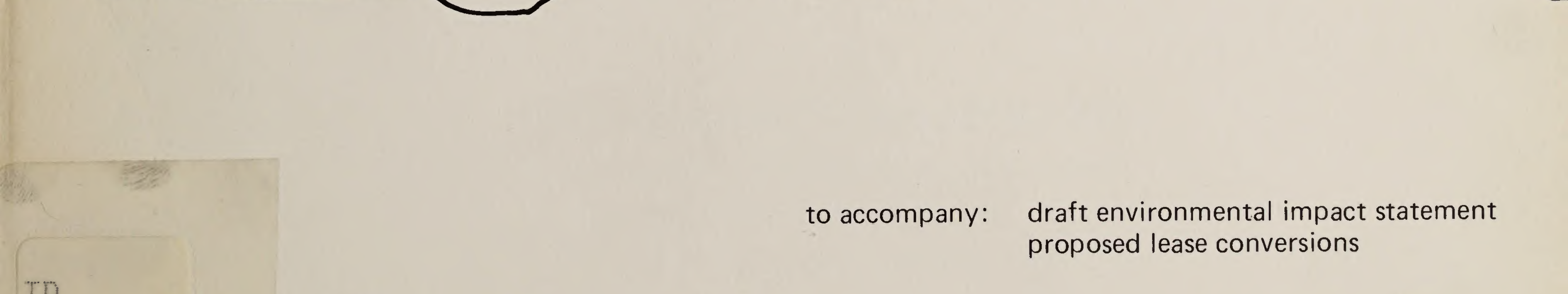
TAR SAND TRIANGLE
UTAH

air quality technical report



to accompany: draft environmental impact statement
proposed lease conversions

TR-83-155-01
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POLLUTANT CONCENTRATION ESTIMATES FOR THE PROPOSED UTAH TAR SAND TRIANGLE PROJECT
(Combined Hydrocarbon Leases)

Prepared by:

J. F. Bowers, A. J. Anderson and W. R. Hargraves

Prepared for:

NATIONAL PARK SERVICE
Air Quality Division
Post Office Box 25287
Denver, Colorado 80225

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H. E. Cramer company, inc.
UNIVERSITY OF UTAH RESEARCH PARK
POST OFFICE BOX 8049
SALT LAKE CITY, UTAH 84108

EXECUTIVE SUMMARY

BACKGROUND AND PURPOSE

The National Park Service (NPS) is responsible for preparing an Environmental Impact Statement (EIS) for the conversion of oil and gas leases to combined hydrocarbon leases for the Tar Sand Triangle in southern Utah. The NPS Air Quality Division has the responsibility of providing the air quality impact analysis for emissions from the Tar Sand Triangle Project that might occur as a result of the proposed lease conversions. The Tar Sand Triangle Project will consist of four phases. Phase III is the pilot/demonstration phase of the project. Depending on the outcome of Phase III, the project will either be terminated or will advance to the full-scale production Phase IV. Delivery Order No. PX-0001-2-0485 (Modification No. 4) of Contract No. CX-0001-1-0115 directed the H. E. Cramer Company, Inc. to assist the NPS Air Quality Division in the air quality impact analysis by performing dispersion model calculations of the air quality impacts of emissions from Phases III and IV of the Tar Sand Triangle Project.

The purpose of this report is to summarize the results of the H. E. Cramer Company's dispersion model calculations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate concentrations attributable to emissions from Phases III and IV of the Tar Sand Triangle Project. Additionally, estimates of the annual dry deposition of the sulfates (SO_4) that are formed from the SO_2 emissions are provided. Special attention is given to the following lands managed by the NPS: (1) Canyonlands National Park, (2) Arches National Park, (3) Capitol Reef National Park, and (4) Glen Canyon National Recreation Area. The three national parks are class I Prevention of Significant Deterioration (PSD) areas, while Glen Canyon is a class II PSD area.

DESCRIPTION OF THE SITE

Figure I is a topographic map of southern Utah that shows the locations of Canyonlands, Arches and Capitol Reef National Parks and Glen Canyon National Recreation Area. Elevations in the figure are in feet above mean sea level (MSL) and the contour interval is 1,000 feet (305 meters). As shown by Figure I, the Tar Sand Triangle site extends into the western portion of Glen Canyon and is about 10 kilometers west of Canyonlands. The nearest boundary of Arches is about 65 kilometers northeast of the site and the nearest boundary of Capitol Reef is about 80 kilometers west-southwest of the site. Although the Tar Sand Triangle site is at a relatively high elevation (6,400 feet or 1,950 meters MSL), terrain features that extend above the stack-top elevations assumed for the sources of Phase III and Phase IV are in the vicinity of the site. Thus, complex terrain dispersion modeling techniques are required to assess the air quality impact of potential emissions from the Tar Sand Triangle site.

CALCULATION PROCEDURES

The concentration calculations described in this report were performed using the SHORTZ/LONGZ complex terrain dispersion models. The SHORTZ/LONGZ models, which were developed and documented by the H. E. Cramer Company (Cramer, *et al.*, 1975; Bjorklund and Bowers, 1982) under contract to the U. S. Environmental Protection Agency (EPA), are considered to be refined (non-screening) complex terrain dispersion models. The versions of the SHORTZ/LONGZ models used in this study differ from the versions described by Bjorklund and Bowers (1982) and available from the National Technical Information Service (NTIS) in that they have been updated by the addition of the algorithms used by the Industrial Source Complex (ISC) Dispersion Model (Bowers, Bjorklund and Cheney, 1979) ISCST/ISCLT computer codes to account for the effects on ambient particulate concentrations of gravitational settling and dry deposition.

FIGURE I. Topographic map of southern Utah showing the location of Arches, Canyonlands and Capitol Reef National Parks and Glen Canyon National Recreation area. Elevations are in feet above mean sea level (MSL) and the contour interval is 1,000 feet (305 meters). The Tar Sand Triangle site is shown by the rectangle that partially extends over the western boundary of Glen Canyon. The filled triangle west of Hanksville shows the location of the IPP Salt Wash tower.

The meteorological inputs to the SHORTZ/LONGZ models were developed from: (1) the 1975 hourly wind-direction, wind-speed, turbulence and temperature measurements from the Intermountain Power Project (IPP) Salt Wash tower, (2) mixing depth statistics for Salt Lake City and Hanksville, Utah and Grand Junction, Colorado, and (3) the rural mixing depth interpolation scheme used by the SHORTZ model's METZ meteorological preprocessor program. The selection of the best available meteorological inputs for use in the SHORTZ/LONGZ model calculations was principally based on a previous, detailed study of the mesoscale meteorology of southern Utah performed by the H. E. Cramer Company (Bowers, et al., 1978) under contract to the Bureau of Land Management (BLM). Within a 10-kilometer radius of the Tar Sand Triangle site, the SHORTZ model was used with hourly meteorological inputs for selected "worst-case" dispersion periods to calculate maximum short-term ground-level concentrations and the LONGZ model was used with climatological meteorological inputs to calculate annual average concentrations. At the longer downwind distances, the SHORTZ model was used with the entire year of hourly meteorological inputs to calculate both short-term and annual average concentrations. (For the same source inputs and meteorological data base, the SHORTZ and LONGZ models yield equivalent annual average concentrations.) The source inputs used in the model calculations were developed from information provided to the H. E. Cramer Company by BLM.

The only dispersion model currently available from the NTIS that is capable of calculating long-term dry deposition is the ISC Model's long-term model ISCLT. We therefore selected the ISCLT model for use in the sulfate deposition calculations in spite of the fact that the ISCLT model is not a complex terrain dispersion model. Our justification for the use of a flat terrain dispersion model in the annual sulfate deposition calculations is based on the following facts: (1) The emission heights above mean sea level of the stacks assumed to be at the Tar Sand Triangle site are in general higher than most of the areas of primary concern (i.e., most of the areas within the national parks and the national recreation area); and (2) Terrain effects on ground-level concentration or deposition values are relatively unimportant at the longer downwind distances of most of the areas of primary concern because emissions tend to be uniformly mixed in the vertical within the surface mixing layer at these distances. We added a sulfate production term (see Equation (8) of Bowers, Saterlie and Cramer, 1979) to the ISCLT model for use in the sulfate deposition calculations. The average transformation rate of SO_2 to sulfates was assumed to be 0.5 percent per hour on the basis of a literature review by Bowers, Saterlie and Cramer (1979). We arbitrarily assumed in the ISCLT model calculations that 20 percent of the sulfates that come in contact with the earth's surface are retained (deposited) at the surface. The statistical wind summary used in the ISCLT model calculations was developed using a modified version of the Mitchell and Timbre (1979) stability classification scheme, which uses hourly turbulence and wind-speed observations to estimate the Pasquill stability category during each hour.

RESULTS OF THE CONCENTRATION CALCULATIONS

The magnitudes and locations of the maximum short-term and annual average ground-level SO_2, particulate and NO_2 concentrations calculated at any point for emissions from Phases III and IV of the proposed Tar Sand Triangle Project are given in Tables I and II, respectively. All of the calculated maximum concentrations are located in Glen Canyon National Recreation Area. We point out that the calculated maximum 24-hour and annual average particulate concentrations in Tables I and II exclude the active work area of Phase III and the storage piles, handling and storage areas and extraction zone of Phase IV because we question the reliability of concentrations calculated within a fugitive dust (particulate) source that are attributable to the source's own emissions. Maximum short-term and annual average ground-level concentrations in complex terrain are determined by the combination of the source characteristics (including locations), the topography and the local meteorological conditions. Thus, the concentrations in Tables I and II cannot be generalized and should be considered specific to the source characteristics assumed in the model calculations. The calculated maximum concentrations in Tables I and II are also likely to change

TABLE I

MAGNITUDES AND LOCATIONS OF MAXIMUM SHORT-TERM AND ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT ANY POINT FOR EMISSIONS FROM PHASE III OF THE PROPOSED TAR SAND TRIANGLE PROJECT

Pollutant	Averaging Time	Location*		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boiler	Diesel Generators	Fugitives	Total
SO_2	3 Hours	0.50	157	1,957	27 Sep 75 (19-21 MST)	336.26	12.21	0.00	348.48
	24 Hours	0.50	028	1,975	15-16 Apr 75 (14-13 MST)	120.12	4.90	0.00	125.02
	Annual	0.32	060	1,960	--	16.77	0.79	0.00	17.56
Particulates	24 Hours	0.67	062	1,975	20 Apr 75 (00-23 MST)	3.51	2.12	19.68	25.30
	Annual	0.79	078	1,926	--	0.34	0.18	4.31	4.83
NO_2	Annual	0.32	060	1,960	--	8.97	11.76	0.00	20.73

* The locations are with respect to the boiler stack. All of the calculated maximum ground-level concentrations are located in Glen Canyon National Recreation Area.

TABLE II

MAGNITUDES AND LOCATIONS OF MAXIMUM SHORT-TERM AND ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT ANY POINT FOR EMISSIONS FROM PHASE IV OF THE PROPOSED TAR SAND TRIANGLE PROJECT

Pollutant	Averaging Time	Location*		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boiler	Furnaces	Fugitives	Total
SO_2	3 Hours	2.15	079	2,073	18 Jul 75 (03-05 MST)	783.53	1.75	0.00	785.28
	24 Hours	0.70	028	2,027	3-4 May 75 (14-13 MST)	529.03	0.53	0.00	529.56
	Annual	0.80	026	2,027	--	24.83	0.25	0.00	25.08
Particulates	24 Hours	1.00	058	1,987	20 Apr 75 (00-23 MST)	0.04	1.39	304.79	306.23
	Annual	2.64	098	2,018	--	0.50	0.45	140.36	141.32
NO_2	Annual	0.80	026	2,027	--	8.33	70.64	0.00	78.97

* The locations are with respect to the boilers stack. All of the calculated maximum ground-level concentrations are located in Glen Canyon National Recreation Area.

if, at some time in the future, the model calculations are repeated for the same sources using more refined onsite meteorological data.

The magnitudes and locations of the maximum short-term and annual average ground-level SO_2, particulate and NO_2 concentrations calculated at Canyonlands, Arches and Capitol Reef National Parks for emissions from Phases III and IV of the proposed Tar Sand Triangle Project are presented in Tables III and IV, respectively. Canyonlands is within the range of applicability of the steady-state SHORTZ model. However, the concentrations calculated by the SHORTZ model at the distances of the Arches and Capitol Reef were calculated in a screening mode because the model does not address factors such as the spatial and temporal variations of wind fields, turbulent intensities and mixing depths. Additionally, the effects of chemical transformations, dry deposition and other removal processes were not considered in the model calculations. Nevertheless, the maximum concentrations calculated at Arches and Capitol Reef are significantly lower than the maximum concentrations calculated at Canyonlands.

RESULTS OF THE SULFATE DEPOSITION CALCULATIONS

Figure II shows the calculated isopleths of annual sulfate dry deposition in milligrams per square meter attributable to the SO_2 emissions from Phase III of the proposed Tar Sand Triangle Project. The corresponding sulfate dry deposition isopleth map for the Phase IV emissions is shown in Figure III. (One milligram per square meter is equal to 10^{-2} kilograms per hectare.) The location of the maximum sulfate deposition is determined by the interaction of two processes: (1) dilution by atmospheric mixing, and (2) sulfate production. If the SO_2 emissions are assumed to be immediately converted to sulfates as they exit the stacks, the locations of the maximum annual average ground-level concentration and the maximum annual dry deposition coincide. However, because the amount of sulfates increases with downwind transport time and hence with downwind distance, the effects of sulfate production partially offset the effects of atmospheric mixing and

TABLE III

MAGNITUDES AND LOCATIONS OF MAXIMUM SHORT-TERM AND ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT CANYONLANDS, ARCHES AND CAPITOL REEF NATIONAL PARKS FOR EMISSIONS FROM PHASE III OF THE PROPOSED TAR SAND TRIANGLE PROJECT

Pollutant	Averaging Time	Location*		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boiler	Diesel Generators	Fugitives	Total
(a) Canyonlands National Park									
SO_2	3 Hours	12.11	067	1,997	2 Feb 75 (03-05 MST)	7.600	0.284	0.000	7.884
	24 Hours	12.11	067	1,997	2 Feb 75 (00-23 MST)	1.068	0.040	0.000	1.108
	Annual	12.11	067	1,997	--	0.095	0.003	0.000	0.098
Particulates	24 Hours	12.36	053	1,463	2 Feb 75 (00-23 MST)	0.213	0.102	0.133	0.447
	Annual	9.90	087	1,798	--	0.014	0.007	0.032	0.053
NO_2	Annual	12.11	067	1,997	--	0.051	0.053	0.000	0.103
(b) Arches National Park									
SO_2	3 Hours	77.28	032	1,524	25 Feb 75 (06-08 MST)	0.449	0.017	0.000	0.466
	24 Hours	83.23	027	1,585	23 Feb 75 (00-23 MST)	0.063	0.003	0.000	0.066
	Annual	70.69	046	1,433	--	0.003	<0.001	0.000	0.003

TABLE III (Continued)

Pollutant	Averaging Time	Location*		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boiler	Diesel Generators	Fugitives	Total
(b) Arches National Park (Continued)									
Particulates	24 Hours	83.23	027	1,585	23 Feb 75 (00-23 MST)	0.006	0.003	0.023	0.031
	Annual	79.07	048	1,524	--	<0.001	<0.001	0.002	0.002
NO_2	Annual	79.07	048	1,524	--	0.002	0.020	0.000	0.022
(c) Capitol Reef National Park									
SO_2	3 Hours	83.30	268	1,829	18 Mar 75 (00-02 MST)	0.493	0.018	0.000	0.511
	24 Hours	83.64	271	1,737	17 May 75 (00-23 MST)	0.063	0.003	0.000	0.066
	Annual	80.38	249	1,829	--	0.002	<0.001	0.000	0.002
Particulates	24 Hours	83.64	271	1,737	17 May 75 (00-23 MST)	0.006	0.003	0.022	0.030
	Annual	80.38	249	1,829	--	<0.001	<0.001	<0.001	0.001
NO_2	Annual	80.38	249	1,829	--	0.001	0.001	0.000	0.003

