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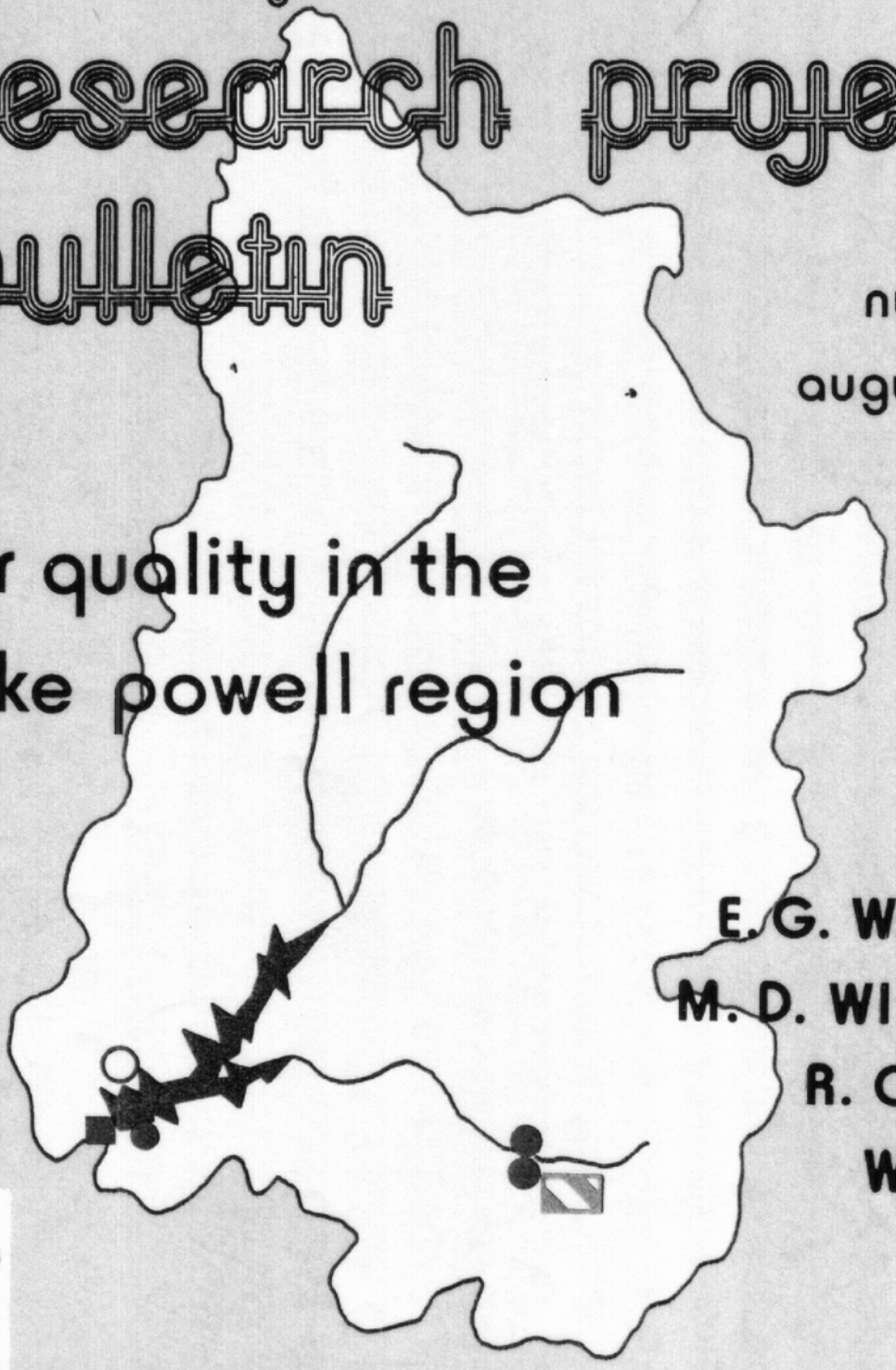

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Research Applied to National Needs

LAKE POWELL RESEARCH PROJECT BULLETIN

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a publication of the research project

COLLABORATIVE RESEARCH ON ASSESSMENT OF MAN'S ACTIVITIES IN THE LAKE POWELL REGION

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AIR QUALITY IN THE LAKE POWELL REGION

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LAKE POWELL RESEARCH PROJECT

The Lake Powell Research Project (formally known as Collaborative Research on Assessment of Man's Activities in the Lake Powell Region) is a consortium of university groups funded by the Division of Environmental Systems and Resources in RANN (Research Applied to National Needs) in the National Science Foundation.

Researchers in the consortium bring a wide range of expertise in natural and social sciences to bear on the general problem of the effects and ramifications of water resource management in the Lake Powell region. The region currently is experiencing converging demands for water and energy resource development, preservation of nationally unique scenic features, expansion of recreation facilities, and economic growth and modernization in previously isolated rural areas.

The Project comprises interdisciplinary studies centered on the following topics: (1) level and distribution of income and wealth generated by resources development; (2) institutional framework for environmental assessment and planning; (3) institutional decision-making and resource allocation; (4) implications for federal Indian policies of accelerated economic development of the Navajo Indian Reservation; (5) impact of development on demographic structure; (6) consumptive water use in the Upper Colorado River Basin; (7) prediction of future significant changes in the Lake Powell ecosystem; (8) recreational carrying capacity and utilization of the Glen Canyon National Recreational Area; (9) impact of energy development around Lake Powell; and (10) consequences of variability in the lake level of Lake Powell.

One of the major missions of RANN projects is to communicate research results directly to user groups of the region, which include government agencies, Native American Tribes, legislative bodies, and interested civic groups. The Lake Powell Research Project Bulletins are intended to make timely research results readily accessible to user groups. The Bulletins supplement technical articles published by Project members in scholarly journals.

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ABSTRACT

In the Lake Powell region, concern about the conflict between maintaining environmental quality and developing coal-fired thermal-electric generating stations has led to measurement of present air quality to provide a reference for determining future changes. In addition to powerplants, other air pollution sources of less concern but no no less importance to the existing air quality in the area include automobiles, motorboats, long-range transport, and blowing sand.

Air quality is defined in terms of the constituent aerosol, gases, and integrated characteristics. In this Bulletin, the available data for all parameters are summarized and discussed. Measurement sites and methods are described and evaluated. The results of the measurements support the conclusion that the air in the Lake Powell region is presently clean and quiet, with excellent average visibility of about 200 km.

AIR QUALITY IN THE LAKE POWELL REGION

INTRODUCTION

Construction of Glen Canyon Dam on the Colorado River led not only to the birth of Lake Powell but also to creation of the nearby construction towns of Page, Arizona, and Glen Canyon City, Utah (Figure 1). The rise in the level of Lake Powell since its creation in 1964 has been accompanied by an increase in recreational use, involving both automobiles and motorboats. The assured supply of cooling water available in Lake Powell is allowing construction of the 2,310-megawatt Navajo Generating Station near Page, Arizona. The municipalities, automobiles, and motorboats are superimposing their effluents on the background air quality of the region. Of course, the background air quality also changes, without the direct influence of man, by the natural variation of wind-blown dust, emission of terpenes by vegetation, and weather.

An evaluation of the background air quality, its variation, and the air quality change caused by man's activity on and around Lake Powell is necessary to determine the impact of the impoundment and its resulting activities upon the quality of life in the Lake Powell region; the effect of resultant air quality upon the Lake Powell recreational area; and interactions between the atmosphere and the lake. Visibility is the most obvious example of an air quality parameter which is crucial to the recreational value of the Lake Powell area. If man degrades visibility there, the recreational value may similarly be degraded.

The increasing emission of contaminants resulting from man's activities (especially motorboating) is increasing the flux of various substances from the atmosphere into the lake. The evaluation of the atmospheric input of substances into Lake Powell may be important in determining the general quality of the impoundment, including the biological-physical interactions of heavy metals in the lake.

Since the water in Lake Powell is used for both recreation and coal-fired thermal-electric power generation, it is important to measure the present air quality and its change in order to determine the impact of the impoundment and resulting activities on water utilization in the Lake Powell region.

Southwest Energy Study

The conflict between maintaining the Lake Powell region's unique natural beauty and environmental quality, on the one hand, and using its coal resources for electric generation, on the other, led to the Southwest Energy Study, (U.S. Dept. of Interior, 1972), organized during 1971. The study received major contributions from both the Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce, in addition to contributions from the various agencies within the Department of the Interior itself.

The Southwest Energy Study looked at the potential effects of electric energy development on air quality, water quality, biota, economics, the Indian tribes, land

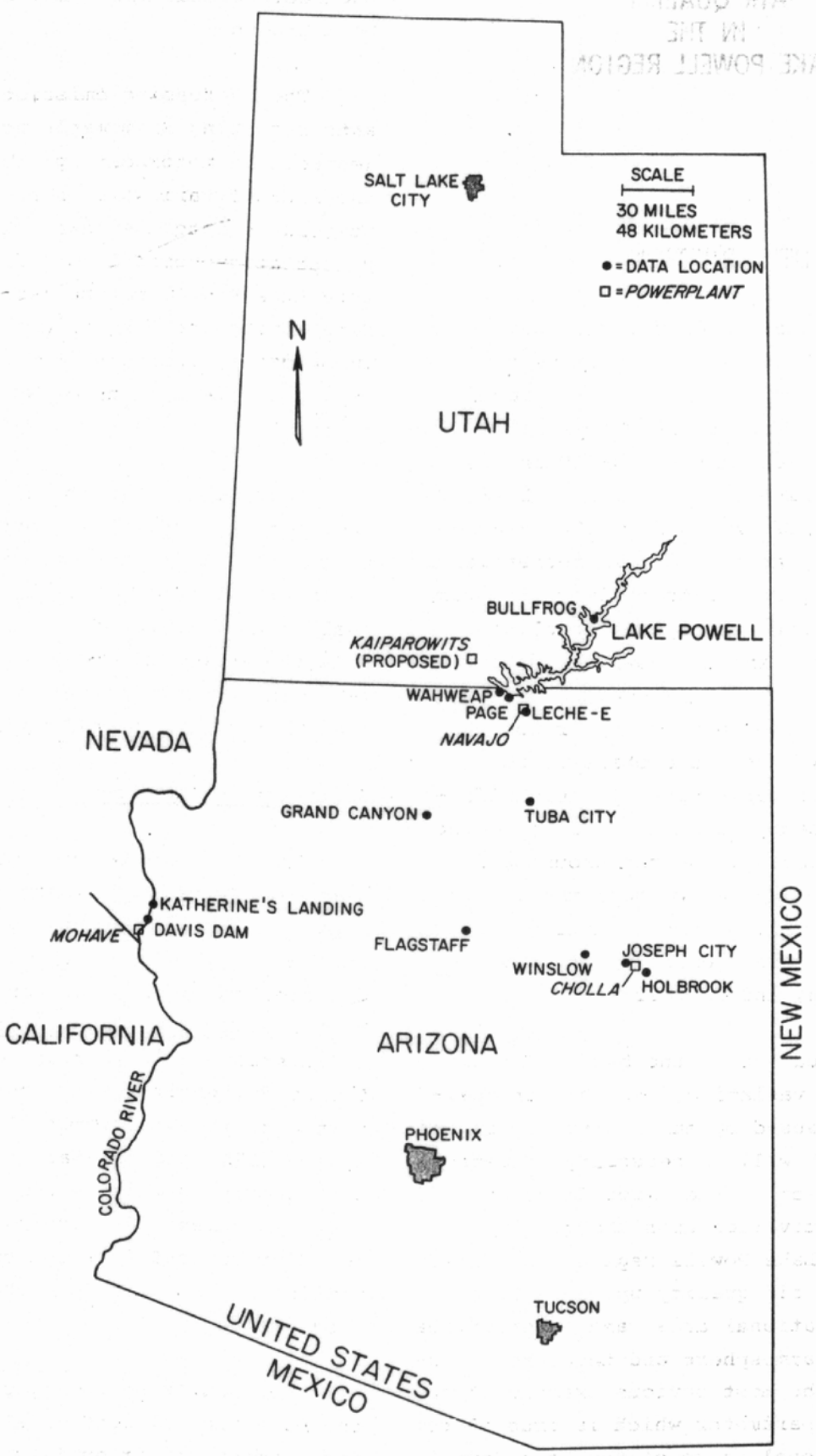

Figure 1: Index Map of Locations for Air Quality Data

use, and the electric energy system. The Study's management team concluded in a summary report that the benefits of electric energy development to the national energy system and to the regional and Indian tribe economies would be greater than the costs in lost environmental quality and depleted resources.

Concerning the air quality portion of the Study more specifically, the Bureau of Mines and the U.S. Geological Survey analyzed the chemical compositions of the various coals in the region. The utility companies provided information on the designs of existing and planned coal-fired thermal-electric generating stations, including rates of coal consumption, furnace design, air pollution control devices, and expected stack emissions. EPA calculated the prevalence of stack emissions while NOAA developed a model of atmospheric dispersion. Combining these efforts, the expected ground-level concentrations were calculated at various locations and under various meteorological conditions. The important meteorological conditions are wind velocity and atmospheric stability, the latter depending on the wind speed and temperature variation with elevation above ground. Under the worst conditions of low wind speed, high terrain nearby, and limited mixing of the atmosphere, some of the calculated maximum ground-level concentrations exceed certain Federal ambient air quality standards for sulfur dioxide (SO_2) and nitrogen dioxide (NO_2).

