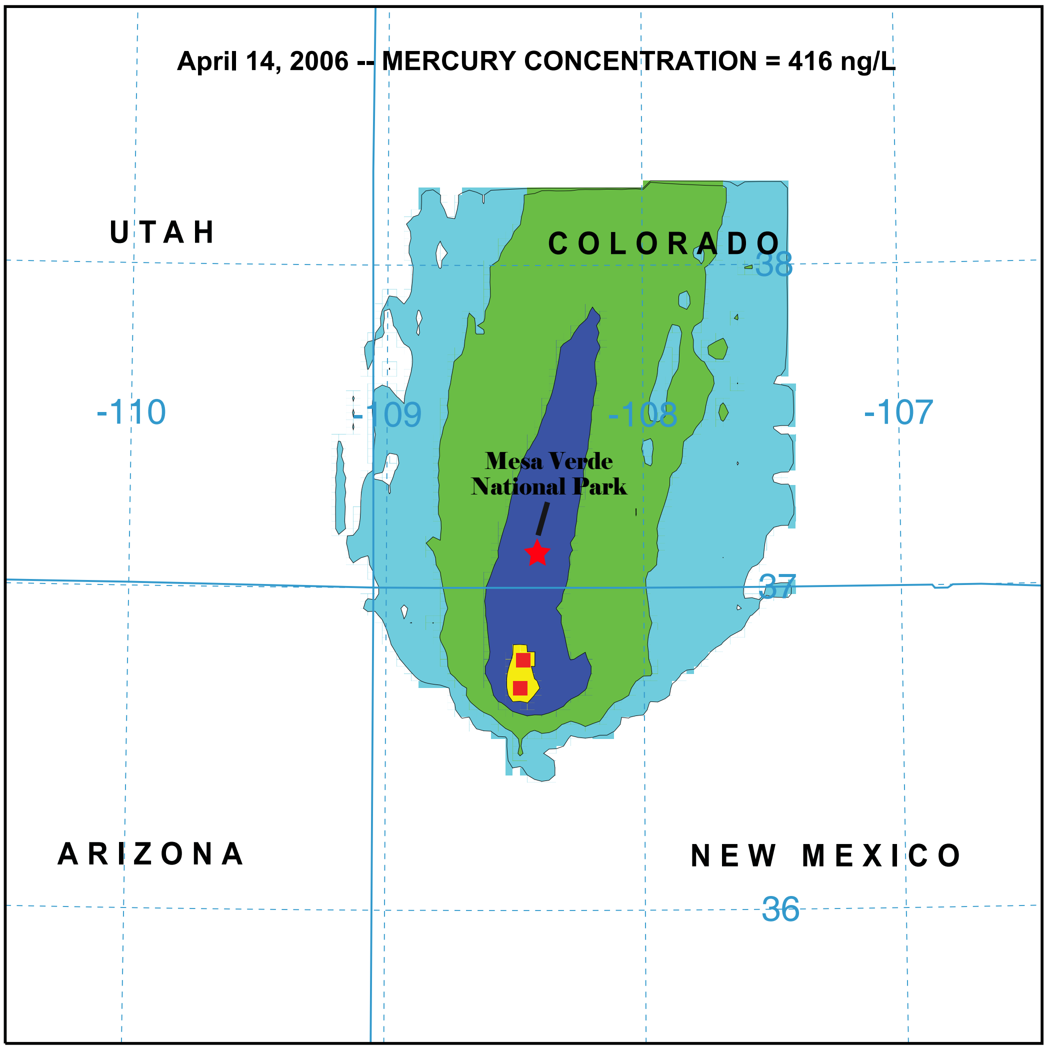
Sources of Atmospheric Mercury Concentrations and Wet Deposition at Mesa Verde National Park, Southwestern Colorado, 2002-08



Mountain Studies Institute, Report 2010-03

Prepared in Cooperation with U.S. Department of the Interior, National Park Service

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Sources of Atmospheric Mercury Concentrations and Deposition at Mesa Verde National Park, Southwestern Colorado, 2002-08

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Mountain Studies Institute
SAN JUAN MOUNTAINS, COLORADO

CONVERSION FACTORS AND ABBREVIATIONS USED IN THIS REPORT

CONVERSION FACTORS:

Multiply	By	To obtain
kilometer (km)	0.62137	mile (m)
foot (ft)	0.3048	meter (m)
gallon	3.78	liter (L)
inch	25.40	millimeter (mm)

Degrees Celsius (^oC) may be converted to degrees Fahrenheit (^oF) by using the following equation:

$$^oF = 9/5(^oC) + 32$$

ABBREVIATIONS:

The following terms and abbreviations may used in this report:

ft (feet)
nanograms per liter (ng/L)
nanograms per square meter (ng/m^2)
milligrams per liter (mg/L)
inches per year (in/yr)
milliliter (mL)
millimeter (mm)
kilometer (km)
micrograms per liter (μg/L)
micrograms per liter (ug/L)
microsiemens per centimeter at 25 degrees Celsius (uS/cm@25^{o}C)
grams per hour (g/hr.)
pounds per year (lb/yr)
kilograms per hectare (kg/ha)

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EXECUTIVE SUMMARY

The source of mercury in precipitation falling at Mesa Verde National Park was investigated in several ways. First, trend analyses were performed to indicate whether the mercury and other constituents in precipitation are increasing or decreasing over time. Second, regression analyses and correlations were done comparing mercury to existing major-ion data, and principal component analyses were conducted to describe correlations in the data. Third, back-trajectory analyses were conducted on 47 single precipitation events to allow tracking of air parcels backwards in time from a set starting location (i.e., Mesa Verde National Park). Fourth, dispersion modeling was conducted on a subset of the single precipitation events to "foreword-track" the estimated path of mercury emissions from existing coal-fired power plants. Finally, back-trajectory and dispersion results were used to estimate below-background versus above-background mercury concentrations and wet deposition at the Park. The approach for the source study includes the null hypothesis which states that mercury concentrations in precipitation have no relationship to where the storm came from.

During 2002-08, mercury was reported in 223 precipitation events at Mesa Verde National Park. The average concentration was 24.65 ng/L (nanograms per liter), and the average mercury deposition was 188 ng/m^2 (nanograms per square meter). Mercury concentrations and deposition appeared to be increasing during this period; however, the trend is not statistically significant and is skewed by outliers, such as the event of July 8, 2008, when the mercury concentration was reported at 381 ng/L (among the highest mercury concentrations reported in the US). During 1981-2008, concentrations and deposition of some major ions (such as sulfate and chloride) decreased significantly. Nitrate concentrations were variable and showed no trend; however, nitrate deposition decreased. Precipitation also became less acidic during 1981-2008; mean pH values increased significantly, and wet deposition of hydrogen ions (H^+) decreased significantly. During this time period when sulfate, chloride, nitrate, and acid deposition declined at the Park, air-pollution control measures were implemented for nitrogen and sulfur emissions at two nearby coal-fired power plants. In contrast, air pollution control measures had just begun to be implemented for mercury in one of the two major power plants by 2008. This difference in control measure implementation may explain the lack of a trend in wet-deposition mercury during the same time period for which deposition of major ions associated with coal combustion have declined.

Principal components analyses (PCA) of major ion and mercury data showed that different groups or patterns were evident, suggesting that sulfate, nitrate, and mercury come from the same source (most likely, coal-fired power plants). In the PCA biplot, chloride falls between the terrestrial earth elements (calcium, magnesium, sodium, and potassium) and the likely coal-fired power plant sources. Ammonia samples plot above the coal-fired power plant group but away from the terrestrial earth elements, indicating a possible connection to power plants, but ammonia also may come from other sources such as agricultural activities (fertilizers and feed lots).

Back trajectory modeling of 47 single storm events from 2002 to 2008, and subsequent identification of storm source direction, indicate that 87 percent of the mercury deposition from the modeled events came from south of the Park. Atmospheric dispersion modeling results that track mercury emissions at two power plants located south of Mesa Verde shows that air-pollution plumes from the power plants travel over Mesa Verde National Park. Furthermore, dispersion modeling shows that the San Juan River Valley can trap air pollution, which can then be transported and deposited at the Park. Therefore, the storms do not need to pass directly over emission sources to affect mercury deposition at Mesa Verde National Park. Back trajectory modeling also shows that storm events at Mesa Verde are influenced by weather from the eastern Pacific Ocean, the Pacific Northwest, monsoons (seasonal flow of moist air masses) from the southwest, and monsoons from the southeast.

Back trajectory storm tracks sourced from 130 to 220 degrees azimuth (i.e., southern source area) were assigned the category of above background, and the other trajectories were assigned a category of below background. The 80th percentile of the below background concentration resulted in a background mercury concentration of 11.73 ng/L. Calculations show that from 2002-08, the annual above-background mercury deposition at Mesa Verde National Park ranged from 54 to 84 percent of the total wet deposition. More than 60 percent of the mercury concentrations reported were greater than the background concentration of 11.73 ng/L.

The combination of evidence from the various analyses conducted for this study lead us to conclude that coal-fired power plants south of Mesa Verde National Park are likely an important source of mercury in wet deposition to the Park. These results are correlative, however, and we cannot determine how much deposited mercury originates from a specific emission source. We also cannot rule out the possibility that above-background concentrations of mercury were already entrained in these storm tracks prior to them passing over the nearby coal-fired power plants.

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Sources of Atmospheric Mercury Concentrations and Wet Deposition at Mesa Verde National Park, Southwestern Colorado, 2002-08

Mountain Studies Institute, San Juan Mountains, Colorado

INTRODUCTION

Mercury has been well known as an environmental pollutant for several decades. As early as the 1950's it was established that emissions of mercury to the environment could have serious effects on human and wildlife health. These early studies demonstrated that fish and other wildlife from various ecosystems commonly attain mercury levels of toxicological concern when directly affected by mercury-containing emissions from human-related activities. For all organisms, the early stages of development (especially embryos) are the most sensitive to mercury. Steps have been taken by regulatory agencies to recognize and limit mercury consumption by humans. However, as described by Dr. David Krabbenhoft of the U.S. Geological Survey, "the social and economic costs of mercury are probably higher than currently estimated, because they don't take into account mercury's impact on wildlife" (Science Daily, http://www.sciencedaily.com/releases/2006/08/060811191845.htm, accessed January 7, 2008).

The sources of mercury (Hg) in the environment are not well understood and could have numerous local, regional, and global sources. Local sources could include natural background mercury in rock formations, emissions from urban centers, automobile exhaust, and coal combustion processes. Regional sources could include coal-fired power plants, dust storms, industrial processes, emissions from urban centers, and forest fires. Global sources could include coal-fired power plants, continental dust storms, and volcanic activity. Human sources of mercury include fossil fuel burning, waste incineration, landfills, refineries, gold mines, cement and brick factories, and chlorine production. Coal-fired power plants are the largest human source of mercury emissions in the US, and atmospheric deposition, which includes mercury in precipitation and dry deposition, appears to be the dominant source of mercury contamination in North America (Norton and others, 1997). While mercury deposition (mass per unit area) is important for the fate and transport of mercury in aquatic ecosystems, high mercury concentration (mass per unit volume) may be more important for the reproduction of sensitive amphibian species that reproduce in temporary ponds.

Mercury contamination is well documented in water bodies of the United States (Evers and Clair, 2005), often triggering public health advisories. In 2008, there were 3,361 fish consumption advisories due to mercury in lakes, rivers, and coastal areas across the US. Most states, including Colorado and New Mexico, have mercury fish consumption advisories on water bodies (USEPA, 2008). In the 1990s, the US began regulating mercury emissions from some sources, such as waste incinerators (but not coal-fired power plants). This led to major reductions in mercury emissions from 220 tons in 1990 to 115 tons in 1999 (USEPA, 1999).

Of all pollutants mentioned in the Clean Air Act, mercury has the greatest potential to impact human health (USEPA, 1997). Human health concerns arise when fish and wildlife from mercury-affected ecosystems are consumed by humans. The greatest potential threat of mercury to human health is conversion of inorganic mercury to highly toxic organic mercury compounds such as methylmercury, a neurotoxin that damages the central nervous system in humans. Contamination of fish with mercury is the most significant problem because this is the dominant pathway of mercury to humans. In 2003, the Centers for Disease Control and Prevention found that 8% of women in the US of childbearing age have blood mercury levels above those deemed safe by the US Environmental Protection Agency (Shober, 2003). A study by the Harvard Center for Risk Analysis estimated that reducing power plant mercury emissions by about 60% could result in up to 5 billion dollars in annual health benefits (Rice and Hammitt, 2005). Mercury also has toxic effects on wildlife. Methylmercury exposure to aquatic birds, mammals, and fish can result in reduced reproduction, slower growth and development, abnormal behavior, and death (Evers, 2005).

Mesa Verde National Park **(Figure 1)** represents one of the most sensitive habitat types in the western US where the piñon-juniper woodlands contain wildlife species that are unique to the desert-mountain transition zone. Amphibian species that reproduce in temporary ponds are sensitive to changes in environmental conditions such as deposition of atmospheric pollutants. Boreal toads, tiger salamanders, chorus frogs, northern leopard frogs, and wood frogs are particularly vulnerable. In the southwestern corner of Colorado, south and west of the San Juan Mountain range, fish from five reservoirs have been tested for mercury and all five now are listed for fish consumption advisories (McPhee, Naraguinnep, Totten, Vallecito, and Navajo Reservoirs). Across the border in northwestern New Mexico, nine water bodies have mercury consumption advisories. In contrast, eight reservoirs on the northern and eastern sides of the San Juan Mountains do not have fish consumption advisories for mercury (CDPHE, 2010).

There are ten coal-fired power plants within a 200 mile radius from Mesa Verde National Park **(Figure 1)**. Two of these are located in San Juan County, New Mexico, within 30 to 35 miles south of the Park. San Juan County is among the highest emitters of mercury among all counties in the nation (Environment Colorado Research and Policy Center 2005). Another power plant (Desert Rock) has been proposed for San Juan County.

Mercury Monitoring at Mesa Verde National Park

As part of the National Atmospheric Deposition Program, Mercury Deposition Network (NADP/MDN), a sampling site has been located at Mesa Verde National Park since February 2002. Annual volume-weighted mean concentrations for Mesa Verde from 2002 to 2008 range from 9.7 to 17.6 ng/L (nanograms per liter), and are among the highest in the nation. On July 8, 2002, a mercury concentration of 129 ng/L (nanograms per liter) was recorded in precipitation at the Mesa Verde MDN site. At the time, this was the highest concentration of mercury in precipitation ever recorded in the US. On April 11, 2006, a mercury concentration of 416 ng/L was recorded in precipitation at the Mesa Verde MDN site. Although the sample was flagged for the small amount of precipitation during the event, this represents by the far the highest concentration of mercury ever recorded in precipitation in the US. Mercury amounts in wet deposition, ranging from 3,300 to 7,000 ng/m^2 (nanograms per square meter) annually for 2002-2008, are not as alarmingly high as the concentrations due to the semiarid climate; however, deposition amounts at Mesa Verde are among the highest of western MDN sites. Furthermore, dry deposition of mercury, which just began to be measured at the MDN stations in southwestern Colorado in 2009, could be high compared to more humid sites, making the total mercury input more than currently perceived. For example, a study in New Mexico found that the total deposition of mercury (including wet and dry) was 2.4 times greater than wet only (Caldwell and others, 2006). High concentrations of mercury in precipitation are more widespread than just Mesa Verde National Park. Sampling of precipitation near Vallecito Reservoir (50 miles northeast of Mesa Verde) has indicated mercury concentrations as high as 72 ng/L during 2007 (Durango Herald, October 25, 2007, http://durangoherald.com/).

During 2009, a pilot study was conducted at Mesa Verde by Mountain Studies Institute to investigate mercury bioaccumulation in wetland songbirds, terrestrial invertebrates (spiders, centipedes, beetles), soil, leaf litter, and aquatic life (fish and crayfish) (Nydick and Williams, 2010). The pilot study collected limited samples of each group, and there was much variability in the results due to differences in species, setting, and trophic level. Total mercury concentrations in blood samples from songbirds were not unusually high compared to other sites in the northeastern US. Given the semi-arid and mountainous terrain of Mesa Verde, there appear to be fewer avenues for mercury methylation and mobilization (possibly due to fewer lakes and wetlands); hence, there were elevated mercury concentrations in soils, but there were not unusually high mercury concentrations in songbirds or aquatic life at Mesa Verde National Park.

During 2008-09, a regional study was conducted by Mountain Studies Institute to investigate mercury in precipitation and lake zooplankton at high-altitude sites in the San Juan Mountains located northeast-of and adjacent-to Mesa Verde National Park (**Figure 1**).

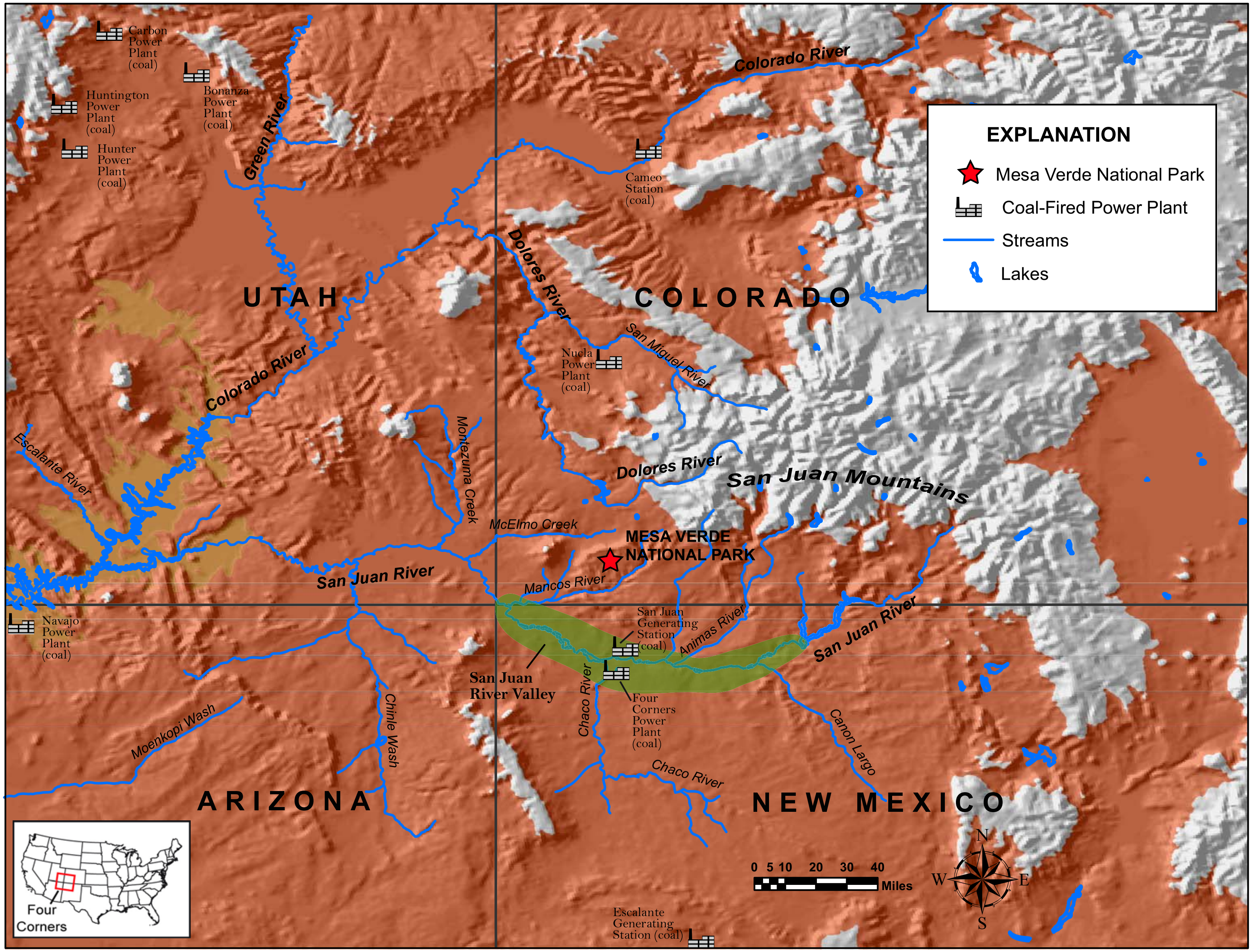


Figure 1. Location of Mesa Verde National Park, coal-fired power plants in the region, and the San Juan River Valley.