TABLE IV

MAGNITUDES AND LOCATIONS OF MAXIMUM SHORT-TERM AND ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT CANYONLANDS, ARCHES AND CAPITOL REEF NATIONAL PARKS FOR EMISSIONS FROM PHASE IV OF THE PROPOSED TAR SAND TRIANGLE PROJECT

Pollutant	Averaging Time	Location*		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boilers	Furnaces	Fugitives	Total
(a) Canyonlands National Park									
SO_2	3 Hours	8.88	107	1,829	2 Dec 75 (15-17 MST)	195.427	0.413	0.000	195.840
	24 Hours	8.88	107	1,829	2 Dec 75 (00-23 MST)	24.490	0.054	0.000	25.544
	Annual	11.94	067	1,997	--	1.160	0.008	0.000	1.168
Particulates	24 Hours	11.54	132	1,640	2 Feb 75 (00-23 MST)	0.000	0.000	46.358	46.358
	Annual	9.74	093	1,844	--	0.127	0.118	10.798	11.043
NO_2	Annual	11.94	067	1,997	--	0.389	2.353	0.000	2.742
(b) Arches National Park									
SO_2	3 Hours	83.11	027	1,585	14 Apr 75 (21-23 MST)	34.570	0.072	0.000	34.642
	24 Hours	83.11	027	1,585	14 Apr 75 (00-23 MST)	5.773	0.012	0.000	5.785
	Annual	67.39	043	1,402	--	0.103	<0.001	0.000	0.103

TABLE IV (Continued)

Pollutant	Averaging Time	Location*		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boilers	Furnaces	Fugitives	Total
(b) Arches National Park (Continued)									
Particulates	24 Hours	83.11	027	1,585	14 Apr 75 (00-23 MST)	0.683	0.214	1.818	2.715
	Annual	67.39	043	1,402	--	0.013	0.008	0.033	0.053
NO_2	Annual	67.39	043	1,402	--	0.035	0.114	0.000	0.149
(c) Capitol Reef National Park									
SO_2	3 Hours	86.38	230	1,554	25 Mar 75 (00-02 MST)	24.030	0.048	0.000	24.078
	24 Hours	86.38	230	1,554	25 Mar 75 (00-23 MST)	3.135	0.006	0.000	3.141
	Annual	79.81	254	1,890	--	0.067	<0.001	0.000	0.067
Particulates	24 Hours	86.38	230	1,554	25 Mar 75 (00-23 MST)	0.371	0.110	0.987	1.468
	Annual	79.81	254	1,890	--	0.008	0.005	0.021	0.034
NO_2	Annual	79.81	254	1,890	--	0.023	0.073	0.000	0.096

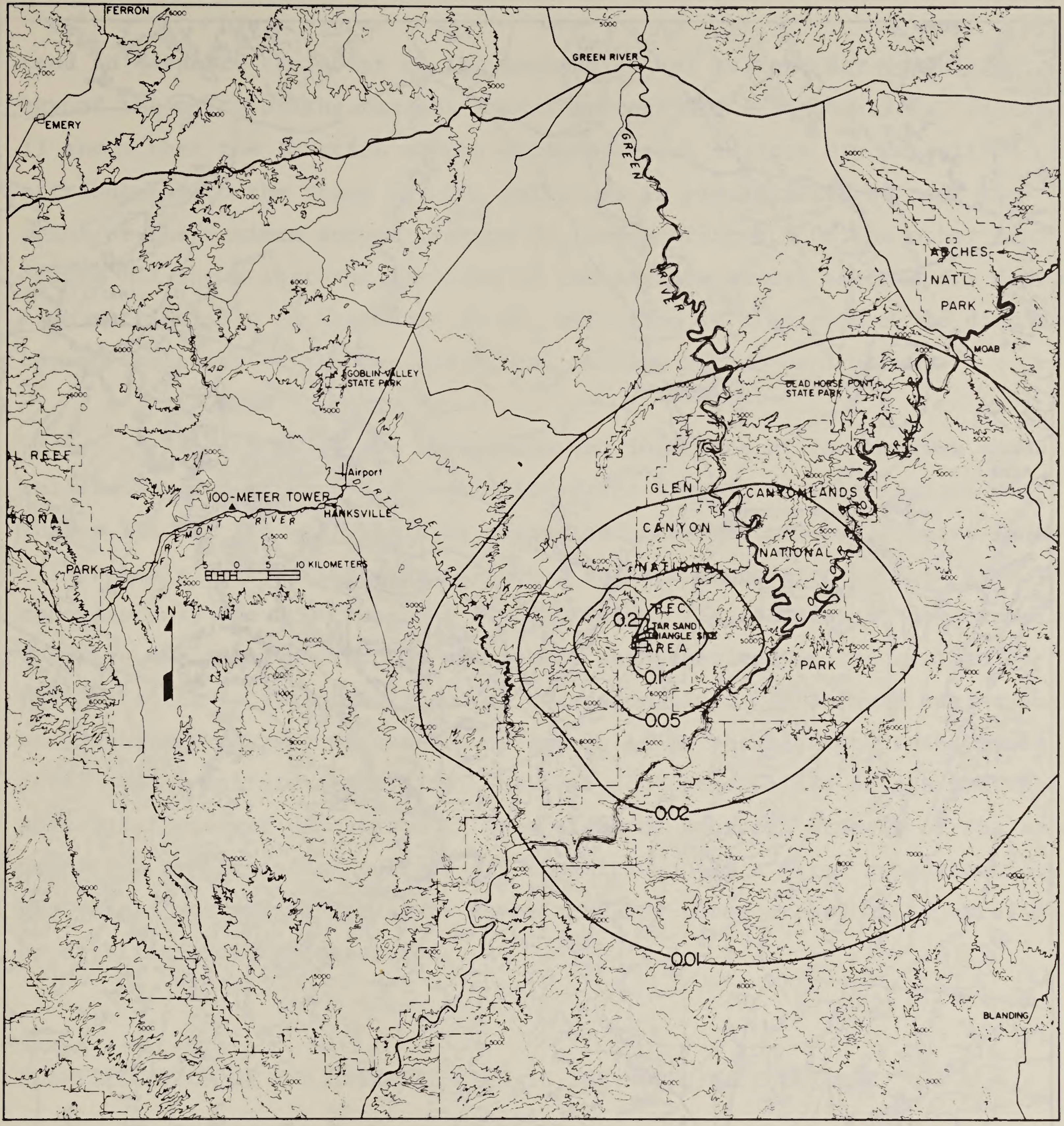

Figure II. Calculated isopleths of annual sulfate dry deposition in milligrams per square meter attributable to the SO_2 emissions from Phase III of the proposed Tar Sand Triangle Project. (One milligram per square meter is equal to 10^{-2} kilograms per hectare.)

Figure III. Calculated isopleths of annual sulfate dry deposition in milligrams per square meter attributable to the SO_2 emissions from Phase IV of the proposed Tar Sand Triangle Project. (One milligram per square meter is equal to 10^{-2} kilograms per hectare.)

tend to displace the point of the maximum annual sulfate dry deposition beyond the point of the maximum annual average SO_2 concentration. Figure II shows that the location of the maximum annual sulfate dry deposition attributable to the Phase III SO_2 emissions is predicted to be near the point of the maximum annual average SO_2 concentration. On the other hand, Figure III shows that the location of the maximum annual sulfate dry deposition attributable to the Phase IV SO_2 emissions is predicted to be displaced beyond the point of the maximum annual average SO_2 concentration.

Table V gives the magnitudes and locations of the maximum annual sulfate dry deposition values calculated for the SO_2 stack emissions of Phases III and IV. It should be recognized that Table V and Figures II and III probably underestimate total annual sulfate deposition because they consider only the dry component of deposition. In addition to dry deposition, sulfates are removed from the atmosphere and deposited at the surface by precipitation in a process known as wet deposition. In an arid region such as southern Utah, dry deposition is likely to be the major contributor to total annual sulfate deposition. However, the possibility exists that the annual sulfate wet deposition in some areas of southern Utah is of the same magnitude as the annual sulfate dry deposition. As a first approximation, the total (wet and dry) sulfate deposition for these areas can be obtained by doubling the dry deposition.

IDENTIFICATION OF THE UNCERTAINTIES IN THE MODEL CALCULATIONS

The principal areas of uncertainty affecting the accuracy of the results of the SHORTZ/LONGZ model concentration calculations described above are the representativeness of the source input parameters, the representativeness of the meteorological input parameters and the accuracy of the SHORTZ/LONGZ models. We assume that the source input parameters used in the model calculations, which were developed from information provided by BLM, are representative. We used in the model calculations what we consider to be the most representative meteorological inputs currently

TABLE V

MAGNITUDES AND LOCATIONS OF MAXIMUM ANNUAL DRY DEPOSITS OF SULFATES CALCULATED AT ANY POINT FOR PHASE III AND PHASE IV SO_2 EMISSIONS

Phase	Location*		Dry Deposition (mg/m^2)**		
	Distance (km)	Azimuth Bearing (deg)	Boiler (Phase III) or Boilers (Phase IV)	Diesel Generators (Phase III) or Furnaces (Phase IV)	Total
III	0.50	045	0.229	0.014	0.242
IV	4.00	270	6.058	0.013	6.071

* The locations are with respect to the stack for the Phase IV boilers.

** One milligram per square meter is equal to 10^{-2} kilograms per hectare.

available for the vicinity of the Tar Sand Triangle. Although we believe the IPP tower winds to be reasonably representative of regional transport winds, they are not necessarily representative of the local winds affecting the initial transport and dispersion of emissions from the sources at the Tar Sand Triangle site. It follows that the concentrations calculated at intermediate transport distances within the range of applicability of the SHORTZ/LONGZ models (for example, at Canyonlands National Park) are likely to be more reliable than the concentrations calculated in the immediate vicinity of the Tar Sand Triangle. The concentrations at the long downwind distances of Arches and Capitol Reef National Parks were calculated using screening techniques.

In studies conducted for EPA by the H. E. Cramer Company, the SHORTZ/LONGZ models have yielded a close correspondence between calculated and observed concentrations for SO_2 sources located in complex terrain at distances up to about 30 kilometers from the source. In a recent performance evaluation of five complex terrain dispersion models that used data collected in the vicinity of a paper mill located in extremely complex terrain, the SHORTZ model was the only model to provide accurate and unbiased estimates of the 25 highest 1-hour, 3-hour and 24-hour average SO_2 concentrations at all monitoring sites at and beyond the distance to plume stabilization, including the sites with both the highest and lowest elevations above the stack-top elevation (Bowers, et al., 1983). At the monitoring sites on elevated terrain within the distance to plume stabilization, the SHORTZ model showed a systematic bias toward overestimation. If it is assumed that this bias is a general one, it does not affect the accuracy of the SHORTZ model when applied to the sources at the Tar Sand Triangle site because the locations of the calculated maximum ground-level concentrations are at or beyond the typical distance to plume stabilization for the plumes from the various stacks. The accuracy of the gravitational settling/dry deposition algorithms as applied to the low-level fugitive particulate sources is difficult to quantify because there have been relatively few verification studies of these algorithms. Perhaps the most rigorous tests of these algorithms are the comparisons of concurrent calculated and observed

24-hour and long-term average particulate concentrations in the vicinity of a large steel mill that were performed using the ISCST/ISCLT computer programs of the ISC Model (Bowers, et al., 1982). On the average, the observed concentrations were overpredicted by as much as 20 percent, although uncertainties in the adjustment of the observed concentrations for background may have contributed to the apparent bias toward overestimation.

In addition to the factors affecting the accuracy of the concentrations calculated by the SHORTZ/LONGZ models, the accuracy of the annual sulfate dry deposition patterns calculated by the ISCLT model is affected by the representativeness of the psuedo-first-order SO_2-to-sulfate transformation rate and the representativeness of the surface reflection coefficient assumed in the deposition calculations. The average transformation rate used in the ISCLT model calculations of 0.5 percent per hour has substantial empirical support in the scientific literature. However, there is at present no empirical or theoretical basis for specifying a surface reflection coefficient for sulfates. The surface reflection coefficient of 0.8 used in the sulfate deposition calculations was selected to result in a deposition rate that would normally be associated with particulates with a settling velocity of about 1 centimeter per second. We believe that a reflection coefficient of 0.8 leads to conservative estimates of sulfate dry deposition.

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SECTION 1

INTRODUCTION

1.1 BACKGROUND AND PURPOSE

The National Park Service (NPS) is responsible for preparing an Environmental Impact Statement (EIS) for the conversion of oil and gas leases to combined hydrocarbon leases for the Tar Sand Triangle in southern Utah. The NPS Air Quality Division has the responsibility of providing the air quality impact analysis for industrial development that might occur as a result of the proposed lease conversions. Delivery Order No. PX-0001-2-0485 (Modification No. 4) of Contract No. CX-0001-1-0115 directed the H. E. Cramer Company, Inc. of Salt Lake City, Utah to assist the NPS Air Quality Division in the air quality impact analysis by performing dispersion model calculations of the air quality impact of emissions from the potential industrial development at the Tar Sand Triangle.

The purpose of this report is to summarize the results of the H. E. Cramer Company's dispersion model calculations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and particulate concentrations attributable to industrial emissions from the proposed Utah Tar Sand Triangle Project, which will consist of four phases. Only the air quality impacts of Phases III and IV are addressed in this report. Phase III is the pilot/demonstration phase of the project. Depending on the outcome of Phase III, the project will either be terminated or will advance to the full-scale production Phase IV. For Phases III and IV, this report presents dispersion model calculations of maximum 3-hour, 24-hour and annual average SO_2 concentrations, maximum 24-hour and annual average particulate concentrations, and maximum annual average NO_2 concentrations. Additionally, estimates of annual sulfate dry deposition are provided. Special attention is given to the following lands managed by the NPS: (1) Canyonlands National Park, (2) Arches National Park, (3) Capitol Reef National Park, and (4) Glen Canyon National Recreation Area. The three national parks are class I

Prevention of Significant Deterioration (PSD) areas, while Glen Canyon is a class II PSD area.

1.2 DESCRIPTION OF THE SITE

Figure 1-1 is a topographic map of southeastern Utah that shows the locations of the Tar Sand Triangle site, Canyonlands National Park, Arches National Park, Capitol Reef National Park and Glen Canyon National Recreation Area. Elevations in the figure are in feet above mean sea level (MSL) and the contour interval is 1,000 feet (305 meters). The Tar Sand Triangle site is in the canyon/plateau region of southeastern Utah on the western boundary of Glen Canyon. The site is approximately 10 kilometers west of Canyonlands, 65 kilometers southwest of Arches and 85 kilometers east of Capitol Reef.

The Tar Sand Triangle site is located on a high plateau that has been extensively eroded. Terrain elevations above mean sea level (MSL) within 10 kilometers of the site range from less than 1,500 meters to nearly 2,200 meters; the plant grade elevation at the site is 1,950 meters. Although much of the terrain near the site is below the plant grade elevation, several nearby terrain features are significantly higher than the plant grade elevation. These features include a hill about 0.7 kilometers north-northeast of the site that rises 85 meters above plant grade, a butte about 2.2 kilometers east of the site that rises 125 meters above plant grade, and Bagpipe Butte 5 kilometers east-southeast of the site that rises 85 meters above plant grade. The terrain elevation of the plateau gradually increases to the south-southeast of the site, reaching a height of about 230 meters above plant grade about 9 kilometers from the site.

