1. INTRODUCTION

The Bay Area Air Quality Management District (BAAQMD or District) is responsible for monitoring ambient air quality within the nine San Francisco Bay Area counties (Bay Area or SFBA), and for developing and enforcing emission control plans for those pollutants that have violated the National Ambient Air Quality Standards (NAAQS) and the California Ambient Air Quality Standards (CAAQS) within its jurisdiction. Based upon historical air quality measurements within the Bay Area "airshed", the U.S. Environmental Protection Agency (EPA) has designated the SFBA as being in non-attainment of the federal 1-hour ozone standard. Over the years, the BAAQMD has developed and submitted several implementation plans to control ozone in the Bay Area. These plans have been effective in reducing ambient ozone levels, and since 1995 the Bay Area 1-hour ozone design value has been reduced to near the federal standard. On April 22, 2004, the EPA determined that the SFBA has attained the 1-hour ozone NAAQS. The original 1-hour ozone standard has now been effectively replaced by a new and more stringent 8-hour ozone standard, and based upon air quality levels within the SFBA between 2001-2003, the area has been designated as a marginal non-attainment area of the federal 8-hour standard. Furthermore, the BAAQMD, the California Air Resources Board (CARB) and districts downwind of the SFBA have continued interest in analyzing the role of regional transport of ozone and precursors.

Recognizing the need to maintain a current state-of-the-science photochemical modeling capability to address the various on-going regulatory activities within the SFBA and throughout central and northern California, the BAAQMD has been developing a new modeling system and supporting database over the past two years. The data and knowledge base gained as a key sponsor and contributor to the Central California Ozone Study (CCOS) has been essential to this effort, especially in regards to developing a modeling system and application methodology.

This report provides an updated photochemical modeling protocol that describes the modeling system, it's supporting databases, the methodology for its application, and results from modeling two historical multi-day ozone episodes in the summers of 1999 and 2000. The report also includes a conceptual model review for ozone events in the SFBA and an episode typing analysis as part of the modeling episode selection process. The original protocol (ENVIRON et al., 2002) was developed at the beginning of the project to establish model selection and application/ evaluation methodologies, and to provide peer and stakeholder review and acceptance of the proposed approach.

The remainder of this section provides background information relevant to the ozone air quality problem in the SFBA, establishes the purpose and objectives of the current study along with an overview of the approach, and describes the relationship to the CCOS. Section 2 discusses the episode selection; Section 3 provides a justification for model selection; and Sections 4 through 7 describe the meteorological modeling approach, emissions modeling approach, photochemical model input data preparation, and base year photochemical model performance evaluation. Our summary and recommendations are provided in Section 8.

BACKGROUND

Ground-level ozone (or "smog") is considered a "secondary" pollutant, meaning that it is not directly emitted, but rather forms "photochemically" in the atmosphere through complex and highly-nonlinear reactions under sunlight among ozone precursors – nitrogen oxides and hydrocarbons – that are emitted from a variety of natural and anthropogenic sources. Ozone is continually formed and destroyed through such chemical reactions, but its formation rate dramatically increases in strong sunlight and high temperature. Coupled with the tendency for higher precursor emissions and stagnant air circulations under such circumstances, it is clearly evident why elevated ozone events in the Bay Area occur during the summer and early fall.

Strategies to control ambient pollutant levels are set forth in a State Implementation Plan (SIP), which must demonstrate that the adopted controls will attain and maintain the standards on a schedule that depends on the severity of the historical exceedances of the standards. The SIP must be reviewed and accepted by the CARB, which is the lead agency that submits all California SIPs to the U.S. EPA.

The ozone regulatory status for the Bay Area over the last decade has been complicated. The EPA initially classified the SFBA as a "Moderate" nonattainment area for 1-hour ozone following the passage of the 1990 Clean Air Act Amendments (CAAA). The EPA approved a re-designation request and maintenance SIP for the area and so re-designated SFBA to be in attainment for ozone in May 1995. However, new violations occurred during the summer of 1995, prompting the EPA to reverse its finding in July 1998 and to again declare the SFBA as nonattainment. Since this action occurred under Section 172 of the CAAA, the SFBA was classified as "Other". In March 2001, the EPA disapproved portions of the revised SFBA SIP, and as a result, the BAAQMD was required to resubmit the SIP on November 30, 2001. Included in that SIP submittal was a commitment to provide another SIP revision to EPA by April 15, 2004 to demonstrate attainment of the 1-hour ozone standard by 2006 based on new photochemical modeling. However, on April 4, 2004 the EPA found that the Bay Area attains the 1-hour ozone standard based on ambient measurement data over the previous three years, negating the need for a revised SIP submittal unless the region violates the standard in summer 2004. In the meantime, EPA announced new nonattainment designations for the 8-hour standard in the spring of 2004, and the Bay Area is now considered a "marginal" 8-hour ozone nonattainment area. This requires that the SFBA attain the new federal standard by June 2007. According to EPA, marginal areas are not required to submit attainment demonstration SIPs. However, the Bay Area will need to participate with downwind districts that are preparing 8-hour ozone demonstrations.

