

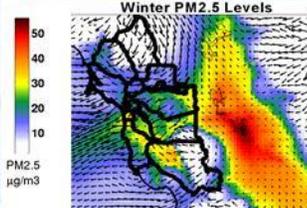
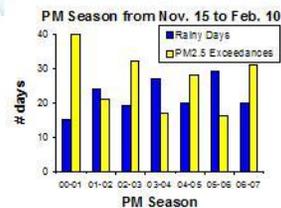
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## Ultrafine Particulate Matter Study in the San Francisco Bay Area Part I: Study Plan

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## Executive summary

Particulate matter is classified as “coarse” PM (PM<sub>10</sub>) with a diameter less than 10 µm; “fine” PM (PM<sub>2.5</sub>) with a diameter less than 2.5 µm; and “ultrafine” PM (PM<sub>0.1</sub>) with a diameter less than 0.1 µm. Both PM<sub>10</sub> and PM<sub>2.5</sub> are currently federally regulated. These particles are studied based on their mass. PM<sub>0.1</sub>, studied based on their numbers, has not been regulated partly because, until recently, they were difficult to measure.

It is generally recognized that smaller particles are more harmful to human health. Unlike larger particles, PM<sub>0.1</sub> can penetrate pulmonary tissue, enter the bloodstream, and circulate throughout the body. Thereby, PM<sub>0.1</sub> can damage a number of internal systems that may be inaccessible to larger particles.

Because of their significant potential adverse health impacts, the Bay Area Air Quality Management District (BAAQMD) plans to study PM<sub>0.1</sub>. The goal of the proposed study is to characterize Bay Area-wide health impacts of PM<sub>0.1</sub>. A combination of measurements, computer simulations, and data analyses will be conducted. The primary results will be the estimation of PM<sub>0.1</sub> population exposure, and associated health and economic impacts at 1-km horizontal resolution over the entire Bay Area, which is home to approximately eight million people. If warranted based on the results of the pilot study, additional studies will be conducted to better understand long-term PM<sub>0.1</sub> exposure.

A critical aspect of the pilot study is to conduct ambient PM<sub>0.1</sub> monitoring. Continuous, year-round monitoring will be conducted over three densely populated urban areas believed to exhibit elevated PM<sub>0.1</sub> levels: San Francisco, Oakland, and San Jose. The initial monitoring will be three years in duration, with a target start date set for the fall of 2011.

This study will investigate levels and characteristics of ambient PM<sub>0.1</sub>, determine its major emission sources, identify weather patterns leading to elevated PM<sub>0.1</sub> levels, and assess its health and economic impacts around the Bay Area. Information obtained from the pilot study will be used for many purposes, including: aiding planners to reduce future PM<sub>0.1</sub> exposure; helping District managers to decide what level of further study and monitoring will be needed to better understand the behavior and health impacts of PM<sub>0.1</sub>; and providing information to the US EPA, the California Air Resources Board, and any other parties interested in conducting similar PM<sub>0.1</sub> studies for other regions. Upon completion, a comprehensive report will be prepared documenting the approach, methodology, and results of the planned pilot study. The report will be peer reviewed and made publicly available.

This concept paper describes the pilot study plan.

## 1. Introduction and background

Ultrafine particulate matter, commonly referred to as  $PM_{0.1}$ , consists of various suspended solids and liquid droplets having aerodynamic diameters less than 0.1 microns (100 nanometers). These particles are studied based on their numbers in the atmosphere different from those regulated particles ( $PM_{10}$  and  $PM_{2.5}$ ) that are studied based on their mass.

It is generally recognized that smaller particles are more harmful to human health. Humans have inadequate natural defenses against  $PM_{0.1}$ . This is in part because  $PM_{0.1}$  particles are much smaller than the cilia that help to filter out larger particles from the nasal passages.  $PM_{0.1}$  particles are sufficiently small to penetrate deep into the human body. They can enter the cardiopulmonary system and subsequently be circulated around the body. These particles have large surface area to volume ratios, readily allowing for desorption of toxic components into human tissues. They contain trace metals that likely contribute strongly to their toxicity; they may contain carcinogenic polycyclic aromatic hydrocarbons (PAHs); and they can even reach the brain, potentially causing brain damage. Adverse health impacts for  $PM_{0.1}$  can be much different than for  $PM_{2.5}$  or  $PM_{10}$ .