1.3 SELECTION OF DISPERSION MODELS

As discussed in Section 1.2, the Tar Sand Triangle is located in an area of complex terrain. Thus, complex terrain dispersion modeling

FIGURE 1-1. Topographic map of southern Utah showing the location of Arches, Canyonlands and Capitol Reef National Parks and Glen Canyon National Recreation area. Elevations are in feet above mean sea level (MSL) and the contour interval is 1,000 feet (305 meters). The Tar Sand Triangle site is shown by the rectangle that partially extends over the western boundary of Glen Canyon. The filled triangle west of Hanksville shows the location of the IPP Salt Wash tower.

techniques are required to assess the air quality impact of industrial emissions from the Tar Sand Triangle. All previous dispersion model analyses that the H. E. Cramer Company has performed in southern Utah under contract to the U. S. Department of the Interior (Cramer and Bowers, 1976; Bowers, et al., 1978) have used the SHORTZ/LONGZ complex terrain dispersion models. The SHORTZ/LONGZ models, which were developed and documented by the H. E. Cramer Company (Cramer, et al., 1975; Bjorklund and Bowers, 1982) under contract to the U. S. Environmental Protection Agency (EPA), are considered to be refined (non-screening) complex terrain dispersion models. As discussed in Appendix H of the report by Bjorklund and Bowers (1982), the SHORTZ/LONGZ models have performed well in studies during the last 8 years that have included direct comparisons of calculated and observed SO_2 concentrations for existing sources located in complex terrain. Under contract to EPA, we just completed the most rigorous test to date of the SHORTZ model using the emissions, meteorological and SO_2 air quality data collected during the 2-year monitoring program in the vicinity of the Westvaco Corporation Luke, Maryland Mill. As discussed by Bowers, et al. (1983), the SHORTZ model closely matched the 25 highest observed 1-hour, 3-hour and 24-hour average SO_2 concentrations at all monitoring sites at and beyond the typical distance to plume stabilization, including the sites with the lowest and highest elevations above the stack-top elevation. At the monitoring sites on elevated terrain within the distance to plume stabilization, the SHORTZ model consistently overestimated the 25 highest observed short-term concentrations. Because the maximum ground-level concentrations presented in this report are at or beyond the typical plume stabilization distances, the results of the Westvaco study indicate that the SHORTZ/LONGZ models should give unbiased estimates of the concentrations attributable to the stack emissions at the Tar Sand Triangle.

In addition to stack emissions, industrial development at the Tar Sand Triangle will result in low-level fugitive dust (particulate) emissions. The versions of the SHORTZ/LONGZ models described by Bjorklund and Bowers (1982) and available from the National Technical Information Service (NTIS) contain algorithms that account for the effects on ambient particulate concentrations of the gravitational settling and dry deposition of particulates with appreciable gravitational settling velocities under the assumption that all particulates that reach the surface by the combined processes of atmospheric turbulence and gravitational settling are retained (deposited) at the surface. These algorithms are earlier versions of the gravitational settling/dry deposition algorithms contained in the ISCST/ISCLT computer codes of the Industrial Source Complex (ISC) Dispersion Model (Bowers, Bjorklund and Cheney, 1979) in which the fraction of particulates retained at the surface ranges from zero (complete deposition) to unity (complete reflection), depending on the terminal fall velocity of the particulates. The H. E. Cramer Company's in-house versions of the SHORTZ/LONGZ models contain the generalized gravitational settling/dry deposition algorithms of the ISCST/ISCLT codes (see Equations (2-40) and (2-54) of Bowers, Bjorklund and Cheney, 1979) rather than the SHORTZ/LONGZ models' original gravitational settling/dry deposition algorithms. The updated versions of the SHORTZ/LONGZ models were used to calculate particulate concentrations attributable to fugitive dust emissions at the Tar Sand Triangle.

As noted in Section 1.1, one of the requirements for the study described in this report was to make estimates of the annual deposition of sulfates formed by the SO_2 emissions from the potential sources at the Tar Sand Triangle. Deposition consists of a wet component attributable to removal from the atmosphere by precipitation washout and a dry component attributable to retention at the surface of some fraction of the material that comes in contact with the surface. On an annual basis, dry deposition is likely to be the principal sulfate deposition mechanism in southern Utah because of the arid climate. The only dispersion model currently available from the NTIS that is capable of calculating long-term dry deposition patterns is the ISC Model's long-term model ISCLT. We therefore selected the ISCLT model for use in the annual sulfate deposition calculations in spite of the fact that the model is not applicable at receptors above stack-top elevations. We executed the ISCLT model in a flat terrain mode in the sulfate deposition calculations for the following reasons: (1) The emission heights above mean sea level of the stacks assumed to be at the Tar Sand Triangle site are in general higher than most of the areas of primary concern (i.e., most of the areas within the national parks and the recreation area); and (2) Terrain effects on ground-level concentration or deposition values are relatively unimportant at the longer downwind distances of most of the areas of primary concern because emissions tend to be uniformly mixed in the vertical within the surface mixing layer at these distance. Assuming that the stack emissions contain no primary sulfates, Bowers, Saterlie and Cramer (1979) give the effective sulfate emission rate Q_s as

$$Q_s\{x\} = Q_o\{SO_2\}\frac{96}{64}\left[1-\exp[-\psi x/u\{H\}]\right] \tag{1-1}$$

where

$Q_o\{SO_2\}$ = the SO_2 emission rate

96 = the molecular weight of sulfates (SO_4)

64 = the molecular weight of SO_2

ψ = the psuedo-first-order SO_2-to-sulfate transformation rate

x = the downwind distance

$\bar{u}\{H\}$ = the mean wind speed at plume height, which is assumed by ISCLT to be represented by the mean wind speed at stack height $\bar{u}\{h\}$

We added Equation (1-1) to the ISCLT model for use in the annual sulfate deposition calculations described in this report.

1.4 REPORT ORGANIZATION

In addition to the Introduction, this report contains three major sections and two appendices. The source and meteorological inputs used in the dispersion model calculations are discussed in Section 2. Section 3 describes the calculation procedures and gives the results of the concentration and deposition calculations. The major areas of uncertainty affecting the results of the dispersion model calculations are identified and discussed in Section 4. The statistical wind summaries used in the LONGZ and ISCLT model calculations are tabulated in Appendix A, and the hourly meteorological inputs used in the SHORTZ model calculations of maximum short-term ground-level concentrations are tabulated in Appendix B.

SECTION 2

SOURCE AND METEOROLOGICAL INPUT PARAMETERS

2.1 SOURCE INPUT PARAMETERS

The source inputs for the Utah Tar Sand Triangle Project were developed from information provided to the H. E. Cramer Company by the Bureau of Land Management (BLM). Table 2-1 lists the source input parameters for both the Phase III and Phase IV stack sources. Electrical power for Phase III will be provided by two 125-kilowatt diesel generators, each with a 4-meter exhaust stack. Because the two stacks will be separated by only a few meters, they are represented for modeling purposes in Table 2-1 by one stack with the pollutant emission rates equal to the combined rates for the two stacks. The remaining stack parameters such as the volumetric emission rate are for a single stack. Emissions from the Phase III boiler will be discharged from a 5-meter stack. The heights of the stacks for the Phase IV boilers and furnaces currently are not known. On the basis of the available information, the maximum stack height that can be justified for the Phase IV stacks for use in dispersion model calculations to assess compliance with the National Ambient Air Quality Standards (NAAQS) and the Prevention of Significant Deterioration (PSD) Increments is 65 meters (Federal Register, Vol. 47, No. 26). The SO_2 emission rate shown in Table 2-1 for the Phase IV boilers stack assumes that the sulfur content of the bitumen will be 4 percent.

Table 2-2 lists the source inputs for the low-level fugitive dust (particulate) sources. About 70 percent of the Phase III low-level particulate emissions are assumed to originate from the active work area at the Tar Sand Triangle site. These emissions include emissions from the storage piles, wind erosion and work on cleared areas, and one-fourth of the emissions from unpaved roads. The active work area is represented in Table 2-2 by a 200-meter square area source. Because vehicular traffic accounts for much of the emissions from this area, the characteristic height scale of the area source is set equal to 2 meters, which is consistent with the semi-empirical HIWAY-2 model (Petersen, 1980). The maximum air quality

TABLE 2-1

SOURCE INPUT PARAMETERS FOR PHASE III AND PHASE IV STACK SOURCES

Source Input Parameter	Parameter Value			
	Phase III Sources		Phase IV Sources	
	Boiler	Diesel Generator	Boilers	Furnaces
Stack Height (m)	5	4	65	65
Stack Inner Radius (m)	0.375	0.25	3.05	0.765
UTM X Coordinate (m)	573,224	573,225	573,390	573,285
UTM Y Coordinate (m)	4,225,339	4,225,340	4,225,386	4,225,440
Stack Base Elevation (m above MSL)	1,950	1,950	1,950	1,950
Volumetric Emission Rate (m^3/sec)	4.1	2.0	472	29.5
Stack Exit Temperature (°K)	589	533	422	422
SO_2 Emission Rate (g/sec)	1.87	0.070	262	0.53
Particulate Emission Rate (g/sec)	0.168	0.08	31	9.5
NO_2 Emission Rate (g/sec)	1.0	1.04	87.8	151

TABLE 2-2

AREA SOURCE INPUTS FOR THE LOW LEVEL PARTICULATE SOURCES

Source	Emission Rate (g/sec)	UTM X (m)	UTM Y (m)	Height Scale (m)	Source Width (m)	Source Length (m)
(a) Phase III						
Active Work Area	0.650	573,619	4,225,487	2	200	200
Unpaved Access Road	0.073	570,500	4,231,500	2	10,000	10,000
	0.073	561,400	4,246,000	2	10,000	10,000
	0.073	556,800	4,260,700	2	10,000	10,000
	0.073	542,000	4,267,500	2	10,000	10,000
(b) Phase IV						
Primary Coke Handling	0.481	573,325	4,225,430	15	30	50
Coke Storage and Secondary Handling	8.91	573,395	4,225,465	12	50	70
	8.91	573,465	4,225,465	12	50	70
Limestone Handing and Storage	4.32	573,470	4,225,415	15	15	50
Onsite Solid Waste Handling	0.121	573,470	4,225,395	6	20	50
Solid Waste Disposal Area Sources	44.46	575,075	4,224,950	15	650	650
Extraction Zone Sources	7.65	572,950	4,224,870	2	1,000	1,200
	7.65	574,150	4,224,870	2	1,000	1,200
Paved Access Road	0.295	570,500	4,231,500	2	10,000	10,000
	0.295	561,400	4,246,000	2	10,000	10,000
	0.295	556,800	4,260,700	2	10,000	10,000
	0.295	542,000	4,267,500	2	10,000	10,000

impact of the Phase III fugitive particulate emissions can be expected in the immediate vicinity of this relatively small area source because it accounts for the majority of the Phase III fugitive particulate emissions. Three-fourths of the Phase III unpaved road particulate emissions are assumed to be generated by vehicular traffic on an access road between the site and Utah Highway 24. An exact representation of this 80-kilometer line source can be obtained by a series of adjacent square area sources with sides equal to the width of the road. However, because this source accounts for only about 30 percent of the total Phase III fugitive particulate emissions and because these roadway emissions are spread over a large geographic area, they are represented in Table 2-2 by four 10-kilometer square area sources, each of which is intended to account for emissions from a 20-kilometer segment of the roadway. Figure 2-1 shows the access road and the four area sources used to model the emissions from the road. The Phase IV primary coke handling, limestone handling and storage, and onsite solid waste handling particulate sources are represented in Table 2-2 by single area sources with horizontal dimensions approximately equal to the dimensions of the areas within which these activities are assumed to take place. The characteristic height scales of these sources are equal to the assumed heights of the conveyers. The coke storage and secondary handling sources are represented by two identical area sources with combined horizontal dimensions approximately equal to the dimensions of the coke storage area; the characteristic height scale for these two sources corresponds to the assumed height of the storage piles. Vehicular traffic and the operation of earth moving equipment in the Phase IV extraction zone will result in low-level particulate emissions which are accounted for in Table 2-2 by two area sources with combined horizontal dimensions approximately equal to the dimensions of the extraction zone. Emissions from unpaved roadways as well as from blading, hauling and drilling in areas with exposed soils are included in these two area sources. The emissions from the Phase IV paved access road were modeled in the same manner as the emissions from the Phase III unpaved access road.

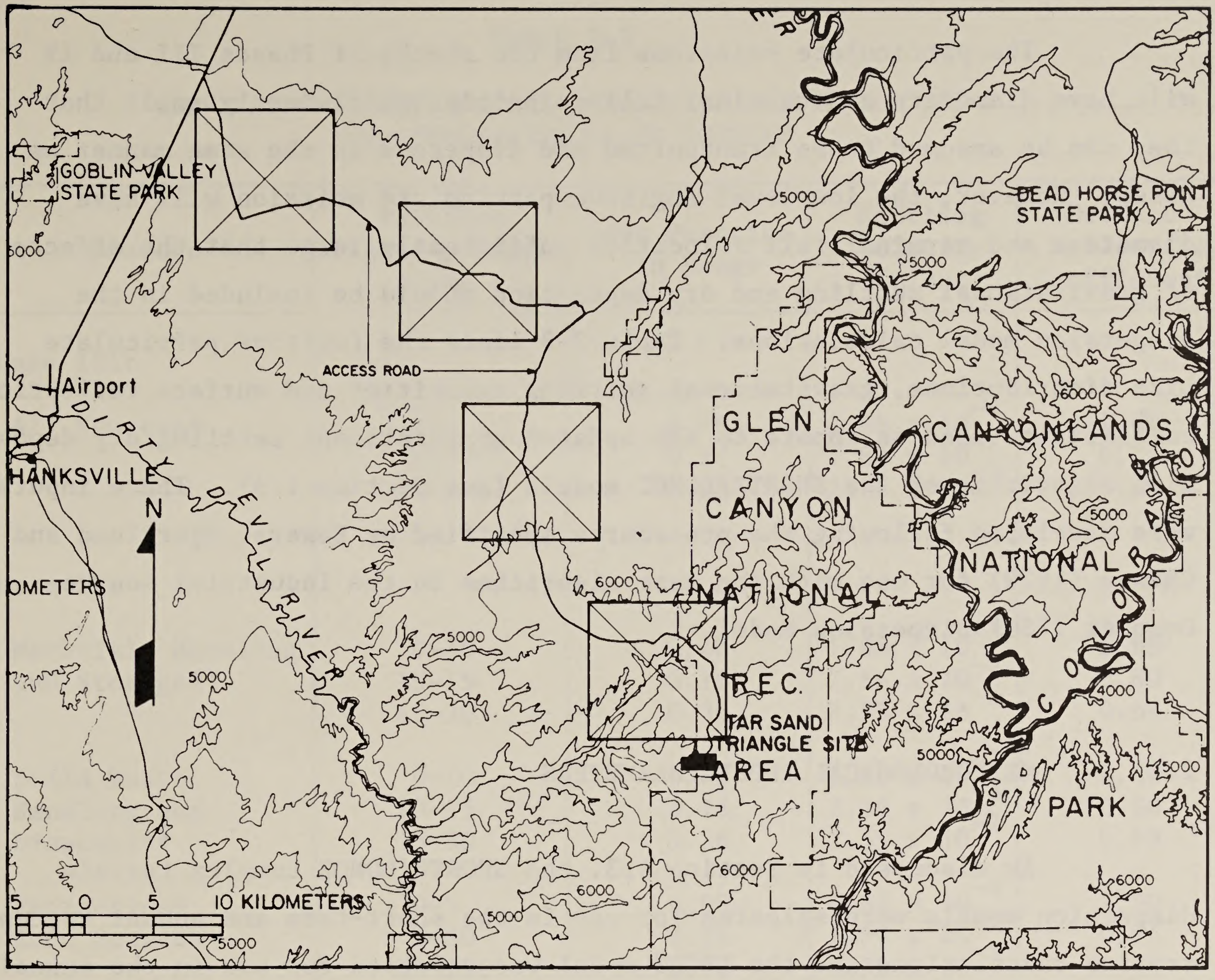

FIGURE 2-1. Map showing the access road from Utah Highway 24 to the Tar Sand Triangle site and the four square area sources used to represent the access road in the dispersion model calculations.