Mercury concentrations in precipitation were lower at higher altitudes than at Mesa Verde; however, because of higher precipitation amounts, mercury deposition was similar to Mesa Verde National Park (Nydick, 2010). Mercury concentrations in zooplankton were variable, ranging from very low to moderately high. The concentrations compare to other studies of zooplankton in lakes in the Eastern and Midwestern US. In general, higher zooplankton mercury concentrations were associated with forested watersheds where lakes have higher dissolved organic matter and moderate productivity leading to lower dissolved oxygen and mercury methylation.

Purpose and Scope

The purpose of this study is to analyze existing data to better understand the sources of atmospheric mercury deposited by precipitation events within Mesa Verde National Park. This critical information can be used to provide comments on proposed new sources of mercury emissions as well as proposed air-pollution control technologies at existing emission sources in the Four Corners region. This data and information may be incorporated into the Park's current planning efforts and will assist in the development of environmental management strategies.

METHODS OF INVESTIGATION

The source of mercury in precipitation falling at Mesa Verde National Park was investigated in several ways. First, trend analyses were performed on time-series data to indicate whether the mercury and other constituents in precipitation are increasing or decreasing over time. The trends also were compared with the timing of implementation of pollution-control technologies at existing sources. Second, regression analyses and correlations were done comparing mercury to existing major-ion data, and principal component analyses were conducted to describe correlations in the data (Keeler and others, 2006). Third, back-trajectory analyses were conducted, which allows tracking of air parcels backwards in time from a set starting location (i.e., Mesa Verde National Park). Single precipitation events were identified coincident with data from 2002-08. Five to eight events per year, stratified by season, were selected for back trajectory and source modeling. Fourth, dispersion modeling was conducted on a subset of the single precipitation events to "foreword-track" the estimated path of mercury emissions from existing coal-fired power plants. In dispersion modeling, the mercury is transported along with the storm by atmospheric dispersion, and the mercury is deposited in precipitation by the rain-out effect (Seinfeld and Pandis, 1998). Finally, back-trajectory and dispersion results were used to estimate below-background versus above-background mercury concentrations and wet deposition at Mesa Verde National Park. The approach for the source study includes the null hypothesis which states that mercury concentrations in precipitation have no relationship to where the storm came from.

Data Sources. Precipitation data, mercury concentrations in precipitation, and major-ion concentrations in precipitation were obtained from the following sources:

- National Atmospheric Deposition Program (NADP), National Trends Network (NTN) -- http://nadp.sws.uiuc.edu/ntn/.
- National Atmospheric Deposition Program, Mercury Deposition Network (MDN) -- http://nadp.sws.uiuc.edu/mdn/.
- National Oceanographic and Atmospheric Administration (NOAA) Air Resources Laboratory, HYSPLIT model download and users guide-- http://ready.arl.noaa.gov/HYSPLIT.php.
- National Oceanographic and Atmospheric Administration (NOAA) Air Resources Laboratory, gridded model input data for HYSPLIT -- ftp://arlftp.arlhq.noaa.gov/pub/archives/edas.
- Clean Air Status and Trends Network (CASTNET) -- http://www.epa.gov/castnet/.
- Environmental Protection Agency, Online Tracking Information System (OTIS) -- http://www.epa-otis.gov/echo/

The NADP sampling site has been located at Mesa Verde National Park since April 1981, and data are concurrent with the MDN samples from 2002 to the present. Major-ion concentrations in precipitation are available for calcium, magnesium, sodium, potassium, ammonia, nitrate, chloride, sulfate, and pH. Precipitation quantity and chemistry data were tabulated and entered into Microsoft Excel and Access data bases; and the data were imported into the S-PLUS Statistical program.

Trend Analysis. Time series data for mercury, major ions, and pH were analyzed for trend over time. The Sen's trend (nonparametric slope estimator that uses the Kendall tau; Helsel and Hirsh, 1992) was determined for major-ion concentration and deposition data. The significance level of α at 0.001 means that there is a 0.1% probability that the values are from a random distribution, and with that probability we make a mistake when rejecting the null hypothesis of no trend. Thus, the significance level 0.001 means that the existence of a monotonic trend is very probable (Helsel and Hirsh, 1992). The significance level 0.1 means that there is a 10% probability that we make a mistake when rejecting the null hypothesis (Helsel and Hirsh, 1992). Generally, statisticians require a significance level of 0.05, but 0.1 is often considered marginally significant. The correlation coefficient, sometimes also called the cross-correlation coefficient, is a quantity that gives the quality of a least squares fitting to the data. If the variables are perfectly correlated, the R-squared value (R^2) equals unity or 1.0. If the variables are uncorrelated, the R-squared value is zero.

Principal Components Analysis. All of the mercury and major-ion data collected at the Mesa Verde National Park MDN and NTN sites were compared using principal components analysis (PCA). PCA is a multivariate analysis technique (Daultrey, 1976; Joreskog and others, 1976; Grundy and Miesch, 1987). Principal components represent a set of new, transformed reference axes that are linear combinations of the original variables; it is a transformation of data, not a statistical treatment. A principal components transformation orients the data points so that the first of the new axes, principal component 1 (PC1), is oriented along the direction of the greatest variance in the data. The second principal component (PC2) is orthogonal to PC1, and is oriented to show the next greatest amount of variance in the data. This is easy to picture in two dimensions. One can imagine drawing a line that would go through the two most distant points in a bivariate plot of data; that would be the direction of PC1. It would be at some angle to the original x and y axes, but any point along the line could be described by a linear equation. PC2 would be drawn perpendicular to PC1, and it would have its own linear equation. In multidimensional space, each subsequent principal component is orthogonal to the first two and represents a decreasing amount of the total variance.

Typically, the first two or three principle components show enough of the variance in the data set to enable the recognition of groups among samples; this is the advantage of using the method for multivariate data. Samples are plotted by their PCA scores, which are the coordinates of the original data points on the new principal component axes. Adding vectors representing the correlations of original variables with the new principal component axes to the plot of scores creates a biplot. The vectors help identify variations in chemistry among the groups of samples. For the analysis of all data, chemical concentrations were converted to millimoles per liter and used in the biplots after logarithmic transformation.

Selection of Precipitation Events for HYSPLIT Modeling. Weather events were identified during 2002-08 where the mercury concentrations from MDN samples were represented by single precipitation events. Back trajectory analyses were conducted on the single precipitation events to indicate the source areas of mercury concentrations in wet deposition at Mesa Verde.

Precipitation data were downloaded and plotted, and single-storm events during 2002-08 were identified **(Appendix A1)**. Many single precipitation events occur at Mesa Verde where the mercury reported within a particular week can be associated with a single storm event. The mercury data network (MDN) site at Mesa Verde National Park is serviced once a week (usually on Tuesday). For mercury detections in precipitation that occurred during an MDN-week, back trajectory of the single storm events were traced using the back trajectory model. From the tabulation of single storms, events were chosen for each season spread throughout the year for a total of 55 events. Of these 55 events, we obtained conclusive results from 47 as explained more fully below.

HYSPLIT modeling. The HYSPLIT (HYbrid Single-Particle Lagrangian Integrated Trajectory) model is a complete system written by the National Ocean and Atmospheric Administration (NOAA) for computing simple air parcel trajectories and complex dispersion and deposition simulations (Draxler and Rolph, 2003). Back trajectory analyses used gridded, interpolated meteorological data to estimate the most likely central path over geographical areas that provided air to Mesa Verde National Park. The method essentially follows a parcel of air backward in hourly steps for a specified length of time. The gridded meteorology data came from EDAS (Eta Data Assimilation System), which is an intermittent assimilation system consisting of successive 3-hour Eta model forecasts and Optimum Interpolation (OI) analyses. Vertical motion was modeled using different calculation methods such as omega field (height field), isentropic (constant entropy), isosigma (simulating orographic lift), isobaric (constant pressure), isopycnic (constant density), and convergence/divergence (convection).

Dispersion modeling was done on selected events to help determine above- and below-background mercury concentrations. The dispersion of a pollutant was calculated by assuming puff dispersion, where puffs expand until they exceed the size of the meteorological grid cell (either horizontally or vertically) and then split into several new puffs, each with it's share of the pollutant mass (Draxler and Rolph, 2003). The model's default configuration assumes a 3-dimensional particle distribution (horizontal and vertical). The dispersion model calculation method is a hybrid between the Lagrangian approach, which uses a moving frame of reference as the air parcels move from their initial location, and the Eulerian approach, which uses a fixed three-dimensional grid as a frame of reference. From the Environmental Protection Agency Online Tracking Information System (OTIS), the annual mercury emissions from the Four Corners Power Plant was determined to be 590 lbs/yr (about 30 grams/hour), and the San Juan Generating Station showed an annual mercury emission rate of 390 lb/yr (20 grams/hour). These emission rates were modeled as continuous outputs during the simulation periods. Wet deposition was included so that the mercury concentrations decrease down wind due to the rain out effect.

Of the 55 single-storm events selected **(Appendix A1)**, inconclusive results were obtained from seven simulations where different back trajectories resulted from different vertical motion options. For one single-storm event, data were absent from the EDAS data file. Inconclusive results were not used, which resulted in 47 successful back trajectories used in the analysis.

Azimuth, an angular measurement in a spherical coordinate system, was assigned to each back trajectory. The vector from the origin at Mesa Verde National Park to a point 50 miles along the trajectory was measured by the clockwise horizontal angle (ranging from 0 to 360 degrees) relative to the north base line (or meridian).

Determination of Background. Background mercury concentrations in precipitation were determined using a combination of methods. First, azimuth of storm back trajectories were plotted according to mercury concentration and deposition. Second, the range of azimuthal directions for above background samples were determined using the HYSPLIT dispersion model for selected mercury deposition events at Mesa Verde National Park.

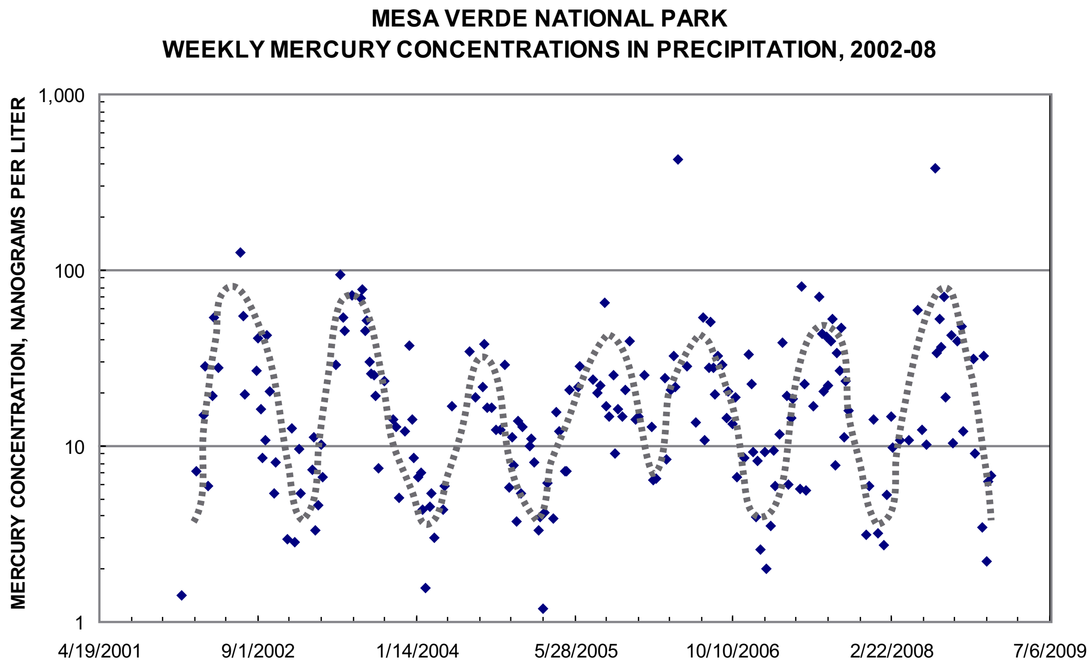
Because the back trajectory analyses indicated that higher concentrations of mercury tended to originate from southern source areas, emissions from the two large coal-fired power plants in San Juan County, New Mexico, were used as source locations as an additional method to help us determine background concentrations. Samples sourced from within the defined azimuthal range were ranked, and the 80th percentile concentration (USEPA, 2002) was used to select the background concentration.

MERCURY AND MAJOR-IONS IN PRECIPITATION AT MESA VERDE NATIONAL PARK

Trend Analyses

During 2002-08 at Mesa Verde National Park, mercury was reported in 223 precipitation events. The average event concentration was 24.65 ng/L, with a standard deviation of 33.1 ng/L. The average event mercury deposition was 188 ng/m^2 (nanograms per square meter), with a standard deviation of 210 ng/m^2. Mercury concentrations and deposition in precipitation at Mesa Verde National Park appear to be increasing slightly from 2002-08 **(Figure 2)**. However, the trend is not significant ($\alpha > 0.5$), and the appearance of an increasing trend may be caused by the variability of mercury data and a few extremely high events (for example, July 8, 2008, Hg = 381 ng/L). The mercury concentrations show seasonal fluctuations; the dashed lines in **Figure 2** show a moving average of 10 days.

Concentrations and deposition of sulfate and chloride in precipitation at Mesa Verde National Park decreased from 1981 to 2008 **(Figure 3)**. Nitrate concentrations were variable, indicating no trend; however, nitrate deposition decreased over the time period with a marginally significant trend (α =0.1).



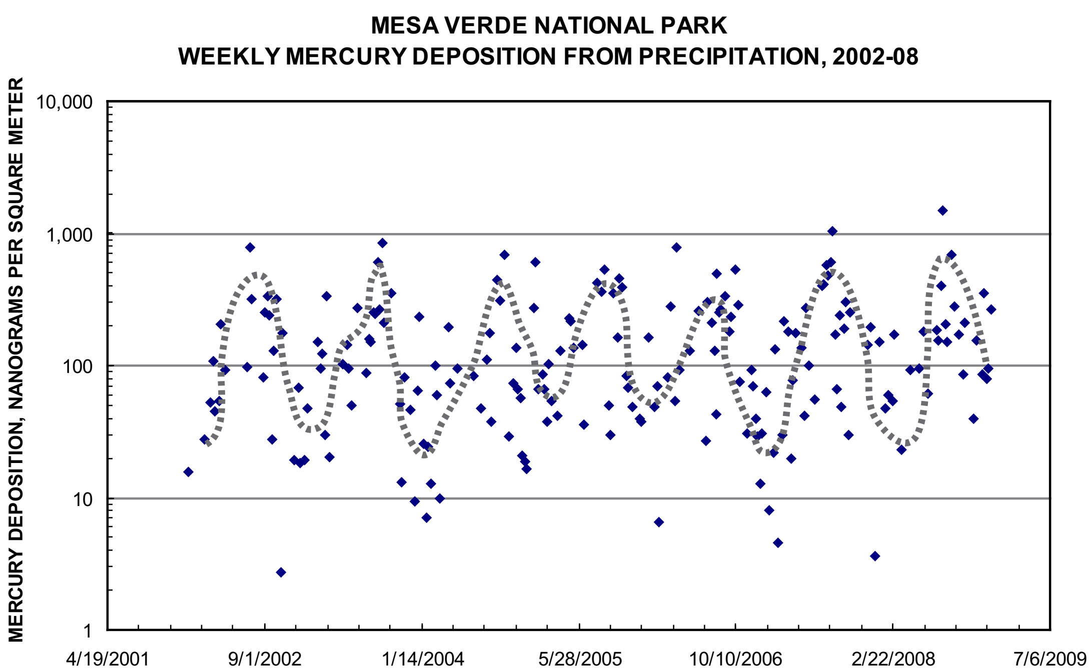


Figure 2. Mercury concentrations and deposition over time at Mesa Verde National Park, 2002-08.

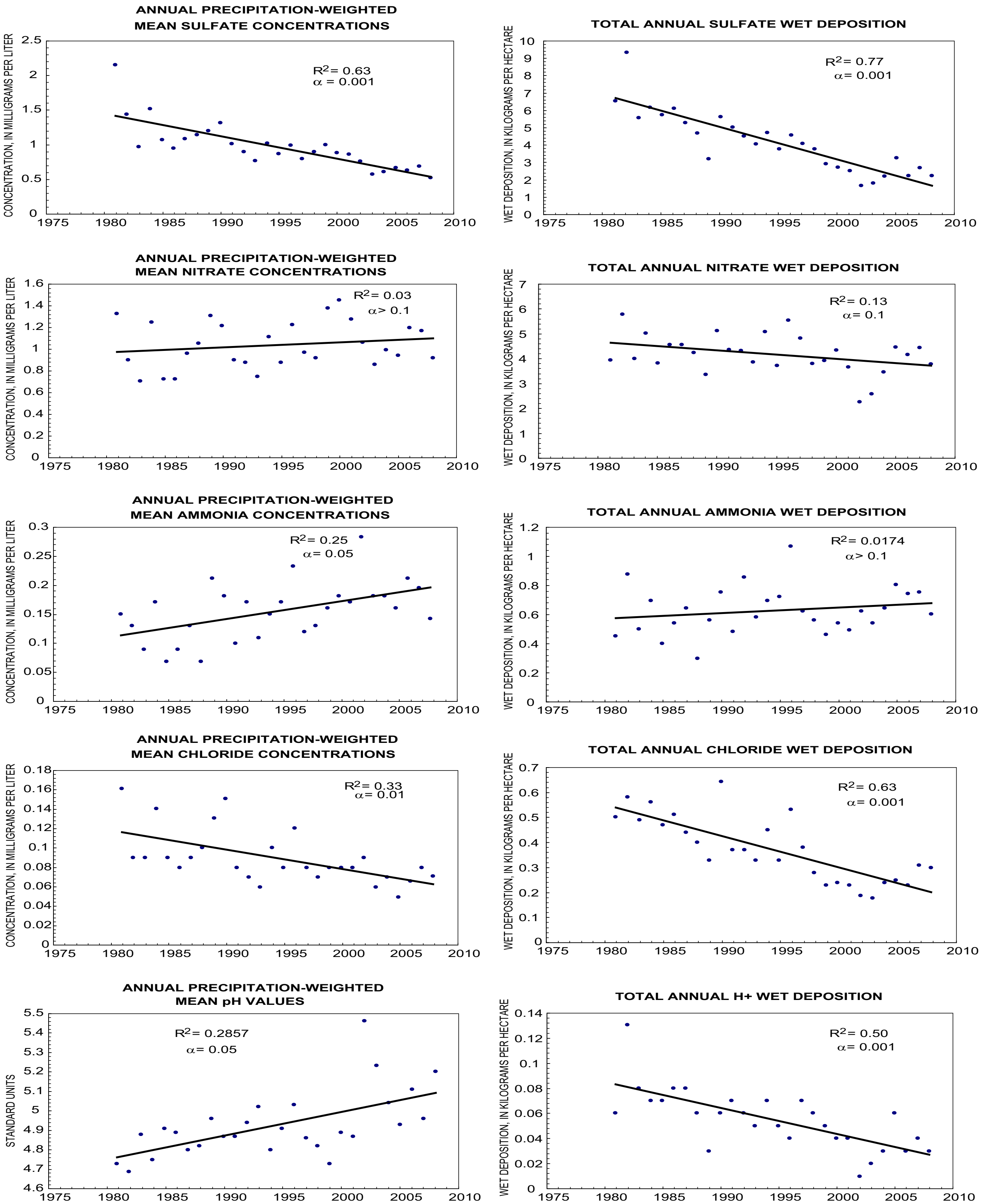


Figure 3. Annual concentrations and wet deposition of selected constituents at Mesa Verde National Park, 1981-2008.

Ammonia concentrations and deposition increased somewhat significantly over the time period. Mean pH values increased significantly (α = 0.05) during 1981-2008, and wet deposition of hydrogen ions (H^+) decreased significantly (α = 0.001) during the time period **(Figure 3)**.