The air quality portion of the Study also reported on the reduction of visibility caused, at that time, by existing powerplants, particularly the Four Corners Power Plant (located several miles west of Farmington, New Mexico), and predicted more such problems, emphasizing the close proximity of the Navajo and of the Kaiparowits Generating Stations to Lake Powell. The Study's contention that the plumes from these latter two generating stations would interact and cause an air quality problem worse than that from two such plants isolated from each other was debated by several meteorological consultants to the utility companies in the Joint Meteorological Report (Dames & Moore et al., 1971). These consultants concluded from the available meteorological data that the topography of the Southwest would separate some of the powerplants from each other in areas called "airsheds." An airshed is that volume of atmosphere over a defined area of land in which the air pollutants from ground-level sources are reasonably well-confined, even though the overall air flow passes from one airshed to another with the prevailing winds. According to the definition of specific airsheds in the Southwest used in the Dames & Moore report, the Navajo and Kaiparowits Generating Stations would both occupy the same airshed around lower Lake Powell. Yet analysis of wind velocity distributions led the authors of the report to conclude that the plumes from the two powerplants would rarely combine to produce a greater effect on air quality than would the plume from each alone.

In summary, there is no clear consensus on the expected effect on air quality from the emissions of powerplants under construction or from those to be built near Lake Powell. In this report, we define the present air quality of the region, using our own measurements and those of others, taken before large air pollution sources such as the powerplants actually began operating. In this way, it

is possible to provide reference values for any changes in air quality that may occur.

DEFINITION OF AIR QUALITY

Air quality is determined by measurement of aerosol, gas concentration, noise, radioactivity, turbidity, and visibility (Table 1).

The constituents of air comprise aerosol and gases. Aerosol consists of all those solid particles and liquid droplets that range in diameter from about 20 Angstroms (Å) to 100 microns (μ) (Figure 2). There are four important aerosol parameters: chemical composition, size distribution, number concentration, and mass concentration. The first is chemical composition, which usually varies with the aerosol size. The health significance of aerosol depends both on its size distribution, which determines the distribution of aerosol deposited in the respiratory tract, and on its chemical composition, which determines the health effect of a particle once it is deposited on the wall of the respiratory tract. The aerosol concentration may be measured in terms of either *number* per unit volume of air or *mass* per unit volume of air. Additional information is contained in the parameter size distribution, which is the number or mass concentration in several size intervals within the overall size range. In the Lake Powell area, up to 1974, aerosol has been generated mostly by automobiles, motorboats, and blowing sand; after June 1974, the 2,310-megawatt coal-fired Navajo Generating Station became another source of aerosol.

The Arizona State Department of Health Services (ASDHS) includes the following constituents in its analysis of

Table 1: Air Quality Parameters

1. Aerosol
   - a. Composition
   - b. Concentration
     - i. Mass
     - ii. Number
   - c. Size Distribution

2. Gas Concentration
   - a. Ammonia (NH_3)
   - b. Carbon Monoxide (CO)
   - c. Hydrocarbons (HC)
     - i. Alkanes
     - ii. Alkenes--Terpenes
   - d. Hydrogen Sulfide (H_2S)
   - e. Nitrogen Dioxide (NO_2)
   - f. Nitric Oxide (NO)
   - g. Oxidant
     - i. Ozone
   - h. Sulfur Dioxide (SO_2)
   - i. Water Vapor (H_2O)

3. Noise
4. Radioactivity
5. Turbidity
6. Visibility

aerosol composition: benzene-soluble component, nitrate, sulfate, arsenic, bismuth, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, tin, titanium, vanadium, and zinc. We believe that the above list should also include phosphorus, selenium, and beryllium.

Among the gases listed in Table 1 as air quality parameters, the following are of obvious significance for national ambient air quality standards: carbon monoxide (CO), hydrocarbons (HC), nitrogen dioxide (NO_2), oxidant, and sulfur dioxide (SO_2). Nitric oxide (NO) is

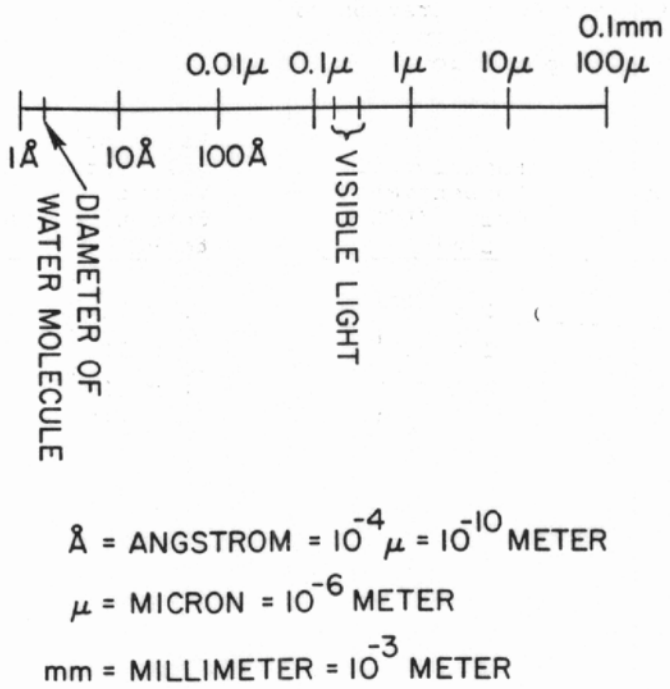

Figure 2: Logarithmic Scale Showing Size Range of Aerosol (20Å to 100μ)

listed because it is the important precursor of NO_2. Around Lake Powell, automobiles and motorboats are the most important sources of NO, despite conversion of it to NO_2. Hydrocarbons are divided into various types because of the importance of (1) methane, an alkane, to the total hydrocarbon concentration and (2) ethylene and terpenes, all alkenes, to anthropogenic and natural sources of reactants in gas-to-aerosol conversions and in photochemical reactivity in general. Water vapor is listed here as an air quality parameter amongst the gases, even though it is usually listed as relative humidity, the meteorological parameter, because it determines the aerosol size distribution for an otherwise specified aerosol chemistry. Ammonia (NH_3) and hydrogen sulfide (H_2S) are present in extremely low concentrations. They play a role in the nitrogen and sulfur cycles, and NH_3 can help convert SO_2 to sulfate (SO_4). The specific gases (listed in Table 1) chosen as air quality parameters are emitted by both natural and anthropogenic sources, and these gases are considered to be the most important with regard to the health of regional biota and the welfare of man. The main sources of CO, HC, and NO_2 around Lake Powell are automobiles and motorboats. The terpene class of hydrocarbons comes from aromatic vegetation. Oxidant is produced naturally, but sources of HC and NO_2 lead to specific photochemical reactions that may produce additional oxidant. The only significant source of SO_2 is the Navajo Generating Station which began operation early in 1974. That station is also a significant source of NO and NO_2.

Although noise is not usually considered as an air quality parameter, it is included here because (1) it is so important to the aesthetic quality of the environment around Lake Powell; (2) it will increase with increasing population, industry, and recreation (motorboats); and (3) it is transmitted through the air medium.

Radioactivity in the atmosphere is carried by gases and aerosol. Total beta-activity in the aerosol collected on a filter with a high-volume sampler at Page in 1969 was low enough to indicate to the Arizona State Department of Health that there was no threat to health and that such measurements could be suspended. Testing of underground nuclear devices in Nevada may be an occasional source of leaked radioactive contamination in the region around Lake Powell, and is capable of elevating the radioactivity of the atmosphere above the background level for a relatively short period of time. Since coal contains radioactive elements, both the Navajo and the proposed Kaiparowits Generating Stations

Table 2: Resulting Maximum Atmospheric Concentration of Certain Radioisotopes To Be Emitted in the Fly Ash from the Navajo Generating Station

Isotope	(1) Maximum Concentration in Fly Ash (pc/g ash)[a]	(2) Volume Concentration in Air (pc/ml)[b]	(3) Radioactivity Concentration Guide (RCG) (pc/ml)	(4) Ratio of Calculated Volume Concentration to RCG
^{226}Ra	2.9	2.4×10^{-10}	2×10^{-6}	1×10^{-4}
^{228}Ra	5.0	4.2×10^{-10}	1×10^{-6}	4×10^{-4}
^{228}Th	5.0	4.2×10^{-10}	2×10^{-7}	2×10^{-3}
^{232}Th	4.9	4.1×10^{-10}	1×10^{-6}	4×10^{-4}

[a] pc/g = picocurie per gram ash
[b] pc/ml = picocurie per milliliter

will be sources of slightly radioactive fly ash. In order to assess whether these sources will be appreciable, it was conservatively assumed, for the Navajo Generating Station, that (1) the emitted fly ash is mixed throughout a limited layer that extends from the ground to the top of the plume at about 610 meters above terrain, (2) horizontal mixing occurs across 0.5 km, and (3) mean wind speed is 3 meters per second. The fly ash emission rate at full load will be 7.25 tons per day or 6.58×10^6 grams per day. The volume of air per unit time through which this fly ash will be mixed is about 0.915×10^6 cubic meters per second. Under these exceedingly severe assumptions, the resulting fly ash concentration would be 83 $\mu g/m^3$, slightly higher than the annual Federal primary ambient air quality standard. The maximum concentrations of four bone-seeking radioactive isotopes in the fly ash (Peters, 1970) are given in column 1 of Table 2. Based on the assumptions above, the volume concentration of radioactivity for each of these four isotopes is given in column 2 of Table 2.

The most restrictive values from the Radioactivity Concentration Guide (RCG), promulgated by the Federal Radiation Council, for these isotopes in air outside restricted areas (Harley, 1968) are given in column 3 of Table 2. As can be seen in column 4, the calculated concentrations are much lower than the RCG values, with the closest case of ^{228}Th being 500 times lower. This calculation indicates that there is no apparent need to measure airborne radioactivity in this region.

Turbidity is the atmospheric aerosol loading that attenuates incident solar radiation by scattering and absorption. Turbidity is quantified by a coefficient, defined as

$$B = \frac{\log_{10} \frac{I_o}{sI} - bM}{M_h} - k$$

from the transmission equation

$$I = \frac{I_o}{s} 10^{-(B + k)M_h - bM}$$

where I = incident solar radiation intensity

I_o = extraterrestrial solar radiation intensity

s = correction factor for actual solar distance compared to mean solar distance

k = absorption coefficient for ozone

b = scattering coefficient for air

M = absolute air mass along observing path $= \frac{P}{P_o} M_h$

P = ambient pressure

P_o = sea level pressure

M_h = relative air mass

Visibility is the quality that allows one to see distant objects, and its numerical value is called visual range. This parameter, probably the one most obvious to the layman, can be measured without instruments. Visibility is limited by the light scattered by gas molecules and aerosol into the path between the object and the observer's eye, and by the light absorbed in the path by these same gas molecules and aerosol, reducing the contrast between the object and its background surroundings. Visibility is considered in the horizontal while turbidity is the roughly analogous parameter in the vertical. All aerosol sources mentioned above potentially can affect visibility. Also, sources of NO, NO_2, and SO_2 can affect visibility after these gases have converted to aerosol in the atmosphere.

Existing Measurements

The measurements of air quality that are presently being made by others are listed in Table 3. Where observed, problems in the placement of specific instruments are noted.

The programs shown in Table 3 measure the parameters listed in Table 4. The remaining parameters being measured in this project are listed in Table 5.

Measurement Program

Measurement Procedure

The parameters listed in Table 5 are being measured at specified locations near Lake Powell. The sampling intervals for these measurements are listed in Table 6. The instrumentation for the measurements is housed in a trailer owned by the Desert Research Institute of the University of Nevada at Reno and is stationed near Lake Powell.

Measurement Methods

o Aerosol Number Concentration

The aerosol number concentration is measured with a portable instrument called a particle detector, which humidifies an air sample to saturation and then subjects the saturated air to an adiabatic expansion. The resulting super-saturation (over 300%) causes the water vapor to condense on all aerosol down to a minimum radius of about 30 Å. In less than one-tenth of a second, all the aerosol has grown to at least 0.1 μ radius and is therefore capable of attenuating the light beam between a lamp and a photocell. The size distribution of background aerosol

Table 3: Existing Air Quality Measurement

Parameter	Agency	Station Location	Sampling Frequency	Method
1. Aerosol composition Benzene-soluble component Nitrate Sulfate	ASDHS[a]	Clarkdale Davis Dam Flagstaff Holbrook Joseph City Leche-e Page[c] Tuba City	Every 6 days	Various methods
2. Aerosol composition Arsenic Bismuth Cadmium Chromium Cobalt Copper Iron Lead Manganese Mercury Nickel Tin Titanium Vanadium Zinc	ASDHS	Clarkdale Davis Dam Flagstaff Holbrook Joseph City Leche-e Page[c] Tuba City	Every month	Various methods
3. Aerosol mass concentration	ASDHS	Clarkdale Davis Dam Flagstaff Holbrook Joseph City Leche-e Page[c] Tuba City	Every 6 days	High-volume gravimetric
4. Aerosol mass concentration	D&M[b]	Page Airport	Every day	
5. Aerosol mass concentration	D&M	Page Airport	Every day	Tape Sampler
6. Aerosol mass concentration	USDH[d]	Wahweap	Every day	High-volume gravimetric
7. Aerosol mass concentration	USDH	Bull Frog Basin	Every day	High-volume gravimetric
8. Aerosol size distribution	D&M	Page Airport	Every other day	Anderson cascade impactor
9. Aerosol dustfall	D&M	19 Sites around Northern Arizona and Southern Utah	Every 2 months	Sticky foil
10. Nitrogen dioxide	ASDHS	Grand Canyon Village	Every 6 days	24-hour bubbler Saltzman

[a] ASDHS = Arizona State Department of Health Services

[b] D&M = Dames & Moore

[c] Only 50 meters (150 feet) from jet aircraft fueling facility

[d] USDH = Utah State Department of Health

Table 3 (continued)