The particulate emissions from the stacks of Phases III and IV will have diameters and terminal fall velocities sufficiently small that they can be assumed to be transported and dispersed in the same manner as gases. However, the low-level fugitive particulate emission will have diameters and terminal fall velocities sufficiently large that the effects of gravitational settling and dry deposition should be included in the dispersion model calculations. Table 2-3 lists the fugitive particulate size distributions, gravitational settling velocities and surface reflection coefficients used as inputs to the updated gravitational settling/dry deposition algorithms of the SHORTZ/LONGZ models (see Section 1.3). These inputs were developed following the procedures specified by Bowers, Bjorklund and Cheney (1979) for use with the same algorithms in the Industrial Source Complex (ISC) Dispersion Model.

2.2 METEOROLOGICAL INPUT PARAMETERS

As discussed in Section 1.3, the SHORTZ/LONGZ complex terrain dispersion models were selected for use in the short-term and annual concentration calculations and the ISCLT model was selected for use in the annual sulfate deposition calculations. Table 2-4 lists the hourly meteorological inputs required by the SHORTZ model, Table 2-5 lists the climatological meteorological inputs required by the LONGZ model and Table 2-6 lists the climatological meteorological inputs required by the ISCLT model. This section discusses the development of the meteorological inputs to the SHORTZ/LONGZ and ISCLT models.

In a previous study for the U. S. Department of the Interior, Bureau of Land Management (BLM), the H. E. Cramer Company acquired and reviewed the meteorological data then available for southern Utah (Bowers, et al., 1978). The wind data considered in our review consisted of winds measured at the 100-meter level of the Intermountain Power Project (IPP) Salt Wash tower, winds measured at the 50-meter level of a tower adjacent to the Emery (Hunter) Power Plant and surface winds measured at the

TABLE 2-3

GRAVITATIONAL SETTING/DRY DEPOSITION INPUTS FOR THE LOW-LEVEL PARTICULATE SOURCES

Sources	Particle Diameter Range (μm)	Mass Fraction in Range	Settling Velocity (m/sec)	Surface Reflection Coefficient
Phase III:				
All Sources*	0-5	0.08	4.65×10^{-4}	1.00
	5-30	0.24	1.89×10^{-2}	0.74
	30-100	0.68	2.35×10^{-1}	0.16
Phase IV:				
Materials Handling and Storage**	0-10	0.48	1.86×10^{-3}	0.89
	10-15	0.16	7.56×10^{-3}	0.80
	15-30	0.36	2.55×10^{-2}	0.69
Solid Waste Handling and Disposal**	0-10	0.48	1.86×10^{-3}	0.89
	10-15	0.16	7.56×10^{-3}	0.80
	15-30	0.36	2.55×10^{-2}	0.69
Extraction* Zone Sources	0-5	0.08	4.65×10^{-4}	1.00
	5-30	0.24	1.89×10^{-2}	0.74
	30-100	0.68	2.35×10^{-1}	0.16
Paved Access Road	0-5	0.50	4.65×10^{-4}	1.00
	5-30	0.40	1.89×10^{-2}	0.74
	30-100	0.10	2.35×10^{-1}	0.16

* From AP-42 (EPA, 1981).

** From Engineering-Science, Inc. (1983).

TABLE 2-4

HOURLY METEOROLOGICAL INPUTS REQUIRED BY THE SHORTZ MODEL

Parameter	Definition
$\bar{u}_R$	Mean wind speed (m/sec) at height z_R
DD	Mean wind direction (deg) at height z_R
p	Wind-profile exponent
σ'_A	Wind azimuth-angle standard deviation in radians
σ'_E	Wind elevation-angle standard deviation in radians
T_a	Ambient air temperature (^{o}K)
H_m	Depth of surface mixing layer (m)
$\frac{\partial\theta}{\partial z}$	Vertical potential temperature gradient (^{o}K/m)

TABLE 2-5

METEOROLOGICAL INPUTS REQUIRED BY
THE LONGZ MODEL

Parameter	Definition
$f_{i,j,k}$	Frequency distribution of wind-speed and wind-direction categories by stability or time-of-day categories
$\bar{u}\{z_R\}_i$	Mean wind speed (m/sec) at height z_R for the i^{th} wind-speed category
$p_{i,k}$	Wind-profile exponent for the i^{th} wind-speed category and k^{th} stability or time-of-day category
$\sigma'_{E;i,k}$	Standard deviation of the wind-elevation angle in radians for the i^{th} wind-speed category and k^{th} stability or time-of-day category
$T_{a;k}$	Ambient air temperature (^oK) for the k^{th} stability or time-of-day category
$\left(\frac{\partial\theta}{\partial z}\right)_{i,k}$	Vertical potential temperature gradient ($^oK/m$) for the i^{th} wind-speed category and k^{th} stability or time-of-day category
$H_{m;i,k}$	Median surface mixing depth (m) for the i^{th} wind-speed category and k^{th} stability or time-of-day category

TABLE 2-6

METEOROLOGICAL INPUTS REQUIRED BY THE ISCLT MODEL

Parameter	Definition
$f_{i,j,k}$	Frequency of occurrence of the i^{th} wind-speed category and j^{th} wind-direction category for the k^{th} Pasquill stability category (STAR summary)
$\bar{u}\{z_R\}_i$	Mean wind speed (m/sec) at height z_R for the i^{th} wind-speed category
$p_{i,k}$	Wind-profile exponent for the i^{th} wind-speed category and k^{th} stability category (default values are assigned on the basis of stability)
$T_{a;k}$	Ambient air temperature (°K) for the k^{th} stability category
$\left(\frac{\partial\theta}{\partial z}\right)_{i,k}$	Vertical potential temperature gradient (°K/m) for the i^{th} wind-speed category and k^{th} stability category (default values are assigned on the basis of stability)
$H_{m;i,k}$	Mixing height (m) for the i^{th} wind-speed category and k^{th} stability category

Hanksville, Utah Airport. The locations of the three sites for which hourly wind data are available are shown in Figure 1-1 in Section 1.2. Additionally, we examined a climatological summary of 3,159 rawinsonde upper-air soundings made in support of mission requirements at the U. S. Army Green River, Utah Launch Complex. These rawinsonde releases were of special interest because they were made throughout the day rather than at the standard release times of 0000 and 1200 GMT. Based in part on the correspondence between the wind-direction distribution at the 100-meter level of the IPP tower and the Green River wind-direction distribution at the typical stabilization height for the plumes from the IPP Power Plant (2,400 meters above mean sea level), we concluded that the 100-meter tower wind directions provide the best available information on regional transport wind directions for tall stack emissions. Although the 100-meter wind directions may not be indicative of the initial transport wind directions for low-level fugitive emissions within this region of complex terrain, it is our opinion that these wind directions provide the best available information on the regional transport of the low-level as well as the stack emissions. We therefore selected the IPP 100-meter tower winds for use in the dispersion model calculations. The period of record for the IPP tower is January 1975 through October 1976, and we used the 1975 data because 1975 is the only calendar year with complete data.

We used the IPP tower 100-meter wind directions (reported to the nearest degree) and wind speeds as direct inputs to the SHORTZ model. Additionally, we used the hourly wind observations with our Meteorological and Air Quality Statistical Analysis Program (MAQSAP) to develop the annual joint distribution of wind-speed and wind-direction categories, classified according to four time-of-day categories, for use in the LONGZ model calculations. This annual statistical wind summary is listed in Appendix A. The four time-of-day categories are defined as follows:

- Morning - Sunrise plus 1 hour to sunrise plus 5 hours

- Afternoon - Sunrise plus 5 hours to sunset minus 1 hour

- Evening - Sunset minus 1 hour to sunset plus 2 hours

- Night - Sunset plus 2 hours to sunrise plus 1 hour

Table 2-7 lists the approximate correspondence between the various combinations of wind-speed and time-of-day categories and the Pasquill stability categories as defined by Turner (1964).

The SHORTZ/LONGZ models use a wind-profile exponent law to adjust the mean wind speed from the measurement height to the stack height for use in the plume rise calculations and to the plume stabilization height for use in the concentration calculations. The IPP tower measured wind speed at 10 and 100 meters. We calculated hourly wind-profile exponents p for use in the SHORTZ model concentration calculations from the expression

$$p = \frac{\ln(\bar{u}\{100m\}/\bar{u}\{10m\})}{\ln(100/10)} \qquad (2\text{-}1)$$

where $\bar{u}\{100m\}$ and $\bar{u}\{10m\}$ are the 100-meter and 10-meter wind speeds, respectively. The exponent p was not allowed to exceed unity or to be less than zero. The hourly p values were then used with MAQSAP to determine, for each combination of wind-speed and time-of-day categories, the median exponent for use in the LONGZ model calculations. Table 2-8 lists these median wind-profile exponents. (In comparing the wind-profile exponents in Table 2-8 with the SHORTZ/LONGZ models' default wind-profile exponents (see Table 2-2 of Bjorklund and Bowers, 1982), it should be remembered that the wind speeds in Table 2-8 are 100-meter rather than 10-meter wind speeds.) If the 10-meter or 100-meter wind speed was missing during an hour so that an exponent could not be calculated for the hour, the appropriate median exponent from Table 2-8 was assigned to the hour for use in the SHORTZ model calculations. Additionally, if the 100-meter wind speed was the missing wind speed, the 10-meter wind speed was adjusted to 100 meters using the appropriate median exponent. If the 100-meter wind speed was less than 1 meter per second, it was redefined as 1 meter per second for modeling purposes.

TABLE 2-7

PASQUILL STABILITY CATEGORIES APPROXIMATELY CORRESPONDING TO THE COMBINATIONS OF WIND SPEED AND TIME OF DAY*

Time of Day	Wind Speed (m/sec)					
	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8
Night	E	E	E	D	D	D
Morning	C	D	D	D	D	D
Afternoon	B	B	C	C	D	D
Evening	E	E	D	D	D	D

* Source: Table 2-8 of Bjorklund and Bowers (1982).

TABLE 2-8

MEDIAN WIND-PROFILE EXPONENTS USED IN THE LONGZ MODEL CALCULATIONS

Time of Day	100-Meter Wind Speed (m/sec)					
	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8
Night	0.03	0.21	0.26	0.20	0.14	0.11
Morning	0.03	0.08	0.14	0.08	0.08	0.08
Afternoon	0.03	0.03	0.05	0.08	0.08	0.08
Evening	0.03	0.09	0.14	0.14	0.13	0.10

The SHORTZ model directly relates the lateral dispersion coefficient σ_y to the lateral turbulent intensity or standard deviation of the wind azimuth angle in radians σ'_A. The IPP tower data includes hourly values of the standard deviations of the wind azimuth angle at the 10-meter and 100-meter tower levels, and we used the 100-meter values as direct inputs to the SHORTZ model. In the IPP Power Plant study described by Bowers, et al. (1978), we adjusted σ'_A from 100 meters to the IPP stack height. Because this study considered both stack and low-level fugitive emissions, we used the 100-meter σ'_A values without adjustment as representative of mean layer values for the surface mixing layer. If an hourly σ'_A was missing, Table 2-9 lists the median values for the 100-meter tower level that were substituted on the basis of wind speed and time of day.

The SHORTZ and LONGZ models directly relate the vertical dispersion coefficient σ_z to the vertical turbulent intensity or standard deviation of the wind elevation angle in radians σ'_E. No σ'_E measurements are available in the IPP tower data. However, we believe that it is possible to infer σ'_E from σ'_A as long as the 100-meter level is within the surface mixing layer. As discussed by Bjorklund and Bowers (1982), the default σ'_A and σ'_E values in the SHORTZ model assume the hourly σ'_A/σ'_E ratio to be 1.43 at heights on the order of 100 meters above the surface. This ratio arises from the approximate equivalence between σ'_A and σ'_E found at this height by Luna and Church (1972) for a 10-minute averaging time, the assumption that σ'_E is effectively constant for averaging times of 10 to 60 minutes and the assumption that σ'_A increases according to a $t^{1/5}$ law (Osipov, 1972 and others). Similarity relationships between the standard deviations of the lateral (σ_v) and vertical (σ_w) wind velocity components also support the 1.43 ratio (for example, Counihan, 1975). We therefore divided the hourly σ'_A observations by 1.43 to obtain the corresponding σ'_E values for use in the SHORTZ model calculations. Similarly, we divided the median σ'_A values in Table 2-9 by 1.43 to obtain the σ'_E values for use in the LONGZ model calculations and to replace missing hourly observations for use in the SHORTZ model calculations.

TABLE 2-9

MEDIAN HOURLY LATERAL TURBULENT INTENSITIES IN RADIANS FOR THE 100-METER TOWER*

Time of Day	100-Meter Wind Speed (m/sec)					
	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8
Night	0.0785	0.0785	0.0785	0.0785	0.0785	0.0785
Morning	0.2356	0.1833	0.1309	0.0785	0.0785	0.0785
Afternoon	0.3054	0.2356	0.1833	0.1309	0.0785	0.0785
Evening	0.0785	0.0785	0.0785	0.0785	0.0785	0.0785

* Source: Table 2-5 of Bowers, et al. (1978).

TABLE 2-10

MEAN AMBIENT AIR TEMPERATURES USED IN THE LONGZ MODEL CALCULATIONS

Time of Day	Ambient Air Temperature (°K)
Night	279
Morning	282
Afternoon	291
Evening	286

The Briggs (1969; 1971; 1972) plume rise equations used by the SHORTZ/LONGZ models require the ambient air temperature and vertical potential temperature gradient as meteorological inputs. The IPP tower hourly temperature measurements were used as direct inputs to the SHORTZ model. Similarly, the average ambient air temperatures by time-of-day categories, which are listed in Table 2-10, were used as inputs to the LONGZ model. In our opinion, the vertical temperature differences ΔT measured on the IPP tower provide a poor indication of the thermal stratification experienced by the stack plumes as they rise to their stabilization heights. That is, the pronounced temperature gradients found at times near the surface generally are not representative of the average temperature gradients in the surface mixing layer. We therefore used the vertical potential temperature gradients listed in Table 2-11 in the SHORTZ/LONGZ model calculations. Table 2-11 was developed from: (1) the potential temperature gradients recommended by Bjorklund and Bowers (1982, Table 2-4) for use with the SHORTZ/LONGZ models in arid regions, and (2) the approximate relationships given in Table 2-7 between the Pasquill stability categories and the joint combinations of wind-speed and time-of-day categories. The vertical potential temperature gradients in Table 2-11 are almost identical to the potential temperature gradients used by Bowers, et al. (1978) in the IPP Power Plant study.

As part of a study for BLM of the air quality impact of emissions from Units 1 and 2 of the Emery (Hunter) Power Plant, Cramer and Bowers (1976) analyzed seasonal tabulations of twice-daily Holzworth (1972) mixing depth estimates and average wind speeds at Grand Junction, Colorado and Salt Lake City, Utah for the period 1960 through 1964 to determine seasonal median early morning and afternoon mixing depths at each site for each wind-speed category. The median early morning mixing depths at Grand Junction and Salt Lake City are essentially the same, but the afternoon median mixing depths at Grand Junction are consistently larger than the corresponding mixing depths at Salt Lake City. Cramer and Bowers (1976) averaged the seasonal median mixing depths at Salt Lake City and Grand Junction to obtain the estimates of median mixing depths in southern Utah

TABLE 2-11

DEFAULT VERTICAL POTENTIAL TEMPERATURE GRADIENTS IN DEGREES KELVIN PER METER*

Time of Day	Wind Speed (m/sec)					
	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8
Night	0.030	0.020	0.010	0.000	0.000	0.000
Morning	0.000	0.010	0.005	0.000	0.000	0.000
Afternoon	0.000	0.000	0.000	0.000	0.000	0.000
Evening	0.030	0.020	0.005	0.000	0.000	0.000

* Based on Table 2-4 of Bjorklund and Bowers, 1982.

that are listed in Table 2-12. Subsequently, Bowers, et al. (1978) compared these mixing depth estimates with mixing depths derived from early morning (sunrise) and afternoon (1400 MST) upper-air soundings made at Hanksville, Utah during the period March 1976 through April 1977 (Aeromet, 1977) and concluded that they supported the use of the median Salt Lake City/Grand Junction mixing depths previously derived by Cramer and Bowers (1976). The climatological summary of Green River Launch Complex rawinsonde soundings reviewed by Bowers, et al. (1978) and briefly discussed above did not contain any information on mixing depths.