Two coal-fired power plants are located in northwestern New Mexico: Four Corners Power Plant and the San Juan Generating Station **(Figure 1)**. Air pollutants such as sulfur dioxide (SO_2), nitrogen oxides (NO_X), and hydrochloric acid are typically emitted from coal-fired power plants, and these emissions create acid rain (low pH), dissolved sulfate, nitrate, and chloride in precipitation (Turk and others, 1993). Air pollution measures have been generally implemented at these power plants in accordance with the Clean Air Act amendments of 1977 and 1990. From 1980 to 2005, sulfur dioxide and nitrogen oxides have generally been reduced in emissions from these plants **(Figure 4)**. These emission reductions correlate with the decreasing trends of sulfate, nitrate, and chloride and increasing trend in pH in precipitation at Mesa Verde National Park **(Figure 3)**. However, air-pollution control measures have not been implemented for mercury, and this may explain the unchanging (or possibly increasing) mercury concentrations and deposition **(Figure 2)**. Ammonia concentrations and deposition at Mesa Verde appear to be increasing, which may be caused by the treatment process to convert nitrogen oxides to a different nitrogen form, or the ammonia could be coming from agricultural processes.

Principal Components Analyses

To describe sources of dissolved constituents in precipitation at Mesa Verde National Park, principal components analysis (PCA) was done on the 2002-08 precipitation analyses combined from the NADP/MDN and NTN data sets **(Appendix A2)**. Although the processes contributing to patterns might not be described through PCA, different groups (or sources) can be identified **(Figure 5)**. The plot indicates the similarities and correlations between samples (Varmuza, 2001). Two distinct groups of samples can be identified: (1) Sulfate, nitrate, and mercury, and (2) terrestrial earth elements **(Figure 5)**. Sulfate, nitrate, and mercury are directly correlated in the PCA analysis. These three constituents individually have several possible sources, but their correlation in Mesa Verde precipitation samples provides strong evidence that their major source is one they share in common, namely coal-fired power plants.

Chloride samples plot between the terrestrial earth elements and coal-fired power plants, indicating that chloride in precipitation may come from both sources. Ammonia samples plot above the coal-fired power plants but away from the terrestrial earth elements, indicating a possible connection to power plants, but ammonia also may come from other sources such as agricultural activities (fertilizers and feed lots).

SOURCES OF MERCURY CONCENTRATIONS AND WET DEPOSITION AT MESA VERDE NATIONAL PARK

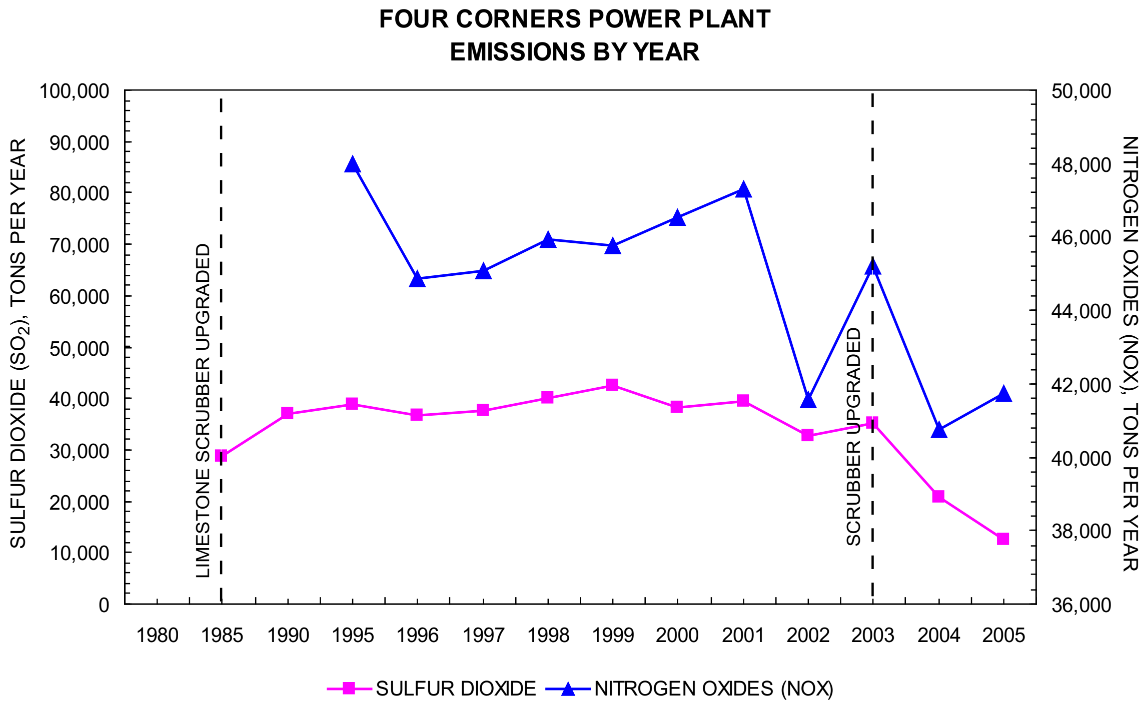
Existing precipitation chemistry data were combined with dispersion and back trajectory modeling to describe the sources of mercury concentrations and wet deposition at Mesa Verde National Park.

Back Trajectory Analyses

Single precipitation events were selected by examining the daily and hourly precipitation records from the NADP and Castnet precipitation sites at Mesa Verde National Park. Back trajectories were modeled for 47 of these events **(Appendix A1)**. All back trajectory modeling results are shown in **Appendix B**. The small, colored circles show the back trajectory in one-hour increments, backwards in time from when the mercury was deposited at Mesa Verde **(Appendix B)**. The azimuth of each storm track from Mesa Verde was determined at 50-mile distance before arriving at the MDN site.

The modeled storm events at Mesa Verde are primarily influenced by weather from four major storm tracks:

- (1) Eastern Pacific Ocean, where storms come in from the southwestern US;
- (2) Pacific northwest (particularly during winter);
- (3) Monsoons (seasonal flow of moist air mass) from the southwest that are affected by eastern Pacific tropical



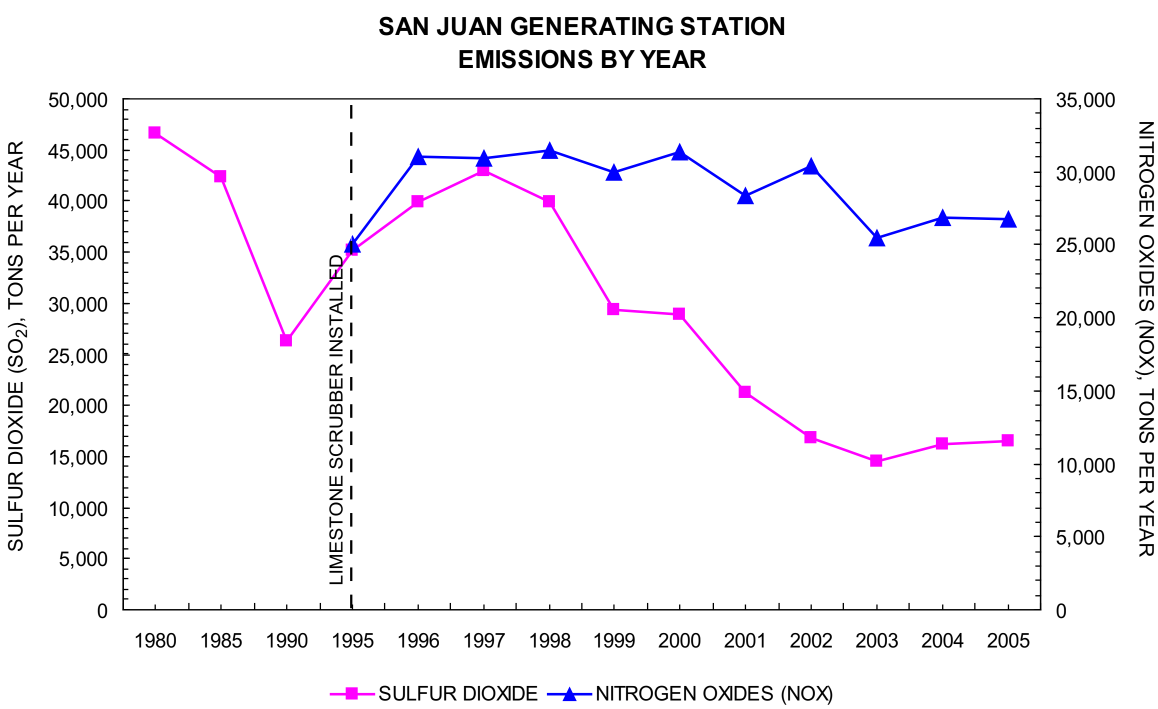


Figure 4. Emission of sulfur dioxide and nitrogen oxides by the Four Corners Power Plant and San Juan Generating Station, northwestern New Mexico (sources: http://www.epa-otis.gov/echo/; http://www.pnm.com/environment/; http://www.aps.com/).

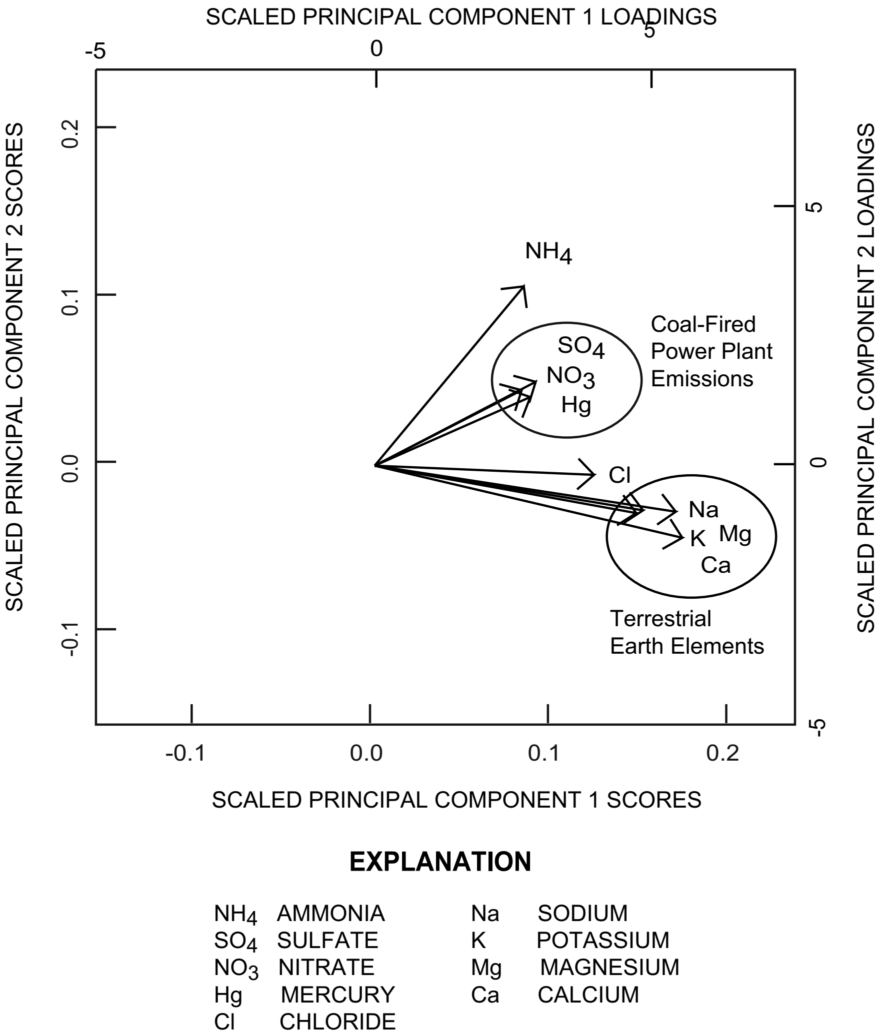


Figure 5. Biplot showing the relationship between mercury detections (2002-08) and dissolved constituents in precipitation at Mesa Verde National Park.

moisture (particularly during El Niño-Southern Oscillation events); and

- (4) Monsoons from the southeast that are affected by moisture from the Gulf of Mexico.

From the back trajectory modeling, most of the single-storm events came from the south, southwest, or southeast. One single-storm event came from the northwest, and another one came from the northeast. In many cases, slow-moving storms (indicated by closely spaced hourly circles) have higher mercury concentrations than do fast-moving storms. For many of the southerly tracks, back trajectories are "S-shaped" as they approach Mesa Verde National Park, allowing the accumulation of mercury and other air pollutants as the storms meander along the San Juan River Valley. Single storm events sourced from the southern direction had the highest mercury concentrations deposited in precipitation. Because of this finding, we rejected the null hypothesis that the concentration of mercury was unrelated to the direction of the storm track. We then used dispersion modeling to determine the geographical extent of emissions dispersion from the two largest mercury emission sources south of the Park. This geographical extent was used to define above-background mercury deposition events as described below.

Dispersion Modeling

Dispersion modeling was done on selected events when mercury was reported in precipitation at Mesa Verde National Park. The results from these selected events were used to describe parameters for determination of background mercury concentrations. Using the Four Corners Power Plant and San Juan Generating stations as starting points for discharge of non-reactive mercury, dispersion was modeled where wet deposition was included; therefore, mercury concentrations theoretically decrease in a down-wind direction due to rain out of atmospheric mercury. The results of the HYSPLIT dispersion modeling show air mercury concentrations (in grams per cubic meter, grams/m^3). The modeling results show that the mercury plumes traveled from the power plant sources to the receptor at Mesa Verde National Park **(Figure 6)**.

Superposition of the azimuth coordinate system over the mercury deposition event of March 13, 2002, the mercury impacting Mesa Verde is sourced from an azimuth between 130 and 220 degrees **(Figure 6A)**. Dispersion modeling of an event on July 4, 2002, indicates the effects of the San Juan River Valley on local trapping of air pollution, which resulted in a mercury concentration of 126.37 ng/L at Mesa Verde **(Figure 6B)**. The simulations of May 15 and July 28, 2003, also show the sources of mercury deposition coming from 130 to 220 degrees azimuth. Three other dispersion simulations were done (July 11, 2002; April 14, 2006; and October 7, 2007), which are not shown, and these simulations confirm that storms do not need to pass directly over the power plants to affect mercury deposition at Mesa Verde National Park.

Background Mercury Concentrations in Precipitation

In order to determine background mercury concentrations at Mesa Verde National Park, single storm events were selected with azimuths ranging from less than 130 and greater than 220 degrees. The data are represented graphically in **Figure 7**. Single storm events sourced from azimuth 130 to 220 degrees have higher mercury concentrations and deposition at Mesa Verde National Park than single storm events coming from other directions. Eight-seven percent of the wet deposition from the modeled events came from within these azimuthal directions. Observations of weather patterns in the western US show frequent storms passing through Mesa Verde National Park consisting of low-pressure systems that have a counter-clockwise rotation **(Figure 8)**. This storm pattern provides a likely mechanism for transporting mercury and other air pollutants from coal-fired power plants in New Mexico to Mesa Verde National Park and other locations in southwestern Colorado. Atmospheric dispersion and pollution trapping in the San Juan River Valley contribute to the dispersion and deposition processes.

Below-background mercury concentrations were ranked and soil background guidelines by the USEPA (2002) were employed to select the background concentration. The 80th percentile concentration of the ranked data was used as a conservative estimate, which yielded a background mercury concentration of 11.73 ng/L for the modeled Mesa Verde data set. Extrapolated to all mercury concentration data during 2002-08 **(Appendix A2)**, 64 percent of the mercury

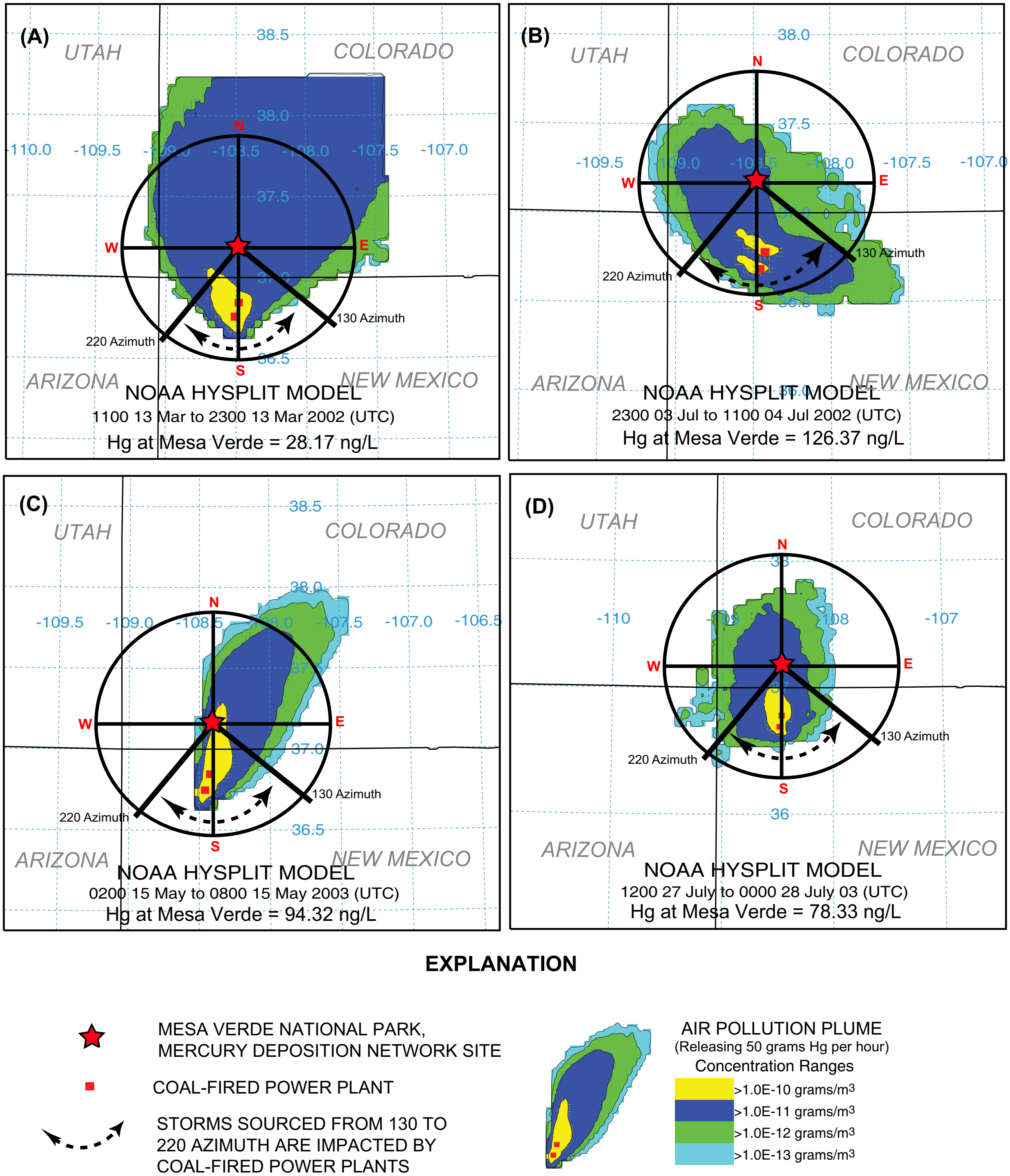
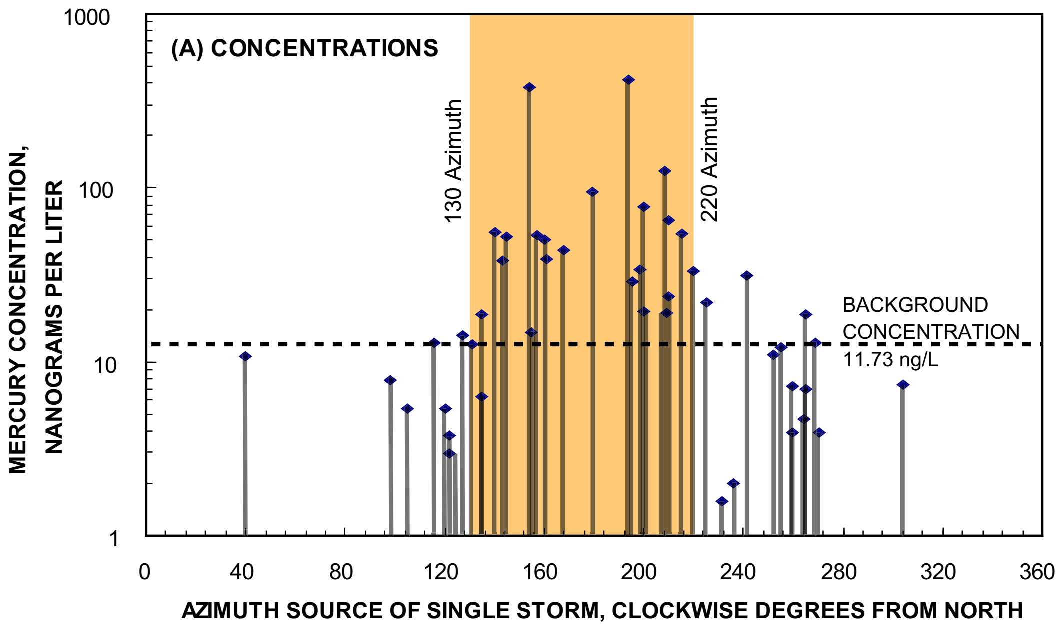


Figure 6. HYSPLIT dispersion modeling results from mercury emissions by coal-fired power plants, azimuth coordinate system, and range of azimuths used to determine above-background concentrations.