Parameter	Agency	Station Location	Sampling Frequency	Method
11. Nitrogen dioxide	ASDHS	Davis Dam	Every 6 days	24-hour bubbler Saltzman
12. Nitrogen oxides	D&M	Page Airport	Twice per week	1-hour bubbler Saltzman
13. Oxidant	D&M	Page Airport	Twice per day	10-minute bubbler Haagen-Smit
14. Oxidant	ASDHS	Grand Canyon Village	Every 6 days	24-hour bubbler
15. Ozone	USDH	Cedar City	Every month	Rubber strip
16. Ozone	USDH	Bull Frog Basin	Every month	Rubber strip
17. Ozone	USDH	Padre Bay	Every month	Rubber strip
18. Ozone	USDH	Wahweap Bay	Every month	Rubber strip
19. Ozone	USDH	Cedar City	Every month	Rubber strip
20. Sulphur dioxide	D&M	Page Airport	Continuous	Conductimetry
21. Sulphur dioxide	D&M	Page Airport	Twice per week	24-hour bubbler
22. Sulphur dioxide	D&M	19 sites	Every 2 months	Lead peroxide candle
23. Sulphur dioxide	ASDHS	Grand Canyon Village	Every 6 days	24-hour bubbler
24. Sulphur dioxide	ASDHS	Davis Dam	Every 6 days	24-hour bubbler
25. Sulphur dioxide	USDH	Wahweap Bay	Every month	Lead peroxide candle
26. Sulphur dioxide	USDH	Padre Bay	Every month	Lead peroxide candle
27. Sulphur dioxide	USDH	Bull Frog Basin	Every month	Lead peroxide candle
28. Sulphur dioxide	USDH	Cedar City	Every month	Lead peroxide candle
29. Water (relative humidity)	BR[e]	Page Airport	Continuous	Hair hygrometer[f]
30. Visibility	D&M	Page Airport	3 hours each morning	Integrating nephelometer (measures local air)
31. Visibility	D&M	Page Airport	Every day	Observer and distant points
32. Visibility	D&M	Page Airport	6 times each day	Camera and Questar

[e] BR = Bureau of Reclamation

[f] Unknown if calibrated for altitude of Page

Table 4: Air Quality Parameters Presently Being Measured by Other Projects

1. Aerosol
   a. Composition
      - benzene-soluble component
      - nitrate
      - sulfate
      - arsenic
      - bismuth
      - cadmium
      - chromium
      - cobalt
      - copper
      - iron
      - lead
      - manganese
      - mercury
      - nickel
      - tin
      - titanium
      - vanadium
      - zinc
   b. Concentration
      i. Mass
   c. Size distribution
2. Gas Concentration
   a. Nitrogen dioxide
   b. Nitric oxide
   c. Oxidant
   d. Sulfur dioxide
   e. Water vapor
3. Visibility

Table 5: Air Quality Parameters Being Measured by Lake Powell Research Project

1. Aerosol
   a. Concentration
      i. Number
2. Gas Concentration
   a. Hydrocarbons
3. Noise
4. Turbidity

is such that most of the particles are smaller than 0.1 μ radius. These small particles do not significantly attenuate visible light. Greatest attenuation per particle is achieved by particles with radii between 0.1 μ and 1.0 μ.

o Gases

Remote air samples are collected in special Saran plastic bags that are designed to minimize gas transmission through their walls and sorption or reaction at the wall surface. The gas concentrations are all measured with a gas chromatograph. Column packings include Poropak N, silica gel, and molecular sieve. Although the measurement procedure for hydrocarbons that are not heavier than either hexane or butylene has been standardized, the measurement of carbon monoxide is more difficult. The approach is to separate it from other gases with a molecular sieve, convert it to methane on a nickel catalyst in a hydrogen-augmented carrier, and measure the resulting methane pulse in a flame ionization detector at a longer retention time than that for the natural methane in the air sample.

o Noise

This parameter is measured by placing a portable sound-level meter at various locations. The sound level, weighted on the A-scale to most closely represent human hearing, is recorded for 24 hours. The resulting plot yields the maximum, minimum, and mean values for the day.

Table 6: Sampling Intervals for Air Quality Measurements

Air Quality Parameter	Sampling Interval
1. Aerosol	Sampled daily
a. Concentration	
i. Number	
2. Gas Concentration	Sampled on at least 1 weekday and 1 day of weekend each week
a. Hydrocarbons	
3. Noise	Sampled continuously for 24 hours on weekdays and during weekends
4. Turbidity	Sampled at 0900, 1200, and 1500 MST[a] on at least 1 clear day of each week

[a] MST = Mountain Standard Time

o Turbidity

An Eppley Sun Photometer is aimed directly at the sun at roughly 0900, 1200, and 1500 Mountain Standard Time (MST) to obtain I_{380} and I_{500}. The subscripts are the mean wavelengths of the two transmitted radiation bands measured in nanometers. The local elevation allows P/P_o to be calculated. The diopter on the instrument yields M_h. M is obtained from the equation

$$M = \frac{P}{P_o} M_h$$

The date of observation and a table of solar distance correction factors yield s. The above information allows the final calculation of B_{380} and B_{500}.

Measurement Instrumentation

The important characteristics of the equipment used in this background air quality measurement program are listed in Table 7.

DATA ANALYSIS, RESULTS, AND DISCUSSION

The available data for each of the air quality parameters listed in Table 1 were collected and, where sufficient data existed, were analyzed for annual, seasonal, and monthly weekday and weekend means, maxima, minima, 90% confidence limits, and frequency distributions. In the discussion, we indicate cases in which results may be skewed by problems of instrument location.

Where possible the data were separated into weekdays and weekends (holidays being included in the latter category). Each of the four seasons includes the following 3 months: winter (December through February), spring (March through May), summer (June through August), and fall (September through November). Three central measures or averages were used: the median, arithmetic mean, and geometric mean. The

Table 7: Instrumentation for the Measurement of Certain Air Quality Parameters

Parameter	Instrument	Company	Model	Power	Sensitivity	Recorder
Aerosol number concentration	Small particle detector	Gardner Associates	Type CN	Battery	100/cm^3	None
Gases	Gas chromatograph	Hewlett-Packard	5711	1.8 kw	---	Linear Instruments 252
Noise	Sound level meter	General Radio Company	1551-C	Battery	22dbA	Linear Instruments 212
	Calibrator	General Radio Company	1562-A	Battery	---	None
Turbidity	Sun photometer	Eppley Labs	---	Sunlight	---	None

median is the middle number of a monotonically ordered series of numbers; the arithmetic mean is the sum of the numbers in a series divided by the number of numbers (n) in the series; and the geometric mean is the nth root of the product of the numbers (and is usually used only for aerosol mass concentrations averaged over months to years). An arithmetic mean exists within some interval around the mean according to the confidence which one wants to attach to the mean. Sometimes the lower and upper 90% or 95% confidence limits around means are given, especially when two means are being compared in order to see if they are statistically significantly different. The confidence interval is proportional to the more familiar standard deviation, but it easier to understand. A frequency distribution gives the proportion or percentage of data that is in various stated intervals for a more complete picture of the variation of the data. The results were compared to those of other locations, including those results from particularly clean and particularly polluted areas.

Aerosol Composition

Results from eight locations in northern Arizona (refer to Figure 1) are presented in Table 8. The locations with the highest concentrations of various constitutents are presented in Table 9, along with the constituents. It is interesting to note that the first three locations (Davis Dam, Flagstaff, and Holbrook) are located within 16 km (10 miles) of some coal-fired thermal-electric generating station. Joseph City is located the closest to a generating station, being about 3 km (2 miles) northwest of the 110-megawatt Cholla Power Plant. Davis Dam is about 5 km (3 miles) north of the 1,600-megawatt Mohave Generating Station in the Colorado River valley between Arizona and

Nevada. Holbrook is about 16 km (10 miles) east-southeast of the Cholla Power Plant. Coal contains small proportions of a large number of elements (U.S. Dept. of Interior, 1972), while coal combustion produces high concentrations of nitric oxide, sulfur dioxide, and aerosol. Oxidation of nitric oxide produces nitrogen dioxide which can then be further oxidized to nitrate. Similarly, the oxidation of

Table 8: Concentration[a] in Micrograms per Cubic Meter of 18 Constituents at 8 Locations in Arizona from 1969 through 1972 in Aerosol Sampled with High-Volume Samplers[b]

	Location							
Constituent	Davis Dam	Flagstaff	Holbrook	Joseph City	Leche-e	Page	Tuba City	Winslow
Sulfate	3.2	2.8	4.4	2.7	1.6	1.4	2.1	2.9
Nitrate	1.6	0.5	0.6	0.6	0.6	0.6	0.8	0.8
Zinc	1.4	0.79	0.08	0.82	0.10	0.90	0.12	0.23
Iron	1.3	0.7[d]	1.0	2.4	0.6	0.3	0.9	0.5
Benzene-soluble organics	1.0	3.0	3.0	1.2	0.9	1.2	1.1	1.3
Copper	0.79	0.08[d]	0.07	0.12	0.10	0.13	0.18	0.09
Lead	0.23	1.2	0.3	0.3	0.1	0.08	0.1	0.1
Manganese	0.04	0.08	0.02[e]	0.09	0.02	0.01	0.02	0.02
Nickel	0.025	0.008[d]	0.024	0.041	0.014	0.004	0.012	0
Bismuth	0.012	0.004	0.008	0.015	0.003	0.005	0.014	0.001
Cobalt	0.010	0.012	0.024	0.021	0.006	0.002	0.004	0
Chromium	0.008	0.001[d]	0.010	0.001	0.004	0.004	0.004	0.003
Cadmium	0.004	0.005	0.001	0.006	0.001	0.001	0	0.001
Mercury	0.004	0.0002	0.0001	0.0002	0	0	0.0001	0.0001
Arsenic	0.003	0.002	0.001	0.003	0.001	0.002	0.002	0
Tin	0.003	0.01	0.01	0.01	0	0.01	0.01	0
Titanium	0.002	0	0	0	0	0	0	0
Vanadium	0.001	0.001	0.001	0	0.002	0	0.001	0
Total Aerosol[c]	32	52	108	63	33	16	52	45

[a] Tabulated value is arithmetic mean of annual arithmetic mean concentrations available from 1969 through 1972;

[b] Annual values supplied by Division of Air Pollution Control, Arizona State Department of Health Services;

[c] Geometric mean of annual geometric means;

[d] Four concentrations in Flagstaff during 1970 excessively high, casting sufficient doubt on validity to exclude from calculation of values in Table 8;

[e] 1972 manganese concentration in Holbrook omitted from calculation because unreasonably high

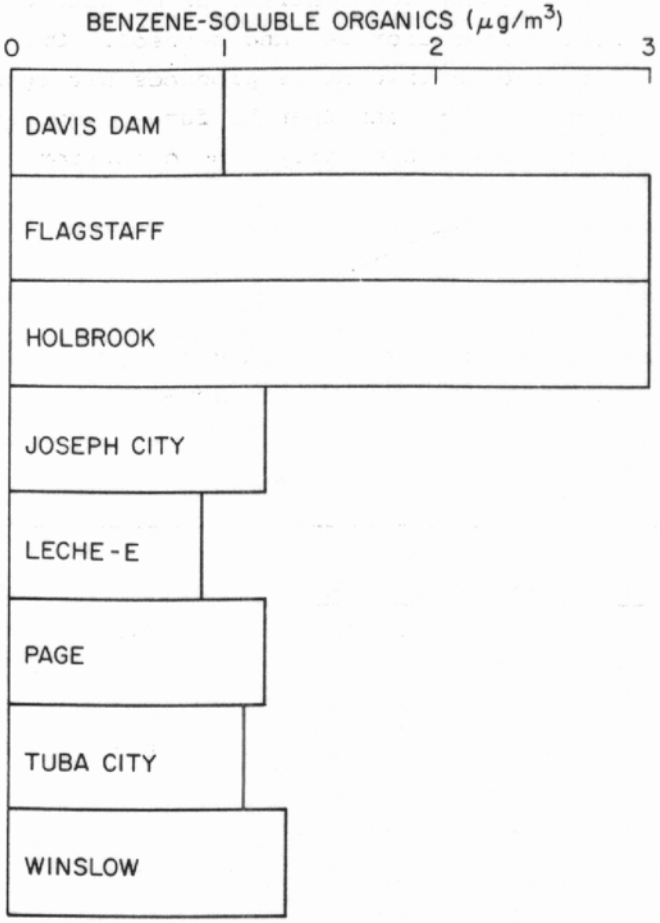

Figure 3: Aerosol Composition: Benzene-Soluble Organics Measured at Various Locations (1969-1972)

Source: Division of Air Pollution Control, ASDHS

sulfur dioxide yields sulfate. The other large sources of aerosol at these locations are automobiles and blowing dust. The latter contains mostly silica, which was not measured by the ASDHS. Automobiles are significant sources of benzene-soluble organics, lead (Martens et al., 1973), nitrogen oxides, and carbon monoxide, of which only the last is not found by aerosol measurement. Flagstaff, with 31,000 residents in 1973, has the highest population of the eight locations listed in Table 8. Automobile population is directly related to human population, probably explaining why Flagstaff has the highest concentration of benzene-soluble organics and lead (Table 9 and Figures 3 and 4). The highest concentrations of sulfate, at Holbrook (Table 9 and Figure 5), and nitrate, at Davis Dam (Table 9 and Figure 6), are best explained by the proximity of these two locations to the above-mentioned generating stations. The highest concentrations of benzene-soluble organics, at Holbrook as well as at Flagstaff (Figure 3), are explained by the fact that Holbrook is located on both sides of the main U.S. Route 66