The METZ meteorological preprocessor program for the SHORTZ model, which is described in Appendix I of the report by Bjorklund and Bowers (1982), uses the mixing depth interpolation scheme illustrated in Figure 2-1 to obtain mixing depths for hours other than the hours when the median early morning and afternoon mixing depths are assumed to apply. The urban scheme, which is shown by the solid line, is based on Holzworth early morning (H_m (min)) and afternoon (H_m (max)) mixing depths. The early morning mixing depth is assumed to apply from sunset plus 2 hours (SS+2) on the preceding day until sunrise (SR); mixing depths for the hours between sunrise and 1600 local standard time (LST), when the afternoon mixing depth is assumed to apply, are obtained by linear interpolation; and mixing depths for the hours between 1600 LST and sunset plus 2 hours, when the early morning mixing depth for the following day is assumed to apply, are also obtained by linear interpolation. The rural mixing depth interpolation scheme, which is shown by the dashed line in Figure 2-1, is identical to the urban scheme except that a rural nighttime mixing depth H_{mn} is substituted for the Holzworth early morning mixing depth. Based on the suggestions of Benkley and Schulman (1979) for calculating the mechanical component of the mixing depth, H_{mn} in meters is given by

$$H_{mn} = \begin{cases} a\,\bar{u}_n & ;\ a\,\bar{u}_n \le H_m\,(\min) \\ H_m(\min) & ;\ a\,\bar{u}_n > H_m\,(\min) \end{cases} \qquad (2\text{-}2)$$

TABLE 2-12

SEASONAL MEDIAN MIXING DEPTHS IN METERS BASED ON GRAND JUNCTION AND SALT LAKE CITY DATA*

Time of Day	Wind Speed (m/sec)					
	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8
(a) Winter						
Early Morning	125	125	125	300	510	840
Afternoon	575	710	1,025	1,250	1,250	1,250
(b) Spring						
Early Morning	125	125	125	225	625	1,075
Afternoon	1,750	2,500	2,625	2,925	3,000	3,000
(c) Summer						
Early Morning	125	125	125	200	450	590
Afternoon	2,500	3,100	3,550	4,100	4,100	4,100
(d) Fall						
Early Morning	125	125	125	180	400	750
Afternoon	900	1,425	1,850	2,300	2,625	2,750

* Source: Table 2-12 of Cramer and Bowers (1976).

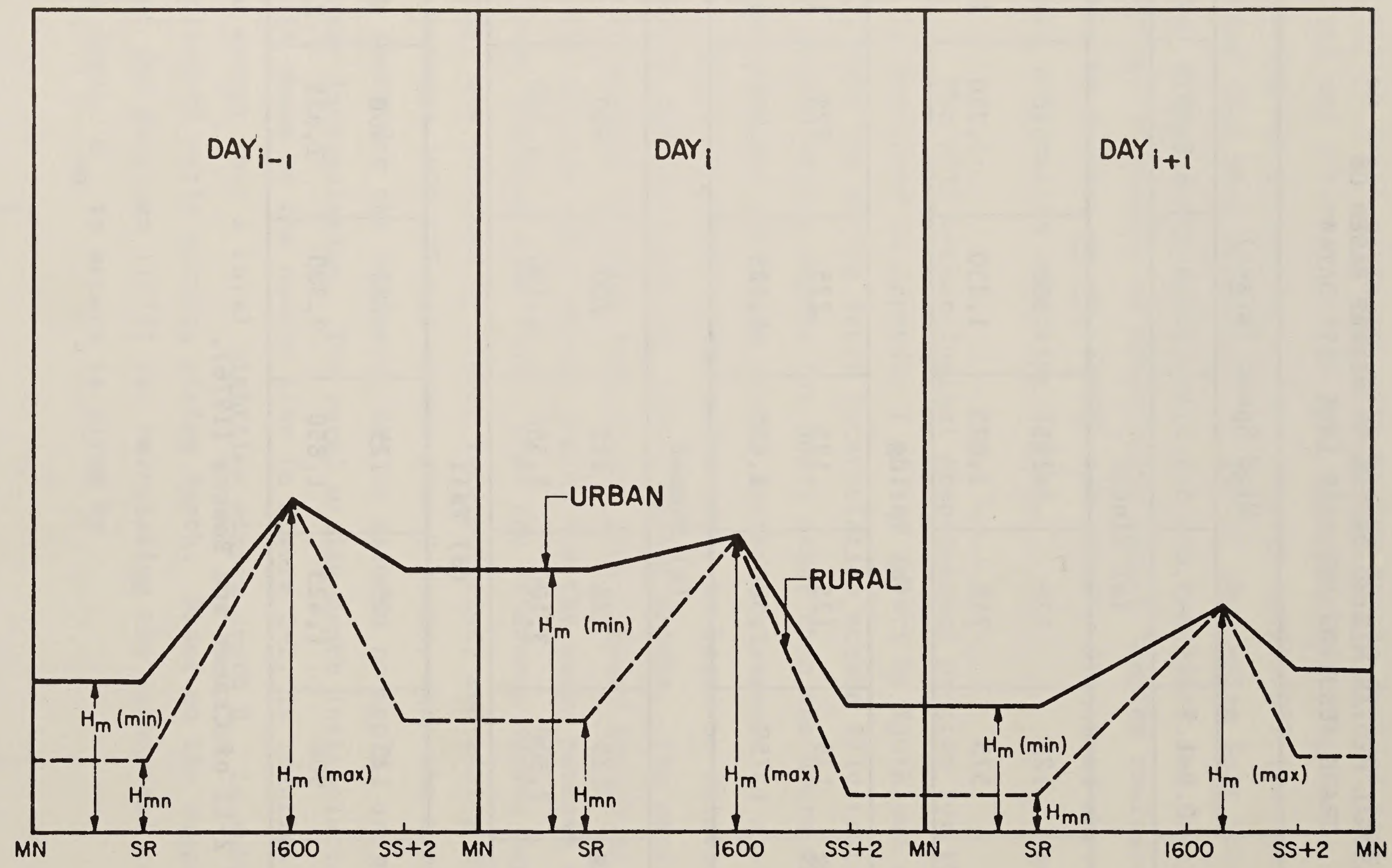

FIGURE 2-1. Mixing depth interpolation schemes for urban (solid line) and rural (dashed line) areas used by the SHORTZ meteorological preprocessor program (from Figure 2-1 of Bjorklund and Bowers, 1982).

where $\bar{u}_n$ is the mean wind speed in meters per second (measured at or near a height of 10 meters) during the hours between sunset plus 2 hours on the preceding day and sunrise and the constant "a" is a function of the local roughness length z_o. A typical value for "a" is 100 for a roughness length of 10 centimeters. Inspection of Equation (2-2) and Figure 2-1 shows that the rural mixing depth is never allowed to exceed the urban mixing depth.

We used the median mixing depths in Table 2-12 with the METZ mixing depth interpolation scheme shown in Figure 2-1 for rural areas to obtain hourly mixing depths for use in the SHORTZ model calculations. The Holzworth early morning and afternoon mixing depths for each day were determined by the combination of the season and the 10-meter wind speeds at sunrise (early morning mixing depth) and 1600 MST (afternoon mixing depth). We have no basis for estimating z_o at the Tar Sand Triangle. Additionally, because z_o is a function of upwind fetch, z_o can be expected to vary with wind direction. A minimum value for z_o in the area where industrial development may occur probably is on the order of 15 centimeters. We therefore assumed a z_o of 15 centimeters, which corresponds to a coefficient "a" in Equation (2-2) of 110. The wind speeds used with Equation (2-2) to calculate the mechanical component of the mixing depth were from the 10-meter level of the IPP tower. We analyzed the hourly mixing depths calculated by METZ to determine median mixing depths for the various combinations of wind-speed and time-of-day categories for use with the LONGZ model. These median mixing depths are given in Table 2-13.

We used the ISCLT model to perform the annual sulfate deposition calculations. Although the ISCLT and LONGZ models are similar in many ways, their meteorological input options are not exactly the same (see Tables 2-5 and 2-6). The principal meteorological inputs to the LONGZ model are statistical summaries of the joint frequency of occurrence of wind-speed and wind-direction categories, classified according to either the four time-of-day categories or the Pasquill stability categories. The ISCLT model requires similar meteorological inputs, but only allows the use

TABLE 2-13

MEDIAN ANNUAL MIXING DEPTHS IN METERS USED IN THE LONGZ MODEL CALCULATIONS

Time of Day	100-Meter Wind Speed (m/sec)					
	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8
Night	125	125	150	250	550	800
Morning	750	950	1,125	1,250	1,200	1,400
Afternoon	800	1,900	2,400	2,550	2,550	2,500
Evening	375	500	675	750	875	1,075

of wind summaries classified according to the Pasquill stability categories. Mitchell and Timbre (1979) proposed a stability classification scheme based on hourly σ'_A and wind-speed measurements at a height of 10 meters that was suggested for use with onsite meteorological data in the October 1980 draft EPA report "Proposed Revisions to the Guideline on Air Quality Models." If the wind azimuth angle standard deviations in the Mitchell and Timbre (1979) paper are converted to radians, Table 2-14 gives the σ'_A ranges corresponding to the Pasquill stability categories for a roughness length z_o of 15 centimeters. We attempted to use this stability classification scheme with the 10-meter σ'_A values to obtain an annual statistical wind summary for input to the ISCLT model. However, the results indicated that the stable E and very stable F Pasquill stability categories occurred during over 58 percent of the hours. This result is highly improbable in complex terrain and is impossible following the Turner (1964) definitions of the Pasquill stability categories. We therefore examined the 10-meter σ'_A observations and found, contrary to theoretical or empirical expectation, that the 100-meter σ'_A values tended to exceed the concurrent 10-meter values. (Although we examined in detail the 100-meter σ'_A values as part of our IPP Power Plant study (Bowers, et al., 1978), we did not attempt to assess the validity of the 10-meter σ'_A values because they were not needed for modeling purposes in the IPP study.) We conclude that the 10-meter σ'_A measurements from the IPP tower are questionable and should be used with caution. Consequently, we did not use the 10-meter σ'_A measurements in this study.

In the absence of reliable 10-meter σ'_A measurements, we adjusted the Mitchell and Timbre (1979) stability classification scheme to a height of 100 meters for use with the 100-meter σ'_A measurements. Cramer (1976) gives the height dependence of σ'_A as

$$\sigma'_A\{z\} = \sigma'_A\{z_R\} \left(\frac{z}{z_R}\right)^{-p} \qquad (2\text{-}3)$$

TABLE 2-14

MITCHELL AND TIMBRE (1979) STABILITY CLASSIFICATION SCHEME FOR A SURFACE ROUGHNESS LENGTH OF 15 CENTIMETERS

Pasquill Stability Category	σ'_A (rad) at 10 meters
A	>0.39*
B	0.31 - 0.38**
C	0.22 - 0.30***
D	0.13 - 0.21
E	0.07 - 0.12
F	<0.07

* Redefine as F stability during the nighttime hours if the 10-meter mean wind speed is less than 2.9 meters per second, as E stability if the 10-meter mean wind speed is between 2.9 and 3.6 meters per second and as D stability if the 10-meter wind speed is above 3.6 meters per second.

** Redefine as F stability during the nighttime hours if the 10-meter mean wind speed is less than 2.4 meters per second, as E stability if the 10-meter mean wind speed is between 2.4 and 3.0 meters per second and as D stability if the 10-meter mean wind speed is above 3 meters per second.

*** Redefine as E stability during the nighttime hours if the 10-meter mean wind speed is less than 2.4 meters per second, and as D stability if the 10-meter mean wind speed is above 2.4 meters per second.

where $\sigma'_A\{z\}$ is the lateral turbulent intensity at height z above the surface, $\sigma'_A\{z_R\}$ is the lateral turbulent intensity at height z_R and p is the wind-profile exponent. If the ISCLT default wind-profile exponents (see Table 2-2 of Bowers, Bjorklund and Cheney, 1979) are used with Equation (2-3) to adjust the 10-meter σ'_A ranges in Table 2-14 to a height of 100 meters, Table 2-15 lists the modified Mitchell and Timbre (1979) stability classification scheme. We used Table 2-15 with the hourly 100-meter σ'_A measurements and the hourly 10-meter wind speeds to generate the annual wind summary listed in Appendix A for use in the ISCLT annual deposition calculations. The ISCLT default wind-profile exponents and vertical potential temperature gradients, which are assigned by the model on the basis of the Pasquill stability category, were used in the deposition calculations. The mean ambient air temperatures used in the ISCLT model calculations were based on the annual afternoon, nighttime and daily average temperatures at the IPP tower. The average afternoon temperature of 291 degrees Kelvin was assumed to apply to the unstable (A, B and C) Pasquill stability categories, the average nighttime temperature of 279 degrees Kelvin was assumed to apply to the stable (E and F) stability categories and the annual average temperature of 283 degrees Kelvin was assumed to apply to the neutral D category. The annual mixing heights used in the ISCLT calculations are listed in Table 2-16. Following the guidance given in the ISC Model User's Guide (p. 2-8) for regulatory applications, the median annual Grand Junction/Salt Lake City afternoon mixing depths from Table 2-13 were multiplied by 1.5 and assigned to the very unstable Pasquill A stability category, while the median annual Grand Junction/Salt Lake City afternoon mixing depths were assigned to the B, C and D categories. The ISCLT model in the Rural Mode assumes unrestricted vertical mixing during hours with E or F stability.

TABLE 2-15

MITCHELL AND TIMBRE (1979) STABILITY CLASSIFICATION SCHEME FOR A SURFACE ROUGHNESS LENGTH OF 15 CENTIMETERS AFTER ADJUSTMENT TO A MEASUREMENT HEIGHT OF 100 METERS

Pasquill Stability Category	σ'_A (rad) at 100 meters
A	>0.31*
B	0.21 - 0.30**
C	0.14 - 0.20***
D	0.07 - 0.13
E	0.03 - 0.06
F	<0.03

* Redefine as F stability during the nighttime hours if the 10-meter mean wind speed is less than 2.9 meters per second, as E stability if the 10-meter mean wind speed is between 2.9 and 3.6 meters per second and as D stability if the 10-meter wind speed is above 3.6 meters per second.

** Redefine as F stability during the nighttime hours if the 10-meter mean wind speed is less than 2.4 meters per second, as E stability if the 10-meter mean wind speed is between 2.4 and 3.0 meters per second and as D stability if the 10-meter mean wind speed is above 3 meters per second.

*** Redefine as E stability during the nighttime hours if the 10-meter mean wind speed is less than 2.4 meters per second and as D stability if the 10-meter mean wind speed is above 2.4 meters per second.

TABLE 2-16

ANNUAL MIXING HEIGHTS IN METERS USED IN THE ISCLT MODEL CALCULATIONS

Pasquill Stability Category	100-Meter Wind Speed (m/sec)					
	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8
A	1,200	2,850	3,600	3,825	3,825	3,750
B	800	1,900	2,400	2,550	2,550	2,500
C	800	1,900	2,400	2,550	2,550	2,500
D	800	1,900	2,400	2,550	2,550	2,500
E	*	*	*	*	*	*
F	*	*	*	*	*	*

*The ISCLT model in the Rural Mode assumes unrestricted vertical mixing during hours with E or F stability.