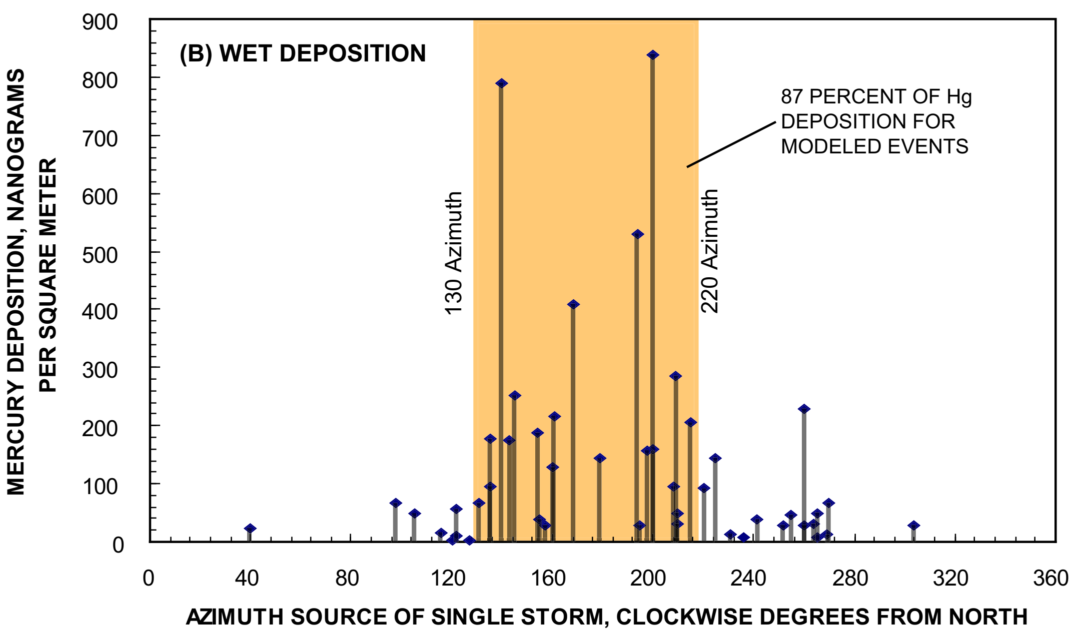


Figure 7. Azimuth of storm source from Mesa Verde National Park and associated mercury concentrations in precipitation (A), and wet deposition (B).

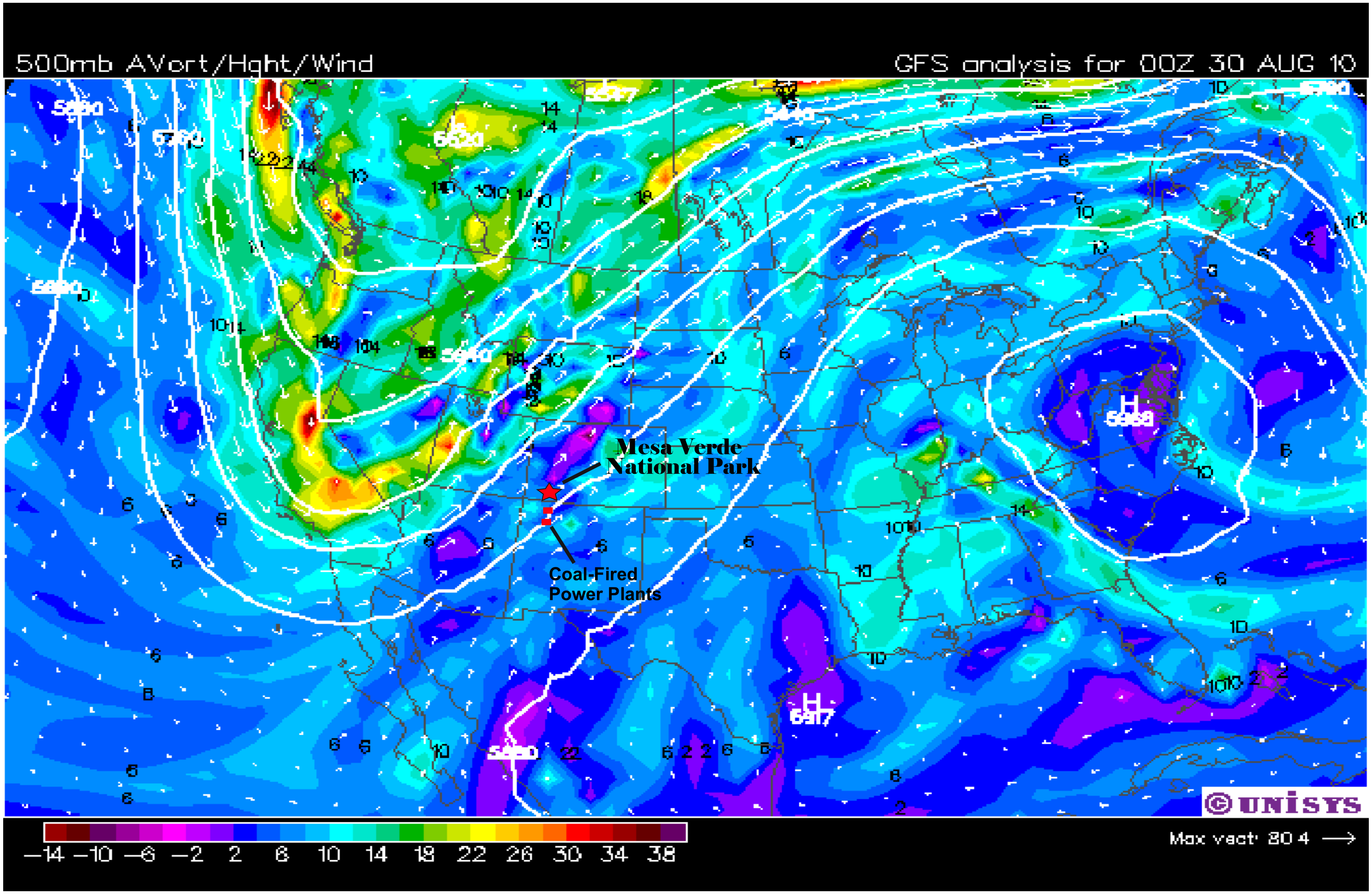


Figure 8. Typical storm track for the western US where mercury concentrations and wet deposition at Mesa Verde National Park are affected by coal-fired power plants (http://weather.unisys.com/).

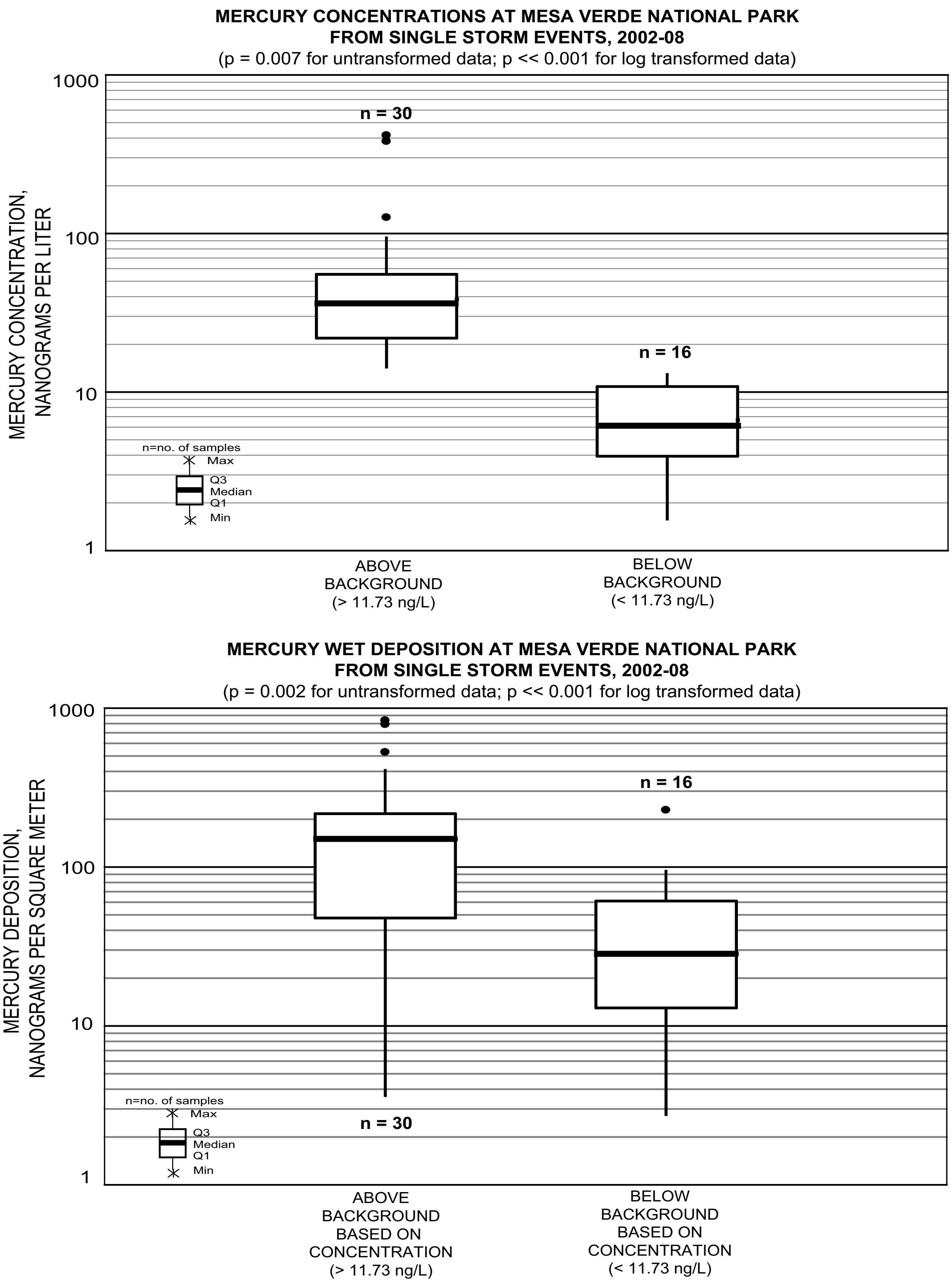


Figure 9. Box plots of mercury concentrations and mercury wet deposition at Mesa Verde National Park for single storm events modeled using HYSPLIT, 2002-08.

detections at Mesa Verde National Park were above the background concentration of 11.73 ng/L.

Comparison of above- and below-background concentrations and wet deposition **(Figure 9)** indicates that the two populations from the modeled data set are significantly different. Analysis of variance (ANOVA) on the concentration data set shows a p-value of 0.007 for untransformed data and a p-value much less than 0.001 for log-transformed data **(Figure 9)** indicating that the above- and below-background data sets are significantly different (Helsel and Hirsh, 1992).

Calculations were done to estimate the percentages of above- and below-background mercury wet deposition from the modeled events. Storm events with mercury concentrations less than or equal to 11.73 ng/L were considered as below-background events. For storm events with mercury concentrations greater than 11.73 ng/L, the background portion of total deposition was subtracted to determine the above-background mercury deposition. For the 2002-08 data, the annual above-background wet deposition ranged from 54 to 84 percent **(Table 1, Figure 10)**. The mercury concentrations from 2004 appear to be anomalously low compared to other years **(Table 1)**. Examination of the data in Appendix A1 shows that many of the mercury concentrations reported during 2004 at Mesa Verde National Park were low, precipitation was high, and wet deposition was high. During a rainy year, concentrations may be lower and deposition may be higher. Conversely, during a dry year, concentrations may be higher and deposition may be lower.

SUMMARY AND CONCLUSIONS

Our investigation provides three lines of evidence that together support the finding that sources of mercury concentrations and wet deposition at Mesa Verde National Park include coal-fired power plants and background mercury concentrations. First, modeling of storm tracks from single precipitation events indicate that the trajectories of storm events do influence the concentration of mercury in precipitation falling at Mesa Verde National Park. Higher mercury concentrations tend to originate from the south (azimuth 130 to 220), which is also the location of mercury emitting coal-fired power plants in the Four Corners region. Dispersion analysis confirmed that emissions originating from these power-plants passed over Mesa Verde National Park during several high concentration mercury precipitation events. Second, principle component analysis demonstrates that mercury in Mesa Verde precipitation is correlated with both nitrate and sulfate but not with terrestrial earth elements like sodium and calcium. Nitrate, sulfate, and mercury in atmospheric deposition individually have several possible sources, but their correlation in Mesa Verde precipitation samples provides strong evidence that their major source is one they share in common, namely coal-fired power plants. Third, trend analyses indicate that sulfate, nitrate, and hydrogen (acid) deposition have decreased over time with the coincident implementation of Clean Air Act control measures in coal-fired power plants. In contrast, mercury control measures (an activated carbon injection system) only just began to be implemented in the San Juan Generating Station in 2008 (PNM, 2009), yet mercury in deposition has not changed significantly over this time. Together, these results suggest that coal-fired power plants to the south of Mesa Verde National Park are a significant source of mercury deposited in precipitation at the Park. These results are correlative, however, and we cannot determine how much mercury originates from a particular power plant. We also cannot rule out the possibility that above-background concentrations of mercury were already entrained in these storm tracks prior to them passing over these nearby coal-fired power plants.

Back trajectory modeling was done for single precipitation events where mercury was reported at Mesa Verde during 2002-08. Azimuth of the storm tracks were determined for 47 of these events. Back trajectories sourced from 130 to 220 degrees azimuth were assigned the category of above background, and the other trajectories were assigned a category of below background. The 80th percentile of the below-background concentration resulted in a background mercury concentration of 11.73 ng/L (nanograms per liter). Calculations show that the annual above-background mercury deposition at Mesa Verde National Park ranges from 54 to 84 percent of the total deposition. More than 60 percent of the mercury concentrations reported during 2002-08 were greater than the background concentration of 11.73 ng/L. Backtrajectory modeling also shows that storm events at Mesa Verde are influenced by weather from the eastern Pacific Ocean, the Pacific Northwest,

Table 1. Below- and above-background mercury deposition by year at Mesa Verde National Park

[ng/m^2, nanograms per square meter]

Year	Total Hg Deposition, ng/m^2	Below Background Hg Deposition, ng/m^2	Above Background Hg Deposition, ng/m^2	Annual Percent Below Background Deposition	Annual Percent Above Background Deposition
2002	3,471	575	2,896	17	83
2003	5,151	1,357	3,794	26	74
2004	3,799	1,734	2,065	46	54
2005	4,561	1,363	3,198	30	70
2006	5,517	882	4,635	16	84
2007	6,708	1,232	5,476	18	82
2008	6,021	1,570	4,451	26	74
				Average	**74**

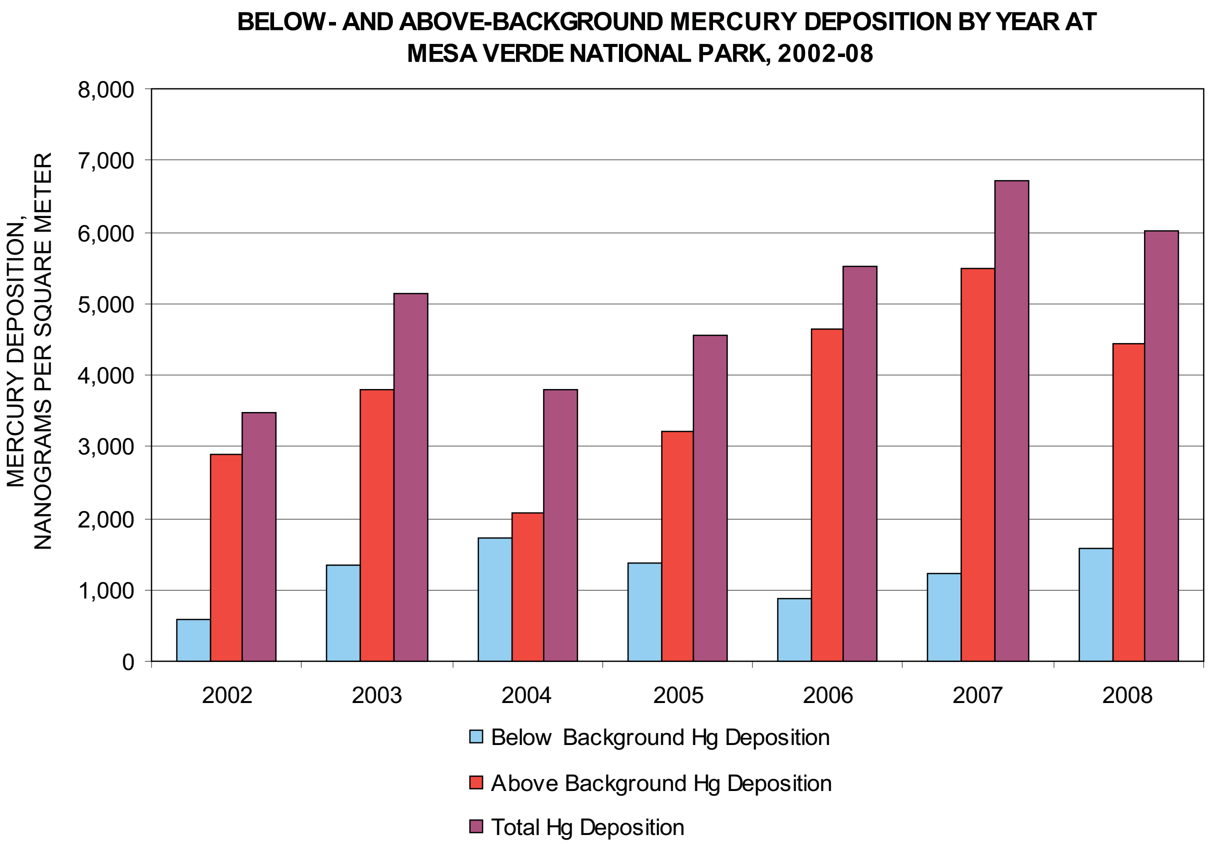


Figure 10. Above- and below-background mercury deposition by year at Mesa Verde National Park, 2002-08.

monsoons from the southwest, and monsoons from the southeast.

Principal components analyses were done which developed correlations between major ions and mercury concentrations in precipitation samples at Mesa Verde. Different groups or patterns were evident in the data, confirming that sulfate, nitrate, and mercury come from the same source (most likely coal-fired power plants). Chloride plots between the terrestrial earth elements (calcium, magnesium, sodium, and potassium) and coal-fired power plant sources. Ammonia samples plot above the coal-fired power plants but away from the terrestrial earth elements, indicating a possible connection to power plants, but ammonia also may come from other sources such as agricultural activities (fertilizers and feed lots).

During 1981-2008, concentrations and deposition of some major ions (such as sulfate and chloride) decreased significantly. Nitrate concentrations were variable; however, nitrate deposition decreased with a marginally significant trend. Acidity also decreased during 1981-2008; mean pH values increased significantly, and wet deposition of hydrogen ions (H^+) decreased significantly. During this time period, air pollution measures were implemented at the two coal-fired power plants in phased approaches. These emission reductions correlate with the decreasing trends of sulfate, nitrate, chloride, and hydrogen in precipitation at Mesa Verde. The relations between decreasing power plant emissions and decreasing major-ion deposition suggests that treatment of power plant emissions can have a beneficial result, and mercury controls at these plants would probably have a similar effect. PNM projects an almost 90% decrease in mercury emissions resulting from mercury controls installed at the San Juan Generating Station by early 2009 (PNM, 2009). Continued monitoring is essential to determine if this power plant upgrade, and any additional changes in emissions, will alter the amount of mercury emitted to the environment in the Four Corners Region.