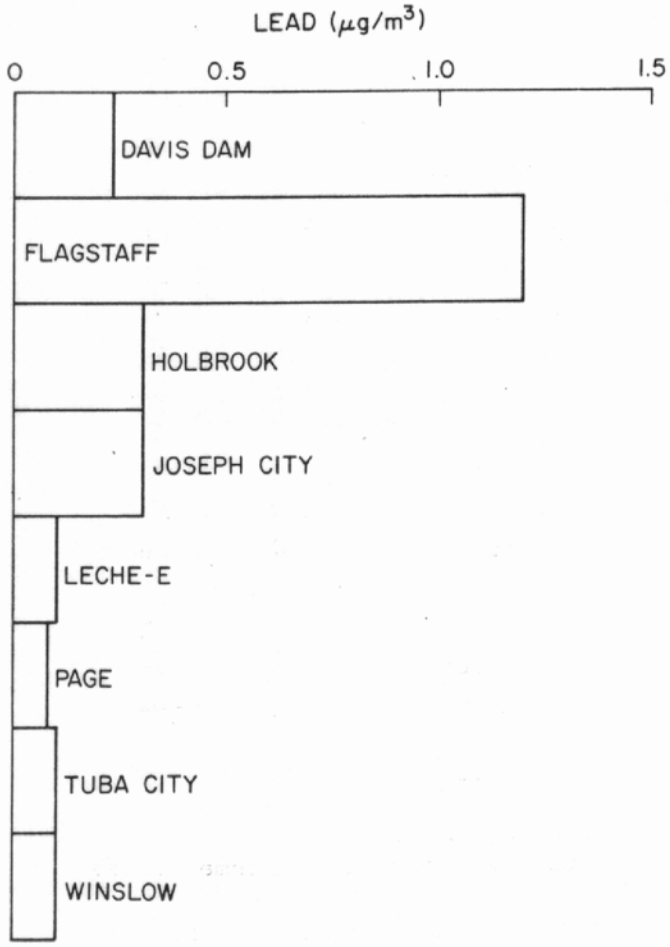

Figure 4: Aerosol Composition: Lead Measured at Various Locations (1969-1972)

Source: Division of Air Pollution Control, ASDHS

Table 9: Locations with Highest Concentrations of Listed Constituents

Joseph City	Davis Dam	Holbrook	Flagstaff
Arsenic	Arsenic	Benzene-soluble organics	Benzene-soluble organics
Bismuth	Copper		
Cadmium	Mercury		
Iron	Nitrate	Chromium	Lead
Manganese	Titanium	Cobalt	Tin
Nickel	Zinc	Sulfate	
Tin		Tin	

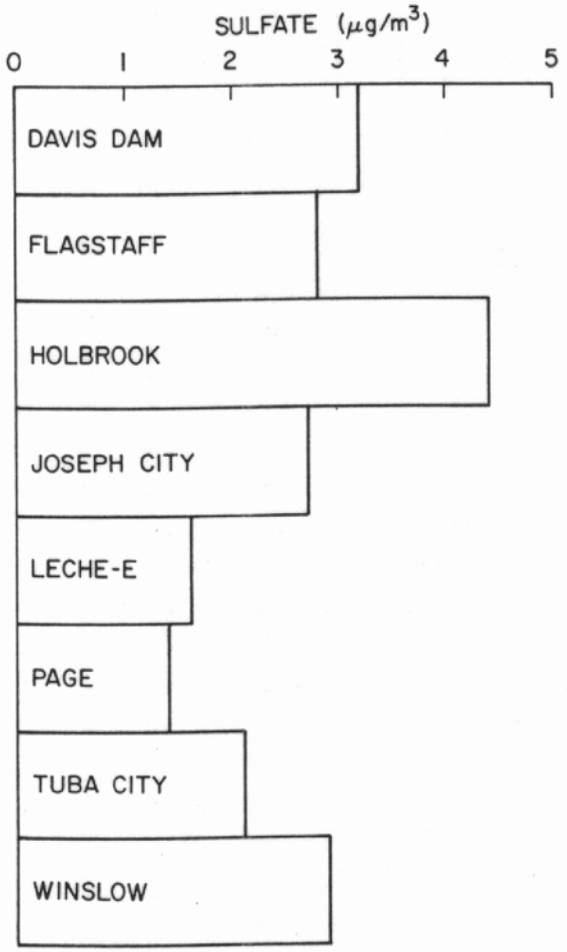

Figure 5: Aerosol Composition: Sulfate Measured at Various Locations (1969-1972)

Source: Division of Air Pollution Control, ASDHS

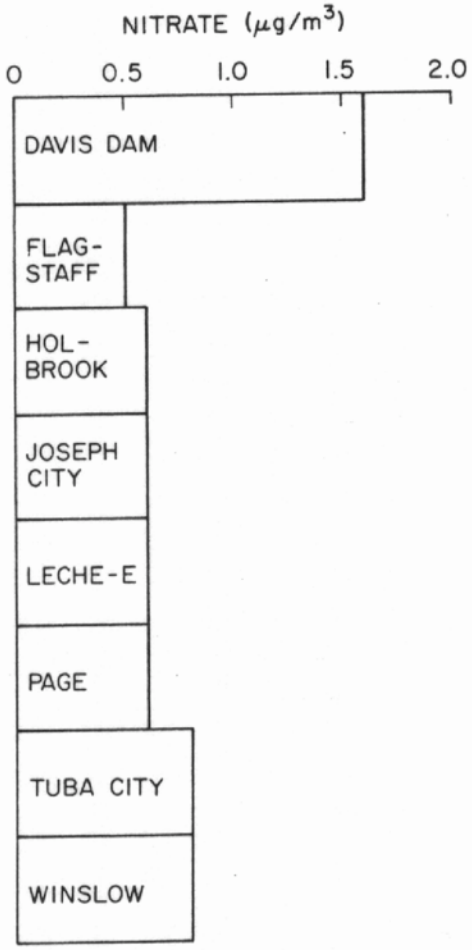

Figure 6: Aersol Composition: Nitrate Measured at Various Locations (1969-1972)

Source: Division of Air Pollution Control, ASDHS

which carries a large amount of tourist automobile traffic. The other constituents are not as easily related to one specific type of source, but they all are found in coal.

The findings listed in Table 10 indicate the expected clean air at Page and Leche-e, but, somewhat surprisingly, the lowest concentration of constituents was found at Winslow. If coal combustion is the important source of the elements listed for Winslow, except for lead, then the absence of a generating station near Winslow may explain these lowest concentrations. Lead, which comes from automobiles, should not be lowest in Winslow, where there is a large amount of traffic on U.S. Route 66 through the middle of the city. Also, Winslow has almost twice the population of Holbrook (8,000 compared to 4,760). The absence of generating stations near both Page and Flagstaff explains the lowest concentrations of sulfate and nitrate, respectively. The former case provides a particularly valuable reference because the Navajo Generating Station has recently begun the operation of one of its three 770-megawatt units. Future measurements of sulfate at Page may indicate a clear effect of the generating station. Leche-e is very near Page and shows a similarly low sulfate concentration (Figure 5). Although the expected clean air of Page was mentioned above, the actual measurement site of the high-volume sampler was only 50 meters (about 160 feet) from a jet aircraft fueling facility at the airport. This location may explain why Page has the only high concentration of zinc of those rural locations listed in Table 8.

The available data were evaluated for trends during the period 1969 through 1972. Data for all 4 years were available only for Davis Dam; data for 3 years were available for Flagstaff, Joseph City, and Page. The other locations had data for less than 3 years and hence were not considered for trend analysis. Unfortunately, over half of the values for Davis Dam and Flagstaff in 1970 were unacceptably high, and hence the 1970 data were rejected for analysis. This process of data elimination left only Davis Dam with at least 3 years of acceptable data for most of the constituents (Table 11). These remaining data indicate an increase in nitrate, a decrease in copper, and little change in the remaining constituents. The increase in nitrate possibly may be explained by the existence of the Mohave Generating Station which did not begin operation until 1970 and which added its second unit in 1971.

Aerosol Mass Concentration

The geometric mean aerosol mass concentration over the 4-year interval from 1969 through 1972 at eight locations in northern Arizona is shown by the histogram in Figure 7. The Federal secondary and Arizona annual ambient air quality standard of 60 micrograms (μg) per cubic meter geometric mean is shown for purposes of comparison. This value was chosen to protect human welfare as well as health. The two highest concentrations, at Holbrook and Joseph City, both exceed the standard and may have shown the influence of the nearby Cholla Power Plant which emitted 13,000 kg (14 tons) of fly ash aerosol per day. During this 4-year period, sawdust burners were other industrial sources in Holbrook, Winslow, and Flagstaff which may have contributed significantly to the amount of observed aerosol.

Blowing dust and sand are other contributors to the aerosol at all of these

Table 10: Locations with Lowest Concentrations of Listed Constituents

Winslow	Page	Leche-e	Flagstaff	Holbrook	Joseph City	Tuba City
Arsenic	Iron	Benzene-soluble organics	Chromium	Copper	Chromium	Cadmium
Bismuth	Manganese		Nitrate	Zinc	Vanadium	Lead
Cobalt	Mercury					
Lead	Sulfate	Lead				
Nickel	Vanadium	Mercury				
Tin		Tin				
Vanadium						

Table 11: Concentration[a] of 18 Constituents for 4 Consecutive Years in Aerosol Sampled at Davis Dam with High-Volume Sampler

	Years Sampled			
	1969	1970	1971	1972
Constituent	(micrograms per cubic meter)			
Sulfate	3.4	2.2	4.4	2.7
Zinc	---	---	0.22	0.15
Benzene-soluble organics	1.4	0.9	0.7	1.1
Nitrate	1.2	1.4	2.1	1.7
Iron	0.6	---	0.5	0.47
Copper	0.4	---	0.15	0.12
Lead	0.1	---	0.1	0.11
Nickel	0.005	---	0.006	0.008
Chromium	0.004	---	0.003	0.001
Cobalt	0.004	---	0.002	0.013
Cadmium	0.002	---	0	0.001
Arsenic	0.001	0.005	0.002	0.003
Manganese	0.02	---	0.02	0.013
Bismuth	---	---	0.021	0.004
Mercury	---	---	---	0.0039
Tin	---	---	0.01	0.001
Titanium	---	---	0	0.002
Vanadium	---	---	0.001	0.001
Total Aerosol	29	31	33	36

[a]Annual arithmetic mean, except for annual geometric mean, of total aerosol supplied by Division of Air Pollution Control, Arizona State Department of Health Services

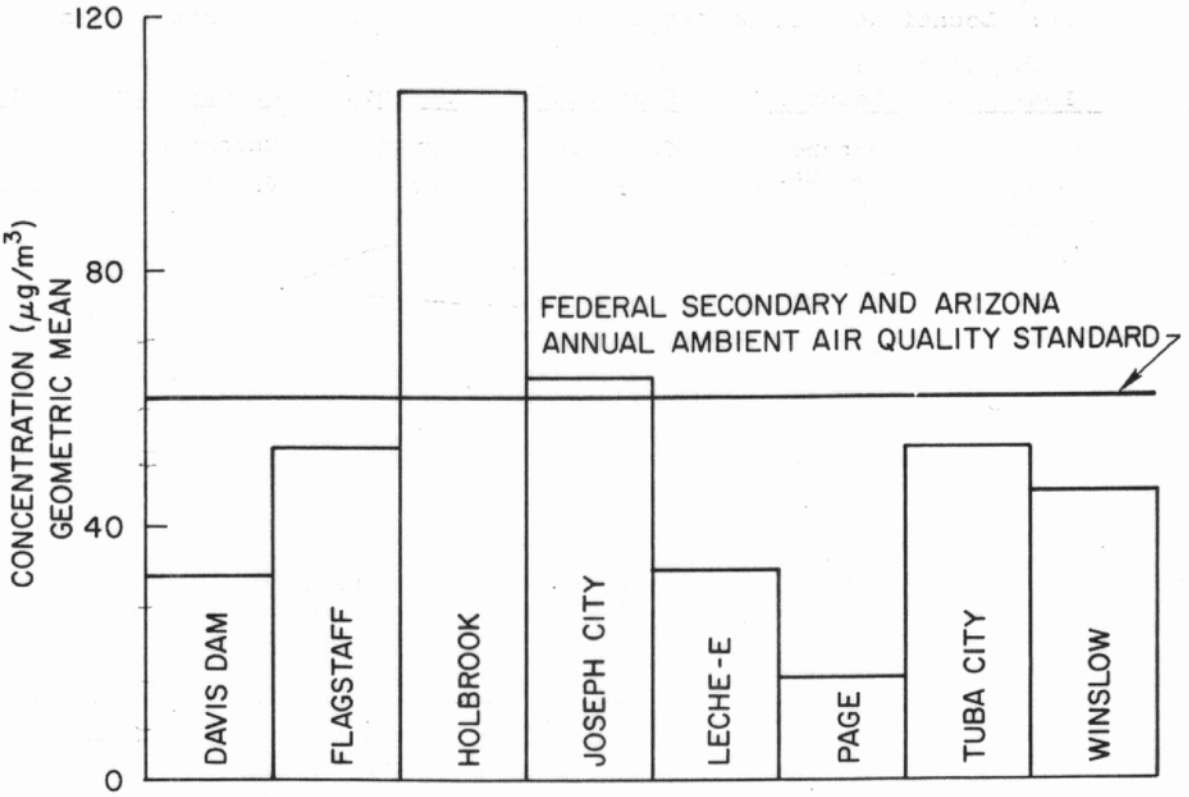

Figure 7: Aerosol Mass Concentration Measured at Various Locations (1969-1972)

Source: Division of Air Pollution Control, ASDHS

eight locations. Unpaved roads expose soil to the wind, and passing vehicles thrust it high enough above ground to allow its entrainment in the wind. If the results in Figure 7 are compared with the results from four other locations (shown in Figure 8), it is found that the Grand Canyon has the lowest concentration as well as the longest time-span of available data. The Grand Canyon data may not be representative of the whole canyon, but instead apply only to the heavily used part of the South Rim near the Visitor Center. The Page Airport measurement site for the result in Figure 8 is near some unpaved roads, and this may account for its higher concentration as compared to the Page Airport result (Figure 7) obtained farther away from an unpaved road but nearer the jet aircraft fueling facility mentioned previously.

