1. Introduction

Project MOHAVE (Measurement of Haze and Visual Effects) was a source attribution monitoring study designed to determine the contribution of emissions from the Mohave Power Project (MPP) to light extinction at the Grand Canyon National Park (GCNP). Experiments took place throughout 1992 in the southwestern United States and included the release and measurement of perfluorocarbon tracer emitted from MPP. The study was principally funded by the United States Environmental Protection Agency (EPA), the National Park Service (NPS), and Southern California Edison (SCE). This report summarizes the findings of Project MOHAVE.

1.1 Background

In 1977, in Section 169A of the Clean Air Act, Congress set as a national goal, "the prevention of any future and the remedying of any existing impairment of visibility in mandatory Class 1 Federal areas which results from manmade air pollution." Section 169A also required EPA to promulgate regulations to assure reasonable progress toward meeting the national goal for mandatory Class 1 areas where visibility is an important air quality related value. On November 20, 1979, EPA identified 156 areas, including GCNP, where visibility is an important air quality related value. On December 2, 1980, EPA promulgated regulations for managing impairment caused by a single source or a small group of sources.

In 1990, Congress reaffirmed its continuing desire to address visibility issues by adding section 169B to the Clean Air Act. Section 169B, which addresses regional haze, calls for a research program to study regional haze, and required the Administrator of EPA to establish a visibility transport commission for the region affecting the visibility in GCNP.

In January and February, 1987, the NPS, acting in its capacity as the federal land manager for GCNP, conducted a study known as the Winter Haze Intensive Tracer Experiment (WHITEX). WHITEX involved a six-week long intensive monitoring period during which an artificial tracer was released from the Navajo Generating Station (NGS) northeast of GCNP (Malm et al., 1989a). National Park Service analysis of optical, air quality, and meteorological data indicated a significant fraction of the haze in GCNP during this time period was due to sulfates resulting from NGS emissions.

Salt River Project (SRP), the operators of NGS conducted a study during early 1990. The SRP study also indicated a contribution of NGS emissions to haze in GCNP, but at a lower frequency of occurrence. A difference in prevailing meteorological conditions during the years of the NPS and SRP studies would at least partially account for the differences in magnitude and frequency of impacts identified by the two studies.

Based on these studies and additional evidence presented, EPA required substantial reduction of sulfur dioxide emissions from NGS. SRP has begun installing scrubbers on NGS and will complete the installation in 1999. While NGS has been linked to a portion of the haze at GCNP, it is generally recognized that a number of other area and point sources also contribute to haze at GCNP. One potential source is the MPP, a 1580 megawatt, coal-fired steam electric power plant located in Laughlin, Nevada, southwest of GCNP and operated by the SCE. MPP burns low sulfur (0.5% by weight) western coal and has no additional pollution control equipment for sulfur dioxide. Congress, desirous of additional information concerning the sources of visibility impairment in GCNP, added $2.5 million to the fiscal 1991 appropriation for EPA to conduct "a pollution tracer study at the Mohave Power Plant." Project MOHAVE is EPA's response to the congressional mandate.

Shortly afterwards, Congress created the Grand Canyon Visibility Transport Commission (GCVTC) to advise the U.S. Environmental Protection Agency on comprehensive strategies for protecting visual air quality at national parks and wilderness areas on the Colorado Plateau. The Commission strongly encouraged the EPA to complete Project MOHAVE and to take action consistent with the results of that study within twelve months of its completion (Mathai, 1995).

A brief description of the previous visibility studies relevant to GCNP and how they led to the design of Project MOHAVE follows.

Outage Studies: MPP was inoperable for the seven month period June through December, 1985. The effect of this outage was examined by Murray et al. (1990), using 1984-1987 SCENES data from Spirit Mountain, Meadview, and Hopi Point. The authors concluded that the average relative contribution of MPP to sulfate at Meadview was less than 15%. Using a similar technique, the daily sulfate concentrations at Spirit Mountain and Meadview were compared with MPP power load over the full range of power output (Switzer et al., 1995). The frequency distribution of sulfate at Meadview did not change discernibly based on the power output of MPP. These studies indicated that a source attribution study for MPP would need to be sufficiently precise to resolve a small sulfate signal (<15%) in a variable background.