For economically developed regions, the majority of  $PM_{0.1}$  originates from internal combustion engines. For example, a recent California Air Resources Board (ARB) study around Los Angeles estimated that over 40% of  $PM_{0.1}$  originated from on-road vehicles and over 30% of  $PM_{0.1}$  originated from stationary sources such as generators.  $PM_{0.1}$  is almost entirely directly emitted. Formation through atmospheric chemistry is likely insignificant relative to direct emissions.

Ultrafine particles are relatively short-lived, as compared to longer-lived  $PM_{2.5}$  particles which may persist in the atmosphere for up to several weeks. The short lifetime for  $PM_{0.1}$  particles results from their very high number concentrations upon emission. Levels may peak on the order of  $10^{14}$  to  $10^{15}$  particles/ $m^3$  near strong  $PM_{0.1}$  sources such as busy freeways. These exceptionally concentrated  $PM_{0.1}$  particles rapidly agglomerate (stick together) with each other and with larger particles (e.g.  $PM_{2.5}$ ) to yield particles with diameters larger than 0.1 microns. Agglomeration, dispersion, and advection are the dominant atmospheric processes determining the  $PM_{0.1}$  spatial distribution. Deposition (settling onto surfaces) plays a minor role in the  $PM_{0.1}$  spatial distribution because gravity does not have a strong influence on  $PM_{0.1}$ . Typically, the  $PM_{0.1}$  level decreases exponentially to reduced levels within 500 m of a strong source.

$PM_{0.1}$  level is typically measured as a number concentration, whereas  $PM_{2.5}$  and  $PM_{10}$  are typically measured using mass concentrations.  $PM_{0.1}$  is a subset of both  $PM_{2.5}$  and  $PM_{10}$ . Because of the very small size of  $PM_{0.1}$ , it contributes little mass to any particulate

matter sample. Thus, there tends to be little correlation between number concentrations for  $PM_{0.1}$  and mass concentrations for  $PM_{2.5}$  or  $PM_{10}$ .

$PM_{0.1}$  is not measured routinely in the United States. The US EPA has recognized that additional monitoring of  $PM_{0.1}$  is needed to explore the consideration of a separate regulation for this particle size fraction (US EPA 2010). There is a pilot monitoring network around Los Angeles jointly operated by ARB and the South Coast Air Quality Management District (SCAQMD). There are also several experimental measurement stations in the State of New York jointly operated by the US EPA and the local agencies. Some European countries have been collecting  $PM_{0.1}$  data routinely for several years.

## **2. Planned study**

The planned study will consist of the following components:

- Ambient measurements.
- Emissions inventory development.
- Meteorological and air quality data analysis.
- Computer simulations.
- Health and economic impacts assessment.
- Documentation of results.

The planned study will be collaborative, involving participants from a multidisciplinary team of experienced scientists and technicians. The District's Research & Modeling Section (R&MS) will lead and manage the overall study. R&MS will also conduct modeling and document the study results. The District's Air Monitoring Section will assist with ambient  $PM_{0.1}$  measurements collection. The District's Emissions Inventory Section and Sonoma Technology, Inc. (STI) will jointly prepare an emissions inventory. The California EPA's Office of Environmental Health Hazard Assessment (OEHHA) will prepare public health and economic impacts assessments. Researchers at UC Davis will conduct advanced data analyses to support the aforementioned tasks. Additional scientists, contractors, agencies, or other parties may be invited to collaborate with the R&MS on an as-needed basis. Interim results will be presented to the District's Modeling Advisory Committee consisting of representatives from the US EPA, ARB, neighboring districts, industry, and universities.