SECTION 3
CALCULATION PROCEDURES AND RESULTS

3.1 GENERAL

There are two basic computational techniques for obtaining estimates of maximum short-term and annual average ground-level pollutant concentrations. The simplest and most straightforward technique is to use a short-term dispersion model (such as the SHORTZ model) to calculate the hourly concentration attributable to emissions from each source at each receptor during each hour of a year. The results of these "brute force" hourly concentration calculations are then used to form concentrations for longer averaging times and to determine the maximum short-term and annual average concentrations. The major drawbacks of the "brute force" approach are that it makes very extensive use of computer resources and that it is often impossible to include an adequate number of receptors to ensure the detection of the maximum short-term concentrations. As an alternative to the "brute force" technique, the H. E. Cramer Company has for many years used our persistence search (PRSIST) data analysis program to scan the hourly meteorological inputs and identify those short-term periods with meteorological conditions conducive to high calculated and observed ground-level concentrations. The SHORTZ model is then used with the hourly meteorological inputs for these selected "worst-case" short-term periods to calculate maximum short-term concentrations, while annual average concentrations are efficiently obtained using the LONGZ model with climatological meteorological inputs. The LONGZ model is based on the same fundamental assumptions as the SHORTZ model, and the equations of the LONGZ model can be derived from the equations of the SHORTZ model (for example, see Calder, 1971). For the same source inputs and meteorological data base, the SHORTZ and LONGZ models yield equivalent annual average concentrations.

We used both of the computational techniques described above in the dispersion model calculations described in this report. The distances from the assumed source locations at the Tar Sand Triangle site to Canyonlands, Arches and Capitol Reef National Parks are sufficiently long that a relatively small number of receptors can adequately cover the nearest boundaries of each of these areas. We therefore used the SHORTZ model in the "brute force" manner to calculate hourly concentrations at the three parks. We then used the calculated hourly concentrations written to tape by the SHORTZ model with the H. E. Cramer Company's POSTZ postprocessor program to determine, for each receptor, the maximum 3-hour and 24-hour average concentrations and the annual average concentration. We required each 24-hour period to contain at least 18 non-calm and non-missing hours to be considered in the maximum 24-hour average concentration calculations. For example, the "24-hour average" concentration for a day with 3 hours of missing wind-direction observations was in fact a 21-hour average concentration. Similarly, we required each 3-hour period to contain at least 2 valid (non-calm and non-missing) hours to be considered in the maximum 3-hour average concentration calculations. The valid hours during days excluded from the 24-hour average concentration calculations because of less that 18 valid hours of meteorological inputs were considered in the maximum 3-hour average concentration calculations. As discussed in detail in the next section, we used the LONGZ model to calculate annual average concentrations in the vicinity of the Tar Sand Triangle, including Glen Canyon National Recreation Area. The maximum short-term concentrations in the vicinity of the Tar Sand Triangle were obtained using the SHORTZ model with hourly meteorological inputs for the "worst-case" dispersion periods identified by PRSIST analyses.

3.2 CONCENTRATIONS AT DISTANCES OF LESS THAN 50 KILOMETERS

Annual Average Concentrations at Class II Areas

We used the LONGZ model with the source inputs given in Section 2.1 and the climatological meteorological inputs given in Section 2.2 and Appendix A to calculate the annual average ground-level SO_2, particulate and NO_2 concentrations attributable to emissions from the sources at the Tar Sand Triangle site. The calculation grid consisted of a 19-kilometer by 20-kilometer rectangle centered on the sources at the Tar Sand Triangle site. (The area 10 kilometers to the east, which approximately corresponds to the nearest boundary of Canyonlands National Park, was considered in the SHORTZ model "brute force" calculations described below.) Receptors were placed at 500-meter intervals within 6 kilometers of the center of this rectangle and at 1-kilometer intervals beyond 6 kilometers. Additional discrete receptors were placed on elevated terrain features not adequately covered by the regular receptor array. The elevations of all receptors were extracted from USGS topographic maps for use in the SO_2 and NO_2 concentration calculations. As pointed out by Bowers, Bjorklund and Cheney (1979, p. 2-51), the gravitational settling/dry deposition algorithms used by the ISC and SHORTZ/LONGZ models can violate mass continuity if applied in complex terrain. Specifically, mass is artificially created at receptor elevations below the base elevation of the source. The majority of the particulate emission from the sources at the Tar Sand Triangle site are low-level fugitive emissions, and a significant fraction of these particulates can be expected to fall out and be deposited near the sources. At the longer downwind distances, the effects on the concentrations calculated for the low-level fugitive particulate emissions of depletion by deposition are more important than are terrain effects. For these reasons, the LONGZ model was executed in a flat terrain mode in the particulate concentration calculations.

The calculated isopleths in micrograms per cubic meter of annual average ground-level SO_2, particulate and NO_2 concentrations attributable to emissions from Phase III of the Tar Sand Triangle Project are shown in Figures 3-1, 3-2 and 3-3, respectively. Similarly, the calculated isopleths of annual average ground-level SO_2, particulate and NO_2 concentrations attributable to emissions from Phase IV are shown in Figures 3-4, 3-5 and 3-6, respectively. The maximum annual average ground-level SO_2, particulate and NO_2 concentrations calculated for the emissions of Phase III and Phase IV

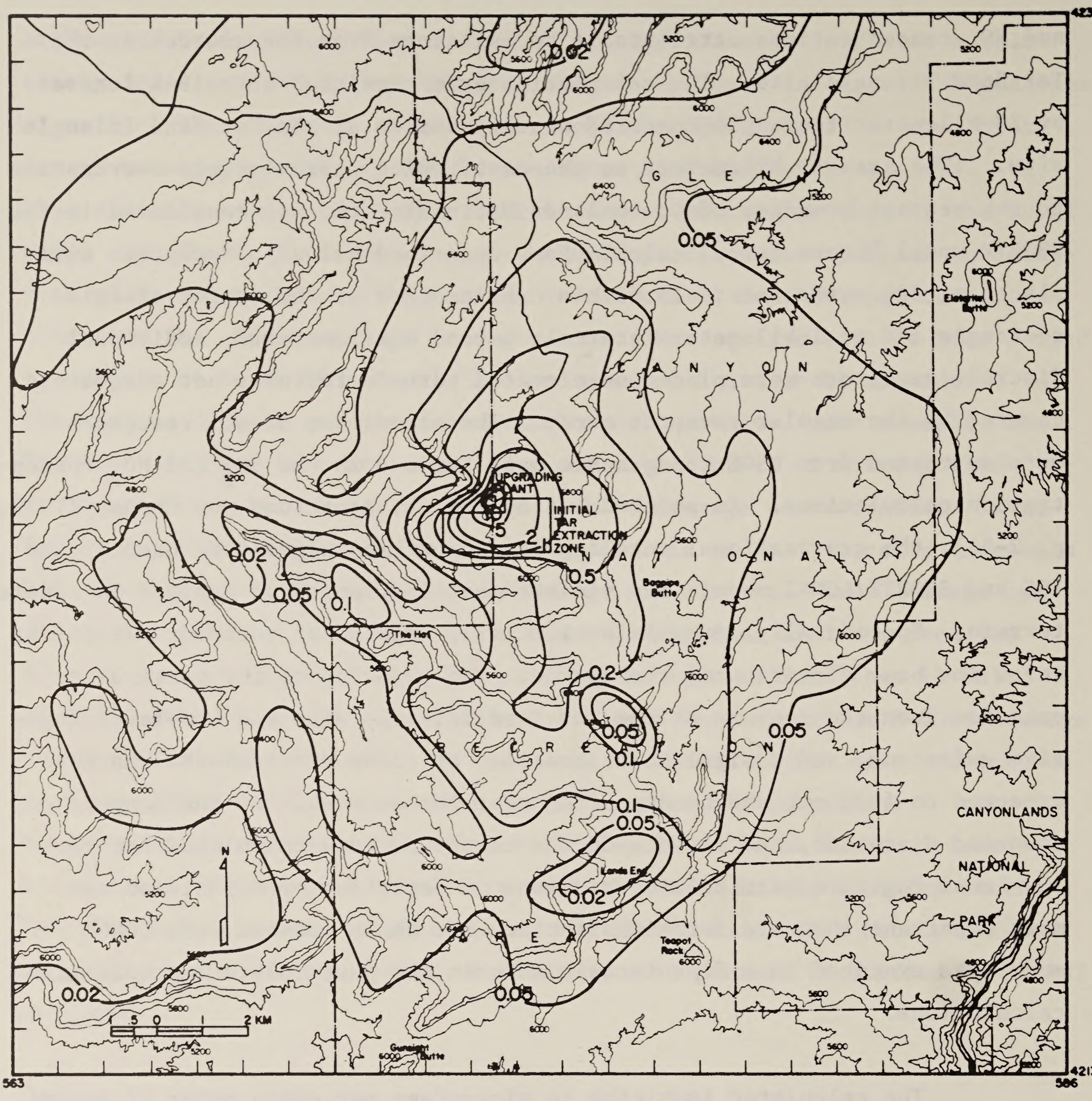

FIGURE 3-1. Calculated isopleths of annual average ground-level SO_2 concentration in micrograms per cubic meter attributable to emissions from Phase III of the proposed Utah Tar Sand Triangle Project.

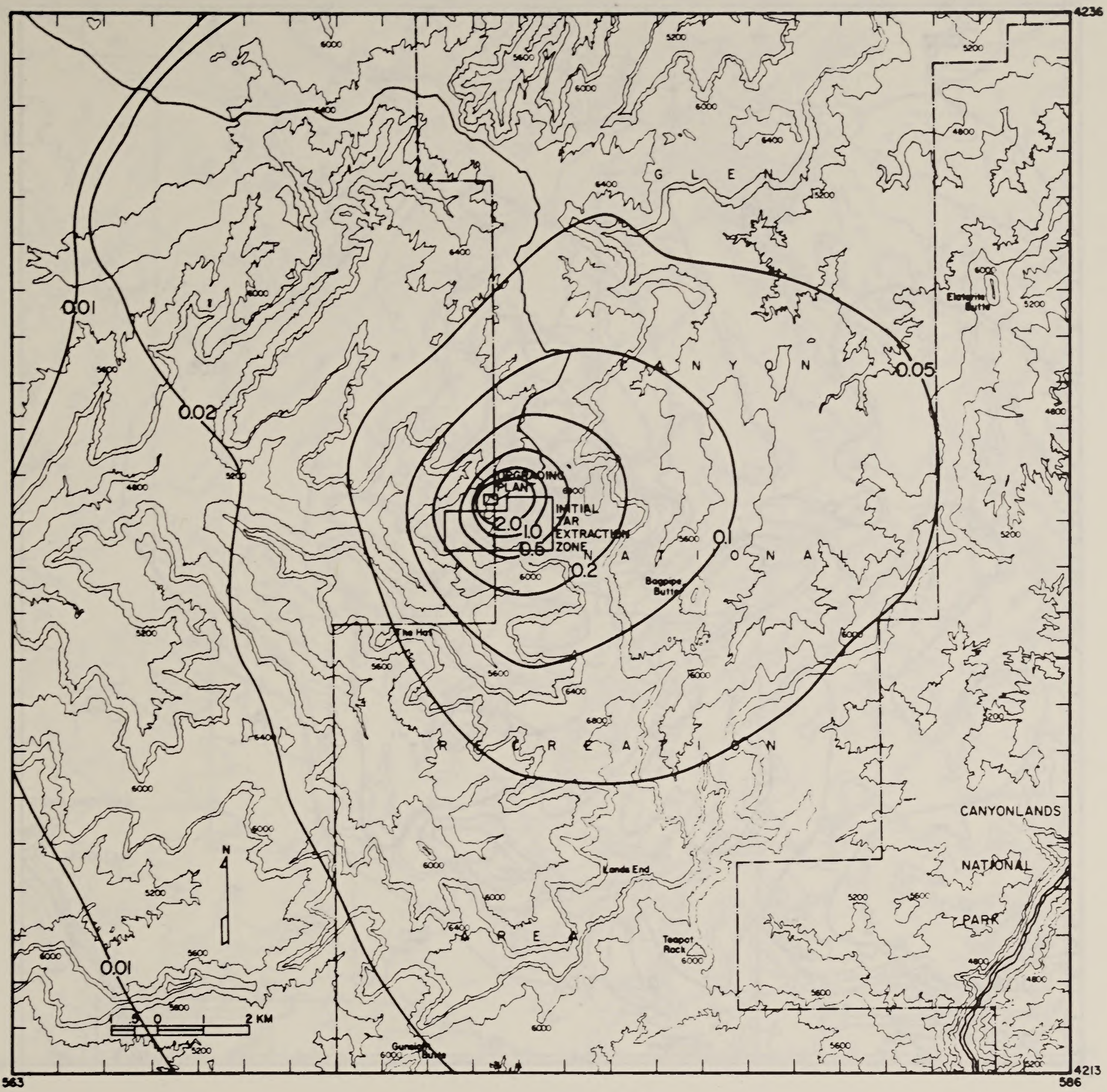

FIGURE 3-2. Calculated isopleths of annual average ground-level particulate concentration in micrograms per cubic meter attributable to emissions from Phase III of the proposed Utah Tar Sand Triangle Project.

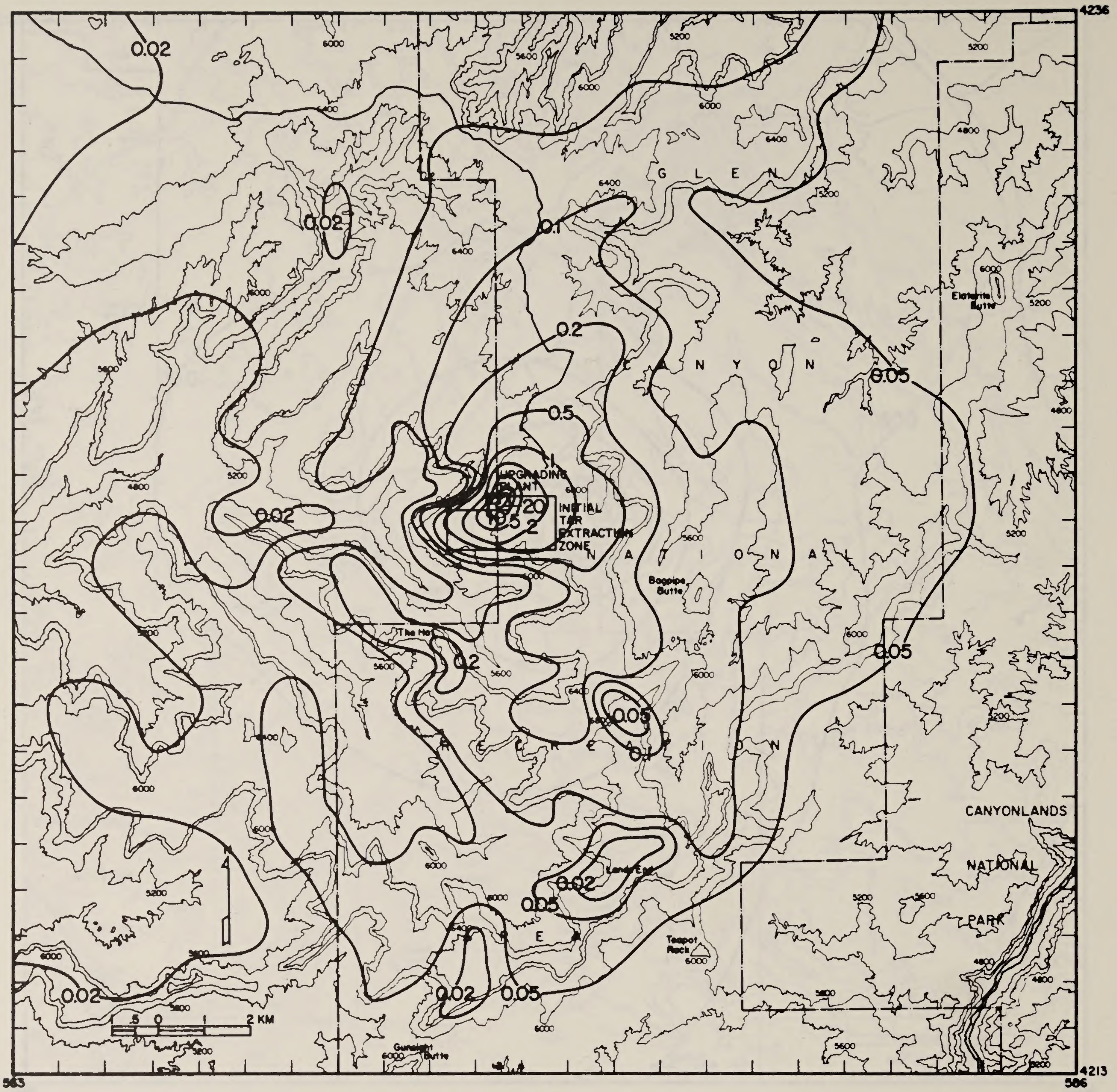

FIGURE 3-3. Calculated isopleths of annual average ground-level NO_2 concentration in micrograms per cubic meter attributable to emissions from Phase III of the proposed Utah Tar Sand Triangle Project.

