICAL ENGINEER
ESD GLOBAL
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CIVIL ENGINEER
KIMLEY HORN
ANTHONY VERA
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STRUCTURAL ENGINEER
HKS
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Dallas texas 75201

ARCHITECT
HKS
DUTCH WICKES
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PLUMBING ENGINEER
ESD GLOBAL
STEVE WUTHRICH
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Suite 5300
Chicago, Illinois 60606

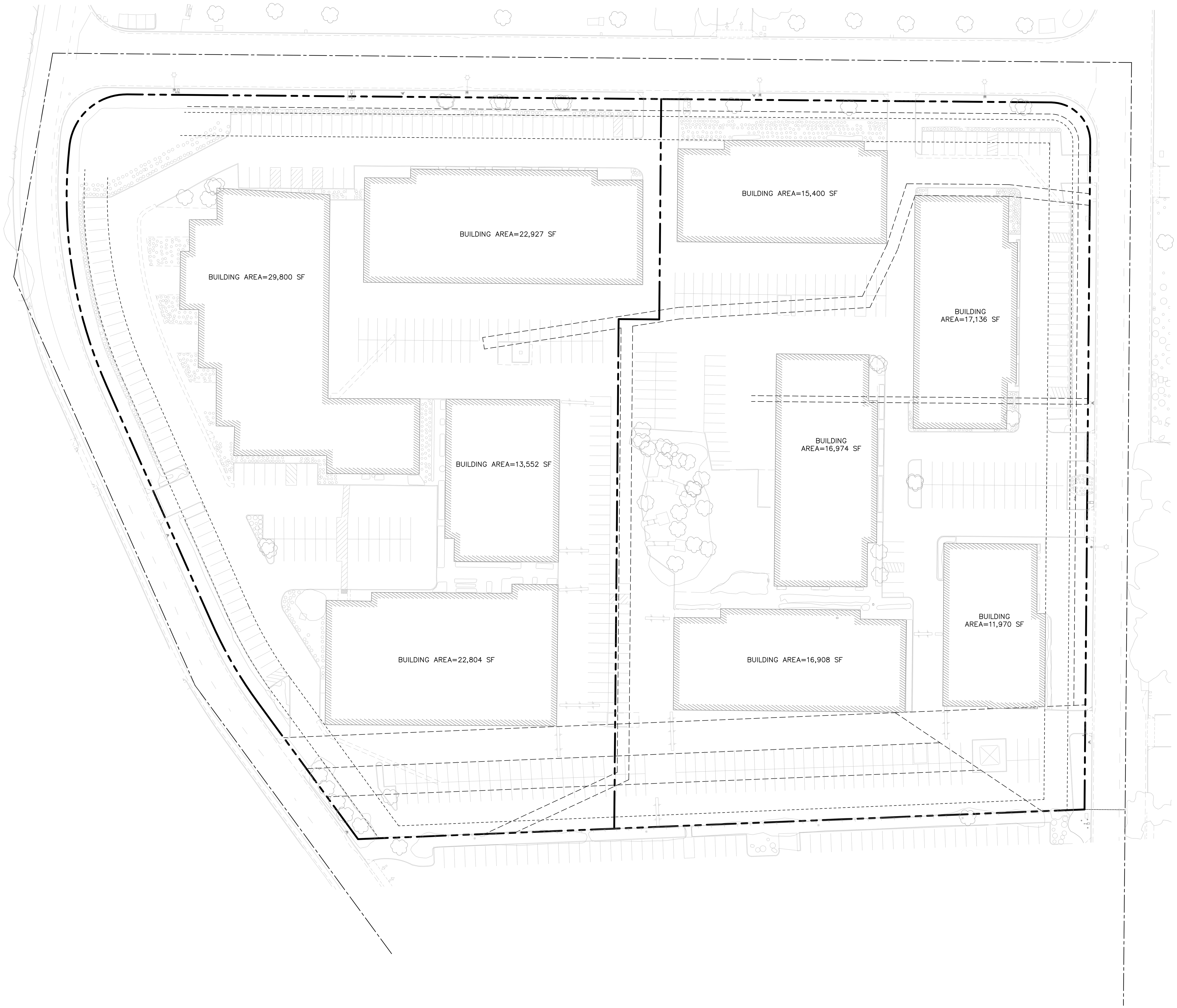
PROJECT: BUILDING A TI

TITLE: PRELIMINARY SITE PLAN

DRAWING: C-200

E1 SCALE: AGILE No: REV:

Attachment B – Site Plan for Existing Building


BUILDING AREA=22,927 SF
BUILDING AREA=15,400 SF
BUILDING AREA=29,800 SF
BUILDING AREA=17,136 SF
BUILDING AREA=16,974 SF
BUILDING AREA=13,552 SF
BUILDING AREA=11,970 SF
BUILDING AREA=22,804 SF
BUILDING AREA=16,908 SF

Attachment C – VMT Map

Vehicle Miles Traveled Per Employee
Central Planning Area
Central Planning Area Average (Target -15%): 19.2 (16.3)
Alameda County Average (Target -15%): 15.9 (13.5)
2020 Vehicle Miles Traveled per Employee by TAZ
> 25.00
20.01 - 25.00
15.01 - 20.00
10.01 - 15.00
0.01 - 10.00
0.00
Data Source: Alameda Countywide Travel Model, Plan Bay Area 2040 version, May 2019
Vehicle miles traveled (VMT) = home-based trips (home-based work, school, shopping/errands, social/recreation) at transportation analysis zone (TAZ) containing residence site
VMT also includes estimates of non-home trips generated by residents at the non-residential end of the home-based trip (e.g. lunch trips from workplace)
VMT per capita = home-based VMT at residence TAZ divided by total population in TAZ
VMT includes all travel within 9-county Bay Area plus San Joaquin County plus estimates of travel distances beyond the 10-county model area
TAZs with zero values (white) did not have population in the 2020 model
Project Site
San Leandro
Hayward
Union City
Fremont
Dublin
Alameda
Piedmont
Albany
Berkeley
Emeryville
Oakland
North Planning Area
Central Planning Area
Pleasanton
Livermore
East Planning Area
South Planning Area
Newark
Alameda County
San Francisco County
Contra Costa County
San Joaquin County
San Mateo County
Santa Clara County
0 1 2 3 4 Miles
ALAMEDA County Transportation Commission