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Appendix A -- Data Tables for Mercury, Major Ions, and Precipitation

Table A1. Reported mercury concentrations at Mesa Verde National Park, associated precipitation events, precipitation amounts, and mercury deposition

[ng/L, nanograms per liter; mm, millimeters; ng/m2, nanograms per square meter]

(Yellow) Single day precipitation events; (Orange) Multi-day events, possible single storms

Week	Mercury Concentration, ng/L	No. of Precip Days	Precip-itation, mm	Mercury Deposition, ng/m2	Precip reported on Date	Comments
12/26/01-1/1/02	1.42	2	10.92	15.52	12/30, 12/31	
2/12/02-2/19/02	7.42	1	3.81	27.6	2/19/2002	Model run 2/19/02 18:00 back 24 hours
3/5/02-3/12/02	14.99	1	3.51	52.55	3/9/2002	
3/12/02-3/19/02	28.17	1	3.81	107.34	3/14/2002	Model run 3/14/02 18:00 back 12 hours
3/19/02-3/26/02	5.9	2	7.62	44.98	3/25, 3/26	
4/2/02-4/9/02	19.35	1	2.79	54.08	4/8/2002	
4/9/02-4/16/02	54.26	1	3.81	206.74	4/16/2002	Model run 4/16/02 23:00, back 24 hours
4/23/02-4/30/02	27.77	2	3.3	91.71	4/26, 4/28	
7/3/02-7/9/02	126.37	2	0.76	96.29	7/4, 7/7	Model run 7/4/02 23:00, back 24 hours
7/9/02-7/16/02	55.32	1	14.26	789.19	7/11/2002	Model run 7/11/02 18:00, back 24 hours
7/16/02-7/21/02	19.71	2	16.26	320.53	7/20, 7/23	
8/21/02-8/27/02	26.94	1	3.05	82.13	8/21/2002	
8/27/02-9/3/02	41.14	1	6.1	250.83	8/30/2002	
9/3/02-9/10/02	16.09	2	20.57	331.13	9/8, 9/9	
9/11/02-9/17/02	8.58	3	27.94	239.78	9/11, 9/12, 9/14	
9/17/02-9/24/02	10.89	1	2.54	27.67	9/19/2002	Model run 9/19/02 15:00 back 24 hours
9/24/02-10/1/02	42.43	1	3.05	129.33	9/30/2002	Data for 9/30/02 not in met file, model aborted
10/2/02-10/8/02	20.3	2	15.75	319.73	10/3, 10/4	
10/16/02-10/22/02	5.42	1	0.51	2.75	10/18/2002	Model run 10/17/02 18:00, back 24 hours
10/23/02-10/29/02	8.15	4	21.59	176.08	10/23, 24, 25, 26	
11/27/02-12/3/02	2.95	3	6.54	19.31	10/27, 29, 30	
12/11/02-12/17/02	12.65	1	5.33	67.48	12/17/2002	Model run 12/16-17/02
12/18/02-12/24/02	2.85	4	6.35	18.09	12/18-12/22	
1/1/03-1/7/03	9.58	2	2.03	19.48	1/1, 1/7	
1/8/03-1/14/03	5.39	1	8.89	47.94	1/11/2003	Model run 1/10/03 18:00, back 24 hours
2/12/03-2/18/03	7.3	2	20.83	152.04	2/14, 2/18	
2/19/03-2/25/03	11.23	1	8.38	94.15	2/25/2003	
2/26/03-3/4/03	3.32	5	37.34	124.03	2/26-3/2	
3/5/03-3/11/03	4.65	1	6.35	29.58	3/5/2003	Model run 3/5/03 08:00, back 24 hours
3/12/03-3/18/03	10.14	3	33.02	335.05	3/17, 3/18	
3/19/03-3/25/03	6.61	2	3.05	20.15	3/20, 3/21	
4/30/03-5/6/03	28.75	1	3.56	102.25	5/5/2003	
5/14/03-5/20/03	94.32	1	1.52	143.75	5/15/2003	Model run 5/15/03 08:00, back 6 hours
5/21/03-5/27/03	53.34	1	1.78	94.83	5/26/2003	
5/28/03-6/3/03	44.87	1	1.11	49.81	5/28/2003	
6/18/03-6/24/03	71.42	4	3.81	272.13	6/18,19,20,21	
7/16/03-7/22/03	69.03	1	1.27	87.66	7/17/2003	
7/23/03-7/29/03	78.33	1	2.03	159.18	7/28/2003	Model run 7/28/03 00:00, back 12 hours
7/30/03-8/5/03	45.36	2	3.3	149.78	8/3, 8/4	
8/6/03-8/12/03	51.99	1	4.83	250.91	8/12/2003	Model run 8/12/03 23:00, back 24 hours
8/13/03-8/19/03	30.06	3	8.13	244.38	8/13, 15, 17	

Table A1. Reported mercury concentrations at Mesa Verde National Park, associated precipitation events, precipitation amounts, and mercury deposition -- continued

Week	MeVe Hg Concentration, ng/L	No. of Precip Days	Precip, total, mm	Hg Deposition, ng/m2	Precip reported on Date	Comments
8/20/03-8/26/03	25.65	3	23.37	599.41	8/22, 23, 24	
8/27/03-9/2/03	25.09	1	10.67	267.66	8/29/2003	
9/3/03-9/9/03	19.28	2	43.43	837.62	9/5, 8	Model run 9/9/03 18:00, back 24 hours
9/9/03-9/16/03	7.53	2	27.94	210.47	9/10	
10/1/03-10/7/03	23.43	3	15.24	357.18	10/3, 4, 5	
10/29/03-11/4/03	14.29	1	3.56	50.81	11/3/2003	
11/5/03-11/12/03	12.97	1	1.02	13.18	11/11/2003	Model run 11/10/03 18:00, back 24 hours
11/13/03-11/18/03	5.06	2	16	81.09	11/13, 14	
12/3/03-12/9/03	12.16	1	3.81	46.33	12/9/2003	Model run 12/8/03 18:00, back 24 hours
12/17/03-12/23/03	37.4	3	0.25	9.35	12/17, 22, 23	
12/24/03-12/30/03	14.04	2	4.57	64.22	12/28, 29	
12/31/03-1/6/04	8.53	2	27.69	236.16	1/3, 4	
1/14/04-1/20/04	6.71	1	3.81	25.58	1/16/2004	
1/21/04-1/27/04	7.02	1	1.02	7.13	1/25/2004	Model run 1/25/04 07:00, back 24 hours
1/28/04-2/3/04	4.35	1	5.59	24.33	2/1/2004	
2/4/04-2/10/04	1.57	2	8.13	12.76	2/5, 6	Model run 2/5/04 07:00, back 24 hours
2/18/04-2/24/04	4.48	4	22.35	100.2	2/22, 23, 24	
2/25/04-3/2/04	5.4	3	10.92	59.05	2/25/04-3/2/04	
3/3/04-3/9/04	2.99	1	3.3	9.88	3/3/2004	Model run 3/3/04 07:00, back 24 hours
3/31/04-4/6/04	4.33	3	45.47	196.86	4/3, 4, 5	
4/7/04-4/13/04	5.95	4	12.19	72.59	4/8, 9, 11, 12	
4/28/04-5/4/04	16.84	2	5.59	94.14	4/30, 5/1	Could not download data
6/23/04-6/29/04	34.69	2	2.41	83.67	6/23, 25	
7/14/04-7/20/04	18.79	1	2.54	47.72	7/19/2004	Model run 7/19/04 06:00, back 48 hours
8/4/04-8/10/04	21.72	1	5.08	110.33	8/6/2004	
8/11/04-8/17/04	38.36	1	4.57	175.38	8/17/2004	Model run 8/16/04 19:00, back 24 hours
8/18/04-8/24/04	16.64	3	2.29	38.05	8/19, 20, 22	
9/1/04-9/8/04	16.41	2	27.18	446.12	9/5, 6	
9/16/04-9/21/04	12.29	3	25.15	309.19	9/19, 20, 21	
9/29/04-10/5/04	12.44	5	55.88	695.37	9/29, 30, 10/1, 2, 4	
10/13/04-10/19/04	28.88	1	1.02	29.34	10/19/2004	Model run 10/19/04 16:00, back 24 hours
10/27/04-11/2/04	5.84	4	12.45	72.69	10/28, 29, 30, 11/1	
11/3/04-11/9/04	11.31	2	11.95	135.18	11/2, 9	
11/10/04-11/16/04	7.72	2	8.64	66.69	11/10, 14	
11/17/04-11/24/04	3.76	2	14.99	56.46	11/21, 22	Model run 11/22/04 07:00, back 24 hours
11/25/04-11/30/04	13.77	2	1.52	20.99	11/27, 30	
12/1/04-12/7/04	5.34	2	3.56	19.01	12/5, 6	
12/8/04-12/14/04	12.89	2	1.27	16.37	12/8, 9	Model run 12/8/04 10:00, back 24 hours
12/29/04-1/4/05	10.08	3	26.92	271.39	12/29, 30, 1/4	
1/5/05-1/11/05	11.03	6	54.61	602.35	1/5, 6, 8, 9, 10, 11	
1/12/05-1/18/05	8.15	2	8.13	66.22	1/12, 13	
1/26/05-2/1/05	3.29	3	25.97	85.43	1/28, 31, 2/1	
2/2/05-2/8/05	3.93	1	17.02	66.88	2/8/2005	Model run 2/8/05 16:00, back 24 hours
2/9/05-2/15/05	1.2	3	30.99	37.19	2/9, 12, 13	
2/16/05-2/22/05	4.2	4	24.13	101.35	2/17, 19, 20, 21	

Table A1. Reported mercury concentrations at Mesa Verde National Park, associated precipitation events, precipitation amounts, and mercury deposition -- continued

Week	MeVe Hg Concentration, ng/L	No. of Precip Days	Precip, total, mm	Hg Deposition, ng/m2	Precip reported on Date	Comments
2/23/05-3/1/05	6.14	5	8.89	54.58	2/23, 24, 25, 26, 28	
3/16/05-3/22/05	3.85	2	10.92	42.05	3/20, 21	
3/23/05-3/29/05	15.71	2	8.13	127.69	3/26/2005	Model not run, 2 precip events
3/30/05-4/7/05	12.22	2	6.85	83.8	3/31, 4/6	
4/20/05-4/25/05	7.25	1	31.5	228.35	4/24, 25	Model run 4/25/2005 16:00, back 24 hours
4/26/05-5/3/05	7.25	3	29.46	213.61	4/29, 5/2, 3	
5/4/05-5/10/05	20.69	3	6.6	136.64	5/4, 6, 8	
6/1/05-6/7/05	21.87	1	6.6	144.43	6/4/2005	Model run 6/3/05 18:00, back 24 hours
6/8/05-6/14/05	28.3	3	1.27	35.94	6/10, 11, 12	
7/20/05-7/26/05	24	2	17.78	426.72	7/24, 26	
8/3/05-8/9/05	20	2	18.29	365.76	8/5, 7	
8/10/05-8/16/05	22.1	5	24.38	538.89	8/10, 12, 14, 15, 16	
8/23/05-8/30/05	65.6	1	0.76	49.99	8/24/2005	Model run 8/24/05 10:00, back 24 hours
8/31/05-9/6/05	16.8	1	1.78	29.87	9/4/2005	
9/7/05-9/14/05	14.8	3	24.13	357.12	9/8, 9, 10	
9/21/05-9/27/05	25.5	3	6.35	161.92	9/21, 22, 23	
9/28/05-10/4/05	9.14	2	50.25	459.27	9/28, 29	High deposition, low concentration, zig-zag storm pattern
10/5/05-10/12/05	16.25	1	24.1	391.61	10/9/2005	
10/19/05-10/25/05	14.79	2	5.59	82.65	10/19, 20	
10/26/05-11/1/05	20.7	2	3.3	68.35	10/27, 30	
11/8/05-11/15/05	39.54	2	1.22	48.12	11/12, 15	
11/30/05-12/6/05	14.29	2	2.79	39.93	12/3, 4	
12/7/05-12/13/05	14.78	1	2.54	37.54	12/13/2005	Model run 12/13/05 01:00, back 12 hours
12/28/05-1/3/06	25.34	3	6.35	160.96	12/29, 1/1, 2	
1/18/06-1/24/06	12.77	1	3.81	48.67	1/20/2005	
1/25/06-1/31/06	6.41	2	10.92	70.05	1/25, 27	
2/1/06-2/7/06	6.51	2	1.02	6.61	2/1, 2	
3/1/06-3/7/06	24.52	1	3.3	80.96	3/7/06 10:00	NADP raingage no data, Castnet not in agreement
3/8/06-3/14/06	8.44	3	33.53	283.11	3/8, 9, 10	
3/22/06-3/28/06	20.97	2	2.54	53.27	3/22, 28	
3/29/06-4/4/06	32.49	3	24.13	784.2	3/29, 30, 4/2	
4/5/06-4/11/06	21.66	2	4.32	93.54	4/6, 7	
4/12/06-4/18/06	416.08	1	0.78	528.43	4/16	Model run 4/15/06 03:00, back 24 hours
5/10/06-5/16/06	28.39	1	4.57	129.82	5/16/2006	
6/7/06-6/13/06	13.6	1	19.05	259.23	6/9/2006	
6/28/06-7/5/06	53.54	1	0.51	27.2	7/5/2006	Model run 7/4/06 13:00, back 6 hours
7/6/06-7/11/06	10.76	2	27.94	300.63	7/9, 11	
7/19/06-7/25/06	28	1	7.62	213.36	7/23/2006	
7/26/06-8/1/06	50.36	1	5.93	127.91	8/1/2006	Model run 7/30/06 21:00, back 24 hours
8/2/06-8/8/06	28.03	4	1.52	42.72	8/2, 4, 5, 7	
8/9/06-8/15/06	19.71	2	12.7	250.32	8/9, 15	
8/16/06-8/22/06	32.53	2	10.49	264.4	8/16, 21	
8/30/06-9/5/06	28.81	3	11.68	336.62	9/2, 3, 5	
9/14/06-9/19/06	14.31	2	12.7	181.74	9/15, 16	
9/20/06-9/26/06	20.35	2	11.43	232.6	9/21, 22	

Table A1. Reported mercury concentrations at Mesa Verde National Park, associated precipitation events, precipitation amounts, and mercury deposition -- continued

Week	MeVe Hg Concentration, ng/L	No. of Precip Days	Precip, total, mm	Hg Deposition, ng/m2	Precip reported on Date	Comments
10/4/06-10/10/06	13.38	5	40.13	536.97	10/6, 7, 8, 9, 10	
10/11/06-10/17/06	19.03	1	14.99	285.18	10/17/2006	Model run 10/17/06 14:00, back 24 hours, fast storm
10/18/06-10/24/06	6.7	1	11.18	74.88	10/18/2006	
11/8/06-11/13/06	8.56	1	3.56	30.44	11/13/2006	
11/22/06-11/28/06	33.3	1	2.79	93.04	11/28/2006	Model run 11/28/06 13:00, back 24 hours
11/29/06-12/5/06	22.71	1	3.05	69.22	11/29/2006	
12/6/06-12/12/06	9.19	2	4.32	39.68	12/11, 12	
12/13/06-12/19/06	3.95	1	7.37	29.1	12/18	Model run 12/19/06 21:00, back 24 hours
12/20/06-12/26/06	8.28	1	1.52	12.62	12/20/2006	
12/27/06-1/2/07	2.57	2	11.94	30.68	12/29, 30	
1/10/07-1/16/07	9.26	2	6.86	63.51	1/12, 14	
1/17/07-1/23/07	1.99	1	4.06	8.08	1/21/2007	Model run 1/21/07 07:00, back 24 hours
1/13/07-2/6/07	3.49	1	6.35	22.17	2/2/2007	
2/7/07-2/13/07	9.46	2	13.97	132.25	2/12, 13	
2/14/07-2/20/07	5.93	1	0.76	4.52	2/20/2007	
2/28/07-3/6/07	11.64	1	2.54	29.57	3/1/2007	
3/7/07-3/13/07	38.75	1	5.59	216.56	3/9/2007	Model run 3/6/07 10:00, back 24 hours
3/21/07-3/27/07	19.47	3	9.4	183.01	3/22, 24, 25	
3/28/07-4/3/07	6.02	1	3.3	19.88	4/1/2007	
4/4/07-4/10/07	14.54	1	5.33	77.59	4/10/2007	
4/11/07-4/17/07	18.74	1	9.4	176.17	4/13/2007	Model run 4/12/07 12:00, back 15 hours, 500 m height
5/2/07-5/8/07	5.74	3	23.88	137.07	5/2, 3, 6	
5/9/07-5/15/07	81.5	1	0.51	41.4	5/14/2007	
5/16/07-5/22/07	22.55	5	12.19	274.96	5/16, 17, 18, 20, 21	
5/23/07-5/29/07	5.59	2	17.78	99.4	5/23, 24	
6/13/07-6/19/07	16.96	1	3.3	56.01	6/13/2007	
7/4/07-7/10/07	70.82	1	5.63	399.04	7/10/07 9:00	Raingage data disagree
7/11/07-7/17/07	43.83	1	9.3	407.61	7/17/2007	Model run 7/4/07 09:00, back 24 hours
7/18/07-7/24/07	20.61	3	27.94	576.09	7/19, 20, 21	
7/25/07-7/31/07	42.12	2	11.43	481.52	7/30, 31	
8/1/07-8/7/07	22.31	6	26.92	600.86	8/1, 2, 3, 4, 5, 6	
8/8/07-8/14/07	39.37	1	26.67	1049.99	8/14/2007	
8/15/07-8/21/07	52.36	2	3.3	172.91	8/16, 17	
8/22/07-8/28/07	7.83	1	8.38	65.69	8/27/2007	Model run 8/27/07 15:00, back 24 hours
8/29/07-9/4/07	33.96	2	7.11	241.55	9/2, 4	
9/5/07-9/11/07	27.04	1	1.78	48.08	9/6/2007	
9/12/07-9/18/07	47.27	2	4.06	192.12	9/17, 18	
9/19/07-9/25/07	11.25	2	27.18	305.97	9/24, 25	
9/26/07-10/2/07	23.64	1	1.27	30.02	10/2/2007	Model run 10/2/07 03:00, back 24 hours
10/3/07-10/9/07	15.9	2	16	254.44	10/5, 6	
11/28/07-12/4/07	3.15	3	44.96	141.84	12/2, 3, 4	
12/5/07-12/11/07	5.89	5	33.02	194.71	12/7, 8, 9, 10, 11	
12/19/07-12/25/07	14.26	1	0.25	3.62	12/18, 25	Model run 12/21/07 10:00, back 24 hours
1/1/08-1/8/08	3.2	3	47.74	152.75	1/5,6,7	
1/22/08-1/29/08	2.74	3	17.15	46.99	1/24,25,28	

Table A1. Reported mercury concentrations at Mesa Verde National Park, associated precipitation events, precipitation amounts, and mercury deposition -- continued