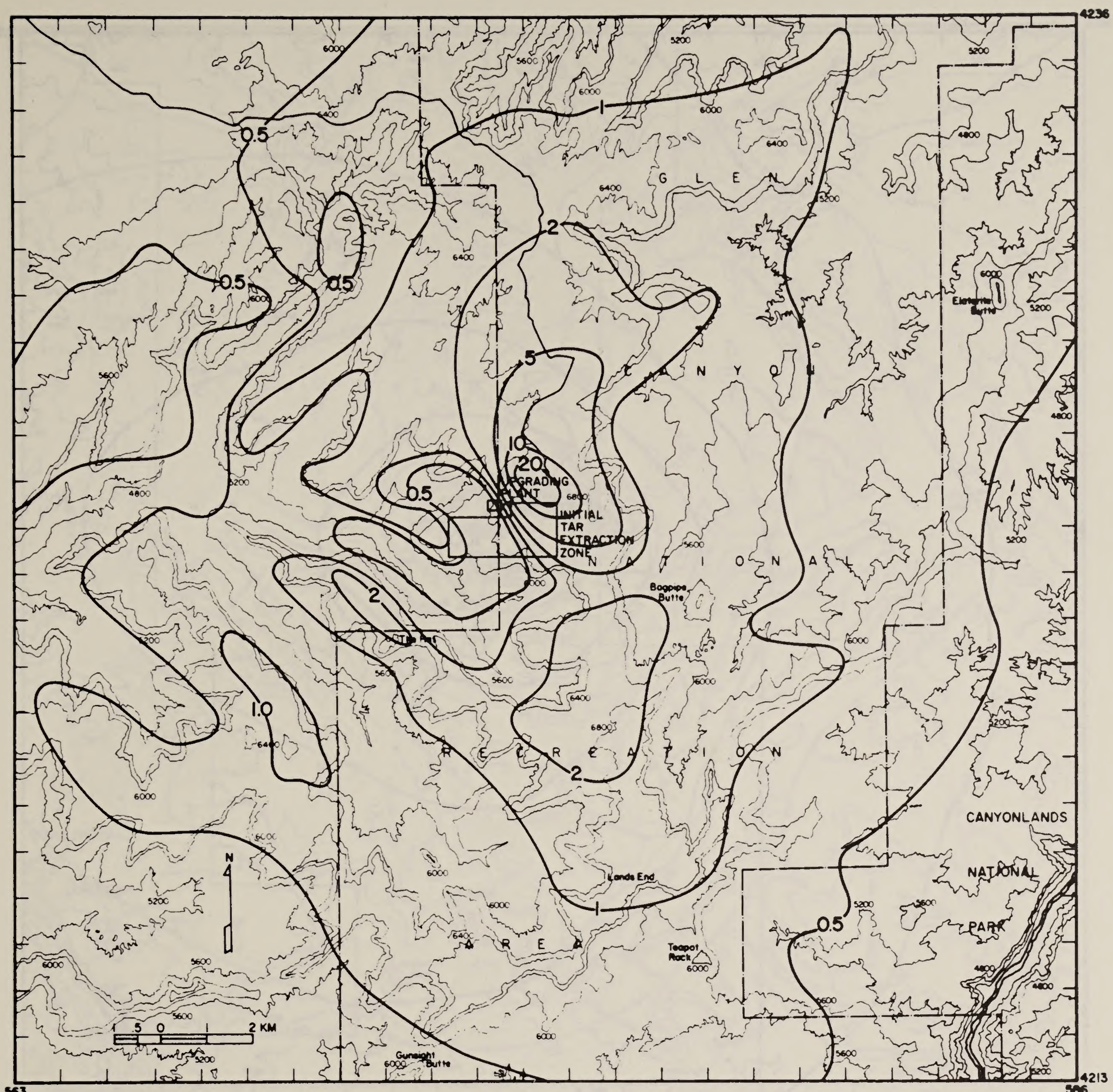

FIGURE 3-4. Calculated isopleths of annual average ground-level SO_2 concentration in micrograms per cubic meter attributable to emissions from Phase IV of the proposed Utah Tar Sand Triangle Project.

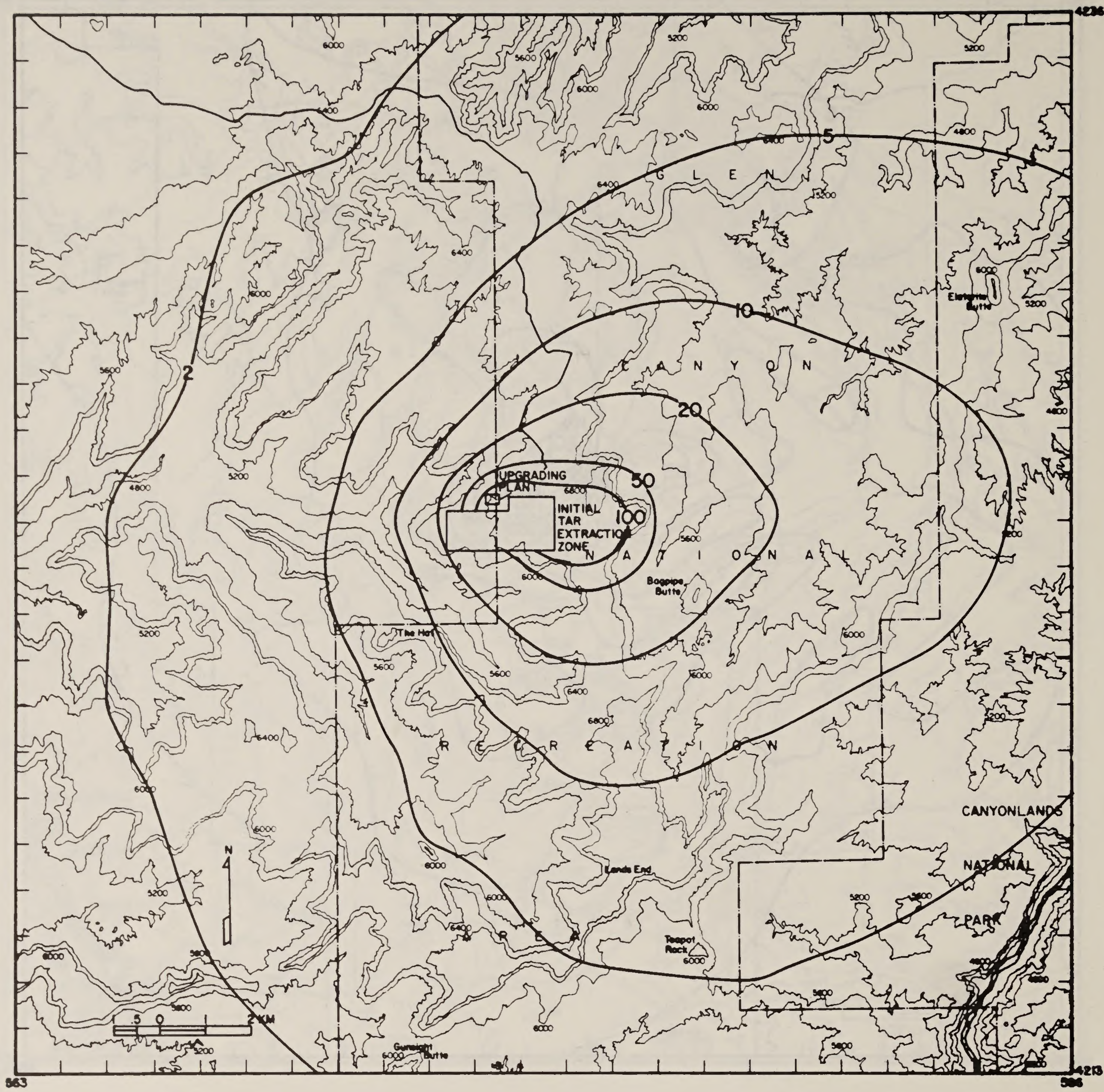

FIGURE 3-5. Calculated isopleths of annual average ground-level particulate concentration in micrograms per cubic meter attributable to emissions from Phase IV of the proposed Utah Tar Sand Triangle Project.

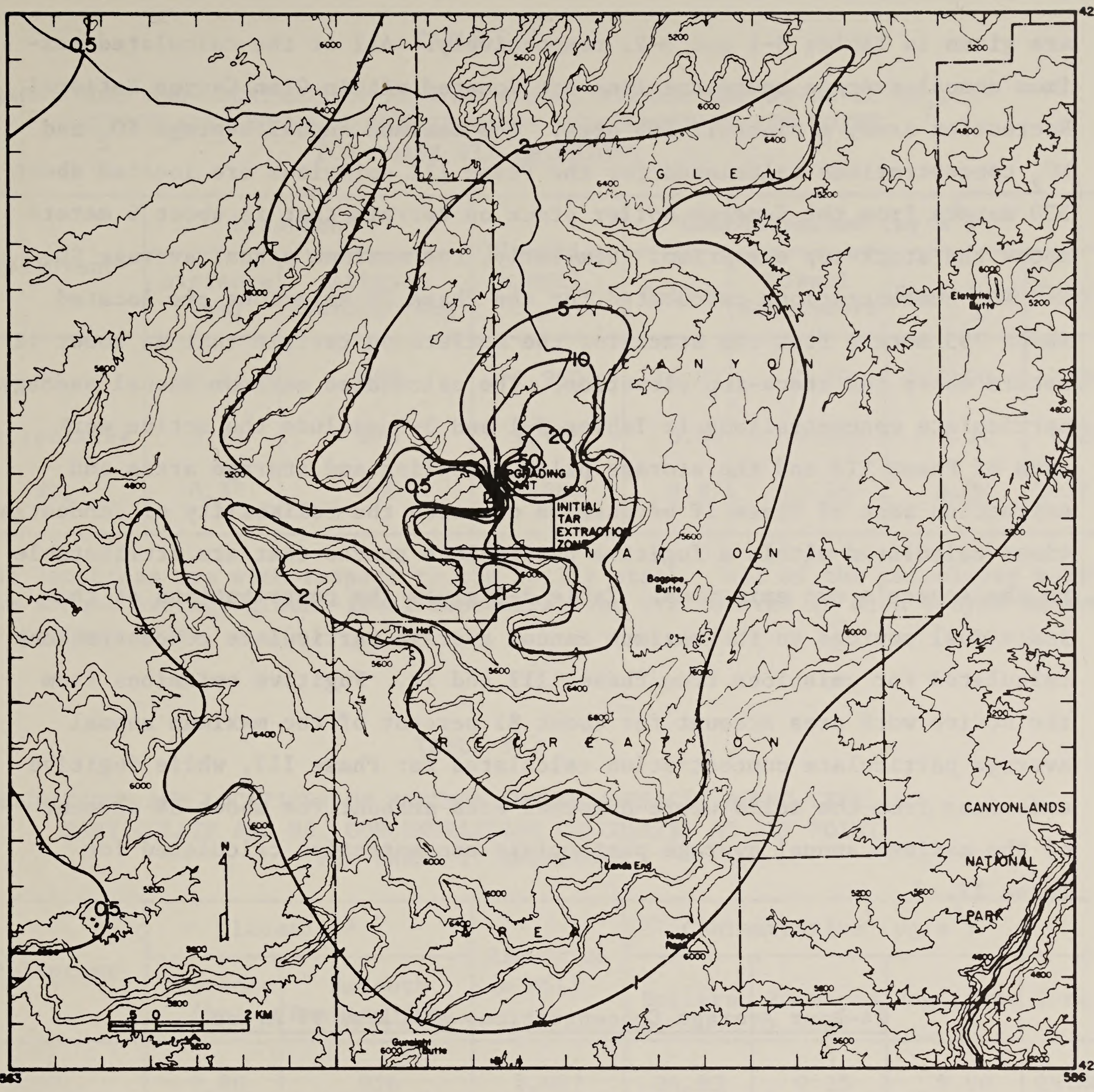

FIGURE 3-6. Calculated isopleths of annual average ground-level NO_2 concentration in micrograms per cubic meter attributable to emissions from Phase IV of the proposed Utah Tar Sand Triangle Project.

are given in Tables 3-1 and 3-2, respectively. All of the calculated maximum annual average concentrations are located within Glen Canyon National Recreation Area, a class II PSD area. The maximum annual average SO_2 and NO_2 concentrations calculated for the Phase III emissions are located about 320 meters from the 5-meter boiler stack on terrain that is about 5 meters above the stack-top elevation. Similarly, the maximum annual average SO_2 and NO_2 concentrations calculated for the Phase IV emissions are located about 795 meters from the stack for the boilers on terrain that is about 12 meters above the stack-top elevation. The calculated maximum annual average particulate concentrations in Tables 3-1 and 3-2 exclude the active work area of Phase III and the storage piles, handling and storage areas and extraction zone of Phase IV because we question the reliability of concentrations calculated within a fugitive particulate source that are attributable to the source's own emissions. Table 3-3 gives the contributions of the individual sources to the maximum annual average particulate concentrations calculated for emissions from Phases III and IV. Fugitive emissions from the active work area account for about 81 percent of the maximum annual average particulate concentration calculated for Phase III, while fugitive emissions from the solid waste disposal area account for about 88 percent of the maximum annual average particulate concentration calculated for Phase IV.

24-Hour Average Concentrations at Class II Areas

The meteorological conditions that maximize the 24-hour average ground-level concentrations produced by buoyant stack emissions generally differ from the meteorological conditions that maximize the 24-hour average ground-level concentrations produced by nonbuoyant low-level emissions. For buoyant stack emissions in open terrain, both theory (Pasquill, 1974 and others) and air quality data (Gorr and Dunlap, 1977 and others) indicate that the highest 24-hour average concentrations occur during periods of persistent moderate-to-strong winds in combination with neutral stability. Additionally, following the terrain adjustment procedures used by the

TABLE 3-1

MAGNITUDES AND LOCATIONS OF MAXIMUM ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT ANY POINT FOR PHASE III EMISSIONS

Pollutant	Location*		Elevation (m MSL)	Concentration ($\mu g/m^3$)			
	Distance (km)	Azimuth Bearing (deg)		Boiler	Diesel Generators	Fugitives	Total
SO_2	0.32	060	1,960	16.77	0.79	0.00	17.56
Particulates	0.79	078	1,926	0.34	0.18	4.31	4.83
NO_2	0.32	060	1,960	8.97	11.76	0.00	20.73

* The locations are with respect to the boiler stack. All of the calculated maximum annual average ground-level concentrations are located in Glen Canyon National Recreation Area.

TABLE 3-2

MAGNITUDES AND LOCATIONS OF MAXIMUM ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT ANY POINT FOR PHASE IV EMISSIONS

Pollutant	Location*		Elevation (m MSL)	Concentration ($\mu g/m^3$)			
	Distance (km)	Azimuth Bearing (deg)		Boilers	Furnaces	Fugitives	Total
SO_2	0.80	026	2,027	24.83	0.25	0.00	25.08
Particulates	2.64	098	2,018	0.50	0.45	140.36	141.32
NO_2	0.80	026	2,027	8.33	70.64	0.00	78.97

* The locations are with respect to the boilers stack. All of the calculated maximum annual average ground-level concentrations are located in Glen Canyon National Recreation Area.