### **2.1 Measurements**

$PM_{0.1}$  instruments will operate at three existing District air quality monitoring stations: San Francisco, Oakland, and San Jose (see Figure 1). Monitoring will be conducted year-round for up to three years, with a target start date set for the fall of 2011. The measurement sampling schedule and/or locations may be modified to accommodate any issues such as cost or availability of room at the stations.

The instruments (TSI model 3031) will count the number concentration of  $PM_{0.1}$  particles. Number concentrations will be reported on both hourly and daily bases.

Hourly-averaged measurements will be directly comparable with computer model inputs and outputs. Daily measurements may be appropriate to link PM<sub>0.1</sub> exposures with human health endpoints. The instruments will measure PM<sub>0.1</sub> number concentrations across several size bins. This size distribution data may be useful for distinguishing between PM<sub>0.1</sub> originating from different source types.

Three locations likely to exhibit significantly elevated urban-scale PM<sub>0.1</sub> levels have been selected for monitoring. Each is an existing, secured PM<sub>2.5</sub> monitoring location. Each location is within a densely populated city and is also believed to be sufficiently distant from near-source PM<sub>0.1</sub> influences such as major freeways. The monitoring locations are intended to sample an urban-scale mixture of PM<sub>0.1</sub>, as opposed to measuring either peak near-source or natural background PM<sub>0.1</sub> levels. The design of the PM<sub>0.1</sub> field measurements program will directly support a variety of purposes listed below:

- Empirically characterize the mean ambient levels, temporal and spatial variability, and size distribution characteristics for an urban-scale mixture of PM<sub>0.1</sub>.
- Develop conceptual models as how the weather impacts urban-scale PM<sub>0.1</sub> pollution, in terms of both day-to-day and seasonal variability. Day-to-day impacts of the weather on PM<sub>0.1</sub> levels will be examined using a meteorological cluster analysis technique (BAAQMD 2009, section 4). This statistical method has been successfully applied to explain meteorological influences on both ozone and PM<sub>2.5</sub> pollution throughout central California.
- Characterize how weekday-weekend differences in PM<sub>0.1</sub> measurements may relate to day-of-week emissions variability.
- Evaluate the PM<sub>0.1</sub> emissions inventory.
- Evaluate computer model simulations for PM<sub>0.1</sub>.
- Estimate local PM<sub>0.1</sub> exposures and health impacts around sampling locations based purely on measured PM<sub>0.1</sub> levels.

Ideally, each PM<sub>0.1</sub> counter would be co-located with an instrument measuring PM<sub>0.1</sub> mass concentration. Simultaneous mass and number concentration measurements could be used to estimate PM<sub>0.1</sub> surface area concentration, which is believed to be an important indicator of PM<sub>0.1</sub> exposure. Furthermore, collected PM<sub>0.1</sub> mass could be chemically assayed to provide composition data for use in source apportionment and exposure assessment. Consultation with the instrument vendor, however, has indicated that collecting PM<sub>0.1</sub> mass using filters may be technically infeasible. An alternative approach is to modify an existing instrument to collect the charged portion of PM<sub>0.1</sub> on a magnetic surface. These samples could then be analyzed for trace metals. When nearing completion of the three-year pilot study, the District will consult with instrument manufacturers to determine the feasibility of collecting PM<sub>0.1</sub> mass samples as part of a follow-up study.

## **2.2 Emissions inventory development**

The District and contractor Sonoma Technology, Inc. (STI) are currently developing an emissions inventory for PM<sub>0.1</sub> modeling over the Bay Area for future year 2015. This year was selected to leverage considerable amounts of input (activity) data and District staff experience from existing PM<sub>2.5</sub> and ozone emissions inventories developed for this same future year. The PM<sub>0.1</sub> emissions inventory is expected to be completed by the end of February 2011.