Given the complexities surrounding the formation and fate of ozone, the development of control strategies to mitigate precursor emissions is always a technically challenging endeavor. As a result, EPA guidance on ozone SIP development requires that nonattainment areas undertake photochemical computer modeling to understand the idiosyncrasies of their area's ozone problem, as well as to develop and evaluate ozone response to the various control scenarios under consideration. Furthermore, EPA and CARB guidance requires the development of a detailed Modeling Protocol that establishes an acceptable methodology to apply and evaluate today's state-of-the-science photochemical models and to develop various supporting datasets.

Modeling Protocol

The modeling protocol delineates the objectives, procedures, and expected results of the modeling study and sets up a process for participation between the regulators and stakeholders to avoid potential technical conflicts. Protocol development should be a dynamic process that is modified as new information is acquired. Proposed changes are to be reviewed by interested parties and incorporated if approved. The California Clean Air Act (CCAA) requires that the modeling protocol be approved by both the local District and the CARB. Both EPA and CARB guidance suggests that at least two review groups be established to review and approve the protocol and to review the results of the study as they become available.

For the Bay Area, the District Board's Executive Committee serves as the policy review group, and a Modeling Advisory Committee (MAC), including stakeholders and representatives from other agencies, was assembled to review the technical aspects of the project. In any study of this type, it is important that the technical underpinnings be fully examined as they are developed. In this manner, to the extent possible, technical issues can be resolved, the focus can be on the many other aspects of this process, and the public can be better assured that the technical community has been rigorous in their review of the work.

Accordingly, a modeling protocol was developed for the photochemical modeling activities described in this report (ENVIRON et al., 2002). The protocol established and described the procedures that were to be used to develop a new ozone modeling system and database for the San Francisco Bay Area, and it followed the requirements provided in two guidance documents:

> "Guideline for Regulatory Application of the Urban Airshed Model," EPA-450/4-91-013, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711, July 1991.
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> "Technical Guidance Document: Photochemical Modeling," California Environmental Protection Agency, Air Resources Board, April 1992.

The development of the Modeling Protocol has been viewed as a joint effort between the contracting Team, the District, and the MAC, and as such, it should be viewed as a "living" document. After the District and MAC reviewed the initial draft, comments were compiled and responses developed. The Modeling Protocol continued to be revised as necessary and was made available to the project participants. For example, as new information necessitated updates to the modeling approach well into the study, the Modeling Protocol was further revised to reflect the alternative methodology. The Modeling Protocol identified work carried out by the CARB to prevent duplication of efforts, and emphasized the synergy between the District's and CARB's modeling of the CCOS episodes and modeling domains. Therefore, this report should be considered a formalization of the latest version of the BAAQMD's SFBA Modeling Protocol.

Other more recent modeling guidance includes a focus on how to use model results for attainment demonstrations, and newer methodologies established for modeling 8-hour ozone:

> "Guidance on Use of Modeled Results to Demonstrate Attainment of the Ozone NAAQS," EPA-454/B-95-007, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711, 1996.

"Draft Guidance on the Use of Models and Other Analyses in Attainment Demonstrations for the 8-Hour Ozone NAAQS." EPA-454/R-99-004, U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC 27711, May 1999.

PURPOSE AND OBJECTIVES OF THIS STUDY

The original purpose of the current study was to modernize the District's modeling capabilities to align with the modeling systems to be evaluated by the CARB under the CCOS program, and to use those systems to develop a new photochemical modeling database to support the 2004 Bay Area SIP revision. With the recent elimination of the need to submit a 2004 SIP revision for 1-hour ozone, the objectives of the study have shifted slightly, but the overall focus remains the same.

The purpose for this study is divided into two distinct goals:

Immediate and foremost goal:
Provide the District with a photochemical modeling system and technical analyses consistent with CARB to support future Bay Area SIP submittals, including assessment of projected future year ozone levels in the SFBA, examination of local and regional control strategy effectiveness, and analyses of the impact of those strategies on regional ozone throughout central California.

Longer-range goal:
Provide the District with a modern tool base that they can use to build a modeling "climatology", consisting of many additional historical episodes with which to evaluate local/regional ozone patterns and issues surrounding inter-basin transport.

Overview of Approach

Based upon the District's suggestions for consistency with their preexisting modeling tools and those to be evaluated by the CARB for CCOS, the original scope specified the use of the following models:

Emissions Processing:	Emissions Modeling System, 1995 version (EMS-95)
Meteorological Modeling:	Regional Atmospheric Modeling System (RAMS)
Photochemical Modeling:	Comprehensive Air quality Model with Extensions (CAMx)

The EMS-95/RAMS/CAMx modeling system was originally selected for this study because it contains all of the technical features necessary to simulate ozone air quality in the SFBA and throughout California. We continue to believe that this system of models has the highest likelihood of generating SIP-quality photochemical modeling databases.