If the aerosol mass concentration data from Bullfrog and Page Airport are separated into values for weekdays and weekends, it is seen that the geometric mean concentrations are significantly different (Table 12). The higher concentrations on weekends may be caused by the increased recreational activity of people, including vehicular traffic on unpaved roads.

Table 12: Aerosol Mass Concentration[a] on Weekday Versus Weekend

Location	Weekday	Weekend	Time Period
Bullfrog	16	18	Oct 1971-Jul 1973
Page Airport	29	28	Jan 1972-Aug 1973

[a]Geometric mean in micrograms per cubic meter

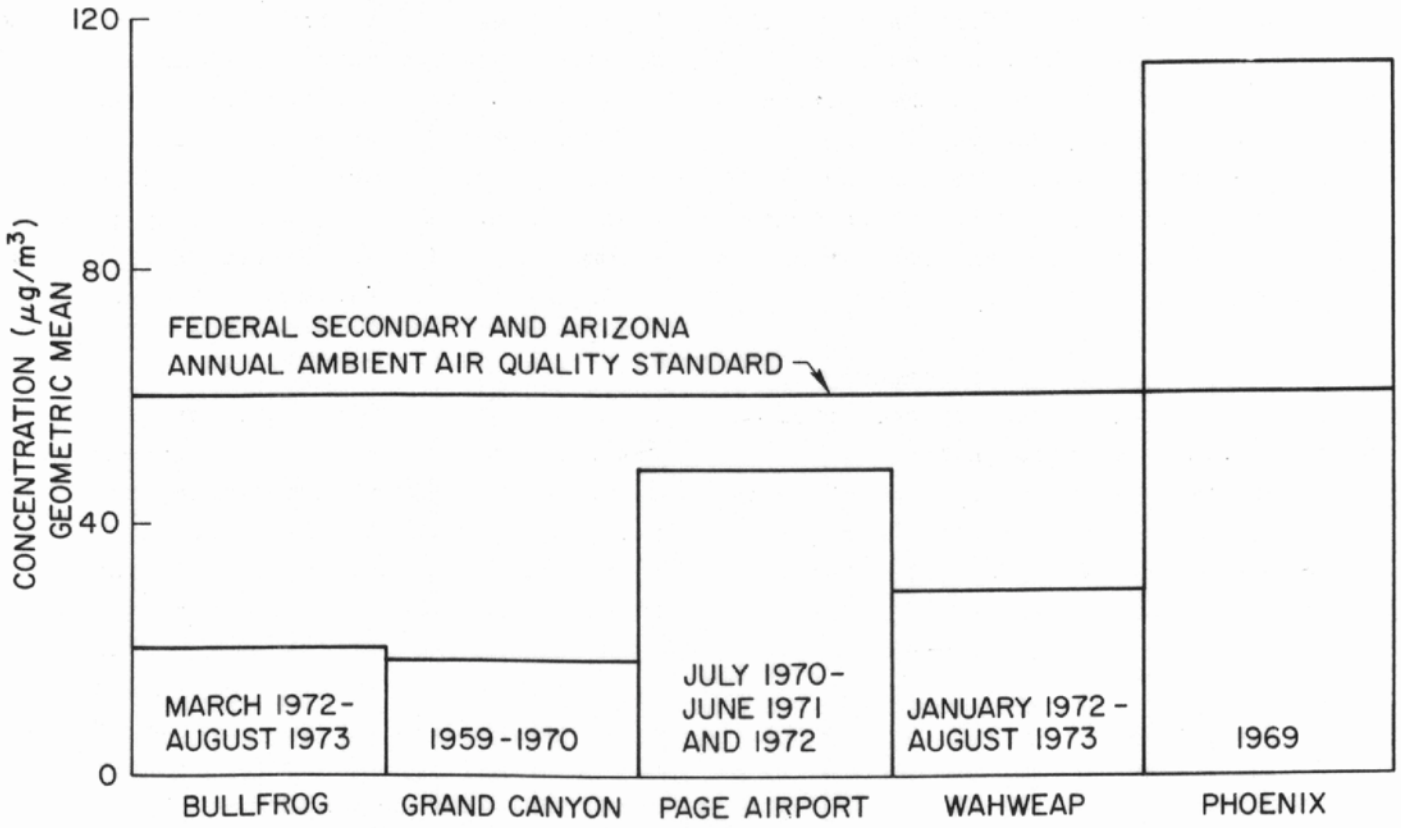

Figure 8: Aerosol Mass Concentration

Source: Air Quality Section, Utah State Division of Health (Bullfrog and Wahweap); DAPC, ASDHS (Grand Canyon); Dames & Moore (Page Airport)

At this point in the discussion of aerosol mass concentration, it may be helpful to discuss the effect of different averages or statistical measures of central tendency. The difference between the arithmetic and geometric means is that the geometric mean depresses the effect of especially high values.

Table 13 presents limited data from the National Aerometric Data Bank for the geometric mean aerosol mass concentration at nine locations in northern Arizona during 1972. These data are separated into calendar quarters. At seven of the nine locations, higher concentrations dominate the warmer half of the year (second and third quarters), and lower concentrations dominate the colder half of the year (first and fourth quarters). These results are expected because the warmer season is the tourist season, with vehicles and unpaved roads receiving more use than in the colder season, when not only is there less traffic, but snow holds down the dust at some locations, such as Flagstaff.

The great variation in measured aerosol mass concentration can be seen from the statistics presented in Table 14. The lowest concentration was 1 $\mu g/m^3$ (Page in the fourth quarter), and the highest concentration was 543 $\mu g/m^3$ (also Page, but in the first quarter).

Aerosol Number Concentration

Single measurements have been made of aerosol number concentrations at remote sites near Page since September 3, 1972, and in downtown Page since March 5, 1973. Continuous measurement has been made at the Wahweap Marina between April 18 and May 6, 1973, and between June 7 and 26, 1973. A manually operated portable Gardner Associates Small Particle Detector is used to make the single measurements, and a motor-driven automatic General Electric Condensation Nuclei Counter is used to make the continuous measurements. The latter instrument is constrained to locations with 115-volt AC electric power.

Some statistics of the single measurements for the period September 1972 through October 1973 are given in Table 15. The monthly arithmetic means are all less than one-seventh of that for downtown Page ($16,430/cm^3$). The latter was measured between March 5 and September 7, 1973, and includes a minimum value of $1,720/cm^3$ and a maximum value of $265,000/cm^3$. With 90% confidence, the mean of $16,430/cm^3$ lies between $10,800/cm^3$ and $22,100/cm^3$. All of the means in Table 15 are higher than the mean of $900/cm^3$ (Junge, 1963) and the median of $520/cm^3$ (Hogan et al., 1967) for oceanic measurements tabulated by others. A comparison of these values is presented in Figure 9. The minimum of $200/cm^3$ for January 1972 is an extreme lower value that usually is obtained only in very clean regions. The highest monthly mean was $2,130/cm^3$ for May 1973. Concentrations below $5000/cm^3$ are considered to be background values, while higher concentrations are considered to be contaminated and are therefore excluded from the analysis of background air quality. The weekday mean of $1,470/cm^3$ is not sufficiently separated from the $1,590/cm^3$ weekend mean to separate their 95% confidence intervals; hence, no conclusion can be drawn about the difference.

So far, seasonal analysis has been completed for single measurements on weekends, but not on weekdays. The statistics in Table 16 indicate a maximum during spring.

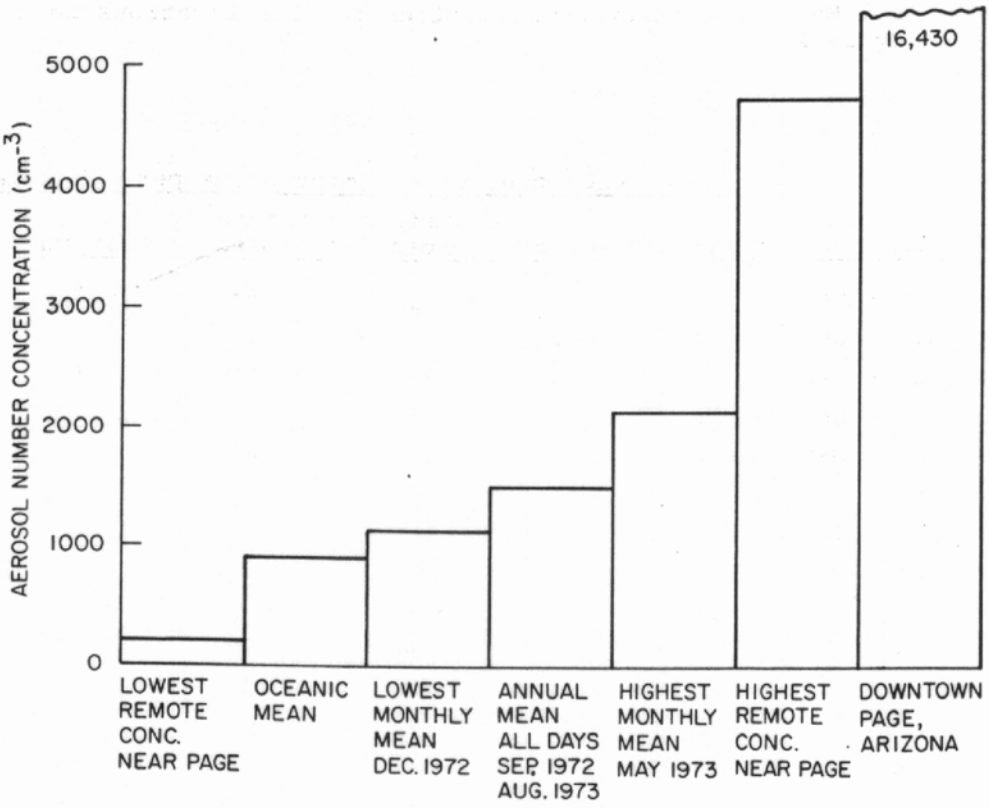

Figure 9: Aerosol Number Concentration

Source: Background Air Quality Subproject, Lake Powell Research Project (except Oceanic Mean from Junge, 1963)

Table 13: Seasonal Variation of Aerosol Mass Concentration in 1972 (Geometric Means)

Location	Quarter			
	Jan - Mar	Apr - Jun	Jul - Sep	Oct - Dec
Flagstaff	No[a]	Yes[b]	High	Low
Page	No	No	High	Low
Tuba City	High	Low	No	No
Leche-e	Low	High	No	No
Winslow	No	No	High	Low
Joseph City	Low	High	No	No
Holbrook	High	Low	No	No
Katherine's Landing	Yes	High	Yes	Low
Davis Dam	Yes	Yes	High	Low

Source: Environmental Protection Agency

[a] No = no data available
[b] Yes = data available

From the statistics (Table 17) for the continuous measurement of aerosol number concentration made at Wahweap Marina, it is clear that the daily minimum occurs in the morning, usually before sunrise, and the daily maximum occurs rather late in the evening. This latter occurrence may be caused by evening emissions being concentrated under a low-level radiation inversion. The second time period seems to have been more contaminated. There is no clear difference between weekdays and weekends.

Aerosol Size Distribution

The only aerosol size distribution measurements near Lake Powell were made by Dames & Moore at Page Airport. Two different instruments were used: a cascade impactor and a high-volume segregator. Both instruments are designed to separate particles from the sampled air in stages, largest particles first and smallest last. The cascade impactor separates aerosol into the nine diameter ranges indicated in Table 18, and the high-volume segregator

Table 17: Aerosol Number Concentration Statistics From Continuous Measurements Made at Wahweap Marina

			Aerosol number (per cubic centimeter)		
Statistic	Day Class	Hour	1973 Apr 18-May 6	1973 Jun 7-26	Hour
Absolute Minimum	Weekend	8-9, 9-10, 10-11 AM	100	600	3-4, 9-10 AM
	Weekday	1-2, 2-3 AM	300	600	2-3, 4-5 AM 1-2, 2-3 PM
Minimum Hourly Mean	Weekend	3-4 AM	2,450	3,100	11-12 AM
	Weekday	2-3 AM	2,950	1,900	3-4 AM
Mean Daily Mean	Weekend	---	5,160	8,230	---
	Weekday	---	5,560	6,990	---
Maximum Hourly Mean	Weekend	10-11 PM	14,900	20,000	9-10 PM
	Weekday	10-11 PM	10,300	13,300	7-8 PM
Absolute Maximum	Weekend	10-11 PM	21,300	29,400	9-10 PM
	Weekday	6-7 AM	28,800	30,000	7-8 PM

Table 18: Cascade Impactor 2-Day Samples at the Page Airport, Sampling Period March through December 1972

Size Range (microns)	Mean (micrograms per cubic centimeter)	Maximum	Minimum	Percent in Interval
0.0 to 0.1	12	32	0	8.6
0.1 to 0.3	14	71	0	10.1
0.3 to 1.0	17	51	2	12.2
1.0 to 2.0	17	54	2	12.2
2.0 to 3.3	13	61	0	9.4
3.3 to 5.5	15	44	0	10.8
5.5 to 9.2	16	49	0	11.5
9.2 to 30	15	54	0	10.8
Above 30	20	69	0	14.4
	139			

separates aerosol into the five diameter ranges indicated in Table 19. For the time period March through December 1972, some overall results from the two instruments are presented in Tables 18 and 19, and monthly results are presented in Tables 20 and 21.