Week	MeVe Hg Concentration, ng/L	No. of Precip Days	Precip, total, mm	Hg Deposition, ng/m2	Precip reported on Date	Comments
1/29/08-2/6/08	5.25	6	11.26	59.13	1/29,30,31,2/2,3,4	
2/12/08-2/19/08	14.73	1	3.65	53.72	2/19	Raingage data disagree, cold weather
2/19/08-2/26/08	9.8	4	17.5	171.53	19,21,22,23,25	
3/11/08-3/18/08	10.74	1	2.17	23.31	3/11	Model run 3/11/08 10:00, back 24 hours
4/8/08-4/15/08	10.73	2	8.63	92.61	4/9,10	
5/6/08-5/13/08	59.11	3	1.6	94.76	7,9,10	
5/20/08-5/27/08	12.26	3	14.73	180.7	23,24,25	
6/3/08-6/10/08	10.15	1	6.1	61.91	6/6	
7/1/08-7/8/08	381.43	1	0.49	187.66	7/3	Model run 6/30/08, back 24 hours
7/8/08-7/15/08	34.02	1	4.58	155.88	7/14	Model run 7/14/08 16:00, back 24 hours
7/15/08-7/22/08	52.33	4	7.58	396.6	15,16,20,21	
7/22/08-7/29/08	36.91	4	40.47	1494.18	23,25,26,27	
7/29/08-8/5/08	70.49	3	2.9	204.15	8/4-5	
8/5/08-8/12/08	18.79	4	7.93	149.03	5,6,7,8	
8/19/08-8/25/08	42.46	2	16.18	686.93	19,25	
8/25/08-9/2/08	10.35	6	26.92	278.82	all week	
9/9/08-9/16/08	39.53	3	4.32	170.71	10,11,12	
9/23/08-9/30/08	47.82	3	1.78	85.02	26,27,28	
9/30/08-10/7/08	12.1	4	17.27	209.02	1,5,6	
10/28/08-11/4/08	31.09	1	1.27	39.48	11/5	Model run 11/2/08 19:00, back 24 hours
11/4/08-11/12/08	9.01	1	17.02	153.34	5	Model run 11/5/08 10:00, back 24 hours
11/25/08-12/2/08	3.48	3	24.64	85.83	27,**28**,29	
12/2/08-12/9/08	32.69	2	10.67	348.74	3,8	
12/9/08-12/17/08	2.19	3	35.81	78.71	9,15,16	
12/17/08-12/22/08	6.31	2	14.99	94.62	18,19	Model run 12/18/08 15:00, back 24 hours
12/22/08-12/31/08	6.82	6	38.86	265.03	23,24,25,26,27,28	

Table A2. Major-ion concentrations, mercury concentrations and deposition, and water properties for precipitation samples at Mesa Verde National Park, 2001-08

[mg/L, milligrams per liter; ng/L, nanograms per liter; ng/m2, nanograms per square meter; S.U., standard units; us/cm, microsiemens per centimeter; mL, milliliters; mm, millimeters]

Sources: National Atmospheric Deposition Program (NADP)
National Trends Network (NTN), http://nadp.sws.uiuc.edu/data/ntndata.aspx
Mercury Deposition Network (MDN), http://nadp.sws.uiuc.edu/data/mdndata.aspx
[Non-precipitation weeks and censored data are not shown]
Site ID: CO99 Date Range: 1/1/2001 to 12/30/08

SiteID	Date On	Date Off	Ca, mg/L	Mg, mg/L	K, mg/L	Na, mg/L	NH4, mg/L	NO3, mg/L	Cl, mg/L	SO4, mg/L	Hg conc, ng/L	Hg Dep, ng/m2	pH Lab, S.U.	Lab Cond, us/cm	Sample vol, mL	Precip, mm
CO99	12/26/2001	1/1/2002	0.01	0.003	0.003	0.003	0.02	0.57	0.01	0.08	1.42	15.52	5.04	5.3	664.2	10.92
CO99	2/12/2002	2/19/2002	0.33	0.022	0.014	0.083	0.17	0.75	0.05	0.28	7.42	27.6	6.04	5.3	263.9	3.81
CO99	3/5/2002	3/12/2002	2.95	0.163	0.115	0.046	0.21	0.84	0.09	0.58	14.99	52.55	7.26	20.4	192.4	3.56
CO99	3/12/2002	3/19/2002	2.56	0.144	0.094	0.321	0.33	3.31	0.44	0.89	28.17	107.34	6.81	20.3	124.8	3.81
CO99	3/19/2002	3/26/2002	0.22	0.017	0.004	0.015	0.12	0.42	0.02	0.2	5.9	44.98	6	3.9	522.7	7.62
CO99	4/2/2002	4/9/2002	1.17	0.101	0.105	0.117	0.49	2.84	0.16	2	19.35	54.08	6.02	15.1	206.7	2.79
CO99	7/1/2002	7/8/2002	5.78	0.45	0.516	0.355	2.61	10.59	0.84	6.28	126.37	96.29	6.78	68.9	27.7	0.76
CO99	7/16/2002	7/23/2002	0.39	0.033	0.056	0.048	0.32	1.38	0.04	1	19.71	320.53	5.28	9.2	1133.2	16.26
CO99	8/20/2002	8/27/2002	1.65	0.063	0.053	0.082	0.81	1.6	0.16	0.74	26.94	82.13	7.04	16.8	210.1	3.05
CO99	9/3/2002	9/10/2002	0.3	0.022	0.031	0.016	0.5	1.07	0.04	1.01	16.09	331.13	5.92	8.5	1208.8	20.57
CO99	9/10/2002	9/17/2002	0.03	0.005	0.008	0.003	0.17	0.44	0.02	0.39	8.58	239.78	5.39	4.1	1753.4	27.94
CO99	10/1/2002	10/8/2002	1	0.068	0.045	0.246	0.42	1.17	0.34	1.37	20.3	319.73	6.49	13.5	1055.9	15.75
CO99	10/21/2002	10/29/2002	0.21	0.019	0.017	0.056	0.43	1.41	0.08	1.3	8.15	176.08	4.95	13.3	1471.3	21.59
CO99	11/26/2002	12/3/2002	0.09	0.005	0.012	0.006	0.07	0.88	0.03	0.5	2.95	19.31	4.88	8.3	540.4	6.54
CO99	12/10/2002	12/17/2002	0.18	0.015	0.019	0.052	0.06	0.56	0.08	0.26	12.65	67.48	5.67	3.5	422.1	5.33
CO99	12/17/2002	12/24/2002	0.46	0.03	0.049	0.047	0.13	1.15	0.12	0.26	2.85	18.09	5.93	5.4	410.4	6.35
CO99	12/31/2002	1/7/2003	0.58	0.029	0.019	0.02	0.1	2.17	0.07	0.27	9.58	19.48	5.42	7.8	134	2.03
CO99	1/7/2003	1/14/2003	0.03	0.003	0.003	0.005	0.07	0.54	0.01	0.4	5.39	47.94	4.94	6.7	557.4	8.89
CO99	2/11/2003	2/18/2003	0.25	0.013	0.013	0.003	0.16	0.5	0.02	0.32	7.3	152.04	5.89	3.8	1343.3	20.83
CO99	2/18/2003	2/25/2003	4.13	0.204	0.33	0.117	0.08	1.42	0.17	1.31	11.23	94.15	7.46	26.8	540.2	8.38
CO99	2/25/2003	3/3/2003	0.12	0.01	0.013	0.035	0.06	0.7	0.06	0.52	3.32	124.03	4.84	7.9	1347.4	37.34
CO99	3/3/2003	3/11/2003	0.31	0.026	0.114	0.015	0.06	1.15	0.15	0.13	4.65	29.58	5.55	8	285.3	6.35
CO99	3/11/2003	3/18/2003	0.09	0.011	0.004	0.013	0.16	0.44	0.02	0.56	10.14	335.05	5.13	5.3	2159.4	33.02
CO99	3/18/2003	3/25/2003	0.04	0.007	0.003	0.003	0.18	0.52	0.01	0.36	6.61	20.15	4.61	12.2	185.2	3.05
CO99	4/29/2003	5/6/2003	3.33	0.168	0.124	0.082	0.08	0.53	0.12	0.4	28.75	102.25	7.39	20.2	248.4	3.56
CO99	5/27/2003	6/2/2003	2.82	0.137	0.083	0.118	0.05	2.52	0.17	1.74	44.87	49.81	6.8	19.5	14.0	1.78
CO99	8/19/2003	8/26/2003	1.54	0.09	0.066	0.021	0.21	1.76	0.06	1.11	25.65	599.41	6.74	12.8	1603.5	23.37
CO99	8/26/2003	9/2/2003	0.36	0.031	0.011	0.013	0.64	2.23	0.07	0.76	25.09	267.66	5.51	10	687.7	10.67
CO99	9/2/2003	9/9/2003	0.15	0.019	0.012	0.055	0.18	0.67	0.09	0.55	19.28	837.62	5.25	6	3141.4	45.97
CO99	9/9/2003	9/15/2003	0.08	0.014	0.008	0.017	0.1	0.26	0.03	0.25	7.53	210.47	5.61	2.6	1892	27.94
CO99	9/30/2003	10/7/2003	0.22	0.019	0.018	0.018	0.45	1.58	0.06	1.02	23.43	357.18	4.9	11.5	1022.4	15.24
CO99	10/28/2003	11/4/2003	1.12	0.091	0.127	0.101	0.67	2.56	0.2	1.35	14.29	50.81	6.87	13.6	234.3	3.56
CO99	11/4/2003	11/12/2003	0.18	0.012	0.017	0.018	0.19	1.18	0.08	0.14	12.97	13.18	5.5	5.2	63.1	1.02
CO99	11/12/2003	11/18/2003	0.06	0.005	0.012	0.004	0.1	0.31	0.02	0.2	5.06	81.09	5.47	3.2	1088.6	16
CO99	12/2/2003	12/9/2003	0.43	0.027	0.036	0.027	0.22	0.94	0.04	0.92	12.16	46.33	5.83	6.6	196.7	3.81
CO99	12/23/2003	12/30/2003	0.1	0.007	0.013	0.008	0.07	0.28	0.02	0.31	14.04	64.22	5.85	3.1	120.4	4.57
CO99	12/30/2003	1/6/2004	0.18	0.01	0.007	0.014	0.1	0.52	0.029	0.32	8.53	236.16	5.65	3.7	1469	27.69
CO99	1/13/2004	1/20/2004	0.12	0.007	0.037	0.01	0.11	1.52	0.06	0.12	6.71	25.58	4.95	8.5	120	3.81
CO99	1/27/2004	2/3/2004	0.1	0.007	0.005	0.013	0.23	2.24	0.04	0.32	4.35	24.33	4.64	14.3	380.3	5.59
CO99	2/3/2004	2/10/2004	0.03	0.003	0.003	0.003	0.02	0.51	0.02	0.24	1.57	12.76	4.98	5.4	425	8.13

Table A2. Major-ion concentrations, mercury concentrations and deposition, and water properties for precipitation samples at Mesa Verde National Park, 2001-08 -- continued

SiteID	Date On	Date Off	Ca, mg/L	Mg, mg/L	K, mg/L	Na, mg/L	NH4, mg/L	NO3, mg/L	Cl, mg/L	SO4, mg/L	Hg conc, ng/L	Hg Dep, ng/m2	pH Lab, S.U.	Lab Cond, us/cm	Sample vol, mL	Precip, mm
CO99	2/17/2004	2/24/2004	0.09	0.008	0.007	0.033	0.08	0.74	0.06	0.37	4.48	100.2	4.96	6.6	1546	22.35
CO99	2/24/2004	3/2/2004	0.18	0.019	0.05	0.07	0.17	0.5	0.13	0.95	5.4	59.05	5.09	7.6	603.3	10.92
CO99	3/29/2004	4/6/2004	0.11	0.008	0.01	0.012	0.07	0.28	0.01	0.16	4.33	196.86	5.78	2.6	3154.3	45.47
CO99	4/6/2004	4/13/2004	0.1	0.01	0.006	0.013	0.24	1.12	0.02	0.66	5.95	72.59	4.94	9.3	822.4	12.19
CO99	4/27/2004	5/4/2004	2.45	0.134	0.085	0.2	0.27	1.31	0.2	1.02	16.84	94.14	7.11	18.5	352	5.59
CO99	7/12/2004	7/20/2004	1.23	0.122	0.09	0.12	0.95	4.96	0.24	1.98	18.79	47.72	5.86	19.3	77.6	2.54
CO99	8/3/2004	8/10/2004	0.54	0.052	0.232	0.069	0.32	2.25	0.304	0.81	21.72	110.33	5.08	12.1	333.4	5.08
CO99	8/10/2004	8/17/2004	0.48	0.046	0.045	0.024	0.29	3.02	0.071	2.12	38.36	175.38	4.27	27.4	286.3	4.57
CO99	8/17/2004	8/24/2004	0.39	0.032	0.027	0.031	0.4	1.32	0.076	0.51	16.64	38.05	5.91	7	140.4	2.29
CO99	8/31/2004	9/8/2004	1.5	0.098	0.046	0.093	0.27	0.94	0.129	0.93	16.41	446.12	7.11	13	1762.2	27.18
CO99	9/15/2004	9/21/2004	0.21	0.019	0.013	0.052	0.2	0.83	0.068	1.02	12.29	309.19	4.9	9.7	1679.8	25.15
CO99	9/28/2004	10/5/2004	0.11	0.011	0.008	0.038	0.16	0.89	0.052	0.61	12.44	695.37	4.87	9	3668.3	55.88
CO99	10/12/2004	10/19/2004	1.51	0.106	0.081	0.408	0.53	2.28	0.478	1.96	28.88	29.34	7.24	17.5	88.1	1.02
CO99	10/26/2004	11/2/2004	0.09	0.006	0.009	0.021	0.1	0.36	0.056	0.31	5.84	72.69	5.46	3.7	760.3	12.45
CO99	11/2/2004	11/9/2004	0.13	0.007	0.009	0.01	0.21	0.52	0.029	0.65	11.31	135.18	5.4	5.5	769.8	11.95
CO99	11/9/2004	11/16/2004	0.05	0.006	0.091	0.032	0.22	1.06	0.122	0.65	7.72	66.69	4.8	10.3	445.8	8.64
CO99	11/16/2004	11/24/2004	0.1	0.008	0.023	0.02	0.17	1.59	0.053	0.73	3.76	56.46	4.61	14.2	871.1	14.99
CO99	11/24/2004	11/30/2004	0.36	0.03	0.024	0.023	0.07	1.95	0.064	0.46	13.77	20.99	4.97	9.2	68.7	1.52
CO99	11/30/2004	12/7/2004	0.08	0.007	0.034	0.011	0.06	2.28	0.061	0.47	5.34	19.01	4.5	18.6	151.7	3.56
CO99	12/28/2004	1/4/2005	0.162	0.031	0.014	0.024	0.11	0.44	0.035	0.452	10.08	271.39	5.61	3.9	1610.7	26.92
CO99	1/4/2005	1/11/2005	0.035	0.003	0.007	0.008	0.04	0.644	0.041	0.359	11.03	602.35	4.82	7.1	3011.8	54.61
CO99	1/11/2005	1/18/2005	0.83	0.05	0.067	0.022	0.046	0.537	0.086	0.467	8.15	66.22	6.72	6.2	573.4	8.13
CO99	1/25/2005	2/1/2005	0.022	0.001	0.002	0.003	0.125	1.025	0.008	0.484	3.29	85.43	4.71	10.1	1796	25.97
CO99	2/1/2005	2/8/2005	0.037	0.004	0.003	0.02	0.12	0.936	0.037	0.487	3.93	66.88	4.78	8.9	820	17.02
CO99	2/8/2005	2/15/2005	0.008	0.001	0.002	0.004	0.007	0.192	0.008	0.083	1.2	37.19	5.29	2.6	1566	30.99
CO99	2/15/2005	2/22/2005	0.02	0.002	0.001	0.004	0.06	0.744	0.008	0.387	4.2	101.35	4.77	8.1	1526	24.13
CO99	2/22/2005	3/1/2005	0.073	0.006	0.038	0.013	0.165	1.523	0.06	0.807	6.14	54.58	4.57	14.9	508	8.89
CO99	3/15/2005	3/22/2005	0.093	0.008	0.004	0.013	0.157	0.693	0.025	0.747	3.85	42.05	4.91	8.4	745.5	10.92
CO99	3/22/2005	3/29/2005	0.319	0.032	0.006	0.083	0.211	1.789	0.115	1.455	15.71	127.69	4.57	17.4	350.3	8.13
CO99	3/29/2005	4/6/2005	3.665	0.158	0.13	0.183	0.005	1.25	0.131	0.954	12.22	83.8	7.1	22	41	6.8
CO99	4/19/2005	4/25/2005	0.147	0.01	0.004	0.01	0.071	0.321	0.016	0.391	7.25	228.35	5.45	3.8	2137.3	31.5
CO99	4/25/2005	5/3/2005	0.209	0.017	0.009	0.026	0.168	0.61	0.039	0.48	7.25	213.61	5.65	5	2079.4	29.46
CO99	5/3/2005	5/10/2005	0.423	0.038	0.041	0.059	0.415	1.811	0.102	1.456	20.69	136.64	4.91	12.5	450.9	6.6
CO99	5/31/2005	6/7/2005	1.194	0.109	0.082	0.341	0.485	1.446	0.518	1.434	21.87	144.43	6.47	14.8	485.9	6.6
CO99	6/7/2005	6/14/2005	1.113	0.108	0.104	0.129	0.433	2.913	0.244	2.436	28.3	35.94	5.07	18.3	181.8	1.27
CO99	7/19/2005	7/26/2005	0.218	0.018	0.087	0.025	0.233	1.47	0.109	0.549	24	426.72	4.88	11	1252.6	17.78
CO99	8/2/2005	8/9/2005	0.2	0.016	0.021	0.014	0.292	1.238	0.051	0.734	20	365.76	4.95	9.3	1147.4	18.29
CO99	8/9/2005	8/16/2005	0.174	0.019	0.008	0.009	0.245	1.79	0.051	1.026	22.1	538.89	4.58	17	1443.3	24.38
CO99	9/6/2005	9/14/2005	0.11	0.009	0.008	0.014	0.264	1.186	0.045	0.975	14.8	357.12	4.7	12.9	1606	24.13
CO99	9/20/2005	9/27/2005	0.612	0.06	0.026	0.092	0.603	2.6	0.146	2.293	25.5	161.92	4.68	19.8	286.9	6.35
CO99	9/27/2005	10/4/2005	0.183	0.014	0.012	0.036	0.261	0.821	0.064	1.004	9.14	459.27	5.01	8.7	3723.2	50.25
CO99	10/4/2005	10/12/2005	0.384	0.035	0.017	0.026	0.141	0.53	0.041	0.67	16.25	391.61	6.17	4.8	1442.4	24.1
CO99	10/18/2005	10/25/2005	0.094	0.009	0.012	0.03	0.212	0.786	0.068	0.652	14.79	82.65	5.02	8.6	351.2	5.59
CO99	10/25/2005	11/1/2005	0.532	0.039	0.021	0.084	0.412	3.205	0.116	2.329	20.7	68.35	4.34	28.4	230.3	3.3
CO99	11/29/2005	12/6/2005	1.38	0.08	0.128	0.115	0.11	1.482	0.149	0.728	14.29	39.93	6.81	12.9	99.1	2.79
CO99	12/6/2005	12/13/2005	0.175	0.018	0.023	0.019	0.078	1.832	0.063	0.542	14.78	37.54	4.63	13.9	97	2.54
CO99	12/27/2005	1/3/2006	2.724	0.112	0.084	0.102	0.308	2.992	0.09	0.826	25.34	160.96	7.12	20.4	236	6.35

Table A2. Major-ion concentrations, mercury concentrations and deposition, and water properties for precipitation samples at Mesa Verde National Park, 2001-08 -- continued