Inventory development will first involve a comprehensive literature review to determine the state-of-the-science methodologies for estimating PM<sub>0.1</sub> emission factors for various sources such as on-road motor vehicles and other types of fuel combustion. Source tests have been performed in the Bay Area on the majority of stationary sources to measure size-resolved PM emissions. For Bay Area sources lacking source test data, emission factors will be assigned using data from other regions of California or from literature values if necessary. Emission factors will be applied to source-specific activity data (e.g. vehicle miles traveled or gallons of fuel burned) to estimate county-level PM<sub>0.1</sub> emissions for 2015. The resulting inventory will be processed and formatted using the Sparse Matrix Operator Kernel Emissions (SMOKE) Modeling System to create a model-ready inventory having 1x1 km horizontal grid resolution. STI will assist the District to configure SMOKE and ensure that the gridded emissions inventory is consistent with the air quality model used to simulate PM<sub>0.1</sub>.

Data sources, assumptions, and methods used to develop the PM<sub>0.1</sub> emissions inventory will be documented.

## **2.3 Data analysis**

In-depth meteorological analyses will be conducted to investigate weather patterns conducive to elevated PM<sub>0.1</sub> concentrations. Day-to-day variability for PM<sub>0.1</sub> levels resulting from meteorological influences will be examined using a meteorological cluster analysis technique (BAAQMD 2009, section 4). This technique has been successfully applied to identify weather patterns associated with elevated PM<sub>2.5</sub> and ozone levels around the Bay Area and other central California air basins. Seasonal variability will be examined by computing seasonal statistics for PM<sub>0.1</sub> levels. The impacts of rain, wind speed, wind direction, temperature, humidity, and large-scale pressure gradients on PM<sub>0.1</sub> levels will be examined.

PM<sub>0.1</sub> size distribution data will be analyzed to identify signatures related to certain source categories and/or weather patterns.

## **2.4 Computer simulations**

PM<sub>0.1</sub> levels will be simulated over the Bay Area at 1x1 km horizontal resolution. Simulations will be conducted for one full month from each season (summer, fall,

winter, and spring), for four months total. Annual average PM<sub>0.1</sub> levels will then be computed as the simple average across the four seasonal modeling periods.

A “base case” simulation will be conducted using the future-year 2015 emissions inventory. Relative to this base case simulation, model sensitivity runs will be conducted to simulate systematic reductions for future-year PM<sub>0.1</sub> emissions. These simulation results will be used to tabulate the estimated benefits of various levels of PM<sub>0.1</sub> emissions reductions (described below in section 2.5).

There are two choices for the air quality model. The prime choice is the CMAQ-MADRID model, an extension of the US EPA CMAQ model that includes PM<sub>0.1</sub> simulation capabilities. It is unclear, however, if CMAQ-MADRID has all features necessary to obtain reasonable model performance over the Bay Area. If not, the contingency plan is to use the ENVIRON CAMx model in its size-segregated aerosol mode (Jung et al., 2010) to simulate PM<sub>0.1</sub> and apply it over the Bay Area. ENVIRON has previously contracted from the District to successfully modify CAMx to include customized toxics simulation capabilities. The District R&MS has significant experience in applying CMAQ for winter PM<sub>2.5</sub> modeling, and CAMx for summer ozone and year-round toxics modeling.

Meteorological fields input to the air quality model will be generated using MM5. This prognostic model is able to capture the main characteristics of meteorology impacting regional air quality. MM5 has been successfully applied over the Bay Area for modeling ozone in the summer, PM<sub>2.5</sub> in the winter, and toxics year-round. The District’s R&MS has significant experience in applying MM5. Recently, the District’s R&MS has started to apply the Weather Research and Forecasting (WRF) model and is in the process of comparing it against MM5. If better performance from the WRF model is obtained, meteorological inputs for PM<sub>0.1</sub> simulations will be prepared using the WRF model.

Both meteorological and air quality model outputs will be rigorously evaluated against observations. Based on these evaluations, the model configurations will be adjusted as necessary to ensure optimal air quality model performance.