The arithmetic mean total concentration of 139 $\mu g/m^3$ in Table 18 suggests a higher overall collection efficiency of the cascade impactor as compared to both the high-volume segregator (57 $\mu g/m^3$ in Table 19) and the high-volume sampler (arithmetic mean of 40 $\mu g/m^3$ from Table 14). The zero and extremely low values in the minimum concentration columns of Tables 18 and 19 indicate the existence of days with very little aerosol in at least some size ranges, while the concentrations in the maximum columns show how much aerosol exists in each range on the dirtiest days. For both instruments, the highest proportion is the largest size range. Since

Table 19: Two-Day Particulate Samples Collected Via High-Volume Segregator at the Page Airport, From March through December 1972

Size Range (microns)	Mean (micrograms per cubic centimeter)	Maximum	Minimum	Percent in Interval	Percent in Interval Cascade Impactor
0.0 to 1.1	12.8	85.7	0.0	22.3	30.9
1.1 to 2.0	6.0	34.7	0.2	10.5	12.2
2.0 to 3.3	8.2	62.9	0.1	14.3	9.4
3.3 to 7.0	11.7	81.8	1.0	20.4	14.1
Above 7.0	18.6	135.9	2.3	32.5	33.4
	57.3				

Table 20: Percentage of Collected Aerosol in Each of Nine Size Ranges According to a Cascade Impactor at Page Airport

	Size Range (microns)								
	0.-0.1	0.1-0.3	0.3-1.0	1.0-2.0	2.0-3.3	3.3-5.5	5.5-9.2	9.2-30	>30
1972					Percentages				
Mar-Dec	8.2	10.2	12.2	12.0	10.1	10.8	11.4	10.6	14.5
Mar	6.5	12.9	9.7	17.2	7.5	14.0	9.7	7.5	15.0
Apr	7.1	9.8	15.2	14.1	16.9	11.8	6.3	7.4	11.4
May	7.9	10.8	10.3	10.3	11.1	10.8	13.9	15.1	9.8
Jun	17.8	10.6	7.4	8.9	7.5	6.3	10.7	12.5	23.3
Jul	21.2	5.8	10.6	12.1	10.0	9.1	15.5	10.6	12.1
Aug	8.3	9.4	9.4	6.2	11.4	6.3	12.0	17.2	19.8
Sep	4.6	10.1	11.8	13.1	7.2	14.8	11.8	11.4	15.2
Oct	7.8	9.4	12.6	11.4	8.2	13.5	11.4	9.4	16.3
Nov	12.4	7.2	15.4	16.0	5.2	14.2	15.4	5.2	9.0
Dec	6.0	15.7	14.9	13.3	8.0	7.6	12.5	8.4	13.6

Source: Dames & Moore

Table 21: Percentage of Collected Aerosol in Each of Five Size Ranges According to a High-Volume Segregator at Page Airport

	Size Range (microns)				
	0.-1.1	1.1-2.0	2.0-3.3	3.3-7.0	>7.0
Time Period 1972			Percentages		
Mar - Dec	22.3	10.5	14.4	20.4	32.4
Mar	41.4	6.3	10.5	15.6	26.2
Apr	22.8	9.6	16.2	21.2	30.2
May	19.5	9.9	15.6	21.7	33.3
Jun	21.5	8.9	14.9	20.5	34.2
Jul	23.7	9.0	14.3	20.7	32.4
Aug	19.9	13.4	15.1	21.6	30.0
Sep	20.7	14.0	15.2	21.2	28.9
Oct	15.6	11.6	11.3	17.9	43.6
Nov	28.1	11.4	12.0	19.8	28.7
Dec	27.3	11.0	14.0	19.7	28.0

mass is proportional to the cube of the size, the combined mass of very few large particles can equal the combined mass of many more small particles. The more numerous size ranges of the cascade impactor are aggregated to provide the results in the last column of Table 19. The two instruments agree in the relative masses collected in three of the five ranges: 0 to 1.1 μ, 3.3 to 7.0 μ, and greater than 7.0 μ.

The monthly results, shown in Table 20, for the cascade impactor show no clear dominance of any size range, while the more highly aggregated size ranges of the high-volume segregator show the dominance of aerosol larger than 7.0 μ in size for all months except November and December (Table 21). Possibly, snow cover and less vehicular traffic on unpaved roads account for this observation.

Gas Concentrations

Ammonia and Carbon Monoxide

At present, there exist no measurements of ammonia and carbon monoxide in the Lake Powell Region.

Hydrocarbons

So far, measurements have been made of the concentration of methane, propane, butane, pentane, hexane, ethylene, propylene, and butylene. Statistics on the methane data are presented in Table 22 for the period October 1972 through June 1973. The overall arithmetic mean of 1.4 parts-per-million (ppm) is in the range between 1.2 ppm (Glueckauf, 1951) and 1.5 ppm (Goldberg, 1951; Goldberg and Mueller,

Table 22: Methane Statistics From Single Measurements at Remote Sites Near Page

Time Period	Concentration (parts per million)					
	Minimum	Median	Mean - 1/2 95% C.I.[a]	Arithmetic Mean	Mean + 1/2 95% C.I.[a]	Maximum
Oct 1972	0.9	1.2	1.5	1.7	1.8	2.7
Nov 1972	1.0	1.8	1.5	1.6	1.6	2.0
Dec 1972	1.3	1.7	1.7	1.7	1.8	2.4
Jan 1973	0.8	1.2	1.2	1.3	1.3	1.9
Feb 1973	0.9	1.4	1.4	1.5	1.5	2.0
Mar 1973	1.0	1.4	1.4	1.4	1.4	1.8
Apr 1973	1.1	1.4	1.3	1.4	1.4	1.5
May 1973	1.2	1.3	1.3	1.3	1.4	2.1
Jun 1973	0.9	1.3	1.3	1.3	1.3	1.6
TOTAL	0.8	---	---	1.4	---	2.7

[a] C.I. = Confidence Interval

1953) measured by others. There is no significant difference between weekday and weekend means. The statistics in Table 22 show that the background methane concentration is quite constant, especially compared to similar aerosol statistics. Therefore, the measurement of methane was terminated on June 29, 1973.

There are a few measurements of other hydrocarbons for which means are shown in Table 23 for remote sites near Page compared to those for Page and Wahweap Marina. As we anticipated, the remote sites have extremely low concentrations of every hydrocarbon for which we have sufficient data. Values for the remote sites are many times lower than the concentrations measured at Page and Wahweap Marina.

Hydrogen Sulfide

No measurements of hydrogen sulfide have been made in the Lake Powell region, and there is no reason to expect that hydrogen sulfide is present there in significant concentration.

Table 23: Statistics for Hydrocarbons Other Than Methane From Single Measurements at Remote Sites Near Page

Hydrocarbon	Formula	Mean Concentration (parts per billion) Remote Sites	Page and Marina
Propane	C_3H_8	3	14
Butane	C_4H_{10}	1	8
Pentane	C_5H_{12}	3	35
Hexane	C_6H_{14}	4	17
Ethylene	C_2H_4	-	10
Propylene	C_3H_6	2	8
Butylene	C_4H_8	-	8

Nitrogen Oxides

Some statistics for nitrogen oxides (NO_2, NO, NO_x) at Page, Grand Canyon, and Davis Dam are shown in Table 24. The one non-zero measurement made in 1970 is high compared to all the other statistics but is still believable because its short 1-hour sampling time may have occurred during a transient high concentration. The Grand Canyon arithmetic mean concentration for NO_2 in 1971 is the highest 1-day mean, probably because the sampler is located on the South Rim behind the Visitor Center, near the most heavily traveled road.

The 1972 monthly mean NO_x concentrations at Page are presented in Figure 10. The annual extrema are also shown. The maximum, in September, is 50 times higher than the minimum, in April. Possibly the spring injection of ozone from the stratosphere causes the minimum by destroying some NO_x.

The seasonal means for Page in 1972 do not differ enough to enable any conclusions to be drawn. There are seasons and individual months for which the amount of NO_2 seems higher than the NO_x. This is impossible in reality and reflects the difficulties of the different measurement methods. Much of these data are based on the Jacobs-Hochheiser method of measuring NO_2, sanctioned and later dropped by the EPA as the reference method (EPA, 1971). Therefore all NO_2 data around the world must be considered in light of the measurement method used. Measurements must be rejected which are based on the Jacobs-Hochheiser method rather than on the Saltzman method or its modification (Levaggi et al., 1973).

Table 24: Statistics on Nitrogen Oxides Measured at Page Airport by Dames & Moore Between 1970 and 1972

Time Period	Sampling Time	Number Samples	Concentration (parts per billion) Arithmetic Mean NO	NO_2	NO_x	
14 Dec 1970	1 hour	1	20	40	--	
1971 (Mar-Nov)	1 hour	11	2	1	--	
Nov 1971	1 day	11	--	--	3	
1972	1 day	145	--	4.5	--	
	1 day	64	--	--	3.7	
Spring 1972	1 day	18	--	4.0	--	
	1 day	--	--	--	1.0	
Summer 1972	1 day	51	--	3.6	--	
		7	--	--	6.7	
Fall 1972	1 day	55	--	5.4	--	
		12	--	--	12.8	
Jan 1972	1 day	8	--	--	1.5	
Feb 1972	1 day	8	--	--	1.1	
Mar 1972	1 day	6	--	--	0.7	
Apr 1972	1 day	15	--	--	0.4	
May 1972	1 day	17	--	4.3	--	
		5	--	--	3.5	
Jun 1972	1 day	18	--	4.0	--	
		4	--	--	3.5	
Jul 1972	1 day	13	--	3.8	--	
		2	--	--	9.8	
Aug 1972	1 day	20	--	3.0	--	
		1	--	--	13	
Sep 1972	1 day	17	--	6.2	--	
		3	--	--	20	
Oct 1972	1 day	19	--	5.4	--	
		4	--	--	14.8	
Nov 1972	1 day	19	--	4.8	--	
		5	--	--	6.9	
Dec 1972	1 day	21	--	4.6	--	
		3	--	--	7.1	
1969	1 day	--	--	12	--	Grand Canyon (ASDHS)
1971	1 day	13	--	12	--	Grand Canyon (ASDHS)
1971	1 day	42	--	8.7	--	Davis Dam (ASDHS)
1972	1 day	--	--	4	--	Davis Dam (ASDHS)
1969	1 day	--	--	90	--	Phoenix (ASHDS)
Jan - Aug 1971	1 day	--	--	21	--	Farmington (N.M.) (New Mexico Environmental Protection Agency)

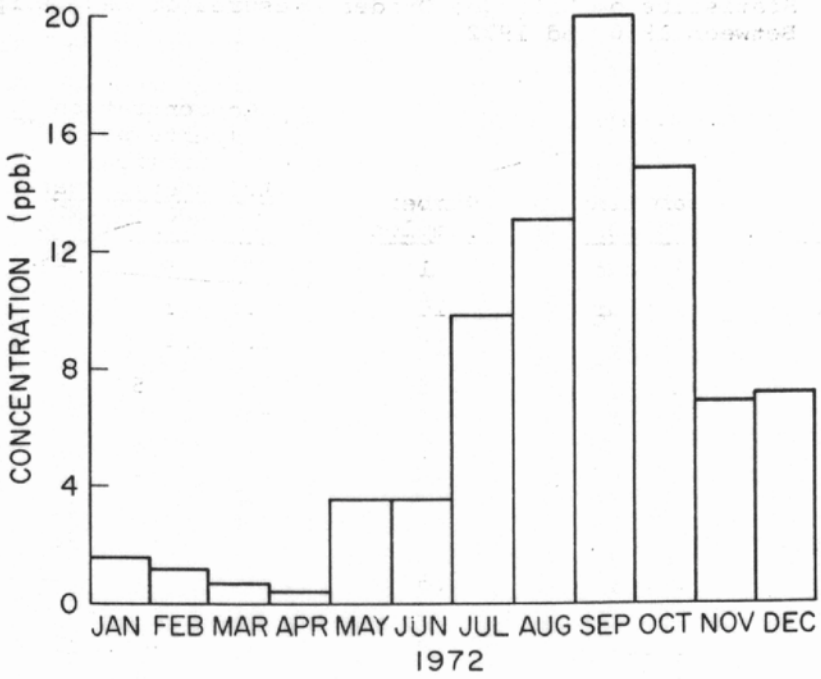

Figure 10: Monthly Arithmetic Mean NO_x Concentrations

Source: Dames & Moore

Oxidant

Oxidant near Lake Powell is being measured by Dames & Moore at Page Airport, beginning in July 1970. Dames & Moore has used three methods at different times, starting with the Haagen-Smit method; adding, on April 25, 1972, an automatic coulometric method; and adding the EPA-approved reference method on May 4, 1972. The major component of oxidant, especially in relatively clean air, is ozone, which is naturally generated in the stratosphere by solar radiation and in the troposphere by photochemical reactions involving hydrocarbons and nitrogen oxides. The monthly and annual means are listed in Table 25. The monthly variations in 1971 and 1972 are shown in Figure 11. The spring maximum is clearly seen in 1971 and barely discernible in 1972. This spring maximum is the result of ozone being injected from the stratosphere into the troposphere upon the seasonal change in the general atmospheric circulation. The 1971 and 1972 annual arithmetic mean concentrations are much more than the concentrations measured at the Grand Canyon and in Phoenix in 1969 (ASDHS, 1972), but are less than the concentrations measured at other clean locations such as Greenland in August 1973 (Walther, 1974) and Whiteface Mountain, New York, between January and July 1973 (Schaefer et al., 1973). These observations are consistent with others (Stasiuk and Coffey, 1974) that indicate ozone concentrations which are higher in rural areas than in urban areas, with the exception of special cases such as Los Angeles.