SiteID	Date On	Date Off	Ca, mg/L	Mg, mg/L	K, mg/L	Na, mg/L	NH4, mg/L	NO3, mg/L	Cl, mg/L	SO4, mg/L	Hg conc, ng/L	Hg Dep, ng/m2	pH Lab, S.U.	Lab Cond, us/cm	Sample vol, mL	Precip, mm
CO99	1/17/2006	1/24/2006	0.436	0.028	0.015	0.074	0.071	3.187	0.091	0.262	12.77	48.67	4.58	18.4	45.3	3.81
CO99	1/24/2006	1/31/2006	0.127	0.01	0.016	0.024	0.228	0.661	0.036	0.753	6.41	70.05	5.09	7.2	380.5	10.92
CO99	1/31/2006	2/7/2006	0.491	0.051	0.02	0.14	0.13	1.258	0.135	0.598	6.51	6.61	5.66	6.9	34.9	1.02
CO99	3/7/2006	3/14/2006	0.28	0.021	0.012	0.031	0.106	0.733	0.051	0.301	8.44	283.11	5.79	4	1084	33.53
CO99	3/21/2006	3/28/2006	1.482	0.21	0.063	0.504	0.383	5.301	0.727	2.646	20.97	53.27	4.61	29.8	80.1	2.54
CO99	3/28/2006	4/4/2006	0.198	0.02	0.018	0.034	0.113	0.702	0.057	0.562	32.49	784.2	5.2	6.2	1447.8	23.37
CO99	5/9/2006	5/16/2006	0.681	0.062	0.048	0.047	0.511	2.401	0.119	1.051	28.39	129.82	5.66	11.9	248.4	4.57
CO99	6/6/2006	6/13/2006	0.475	0.047	0.028	0.028	0.351	1.007	0.045	0.628	13.6	259.23	6.1	6.8	1303.2	19.05
CO99	6/27/2006	7/5/2006	1.938	0.213	0.18	0.114	1.174	6.08	0.278	2.936	53.54	27.2	5.46	30.1	21	0.51
CO99	7/5/2006	7/11/2006	0.08	0.008	0.006	0.007	0.177	0.824	0.029	0.298	10.76	300.63	5.09	5.8	1955.5	27.94
CO99	7/18/2006	7/25/2006	0.473	0.038	0.027	0.028	0.294	1.691	0.058	0.812	28	213.36	5.14	9.6	875.9	7.62
CO99	7/25/2006	8/1/2006	0.469	0.048	0.044	0.036	0.635	3.078	0.102	1.074	50.36	127.91	4.91	16	300.8	2.54
CO99	8/1/2006	8/8/2006	0.676	0.098	0.02	0.1	0.183	4.158	0.211	1.697	28.03	42.72	4.36	28.8	118.7	1.52
CO99	8/8/2006	8/15/2006	0.17	0.022	0.009	0.024	0.142	1.184	0.056	0.352	19.71	250.32	5.27	6.9	894.3	12.7
CO99	8/15/2006	8/22/2006	0.377	0.04	0.024	0.05	0.136	2.308	0.097	0.865	32.53	264.4	4.67	15.7	614.7	8.13
CO99	8/29/2006	9/5/2006	0.504	0.058	0.024	0.06	0.314	3.938	0.122	1.743	28.81	336.62	4.3	29.5	735.3	11.68
CO99	9/12/2006	9/19/2006	0.62	0.076	0.036	0.06	0.457	1.706	0.102	0.992	14.31	181.74	6.14	9.1	860	12.7
CO99	9/19/2006	9/26/2006	1.863	0.185	0.058	0.188	0.289	1.26	0.154	0.873	20.35	232.6	7	15.4	680.3	11.43
CO99	10/3/2006	10/10/2006	0.148	0.011	0.012	0.027	0.254	0.824	0.045	0.698	13.38	536.97	5.11	7	2722.1	40.13
CO99	10/10/2006	10/17/2006	0.055	0.005	0.004	0.013	0.125	0.576	0.028	0.451	19.03	285.18	4.98	6.2	1072.3	14.99
CO99	10/17/2006	10/24/2006	0.945	0.143	0.015	0.098	0.226	0.663	0.12	0.726	6.7	74.88	6.58	9.3	750.1	11.18
CO99	11/7/2006	11/13/2006	0.1	0.009	0.01	0.033	0.127	1.237	0.052	0.761	8.56	30.44	4.75	11	194.1	3.56
CO99	11/21/2006	11/28/2006	0.606	0.056	0.066	0.093	0.104	1.814	0.159	0.585	33.3	93.04	5.57	7.7	107.5	2.79
CO99	11/28/2006	12/5/2006	1.018	0.058	0.041	0.087	0.027	0.658	0.107	0.255	22.71	69.22	6.58	7.6	29.8	3.05
CO99	12/5/2006	12/12/2006	0.468	0.03	0.024	0.056	0.126	0.76	0.094	0.577	9.19	39.68	5.86	5.6	39.4	4.32
CO99	12/12/2006	12/19/2006	0.027	0.003	0.004	0.012	0.067	0.215	0.02	0.31	3.95	29.1	5.2	3.8	558.2	7.37
CO99	12/19/2006	12/26/2006	0.671	0.047	0.068	0.057	0.101	1.578	0.143	0.941	8.28	12.62	5.22	11.4	30.9	1.52
CO99	12/26/2006	1/2/2007	0.041	0.004	0.005	0.009	0.05	0.401	0.023	0.222	2.57	30.68	5.13	4.1	783.2	11.94
CO99	1/16/2007	1/23/2007	0.042	0.002	0.003	0.006	0.009	0.272	0.011	0.025	1.99	8.08	5.44	2.6	180.2	4.06
CO99	1/29/2007	2/6/2007	0.04	0.002	0.002	0.005	0.04	0.692	0.02	0.132	3.49	22.17	5.06	5.1	249.5	6.35
CO99	2/6/2007	2/13/2007	0.034	0.004	0.004	0.011	0.132	0.895	0.038	0.46	9.46	132.25	4.82	8.4	922.1	13.97
CO99	2/13/2007	2/20/2007	0.372	0.033	0.017	0.054	0.259	1.897	0.073	0.91	5.93	4.52	4.87	11.7	108.6	0.76
CO99	2/27/2007	3/6/2007	2.332	0.139	0.041	0.262	0.004	1.765	0.371	0.744	11.64	29.57	6.84	15.8	38.7	2.54
CO99	3/6/2007	3/13/2007	0.059	0.005	0.001	0.006	0.045	1.188	0.026	0.577	38.75	216.56	4.6	12	383	5.59
CO99	3/20/2007	3/27/2007	1.709	0.071	0.041	0.084	0.147	1.16	0.088	0.983	19.47	183.01	6.82	12.5	570.4	9.4
CO99	3/27/2007	4/3/2007	0.873	0.077	0.027	0.067	0.004	0.251	0.058	0.32	6.02	19.88	6.59	6.1	134.4	3.3
CO99	4/3/2007	4/10/2007	0.549	0.065	0.029	0.11	0.25	1.076	0.133	0.462	14.54	77.59	6.33	6.5	238.6	5.33
CO99	4/10/2007	4/16/2007	1.238	0.095	0.06	0.284	0.402	1.925	0.326	0.811	18.74	176.17	6.66	13.2	542.8	9.4
CO99	5/1/2007	5/8/2007	0.254	0.028	0.014	0.021	0.116	0.529	0.025	0.4	5.74	137.07	5.78	3.7	1529.2	23.88
CO99	5/8/2007	5/15/2007	4.162	0.619	0.218	0.388	2.06	9.472	0.605	8.826	81.5	41.4	6.32	58.6	19.9	0.51
CO99	5/15/2007	5/22/2007	0.565	0.073	0.026	0.073	0.305	2.13	0.131	1.245	22.55	274.96	4.95	12.6	724.8	12.7
CO99	5/22/2007	5/29/2007	0.223	0.036	0.02	0.095	0.228	0.774	0.145	0.703	5.59	99.4	5.45	6.1	1113	17.78
CO99	6/12/2007	6/19/2007	0.473	0.079	0.076	0.119	0.114	1.327	0.184	0.933	16.96	56.01	4.93	10.7	250	3.3
CO99	7/17/2007	7/24/2007	0.209	0.019	0.023	0.027	0.333	1.167	0.063	0.588	20.61	576.09	5.23	7	2150.8	30.23
CO99	7/31/2007	8/7/2007	0.31	0.041	0.033	0.092	0.583	3.118	0.14	1.876	22.31	600.86	4.4	24.4	1902.5	26.92
CO99	8/7/2007	8/14/2007	0.254	0.027	0.011	0.029	0.153	2.24	0.067	1.077	39.37	1050	4.45	19.2	1764.1	26.67
CO99	8/21/2007	8/28/2007	0.318	0.038	0.011	0.011	0.085	0.476	0.024	0.2	7.83	65.69	6.11	3.5	563.2	8.38

Table A2. Major-ion concentrations, mercury concentrations and deposition, and water properties for precipitation samples at Mesa Verde National Park, 2001-08 -- continued

SiteID	Date On	Date Off	Ca, mg/L	Mg, mg/L	K, mg/L	Na, mg/L	NH4, mg/L	NO3, mg/L	Cl, mg/L	SO4, mg/L	Hg conc, ng/L	Hg Dep, ng/m2	pH Lab, S.U.	Lab Cond, us/cm	Sample vol, mL	Precip, mm
CO99	8/28/2007	9/4/2007	0.338	0.039	0.014	0.027	0.212	4.15	0.085	1.729	33.96	241.55	4.17	35.2	492.2	7.11
CO99	9/11/2007	9/18/2007	2.992	0.236	0.084	0.484	0.877	3.037	0.773	2.248	47.27	192.12	6.91	28.2	270.9	4.06
CO99	9/18/2007	9/25/2007	0.072	0.005	0.004	0.011	0.064	0.325	0.026	0.339	11.25	305.97	5.17	4.3	1853.6	27.18
CO99	9/25/2007	10/2/2007	1.296	0.135	0.056	0.158	0.366	1.874	0.15	1.894	23.64	30.02	6.56	13.5	89.2	1.27
CO99	10/2/2007	10/9/2007	0.128	0.012	0.006	0.028	0.17	0.786	0.054	0.587	15.9	254.44	5.04	7.2	1080.5	16
CO99	11/27/2007	12/4/2007	0.02	0.003	0.004	0.003	0.037	0.148	0.012	0.225	3.15	141.84	5.51	3.9	2941.6	44.96
CO99	12/4/2007	12/11/2007	0.296	0.024	0.009	0.029	0.105	0.46	0.029	0.262	5.89	194.71	6.02	3.5	2267.4	33.02
CO99	1/1/2008	1/8/2008	0.231	0.012	0.009	0.017	0.031	0.214	0.03	0.179	3.2	152.75	5.85	2.7	3062.6	47.74
CO99	1/22/2008	1/29/2008	0.354	0.019	0.031	0.084	0.012	0.272	0.127	0.133	2.74	46.99	6.05	3.4	1366.6	17.15
CO99	1/29/2008	2/6/2008	1.097	0.062	0.022	0.02	0.047	0.656	0.021	0.38	5.25	59.13	6.68	7.8	828.5	11.26
CO99	2/12/2008	2/19/2008	0.162	0.011	0.008	0.036	0.19	1.114	0.046	0.356	14.73	53.72	5.16	6.4	223	3.65
CO99	2/19/2008	2/26/2008	0.049	0.005	0.009	0.019	0.138	0.729	0.03	0.347	9.8	171.53	5.11	5.9	1301.2	17.5
CO99	3/11/2008	3/18/2008	0.516	0.043	0.013	0.071	0.207	0.726	0.111	0.448	10.74	23.31	6.56	5.8	178.6	2.17
CO99	4/8/2008	4/15/2008	0.391	0.042	0.02	0.077	0.235	1.035	0.105	0.715	10.73	92.61	5.95	6.3	561.7	8.63
CO99	5/6/2008	5/13/2008	1.255	0.138	0.559	0.214	0.232	2.389	0.288	1.396	59.11	94.76	6.46	14.4	136.7	1.6
CO99	5/20/2008	5/27/2008	1.081	0.092	0.043	0.114	0.263	1.018	0.137	1.022	12.26	180.7	6.52	10.3	833.8	14.73
CO99	6/3/2008	6/10/2008	0.343	0.021	0.003	0.025	0.064	0.291	0.034	0.156	10.15	61.91	5.94	3.6	358.2	6.1
CO99	7/8/2008	7/15/2008	0.692	0.067	0.067	0.035	0.416	2.796	0.098	1.153	34.02	155.88	4.85	15.2	268	4.58
CO99	7/22/2008	7/29/2008	0.175	0.016	0.016	0.017	0.359	2.185	0.048	0.702	36.91	1494.2	4.71	14.3	2665	40.47
CO99	7/29/2008	8/5/2008	1.135	0.137	0.102	0.22	0.83	4.876	0.353	2.086	70.49	204.15	5.01	22.1	184.5	2.9
CO99	8/5/2008	8/12/2008	0.091	0.01	0.016	0.01	0.194	1.262	0.048	0.288	18.79	149.03	4.77	8.8	513.9	7.93
CO99	8/19/2008	8/27/2008	0.452	0.045	0.018	0.058	0.232	2.041	0.097	1.515	42.46	686.93	4.61	17.2	1134.1	16.18
CO99	8/27/2008	9/2/2008	0.084	0.007	0.007	0.014	0.214	0.526	0.043	0.471	10.35	278.82	5.28	5.4	1239.9	26.92
CO99	9/9/2008	9/16/2008	0.453	0.046	0.014	0.121	0.241	2.139	0.218	1.18	39.53	170.71	4.67	15.5	315.3	4.32
CO99	9/23/2008	9/30/2008	2.999	0.338	0.105	0.473	0.498	5.315	0.39	4.983	47.82	85.02	6.01	29.5	82.5	1.78
CO99	9/30/2008	10/7/2008	0.108	0.016	0.071	0.048	0.102	0.35	0.065	0.416	12.1	209.02	5.61	3.8	1100.7	17.27
CO99	10/28/2008	11/4/2008	2.63	0.162	0.145	0.105	0.561	2.387	0.212	1.771	31.09	39.48	6.67	21.1	37.1	1.27
CO99	11/4/2008	11/12/2008	0.705	0.061	0.034	0.059	0.152	1.11	0.061	0.445	9.01	153.34	6.28	6.6	423.1	17.02
CO99	11/25/2008	12/2/2008	0.048	0.003	0.005	0.006	0.077	0.435	0.016	0.214	3.48	85.83	5.18	4.1	1550.8	24.64
CO99	12/2/2008	12/9/2008	0.181	0.013	0.048	0.032	0.031	0.86	0.24	0.544	32.69	348.74	4.88	7.8	348.1	10.67
CO99	12/9/2008	12/17/2008	0.754	0.077	0.027	0.023	<0.006	0.233	0.025	0.169	2.19	78.71	6.57	4.9	888.5	35.81
CO99	12/17/2008	12/22/2008	0.311	0.057	0.081	0.057	<0.006	0.329	0.103	0.536	6.31	94.62	5.78	4.2	250	14.99

Appendix B -- Maps Showing Back Trajectory Modeling Results

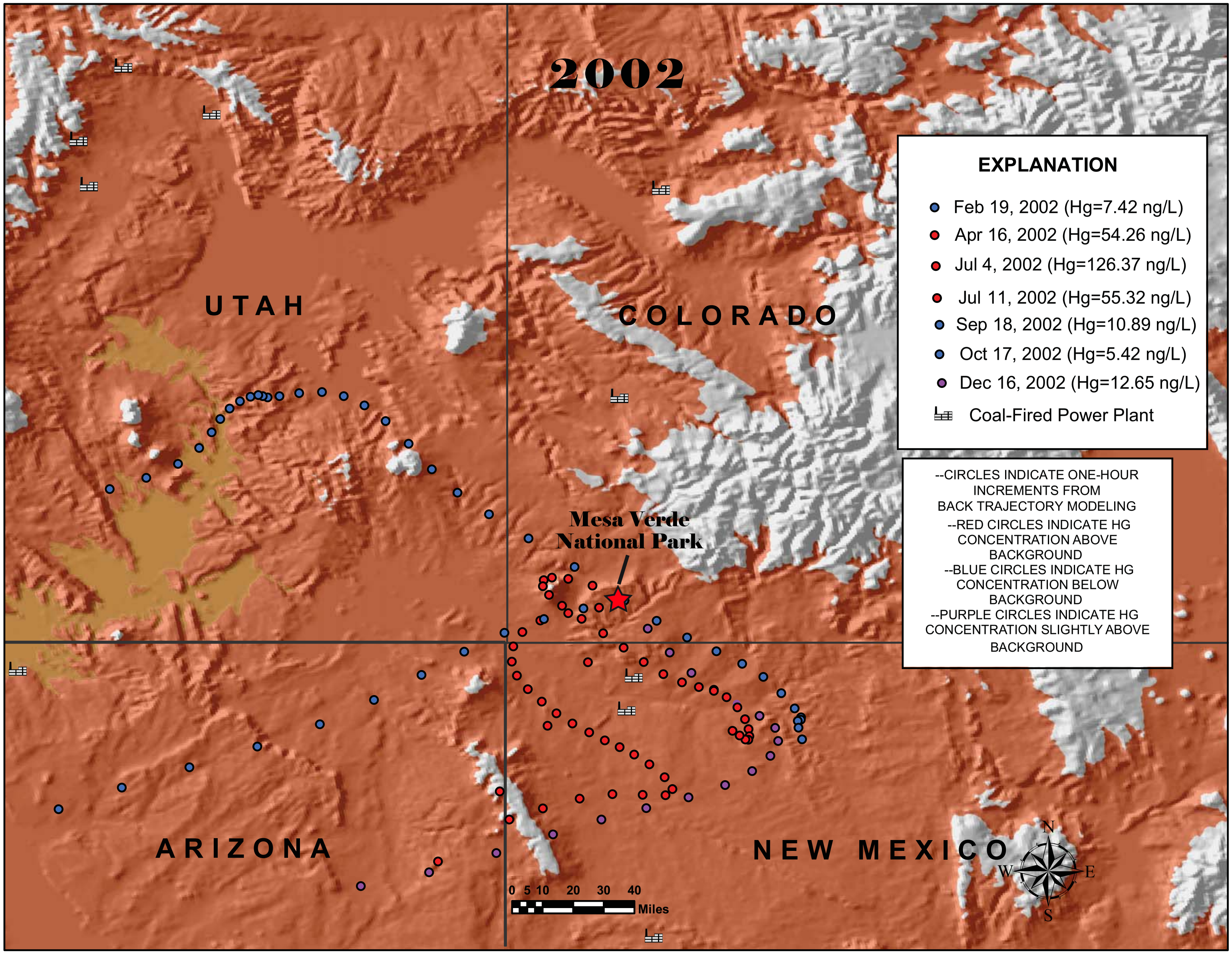

Figure B1. Back trajectory model results for single storm events where mercury concentrations were reported in precipitation at Mesa Verde National Park, 2002.

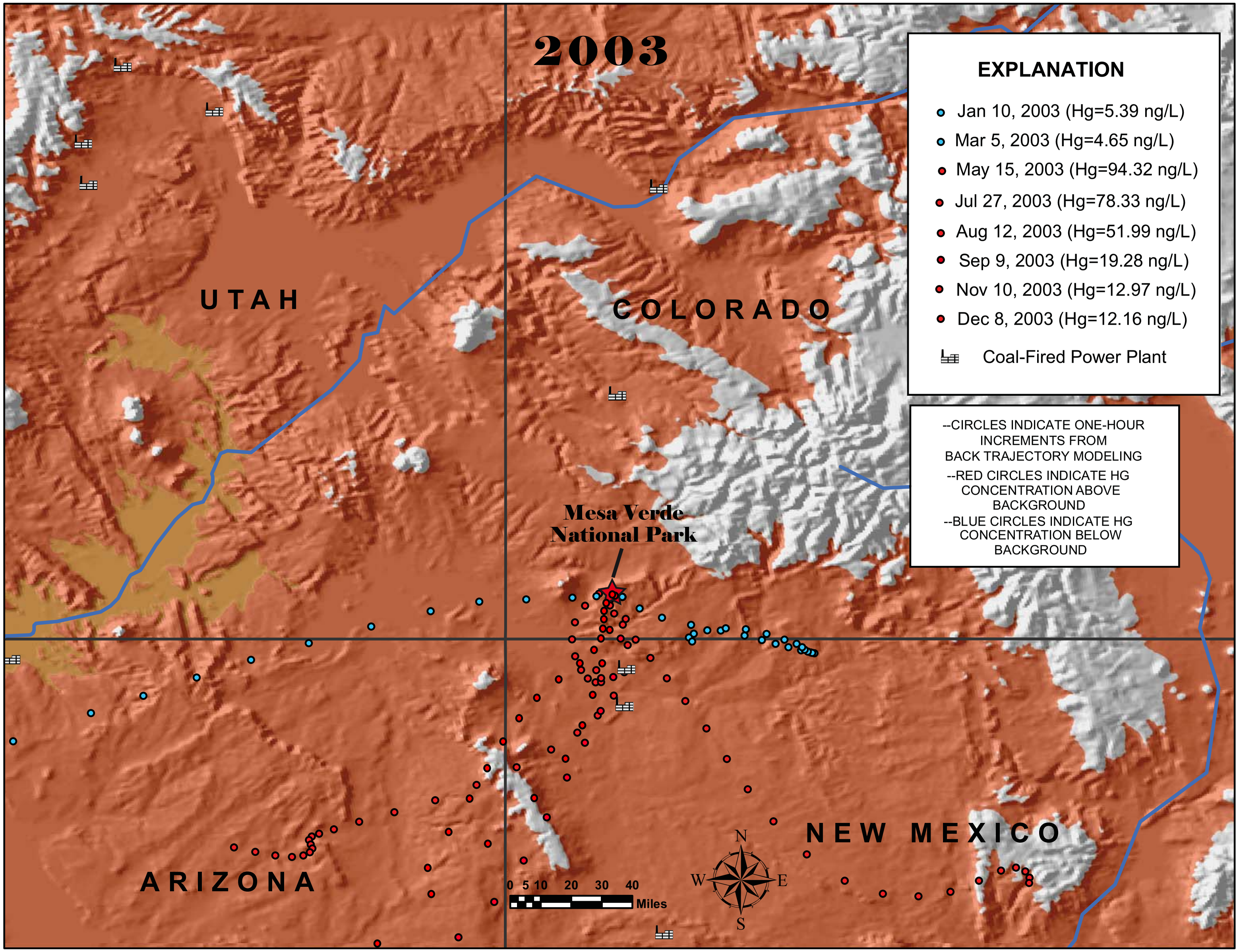

Figure B2. Back trajectories for single storm events where mercury concentrations were reported in precipitation at Mesa Verde National Park, 2003.