WHITEX: This study was designed to evaluate the feasibility of attributing single point source emissions to visibility impairment in GCNP. WHITEX was conducted during a six week period in January and February 1987. During this time, an artificial tracer, deuterated methane (CD_4), was released from the NGS at Page, AZ near the eastern end of the Grand Canyon. Aerosol, optical, tracer, and other properties were measured at Hopi Point (on the south rim of the Grand Canyon) and other locations. Using the tracer, 70 to 80% of the sulfate at Hopi Point under certain meteorological conditions in the winter was attributed to the NGS (Malm et al., 1989b). Some controversy arose from this attribution since the ratio of the CD_4 emissions rate to power plant load was not maintained at a stable value (Markowski, 1992). In addition, while the measurement of CD_4 concentrations is quite precise, the analytical costs are high. As a result, only a fraction of the samples collected were ever analyzed. WHITEX demonstrated the potential of tracer techniques for single source attribution. The study also showed that maintaining a stable tracer/power load emission ratio and using a low cost tracer analytical technique could improve the quality of the source attribution.

NGS Visibility Study: The NGS Visibility Study was conducted by the SRP, the operators of NGS, from January 10 through March 31, 1990. Its purpose was to address visibility impairment in GCNP during the winter months and the levels of improvement that might be achieved if SO_2 emissions from NGS were reduced. The study was performed to provide input to the rulemaking process of the EPA regarding NGS SO_2 controls (Richards et al., 1991). Perfluorocarbon tracers (PFT) were released from the three stacks of NGS. Surface and upper air meteorology, particle and gaseous components, and tracer were measured at many sites. The study concluded that the NGS plume was not present at Hopi Point for most of the days. The tracer data quality from this experiment was insufficient for quantitative source apportionment and the results emphasized the need for better tracer measurements in future studies.

1.2 Project MOHAVE Goals and Objectives

The primary goal of Project MOHAVE is to determine the contribution of the MPP emissions to haze at GCNP and other nearby mandatory Class I areas where visibility is an important air quality related value. This implies a quantitative evaluation of the intensity, spatial extent, frequency, duration and perceptibility of the MPP contribution. The improvement in visibility that would result from control of MPP emissions is included in the primary goal. Secondary goals include an increased knowledge of the contributions of other sources to haze in GCNP and the southwestern United States in general. Because knowledge of regional transport and air quality levels is necessary to separate the effect of MPP from other sources, meeting the primary goal will result in increased knowledge about the impacts from other sources.

These goals are to be attained by completing the following specific objectives:

1. Evaluate the measurements for applicability to modeling and data analysis activities.
2. Describe the visibility, air quality and meteorology during the field study period and to determine the degree to which these measurements represent typical visibility events at the Grand Canyon.
3. Further develop conceptual models of physical and chemical processes which affect visibility impairment at the Grand Canyon.
4. Estimate the contributions from different emissions sources to visibility impairment at the Grand Canyon, and quantitatively evaluate the uncertainties of those estimates.
5. Reconcile different scientific interpretations of the same data and present this reconciliation to policy-makers.

1.3 Guide to Report

The report is divided into 10 sections. This section states the background and objectives of Project MOHAVE. Section 2 describes the study area including the land use, topographical, and meteorological issues that are important to the study. The types of measurements performed as part of the study are documented in Section 3. Section 4 reviews the data quality of these measurements. Section 5 describes the spatial and temporal behavior of light extinction and its components over the study area. Section 6 relates light extinction to airborne chemical composition throughout the region. Section 7 compares the meteorology and air quality during the Project MOHAVE year to previous years. Section 8 summarizes the attribution methods used to attribute light extinction at the Grand Canyon to the Mojave Power Project and other regional sources. Section 9 attempts to reconcile the various attribution methods and presents the range of visibility impairment assessements at Grand Canyon due to the Mojave Power Project. The project accomplishments are compared against its objectives in Section 10 and lessons learned are presented. The appendices describe the MOHAVE database and the unpublished attribution and evaluation methods.