Table 25: Oxidant Concentration: Measured at Page Airport by Dames & Moore (unless otherwise indicated)

Period		Concentration (parts per billion) Arithmetic Mean	
1970	Jul	36	
	Aug	32	
	Sep	37	
	Oct	37	
	Nov	16	
	Dec	17	
1/2-Year	Mean	33	
1971	Annual	21	
	Jan	11	
	Feb	12	
	Mar	35	
	Apr	35	Spring Maximum
	May	--	
	Jun	33	
	Jul	19	
	Aug	18	
	Sep	15	
	Oct	13	
	Nov	13	
	Dec	15	
1972	Annual	19	
	Jan	18	
	Feb	19	
	Mar	18	
	Apr	20	
	May	23	
	Jun	20	
	Jul	21	
	Aug	20	
	Sep	17	
	Oct	16	
	Nov	18	
	Dec	16	
Greenland	1973		(Walther,
	Aug	32	1974)
Whiteface Mountain, New York	1973		(Schaefer et al., 1974)
	Jan	24	
	Feb-Mar	28	
	Apr-May	37	
	Jun-Jul	53	
Grand Canyon, Arizona 1969 Annual Arithmetic Mean		5	(ASDHS, 1972)
Phoenix, Arizona 1969 Annual Arithmetic Mean		9	(ASDHS, 1972)

Sulfur Dioxide

Sulfur dioxide (SO_2) has been measured directly by Dames & Moore at Page Airport and by the Arizona State Department of Health at several locations in the state, using the West-Gaeke method. It has also been measured indirectly by the sulfation rate of lead peroxide candles by Dames & Moore and the Utah State Division of Health. The latter indirect method is important because the SO_2 concentration is so low in the Lake Powell region as to be unmeasureable by direct methods much of the time. The frequency distributions in Table 26 show how seldom the 1-day average concentration exceeds 1 ppb, below which the instruments cannot measure. The annual arithmetic mean sulfation rates for 1970 through 1973 at 15 different locations (Table 27) show no clear trend in time. The four rates in Table 27 that are higher than 0.1 mg SO_3 per 100 cm^2 per day (Crossing of the Fathers, Utah, 1973; Wahweap, Arizona, 1973; Kaibito, Arizona, 1970; Monument Valley, Arizona, 1970) have no obvious explanation because there are no man-made SO_2 sources near any of these locations.

Water Vapor

Possibly, the main importance of water vapor in the atmosphere to air pollution is its effect on the size distribution of hygroscopic aerosol and the rate of various gas-to-aerosol conversions, such as SO_2 to sulfate. The most common measure of water vapor content is relative humidity.

Relative humidity is measured with a hair hygrograph at Page Airport by the Bureau of Reclamation. It is unclear whether the instrument has been

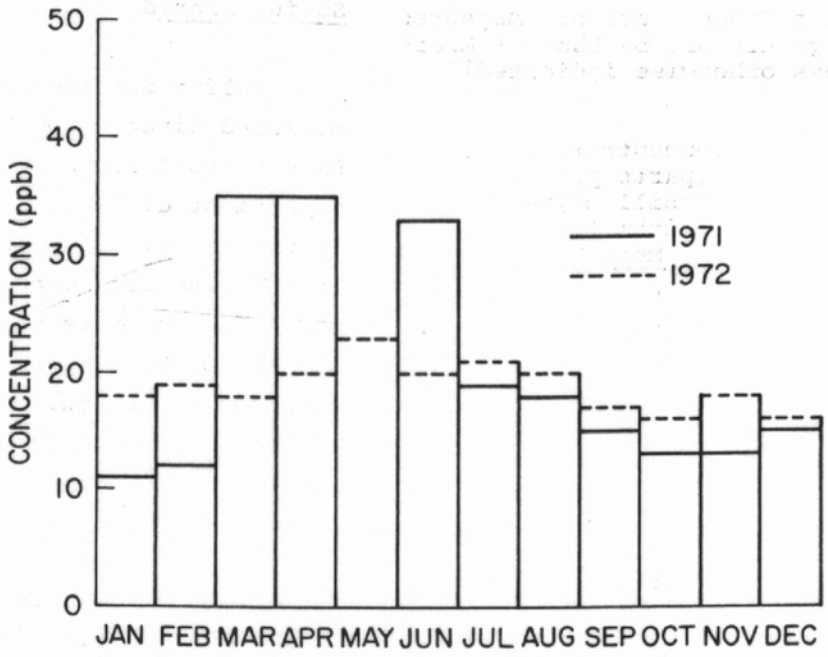

Figure 11: Oxidant Concentration

Source: Dames & Moore

Table 26: Frequency Distribution of Sulfur Dioxide Concentrations at Page Airport[a,b]

Concentration (parts per billion)	15 May 1970-31 Dec 1971 24-hour Colorimetric	15 May 1970-31 Dec 1970 1 hour Conductimetric	1972 24-hour Colorimetric
	(Percentages)		
0-1	95.8	58.1	97.9
1-2	1.87	22.4	1.4
2-3	0.6	14.7	4.7
3-4	0	3.6	---
4-5	0.3	0.6	---
5-6	0	0	---
6-7	0	0	---
7-8	0.3	0.6	---
8-9	0.63	---	---
9-10	0	---	---
10-11	0	---	---
11-12	0	---	---
12-13	0.3	---	---

[a] Arizona annual ambient air quality standard is 23 parts per billion

[b] Grand Canyon 1969 annual arithmetic mean is 4 parts per billion (ASDHS, 1972), Phoenix 1969 annual arithmetic mean is 4 parts per billion (ASDHS, 1972), and Farmington 1969 annual arithmetic mean for period from October 10, 1970, through August 10, 1971, is 2 parts per billion (New Mexico Environmental Improvement Agency, 1972)

calibrated with an acceptable standard such as a wet-and-dry bulb psychrometer. For the limited analysis of hygrograph records from January through April 1972, the monthly arithmetic means are shown in Table 28 along with regional long-term means.

The decrease in relative humidity that is expected from winter to spring is obvious in both data sets, but the airport seems to be drier than the region in general.

Noise

Increasingly, in recent years, noise is becoming recognized as a special form of air pollution, requiring air as the medium for transmitting a purely mechanical vibration. To our knowledge, noise is only being measured in the Lake Powell region by the Lake Powell Research Project. Some extrema (minima and maxima) are listed in Table 29 for 10 days in early 1973 when noise was measured

Table 27: Sulfation Rates

Location	Sulfation Rates (milligrams SO_3 per 100 square centimeters per day) 1970 Aug-Dec	1971	1972	1973 Jan-Sep	Source
Moab, Utah	---	---	0.060		USDH[a]
Bullfrog, Utah	---	---	0.044	0.061	USDH
Crossing of the Fathers, Utah	---	---	0.065	0.13	USDH
Wahweap, Arizona	---	---	0.069	0.15	USDH
Grand Canyon, Arizona	0.07	0.029	0.014	---	D&M[b]
Flagstaff, Arizona	0.07	0.016	0.021	---	D&M
Kaibito, Arizona	0.11	0.010	0.013	---	D&M
Monument Valley, Arizona	0.12	0.018	0.025	---	D&M
Bullfrog, Utah	---	0.006	0.010	---	D&M
Navajo Mountain, Arizona	0.07	0.021	0.009	---	D&M
Page Airport, Arizona	0.05	0.022	0.014	---	D&M
Leche-e Rock, Arizona	---	0.008	0.008	---	D&M
Lees Ferry, Arizona	0.04	0.028	0.008	---	D&M
Wahweap, Arizona	0.06	0.030	0.012	---	D&M
Padre Bay, Utah	---	0.008	0.010	---	D&M
Rainbow Bridge, Utah	---	0.016	0.018	---	D&M
Hole-in-the-Rock, Utah	---	0.010	0.008	---	D&M
All of Above	0.07	0.017	0.024	0.114	

Overall Mean: 0.056

[a] USDH = Utah State Division of Health

[b] D&M = Dames & Moore

Table 28: Relative Humidity

Location	1972 Relative Humidity (percent) Jan	Feb	Mar	Apr	Source
Page Airport	41	36	26	27	Bureau of Reclamation
Lake Powell Region	60	60	50	38	Climatic Atlas of United States (U.S. Dept. of Commerce, Environ. Data Service, 1968)

continuously at various locations. It is so quiet at these locations that the actual minima may be less than the tabulated values, which are at or close to the lowest noise level measureable with the instrument. The instrument's lower limit is determined by the amount of the internal electrical noise level within it. All the values are expressed in the accepted unit of decibel (db), and the noise frequency (pitch) spectrum is weighted to represent the hearing response of the average normal human ear (the A scale). The tabulated maxima give some measure of the occasional noisiness of these locations. Because the noise level is recorded automatically and the recorder is unattended, no record

Table 29: Noise Data

Date (1973)	Day	Location	Minimum (dbA)[a]	Time (MST)[b]	Maximum (dbA)[a]	Time (MST)[b]
1 Feb	Thur.	Antelope Rock	27.5	1730	28	1115
8 Feb	Thur.	Leche-e Rock	27	0100	31	1130
10 Feb	Sat.	Leche-e Rock	27.5	1730	65	1745
13 Feb	Tues.	Leche-e Rock	22.3	1500	53	1400
17 Feb	Sat.	Leche-e Rock	23.5	1230	58	1245
20 Feb	Tues.	Utah Fish and Game	26	1430	63	2030
27 Feb	Tues.	North side, Wahweap Bay	22.5	1700	64.8	1415
3 Mar	Sat.	North side, Wahweap Bay	23	1515	70	1530
4 Apr	Wed.	Wahweap sewage lagoon	24	1830-1930	70	1300-1430
16 Apr	Mon.	Wahweap Bay	24	1300	70	1845

[a] dbA = decibels in A scale

[b] MST = Mountain Standard Time

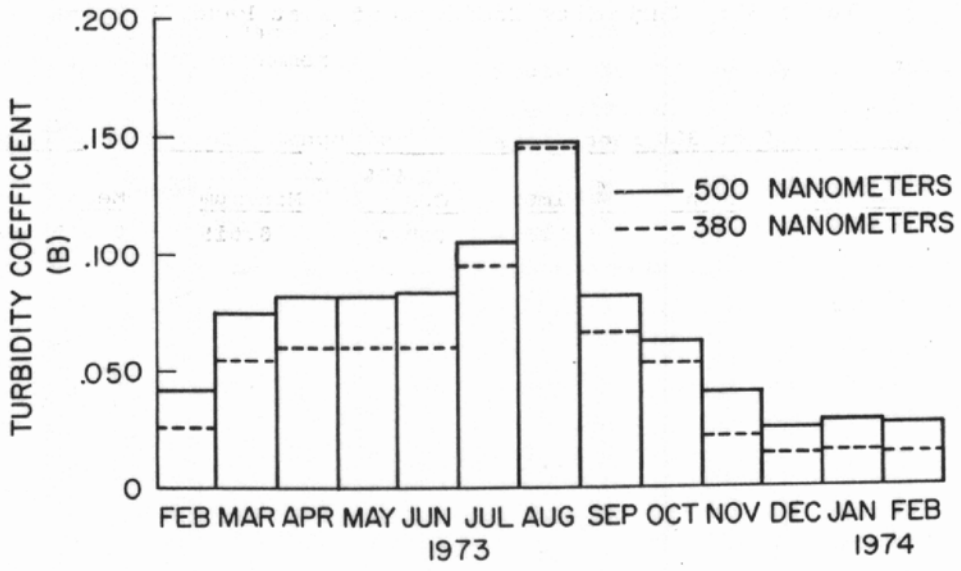

Figure 12: Turbidity Coefficient (B)

Source: Dames & Moore

is available of the sources of the noise maxima. The very low maximum of 31 dbA which was recorded on February 8, 1973, incicates an exceptionally quiet day.

Radioactivity

As mentioned in the section entitled Definition of Air Quality, we have not measured radioactivity in the Lake Powell area. To our knowledge, it it not being measured now by others.

Turbidity

Turbidity is a measure of the total aerosol in a vertical column of atmosphere. It is measured only on clear days because the measurement method is based on the solar radiation reaching the earth's surface at the two wavelengths of 380 and 500 nanometers (nm = 10^{-9} meter). The 1-year, seasonal, and monthly arithmetic means for February 1973 through February 1974 are listed in Table 30. The monthly means are plotted in Figure 12. The higher coefficients at 500 nm indicate the greater effect of the atmospheric aerosol at the red end of the spectrum (500 nm) than at the blue end (380 nm). The atmosphere was most turbid during August, on a monthly basis, and during summer, on a seasonal basis. The atmosphere was least turbid during winter. The difference may be due to the relative ease with which the dry soil of summer, as compared to the wet soil of winter, can be lifted into the atmosphere.