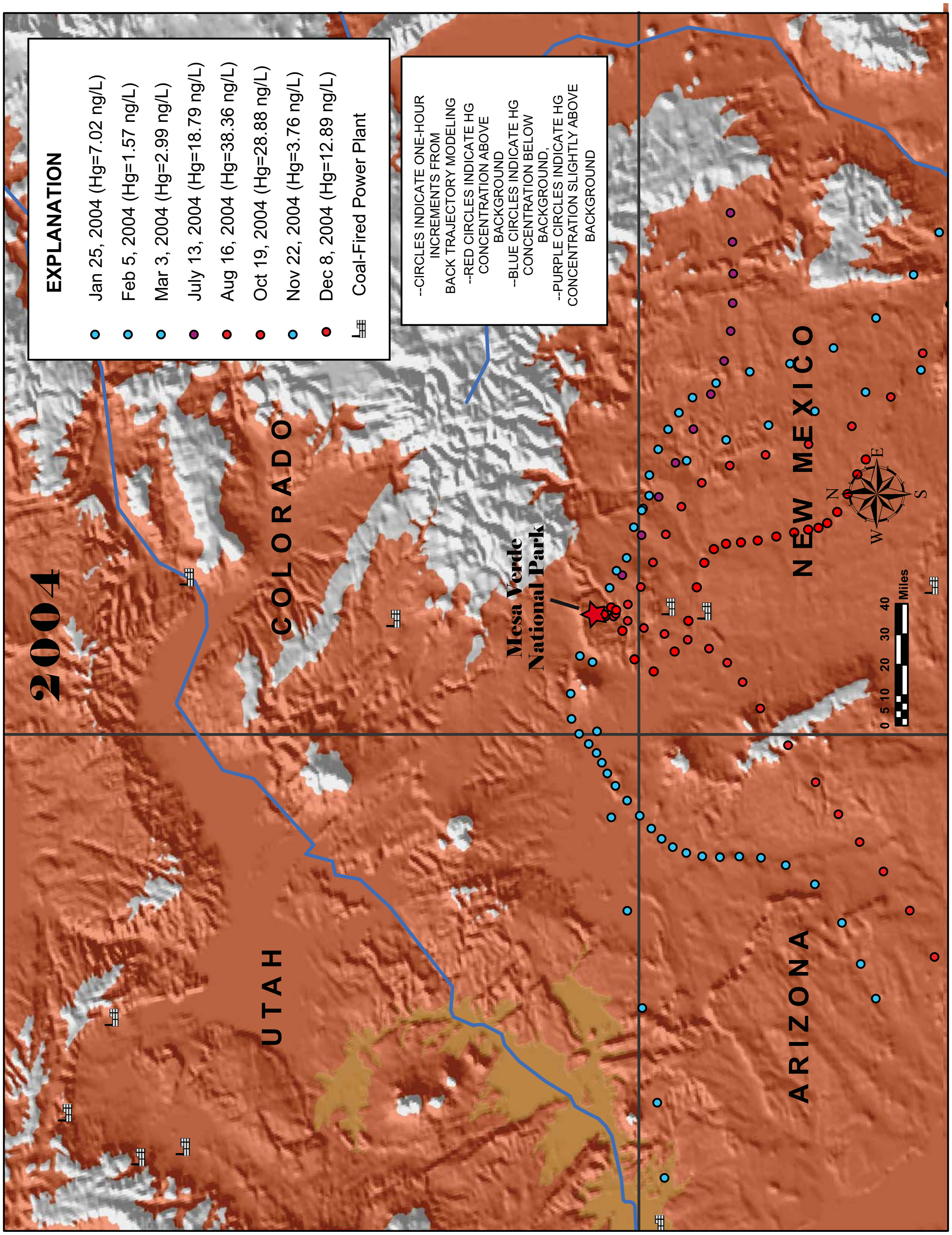

Figure B3. Back trajectories for single storm events where mercury concentrations were reported in precipitation at Mesa Verde National Park, 2004.

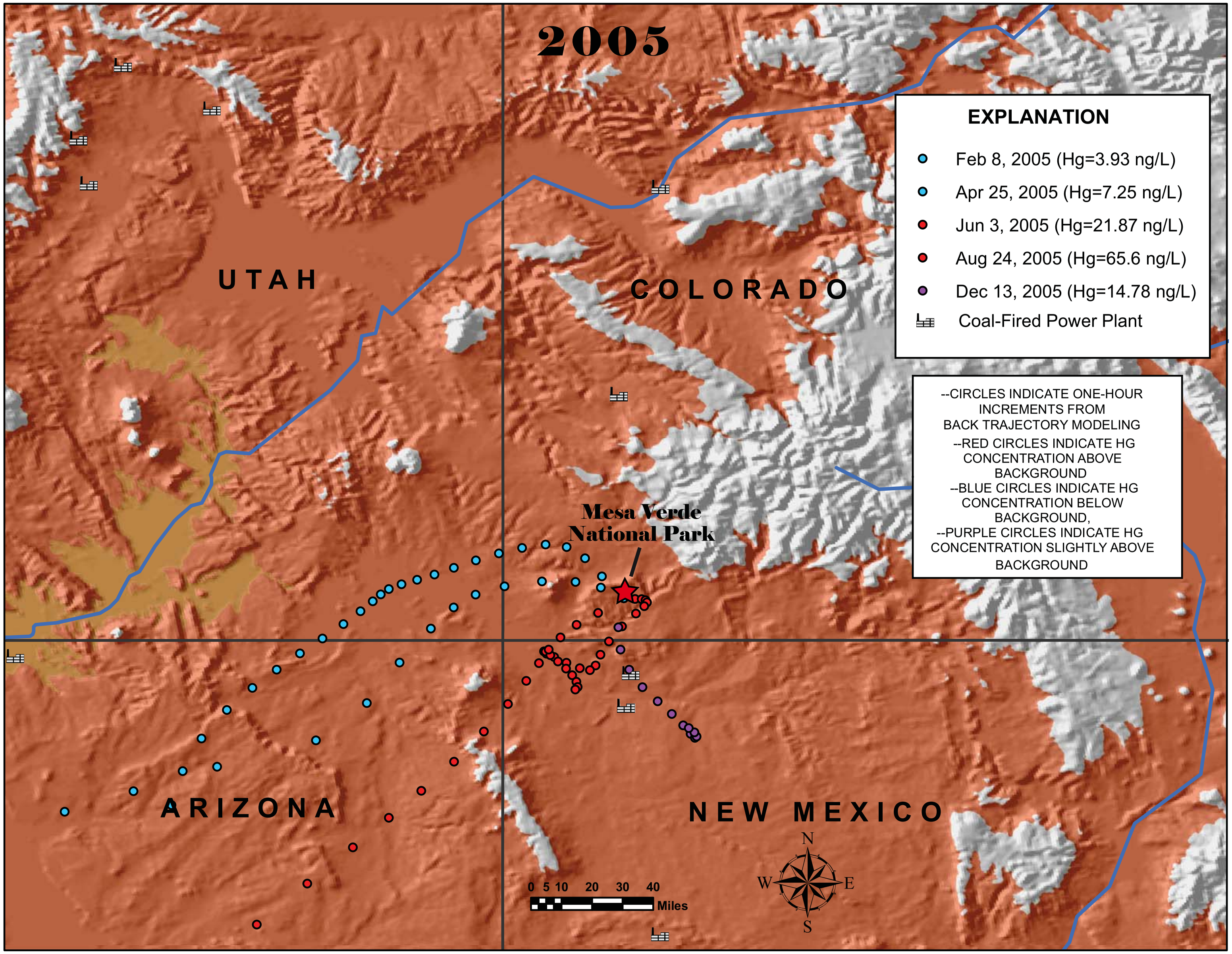

Figure B4. Back trajectories for single storm events where mercury concentrations were reported in precipitation at Mesa Verde National Park, 2005.

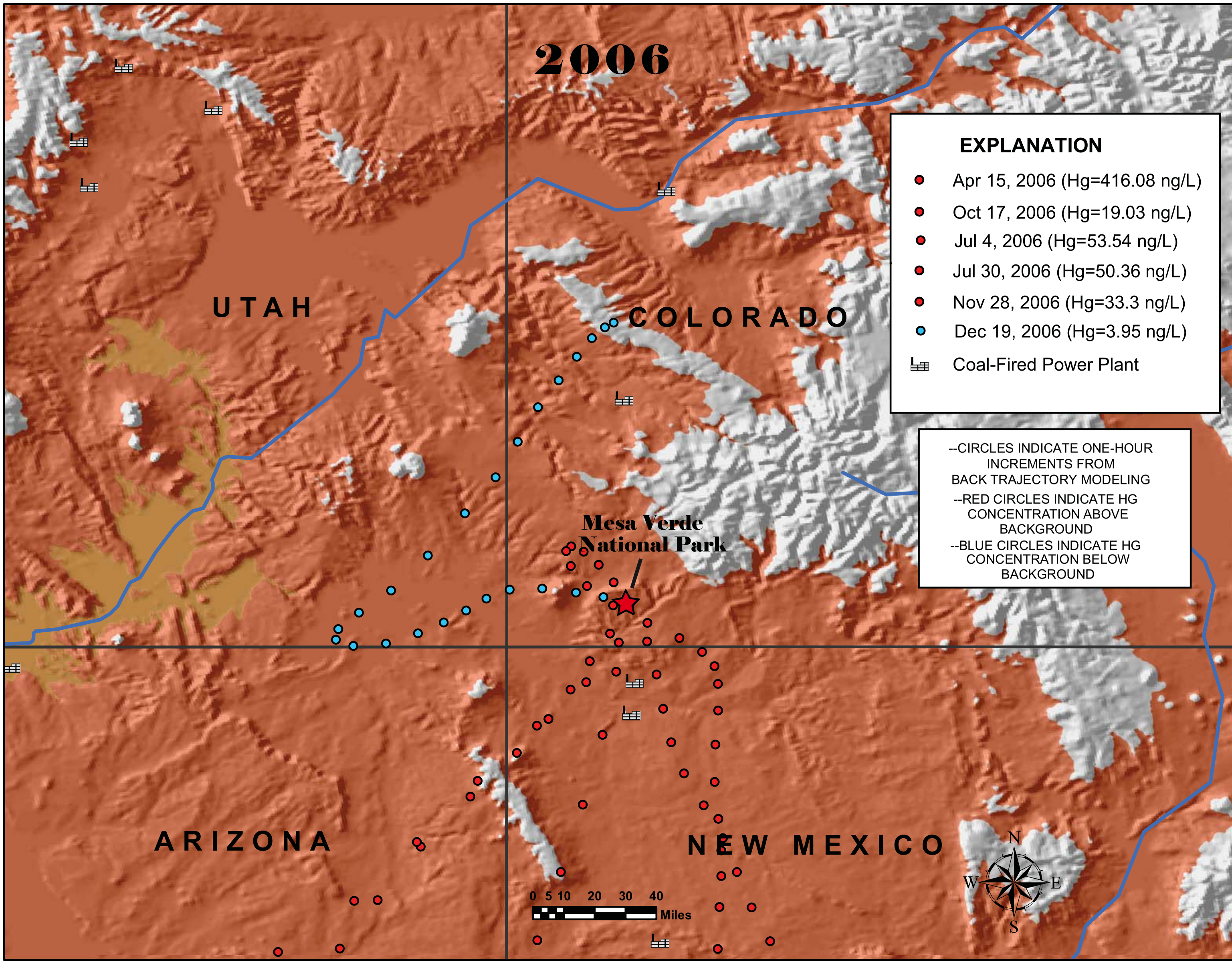

Figure B5. Back trajectories for single storm events where mercury concentrations were reported in precipitation at Mesa Verde National Park, 2006.

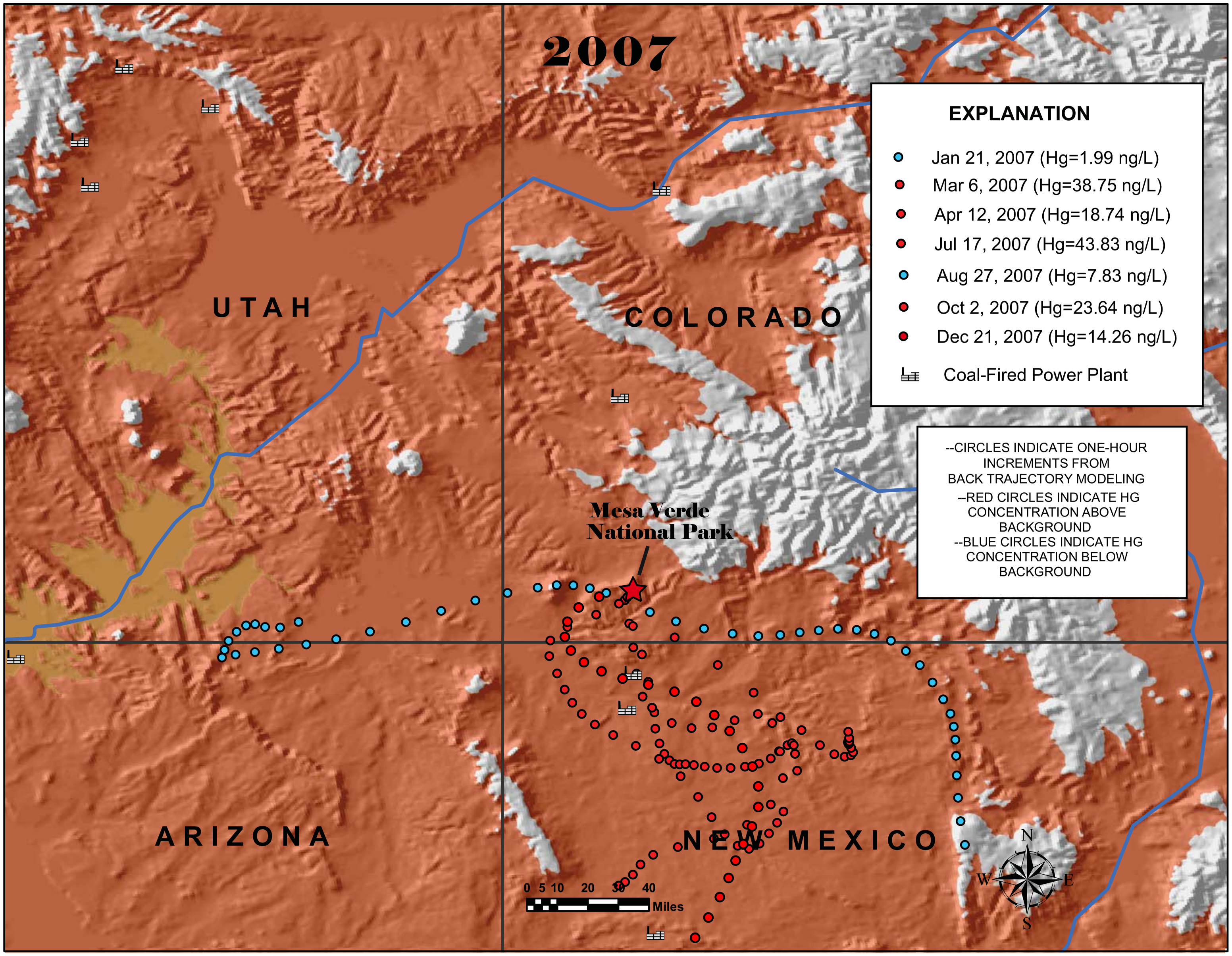

Figure B6. Back trajectories for single storm events where mercury concentrations were reported in precipitation at Mesa Verde National Park, 2007.

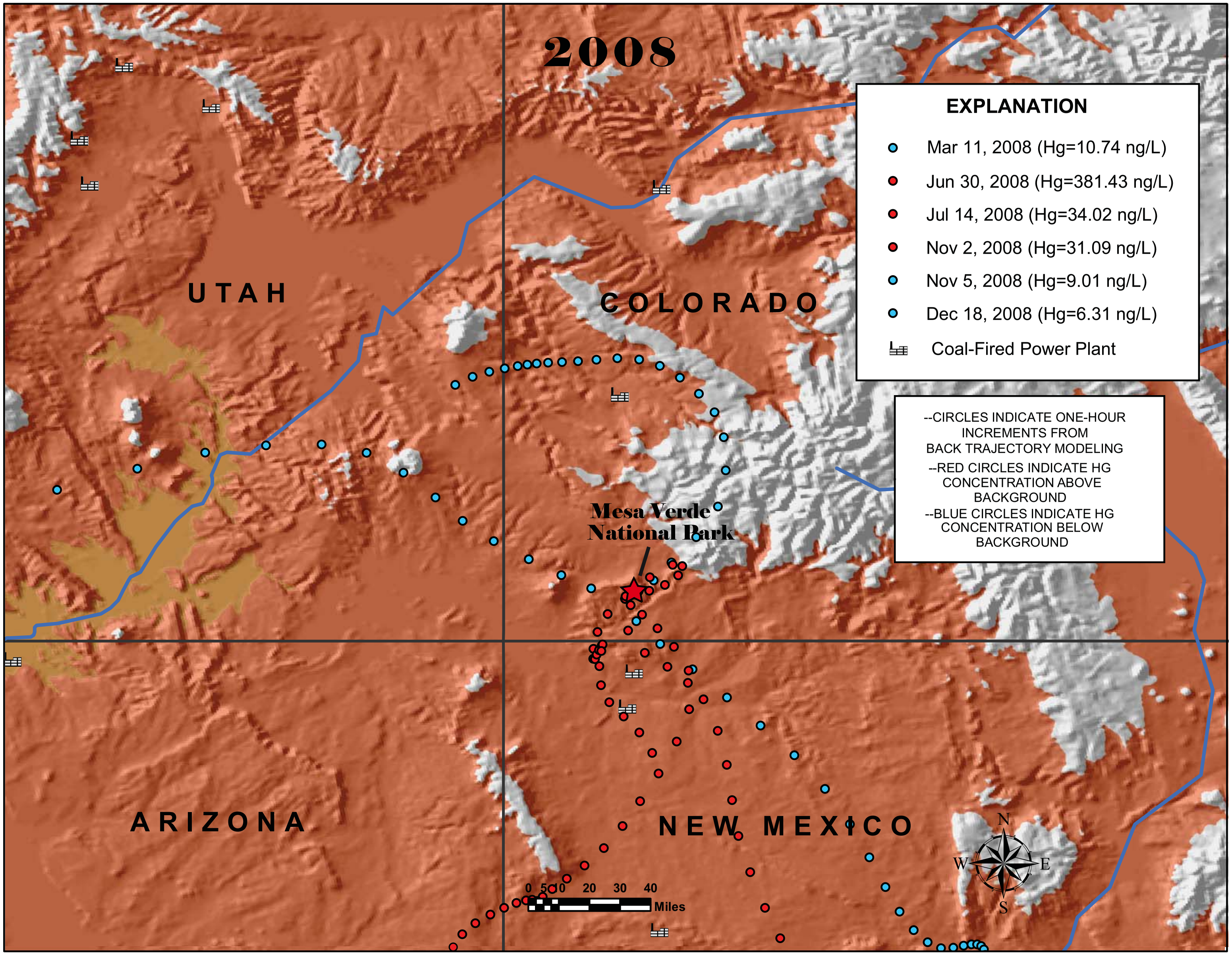

Figure B7. Back trajectories for single storm events where mercury concentrations were reported in precipitation at Mesa Verde National Park, 2008.

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