## **2.5 Assessing health and economic impacts**

Health and economics impacts assessment will first involve a comprehensive literature review of epidemiological, clinical, and toxicological studies of PM<sub>0.1</sub>. This information will be used to determine dose-response functions that are likely to represent the relationship between PM<sub>0.1</sub> exposure and incidences of health outcomes. Monetary valuations for health outcomes will mostly be taken from existing data used for assessing the economic impacts of criteria pollutants (e.g. PM<sub>2.5</sub> and ozone); however, PM<sub>0.1</sub> does exhibit some unique health outcomes for which monetary valuations will be taken from the literature. The range of literature values for dose-response function parameters and monetary valuations will be compiled to determine upper and lower confidence bounds for these quantities. Confidence bounds will be computed by weighting each literature value according to the level of applicability of the particular

study from which it was derived to represent the Bay Area population. These confidence bounds will be used to estimate the uncertainties for the health and economic impacts assessment. The OEHHA team is knowledgeable of epidemiological studies for PM<sub>0.1</sub> and will draw from significant experience researching the adverse health effects of PM<sub>2.5</sub>.

The dose-response functions, monetary valuations for health outcomes, ambient measurements, and simulation results will be used as inputs to the US EPA Environmental Benefits Mapping and Analysis Program (BenMAP). This program will be used to provide estimates of the cumulative health and economic impacts of PM<sub>0.1</sub> on the District's population of around 8 million people. A Monte Carlo strategy will be used to quantify the uncertainties for the health and economic impacts estimates. These primary results of the PM<sub>0.1</sub> pilot study will include:

- Health and economic impacts associated with PM<sub>0.1</sub> exposure.
- Health and economic benefits associated with various levels of PM<sub>0.1</sub> emissions reductions.
- Impacts and benefits for sensitive groups (e.g. the elderly and children).
- Uncertainties for the above quantities.

The pilot study results will provide information on the importance of PM<sub>0.1</sub> exposure in the Bay Area. Comparison of the levels of impacts and benefits against their respective uncertainties will allow assessment of the significance of the pilot study results.

### **3. Pilot study timeline**

This pilot study is conceived within the context of the District being a public agency tasked with protecting public health. The study will yield information on the magnitude of the PM<sub>0.1</sub> problem in the Bay Area. These results will be used to determine whether additional resources are warranted for more extensive studies. Identification of the major uncertainties in the pilot study results will be useful to identify knowledge gaps for focusing any future studies. Additional research, such as the impacts of near-source PM<sub>0.1</sub> exposure, would likely be necessary to design technically sound PM<sub>0.1</sub> control strategies.

The pilot study is slated for implementation over the course of three years. The District intends to conduct a study as comprehensive as possible within this timeline, given the available resources. The study will leverage existing information if available, particularly for emissions activity, health impacts, and monetary valuation data. These data can be updated with more pertinent local information in a follow-up study, if warranted by the results of the pilot study. The emissions inventory development task for this study is already under way. Significant research has been conducted on modeling and health impacts of PM<sub>0.1</sub>.

Air sampling to measure PM<sub>0.1</sub> levels will provide critical data needed to ensure the validity and representativeness of the study results. This sampling requires the purchase

of special equipment. The BAAQMD seeks to obtain funding through grants from the US EPA for this equipment. All other costs, including operating instruments in the field, developing an emissions inventory, analyzing data, computer modeling, and documenting the study, will be absorbed by the BAAQMD. There are many volunteer scientists and organizations dedicated to participate in the study. Most of them have been involved with the District's on-going PM<sub>2.5</sub> study and documented the results in an interim report (BAAQMD 2009).

The PM<sub>0.1</sub> study described in this concept paper is the first of its kind. As such, the approach, methodology, and results obtained in this study would be helpful as a model for other studies to build upon. Upon completion, a comprehensive report thoroughly documenting the study will be made publicly available to all interested parties.