The same EMS-95 emissions processor and input databases used by the CARB were used in this project to assure CARB compatibility and acceptability. We believe that this was an essential element of the study. Alpine Geophysics (AG), one of the developers of EMS-95, took the lead

of the emissions modeling task and worked closely with CARB to assure consistency and compatibility with the CARB's emissions development efforts. AG was concurrently under contract with CARB to develop on-road mobile source VMT estimates for the CCOS domain.

The RAMS prognostic meteorological model was originally selected for the modeling system because of its demonstrated successful application in the Bay Area in the past, its inclusion of all the technical features necessary for simulating the complex Bay Area meteorology, and its familiarity to District staff. Meanwhile, the CARB has utilized the Fifth Generation PSU/NCAR Mesoscale Model (MM5) for their CCOS modeling effort. Thus, a methodological consistency issue immediately presented itself to the District as we moved forward with modeling of the CCOS episodes. The original protocol was therefore revised to include an inter-comparison of RAMS and MM5 performance and to select the most appropriate for use in the photochemical modeling component. Ultimately, the District also undertook MM5 simulations on their own. Subcontractor Dr. Craig Tremback of ATMET is one of the developers of RAMS and has led the RAMS application task. ATMET configured RAMS for optimal high speed performance on the project's computer cluster. We evaluated both CARB and District MM5 applications in this project as well.

The CAMx photochemical grid model was selected for the modeling system as it is publicly available, contains all of the technical options needed to simulate ozone in the Bay Area, and contains some superior capabilities to the other state-of-science models. In particular, the CAMx contains several "probing tools", including the decoupled direct method (DDM) of sensitivity evaluation, ozone source apportionment technology (OSAT), and Process Analysis, all of which will increase the likelihood of obtaining a photochemical base case simulation that fully achieves the model performance objectives. The CAMx modeling was led by its developers, ENVIRON. The CAMx modeling domain was based upon concurrent MM5/SAQM/CMAQ/CAMx model testing and evaluation undertaken by the CARB. ENVIRON set up and assisted the District in evaluating CAMx for one CCOS episode during July/August 2000 and an ancillary episode in July 1999, and transferred and trained District staff on its use.

Project-Specific Computer and Web Site

The District has very specific computer performance goals for operation of simultaneous meteorological and air quality model simulations. As part of the current study, the project team worked with District staff to identify an appropriate Linux multi-node cluster system, purchase and test the system, install models and supporting databases, and deliver the system to District offices. This system can also be enhanced and expanded as new technology becomes available.

It was agreed that we would keep all project participants advised of the project through a web site maintained by ENVIRON, and to which we would post new information for the MAC as it was developed. Because this is a project site, and was intended to be a resource primarily for those that are expected to make meaningful contributions to the technical review effort, we have provided password protection.

Address: http://www.environ.org/basip2004
Username: basip2004
Password: goldengate

Links to small documents such as reports, meeting minutes, summaries, and certain model results were provided via the web site to ease dissemination.

Relationship to CCOS

As noted above, the CARB has led an effort spanning several years and expending millions of dollars to develop a robust and highly credible data base to be used in photochemical modeling over much of California. The CCOS project yielded results in the form of very large datasets that can be used by those engaged in photochemical modeling. Data were collected for several groups of intensive operating periods ("episodes") in 2000. As discussed elsewhere, a subset of those episodes were evaluated for use in this study.

Because of the complexities of photochemistry, emissions, and meteorology, it is important that air pollution management decisions be based on the best science and most comprehensive data available. The CCOS study provided significant information in many areas. Not withstanding the potential for different approaches in some aspects of the CARB and District studies, the Bay Area study participants and the CCOS sponsors agreed to share all technical information as both studies proceeded, thus minimizing any differences in results that could not be accounted for in an objective fashion.

Considerations for Regional Pollutant Transport

Pollution does not respect political boundaries. There is documented air mass flow from the Bay Area into inland areas of the State, and vice-versa. The Federal Clean Air Act recognizes such transport and addresses the manner in which up- and down-wind areas are interconnected in the regulatory process. One of the goals of this study is to provide information that should assist in that regulatory assessment. In addition to air mass and pollutant flow, there are also mobile source emissions that originate within one area but continue as vehicles move to another area. For example, automobiles registered in the San Francisco Bay Area clearly transit outside of that area. The same is true of vehicles registered elsewhere.

Both of these phenomena can be addressed from the photochemical modeling system developed in this study. Pollutant mass transport can be explicitly addressed because the modeling domain used in this study extends well beyond the SFBA, thus accounting for such air mass movement within the modeling system. The movement of vehicles can be addressed through the use of complex transportation model output results being used in estimating mobile source emissions. Such transportation models are used by Metropolitan Transportation Commission (MTC) in the San Francisco area, and Sacramento Association of Governments (SACOG) in the Sacramento area. As described earlier, Alpine Geophysics developed a California-wide Integrated Transportation Network that should facilitate such analyses in the future.