Visibility

In the Lake Powell region, the only measurement of visibility is being made by Dames & Moore, using the following three methods. Their best method for the long path measurement of regional

Table 30: Turbidity Coefficient B at Page, Arizona

	B at 380 nanometers				B at 500 nanometers			
	Minimum	Mean	Maximum	1/2 90% C.L.[a]	Minimum	Mean	Maximum	1/2 90% C.L.
One Year (13 Feb 73- 8 Feb 74)	~0	0.063	0.225	0.004	0.015	0.079	0.221	0.005
Season								
Spring 73 (Mar - May)	~0	0.058	0.161	0.005	0.036	0.081	0.205	0.005
Summer 73 (Jun - Aug)	0.008	0.098	0.225	0.005	0.041	0.113	0.221	0.009
Fall 73 (Sep - Nov)	0.003	0.050	0.121	0.003	0.019	0.066	0.129	0.006
Winter 73-74	~0	0.021	0.081	0.002	0.015	0.035	0.056	0.003
Month								
Feb 1973	0.013	0.026	0.044	0.005	0.026	0.042	0.062	0.006
Mar 1974	0.023	0.054	0.103	0.009	0.045	0.074	0.126	0.010
Apr 1973	~0	0.060	0.161	0.008	0.036	0.082	0.205	0.009
May 1973	~0	0.061	0.116	0.007	0.043	0.082	0.127	0.005
Jun 1973	0.008	0.060	0.107	0.005	0.041	0.087	0.131	0.004
Jul 1973	0.059	0.095	0.143	0.005	0.078	0.110	0.154	0.004
Aug 1973	0.069	0.146	0.225	0.009	0.088	0.147	0.221	0.007
Sep 1973	0.036	0.066	0.099	0.003	0.056	0.087	0.129	0.004
Oct 1973	0.003	0.048	0.121	0.004	0.027	0.062	0.113	0.004
Nov 1973	0.003	0.022	0.043	0.003	0.019	0.040	0.060	0.003
Dec 1973	~0	0.014	0.028	0.002	0.016	0.029	0.043	0.003
Jan 1974	0.010	0.026	0.081	0.006	0.015	0.036	0.043	0.003
Feb 1974	0.001	0.021	0.036	0.004	0.015	0.043	0.089	0.005

[a] C.L. = Confidence Limit

visual range, the quantitative measure of visibility, utilizes a camera and telescope. Some 1973 statistics for weekend daily means and weekday readings at 0900 MST are listed in Table 31. The excellent visibility around lower Lake Powell is obvious. The lower minimum of 90 km (56 miles) is still great visual range compared to our large cities, and the maximum of 249 km (155 miles) is almost non-existent in most of the United States. The weekend daily means are plotted in Figure 13 and show the lack of a clear seasonal trend.

A second method used by Dames & Moore to estimate regional visual range is the viewing of distant objects by observers. Because of the subjectivity of this method, their results are not presented here.

Table 31: Visual Range Near Page as Measured by Photogrammetry

Time Period 1973	Visible Range in Kilometers: Weekend Daily Mean	Visible Range in Kilometers: 0900 MST Weekday
Jan. - Aug.		
Minimum	119	90
Lower 90% C.L.[a]	188	200
Mean	195	207
Upper 90% C.L.	203	214
Maximum	249	249
January	207	183
February	177	192
March	182	222
April	208	228
May	183	212
June	200	206
July	188	227
August	221	179

[a]C.L. = Confidence Limit

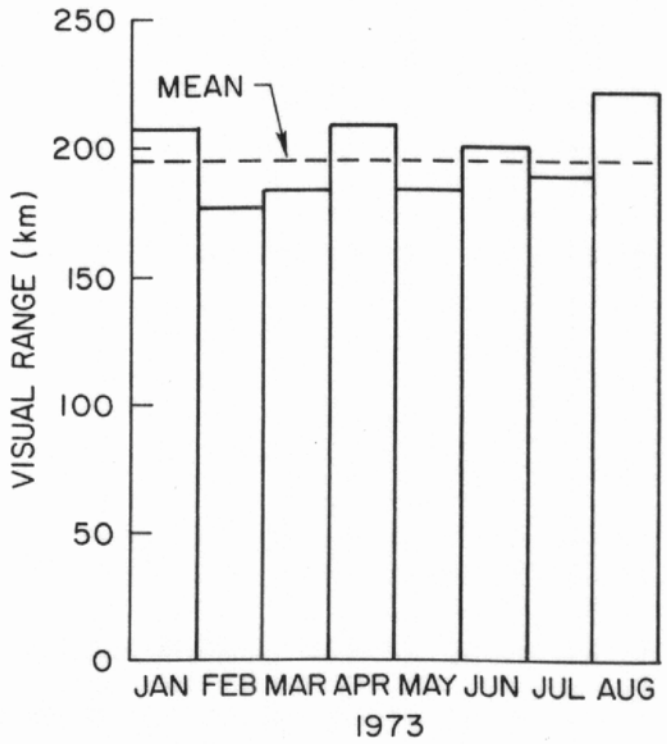

Figure 13: Visual Range Near Page (Weekend Daily Means)
Source: Dames & Moore

The third method used by Dames & Moore for the study of visibility utilizes the integrating nephelometer. This instrument measures the aerosol-scattering coefficient in a small volume of air from which the visual range is obtained by past field observations of both parameters. Some statistics on daily local visual range during 1972 are listed in Table 32 and plotted in Figure 14. The local visual range is less than the regional visual range, probably because of the more intense human activities associated with the

Table 32: Daily Local Visual Range Measured by Integrating Nephelometer at Page Airport

	Visual Range in Kilometers Jan - Dec 1972: Weekday	Visual Range in Kilometers Jan - Dec 1972: Weekend
Overall		
Minimum	63	53
Arithmetic Mean	139	142
Maximum	324	295
Monthly Means		
January	125	134
February	160	161
March	124	115
April	107	119
May	99	104
June	142	156
July	142	134
August	133	119
September	165	165
October	107	102
November	150	147
December	229	229

Overall Mean for 1970: 84
22 July 1970 - 21 July 1971: 111

Source: Dames & Moore

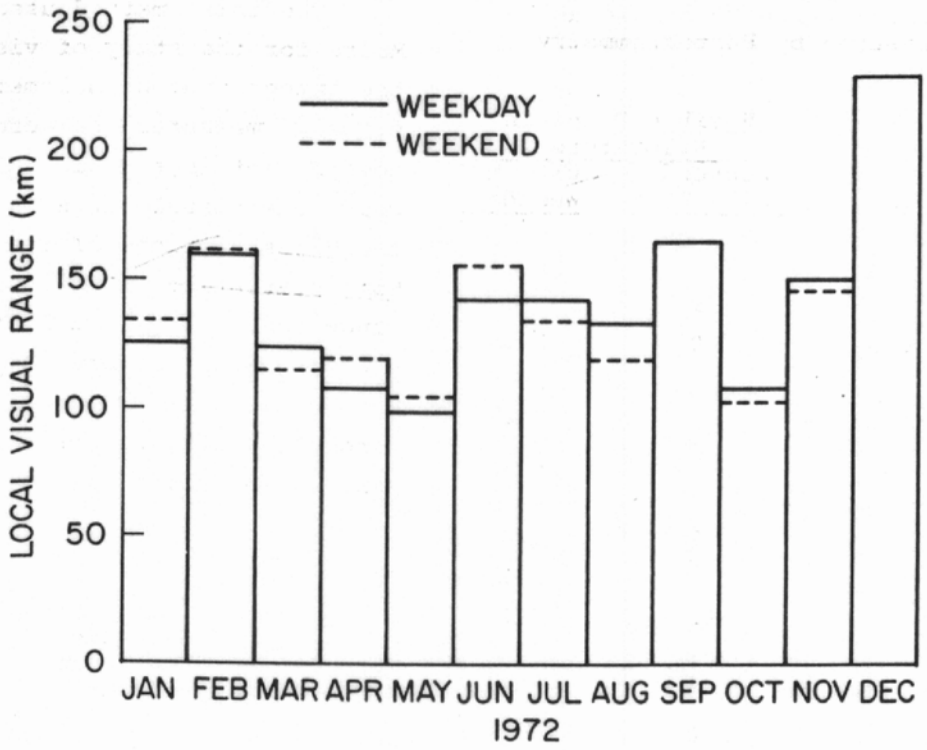

Figure 14: Local Visual Range

Page Airport and nearby residential areas. Traffic alone on the unpaved roads near the airport would put more soil dust in the local air. Although Figure 14 does not clearly show a seasonal cycle, the minimum can be seen in May and the maximum in December. The timings of these extrema seem to agree with the seasonal cycle of human activity. Also, the duststorms that are common to spring may help account for the May minimum.

We investigated the possible correlation between regional visual range as measured by photographic photometry and turbidity coefficient as measured by sun photometry. Contrary to expectation, there was no correlation for data between February 13 and May 2, 1973. Therefore, the aerosol near the ground cannot be correlated with that in a vertical column through the entire atmosphere.

CONCLUSIONS

The results of our measurement program show that the air is clean in the Lake Powell region. Generating stations already in operation, such as Cholla and Mohave, have affected the concentration of aerosol and its sulfate component. Remote areas near Page are so quiet as to be near or at the limit of instrumental measurement. The excellent average visibility of about 200 km (124 miles) in the Lake Powell region is in stark contrast to the visibility in our major cities.

ACKNOWLEDGMENT

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GLOSSARY

A-scale	the magnitude scaling of sound or noise of different frequencies that represents the hearing response of a typical human ear
adiabatic	denotes a process (such as a parcel of air undergoing expansion or compression) in which there is no transfer of heat energy into or out of the system
alkanes	the class of hydrocarbons (organic compounds of hydrogen and carbon) in which the atoms are joined by simple single bonds
alkenes	the class of hydrocarbons in which at least two of the atoms are joined by a double bond
ambient air quality standard	a concentration of an air pollutant in the air for a specified time period designated to be the allowable maximum to protect public health (primary) or welfare (secondary)
anthropogenic	caused by humans
aromatic	having an aroma or smell
background air quality	the quality of air without significant local sources of man-made air pollution
beta-activity	a form of radioactive nuclear change that emits electrons
blue (and red) ends of scale	the wavelengths of light that correspond to these colors (roughl 350 and 500 nanometers respectively)
carcinogenic	cancer-causing
conductimetry	an electrical method of measurement based on the ability of a substance to conduct electricity
confidence limit (90%)	a statistical measure of the scatter of data; it is the upper

	or lower end of the confidence interval in which the mean exists with a specified probability (90%)
DAPC; ASDHS	Division of Air Pollution Control; Arizona State Department of Health Services
deposition	the set of physical processes that transfer a substance from the atmosphere to the Earth's surface
diopter	a device that uses a beam of light through a small hole to measure the elevation angle of the sun
dispersion	the physical process of diluting the concentration of a substance in a fluid by molecular and turbulent motion; e.g., smoke in air
entrainment	a process of transferring by turbulence a substance into a moving fluid; in this case, the transfer of dust and sand into the atmosphere by wind
fly ash	the solid particles that are carried out of a combustion furnace in the exhaust gas flow
flux	the transfer of something across a unit area during a unit time
gravimetric	a physical method of measuring mass or weight based on the force of gravitation
hygroscopic	readily attracting and retaining water
megawatt	one million watts, a unit of power or energy per unit time
nanometer	one billionth (10^{-9}) of a meter
oxidant	a gas that oxidizes; usually ozone
photochemical	referring to chemical reactions that require light
photometry	a physical method of measurement based on the transmission of light
picocurie	one trillionth (millionth millionth or 10^{-12}) of a curie, a measure of radioactivity
respiratory tract	the set of tubes and sacs which comprise the human-breathing system
stratosphere	the second major layer of the atmosphere, just above the troposphere, roughly

	between altitudes of 10 and 50 kilometers
supersaturation	the state of air containing more than the saturated concentration of water vapor at a specified temperature
terpenes	members of a subset of the alkene class
	which are emitted by vegetation
turbidity	the light-reducing characteristic of a fluid; in this case the light-reducing ability of the atmospheric particles along a vertical path through the atmosphere

THE AUTHORS

Dr. Eric G. Walther has been the Principal Investigator of the Air Quality Subproject since 1972. He has been conducting air quality research in association with the Museum of Northern Arizona, in Flagstaff, Arizona, and the Atmospheric Sciences Research Center of the State University of New York at Albany since 1967. The research has included the study of gas-to-aerosol conversions, the analysis of air pollutants and their source by effect rather than by mass, and the analysis of air quality and ecosystem impact, as well as field measurement of air quality in the southwestern United States and over Greenland. In addition, Dr. Walther is Grants Manager in Science and Technology at the Charles F. Kettering Foundation, in Dayton, Ohio, where he is supporting studies of the interrelationships of world food production with climate, environmental quality, energy, land use, and population. While Executive Director of the Colorado Plateau Environmental Advisory Council (1970-1973), Dr. Walther participated in the National Academy of Sciences study of the rehabilitation potential of western coal lands.

Dr. Michael D. Williams is Research Coordinator for the John Muir Institute for Environmental Studies, conducting analyses of the air pollution potential of various coal-fired generating station sites around the nation. In addition he reviews environmental impact statements and acts as one of the key technical representatives of national environmental groups such as the Sierra Club.

On the Lake Powell Research Project, he has been Senior Investigator on the Air Quality Subproject since 1972, analysing air quality data and calculating the theoretical dispersion of plumes. Beginning June 1974, he is the Principal Investigator of the Plume Analysis Subproject for which he will begin the field measurement of the Navajo Generating Station plume.

Robert A. Cudney has been a research associate on the Air Quality Subproject since 1972. He operates the Page, Arizona, field station of the subproject, collecting air samples in the Lake Powell region and measuring various air quality parameters. In addition, he continues his development of electronic instrumentation for the measurement of atmospheric electrification, a subject on which he worked for several years at the Atmospheric Sciences Research Center of the State University of New York at Albany.

Dr. William C. Malm is Assistant Professor of Environmental Science at Northern Arizona University in Flagstaff, where he teaches courses in air pollution and conducts research in air quality, both at Lake Powell with the Air Quality Subproject and in the Grand Canyon with the National Park Service. He is also continuing some of his physics research in ellipsometry and water adsorption on silver iodide films which is related to cloud physics and weather modification.

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