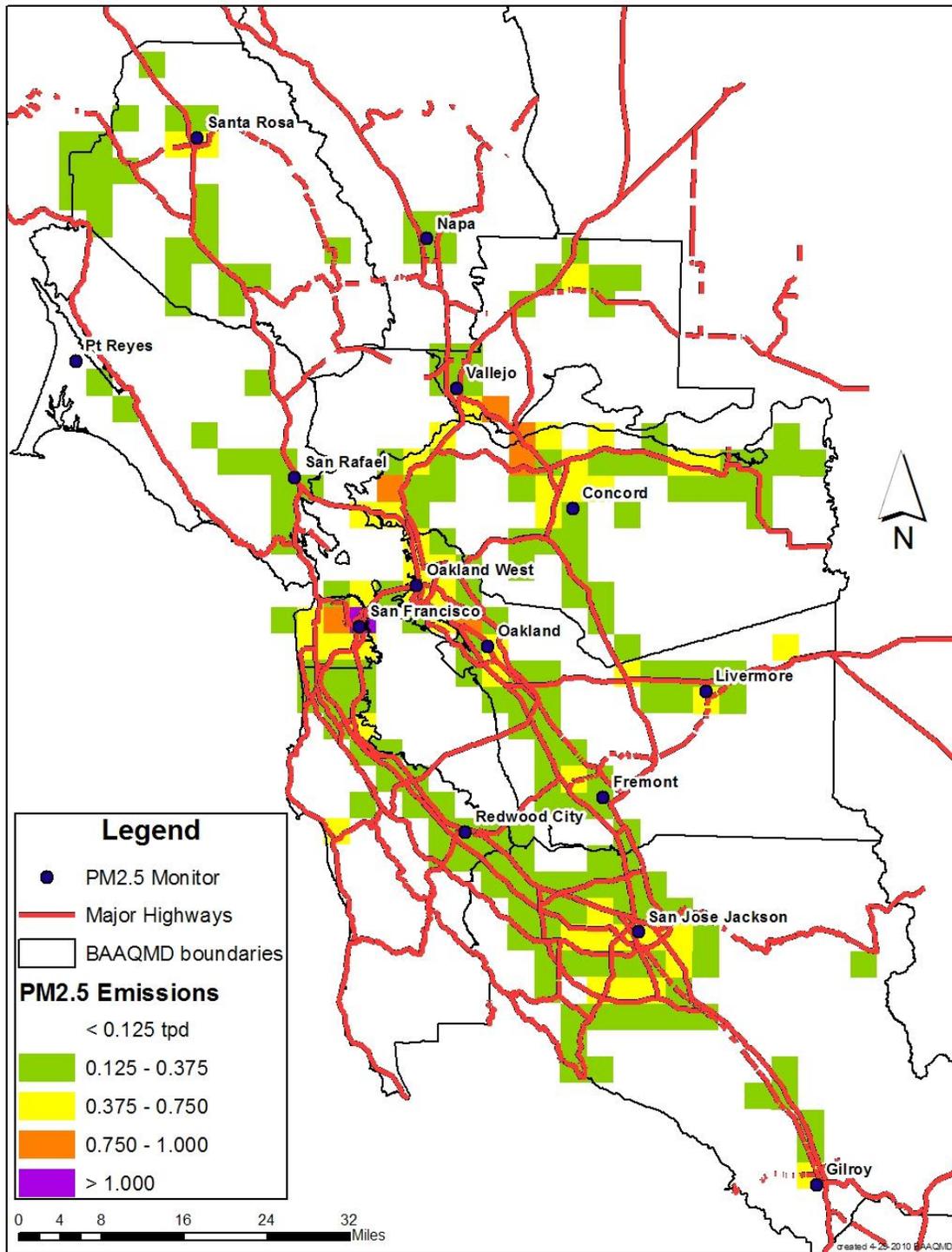


Figure 1. Map of Bay Area showing locations of existing PM<sub>2.5</sub> monitoring stations (filled circles). Major freeways are indicated by red lines. Directly emitted PM<sub>2.5</sub> emissions inventory on a 4x4 km horizontal grid is shown using color scale. Areas with freeways and/or relatively large PM<sub>2.5</sub> emissions rates are likely to exhibit significant PM<sub>0.1</sub> emissions.

## References

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