TABLE 3-3

CONTRIBUTIONS OF THE INDIVIDUAL SOURCES TO THE MAXIMUM ANNUAL AVERAGE GROUND-LEVEL PARTICULATE CONCENTRATIONS CALCULATED AT ANY POINT FOR PHASE III AND PHASE IV EMISSIONS

Source	Concentration ($\mu g/m^3$)
(a) Phase III	
Boiler	0.34
Diesel Generators	0.18
Active Work Area	4.31
Unpaved Access Road	<0.01
Total	4.83
(b) Phase IV	
Boilers	0.50
Furnaces	0.45
Primary Coke Handling	0.26
Coke Storage and Secondary Handling	9.92
Limestone Handling and Storage	2.48
Onsite Solid Waste Handling	0.07
Solid Waste Disposal Area	124.10
Extraction Zone Sources	3.50
Paved Access Road	0.03
Total	141.32

SHORTZ/LONGZ models, the highest 24-hour average concentrations calculated for buoyant stack emissions in complex terrain usually occur when persistent moderate-to-strong winds blow toward nearby elevated terrain. If turbulent intensities are available for direct input to the SHORTZ model (as they were in this study), the highest concentrations calculated on nearby elevated terrain also tend to be associated with relatively small turbulent intensities and hence with relatively small plume dimensions. For some combinations of stack characteristics (including location) and topography, the highest 24-hour average concentrations calculated by the SHORTZ model are determined by a relatively short period of hours when light-to-moderate winds blow toward nearby elevated terrain and the hourly plume dimensions are relatively small. These facts formed the basis for our selection of the "worst-case" 24-hour periods for the stack emissions.

We used our PRSIST data analysis program with the 1975 hourly meteorological inputs described in Section 2.2 to identify 32 periods when winds of any speed persisted within any 20-degree sector for 12 or more hours. Following an examination of the hours before and after these persistent wind events, we selected eighteen 24-hour periods when the wind direction was within a 10-degree sector for 12 or more hours. The wind speed was moderate-to-strong during these periods. We then selected for use in the SHORTZ model calculations all of the 24-hour periods that satisfied one or more of the following criteria:

- The wind direction was within a 10-degree sector for 18 or more hours
- The wind direction was within a 10-degree sector for at least 15 hours and the average of the hourly lateral turbulent intensities for these hours was less than or equal to 0.05
- The wind direction was within a 10-degree sector blowing toward nearby elevated terrain for 12 or more hours and the average of the hourly lateral turbulent intensities for these hours was less than or equal to 0.10

Table 3-4 gives the dates and hours of the five "worst-case" 24-hour periods with moderate-to-strong winds selected for use in the SHORTZ model 24-hour average SO_2 concentration calculations for the tall stack emissions. The fourth and fifth cases in Table 3-4 have persistent winds toward nearby elevated terrain.

In theory, the meteorological conditions associated with the maximum 24-hour average ground-level concentrations produced by low-level emissions are stable to neutral conditions in combination with light-to-moderate winds that persist within a narrow angular sector for a number of hours. However, because moderate-to-strong winds tend to be far more persistent within a narrow sector than light-to-moderate winds, the maximum 24-hour average concentrations attributable to low-level emissions at some geographic locations are associated with periods of persistent moderate-to-strong winds rather than with periods of light-to-moderate winds. We therefore considered two sets of "worst-case" 24-hour periods for the low-level emissions. The first set consisted of the five "worst-case" 24-hour periods of persistent moderate-to-strong winds discussed above. To assist in the selection of the second set of "worst-case" 24-hour periods (light-to-moderate winds), we used PRSIST to search the 1975 hourly meteorological inputs and identify the periods satisfying either of the following criteria:

- The wind direction persisted within a 20-degree sector for 10 or more hours and the average of the hourly wind speeds during this period was less than 4 meters per second

- The wind direction persisted within a 10-degree sector for 6 or more hours and the average of the hourly wind speeds during this period was less than 3 meters per second

Table 3-5 gives the dates and hours of the second set of "worst-case" 24-hour periods for the low-level emissions. The third and sixth of the cases in Table 3-5 (Cases 8 and 11) are the cases that satisfied the second of the two selection criteria listed above. As discussed above, the meteorological conditions during the 24-hour periods listed in Table 3-5 also maximize the

TABLE 3-4

DATES AND HOURS OF "WORST-CASE" 24-HOUR PERIODS WITH MODERATE-TO-STRONG WINDS USED IN THE SHORTZ MODEL CONCENTRATION CALCULATIONS FOR THE CLASS II AREAS*

24-Hour Case No.	Date	Hour
1	21-22 Feb 1975	0500-0400 MST
2	15-16 Mar 1975	2200-2100 MST
3	26-27 Mar 1975	0900-0800 MST
4	15-16 Apr 1975	1400-1300 MST
5	03-04 May 1975	1400-1300 MST

* The 24-hour periods listed in Table 3-5 were also used in the SHORTZ model 24-hour average concentration calculations.

TABLE 3-5

DATES AND HOURS OF "WORST-CASE" 24-HOUR PERIODS WITH LIGHT-TO-MODERATE WINDS USED IN THE SHORTZ MODEL CONCENTRATION CALCULATIONS FOR THE CLASS II AREAS*

24-Hour Case No.	Date	Hour
6	12 Jan 1975	0000-2300 MST
7	14 Jan 1975	0000-2300 MST
8	8-9 Feb 1975	0600-0500 MST
9	12 Feb 1975	0000-2300 MST
10	20 Apr 1975	0000-2300 MST
11	27 Nov 1975	0000-2300 MST

* The 24-hour periods listed in Table 3-4 were also used in the SHORTZ model 24-hour average concentration calculations.

24-hour average ground-level concentrations calculated for buoyant stack emissions for some unique combinations of stack characteristics and topography.

We used the stack and fugitive particulate source inputs given in in Section 2.1 and the hourly meteorological inputs for the "worst-case" 24-hour periods listed in Tables 3-4 and 3-5 with the SHORTZ model to calculate hourly and 24-hour average ground-level SO_2 and particulate concentrations. A polar receptor array with its origin at the stack for the Phase III boiler was used in the 24-hour average SO_2 and particulate concentration calculations for Phase III. Similarly, a polar receptor array with its origin at the stack for the Phase IV boilers was used in the 24-hour average SO_2 and particulate concentration calculations for Phase IV. Concentrations were calculated for receptors placed at 500-meter intervals along the trajectories defined by the hourly wind directions during the "worst-case" 24-hour periods. The elevations of all receptors were extracted from USGS topographic maps for use in the SHORTZ model SO_2 concentration calculations. The SHORTZ model was executed in a flat terrain mode in the particulate concentration calculations for the reasons given in the discussion of the annual average particulate concentration calculations.

The maximum 24-hour average ground-level SO_2 and particulate concentrations calculated for the Phase III and Phase IV emissions are given in Tables 3-6 and 3-7, respectively. The maximum 24-hour average SO_2 concentration produced by the Phase III emissions is located 500 meters from the 5-meter boiler stack on terrain at an elevation about 20 meters above the stack-top elevation. The maximum 24-hour average SO_2 concentration produced by the Phase IV emissions is located 700 meters from the 65-meter stack for the boilers on terrain that is about 12 meters above the stack-top elevation. The calculated maximum 24-hour average particulate concentrations in Tables 3-6 and 3-7 exclude the active work area of Phase III and the storage piles, handling and storage areas and extraction zone of Phase IV for the reason given above. Table 3-8 gives the contributions of

TABLE 3-6

MAGNITUDES AND LOCATIONS OF MAXIMUM 24-HOUR AVERAGE GROUND-LEVEL SO_2 AND PARTICULATE CONCENTRATIONS CALCULATED AT ANY POINT FOR PHASE III EMISSIONS

Pollutant	Location*		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
	Distance (km)	Azimuth Bearing (deg)			Boiler	Diesel Generators	Fugitives	Total
SO_2	0.50	028	1,975	15-16 Apr 75 (14-13 MST)	120.12	4.90	0.00	125.02
Particulates	0.67	062	1,975	20 Apr 75 (00-23 MST)	3.51	2.12	19.68	25.30

* The locations are with respect to the boiler stack. All of the calculated maximum 24-hour average ground-level concentrations are located in Glen Canyon National Recreation Area.

TABLE 3-7

MAGNITUDES AND LOCATIONS OF MAXIMUM 24-HOUR AVERAGE GROUND-LEVEL SO_2 AND PARTICULATE CONCENTRATIONS CALCULATED AT ANY POINT FOR PHASE IV EMISSIONS

Pollutant	Location*		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
	Distance (km)	Azimuth Bearing (deg)			Boilers	Furnaces	Fugitives	Total
SO_2	0.70	028	2,027	3-4 May 75 (14-13 MST)	529.03	0.53	0.00	529.56
Particulates	1.00	058	1,987	20 Apr 75 (00-23 MST)	0.04	1.39	304.79	306.23

* The locations are with respect to the boilers stack. All of the calculated maximum 24-hour average ground-level concentrations are located in Glen Canyon National Recreation Area.

TABLE 3-8

CONTRIBUTIONS OF THE INDIVIDUAL SOURCES TO THE MAXIMUM 24-HOUR AVERAGE GROUND-LEVEL PARTICULATE CONCENTRATIONS CALCULATED AT ANY POINT FOR THE PHASE III AND PHASE IV EMISSIONS

Source	Concentration ($\mu g/m^3$)
(a) Phase III	
Boiler	3.51
Diesel Generators	2.12
Active Work Area	19.68
Unpaved Access Road	< 0.01
Total	25.30
(b) Phase IV	
Boilers	0.04
Furnaces	1.39
Primary Coke Handling	4.56
Coke Storage and Secondary Handling	231.44
Limestone Handling and Storage	34.48
Onsite Solid Waste Handling	0.81
Solid Waste Disposal Area	24.43
Extraction Zone Sources	9.06
Paved Access Road	0.01
Total	306.23

the individual sources to the maximum 24-hour average ground-level particulate concentrations calculated for the Phase III and Phase IV emissions. Emissions from the active work area account for about 78 percent of the maximum 24-hour average particulate concentration calculated for the Phase III emissions, while emissions from the coke storage and secondary handling area account for about 76 percent of the maximum 24-hour average particulate concentration calculated for the Phase IV emissions.

3-Hour Average SO_2 Concentrations at Class II Areas

The 3-hour average ground-level SO_2 concentrations calculated by the SHORTZ model for buoyant stack emissions are maximized during 3-hour periods which satisfy one or more of the following conditions: (1) there is little or no hour-to-hour variation in the wind direction, (2) the wind direction is toward nearby elevated terrain, and (3) the turbulent intensities and hence the plume dimensions are small. Additionally, light wind speeds are associated with high calculated 3-hour average concentrations on elevated terrain if the plume height is at or near the height of the elevated terrain. We therefore used PRSIST to search the 1975 hourly meteorological inputs and identify the 3-hour periods when winds of any speed persisted within a 2-degree sector. From these 30 cases, we selected fourteen 3-hour periods that satisfied one or more of the following criteria:

- The wind direction was constant during the 3-hour period and the average of the hourly wind speeds was less than 15 meters per second

- The wind direction was within a 2-degree sector and the average of the hourly lateral turbulent intensities was less than or equal to 0.06

- The wind direction was within a 2-degree sector, the average of the hourly lateral turbulent intensities was less than or equal to 0.20 and the average of the hourly wind speeds was less than or equal to 5 meters per second

Table 3-9 gives the dates and hours of the fourteen "worst-case" 3-hour periods selected for use in the SHORTZ model 3-hour average SO_2 concentration calculations for the stack emissions. Cases 1, 6, 7 and 10 have wind directions toward nearby elevated terrain.

Table 3-10 lists the maximum 3-hour average ground-level SO_2 concentrations calculated for the stack emissions from Phases III and IV. These concentrations were calculated using the same modeling techniques as used in the 24-hour average SO_2 concentration calculations. The maximum 3-hour average concentration calculated for each case is located within Glen Canyon National Recreation Area. The maximum 3-hour average concentration calculated for Phase III is located 500 meters from the 5-meter boiler stack on terrain that is about 2 meters above the stack-top elevation. The maximum 3-hour average concentration calculated for Phase IV is located 2,150 meters from the 65-meter stack for the boilers on terrain that is about 58 meters above the stack-top elevation.

Concentrations at Canyonlands National Park

Canyonlands National Park is the only class I PSD area within a 50-kilometer radius of the Tar Sand Triangle site. We placed receptors at 1-kilometer intervals along the boundary of Canyonlands nearest to the Tar Sand Triangle site. This receptor spacing corresponds to an angular separation of receptors, as measured from the Tar Sand Triangle site, of less than 6 degrees. For comparison, the angular separation of receptors used in most of the current short-term EPA dispersion models is 10 degrees. With the exception of Elaterite Butte, the terrain elevations within Canyonlands are below the elevation of the Tar Sand Triangle site.

TABLE 3-9

DATES AND HOURS OF THE "WORST-CASE" 3-HOUR PERIODS USED IN THE SHORTZ MODEL SO_2 CONCENTRATION CALCULATIONS FOR THE CLASS II AREAS

3-Hour Case No.	Date	Hours
1	10 Feb 1975	0600-0800 MST
2	17 Feb 1975	1000-1200 MST
3	15 Mar 1975	0600-0800 MST
4	5 May 1975	1800-2000 MST
5	9 May 1975	2000-2200 MST
6	18 May 1975	2100-2300 MST
7	18 Jul 1975	0300-0500 MST
8	18 Sep 1975	0400-0600 MST
9	18 Sep 1975	1900-2100 MST
10	24 Sep 1975	0100-0300 MST
11	27 Sep 1975	1900-2100 MST
12	14 Oct 1975	1700-1900 MST
13	18 Oct 1975	0500-0700 MST
14	9 Nov 1975	0300-0500 MST

TABLE 3-10

MAGNITUDES AND LOCATIONS OF MAXIMUM 3-HOUR AVERAGE GROUND-LEVEL SO_2 CONCENTRATIONS CALCULATED AT ANY POINT FOR PHASE III AND PHASE IV EMISSIONS

Phase	Location*		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)		
	Distance (km)	Azimuth Bearing (deg)			Boiler (Phase III) or Boilers (Phase IV)	Diesel Generators (Phase III) or Furnaces (Phase IV)	Total
III	0.50	157	1,957	27 Sep 75 (19-21 MST)	336.26	12.21	348.48
IV	2.15	079	2,073	18 Jul 75 (03-05 MST)	783.53	1.75	785.28

* The locations are with respect to the boiler(s) stack. All of the calculated maximum 3-hour average ground-level SO_2 concentrations are located in Glen Canyon National Recreation Area.

Consequently, Elaterite Butte was the only elevated terrain feature internal to Canyonlands that we considered in the dispersion model calculations. The elevations of all receptors were extracted from USGS topographic maps for use in the model calculations.

We used the SO_2 source inputs given in Table 2-1 in Section 2.1 and the 1975 hourly meteorological inputs discussed in Section 2.2 with the SHORTZ model to calculate, for each hour of the year, the SO_2 concentration at each receptor described above. We then used the POSTZ postprocessor program with the results of the SHORTZ model "brute force" hourly concentration calculations to determine, for each receptor, the maximum 3-hour and 24-hour average SO_2 concentration and the maximum annual average SO_2 concentration. We multiplied the annual average SO_2 concentration calculated for each stack by the ratio of the stack's NO_2 and SO_2 emission rates to obtain annual average NO_2 concentrations attributable to the stack's emissions. The meteorological conditions associated with high concentrations attributable to the stack emissions at the distance of Canyonlands from the Tar Sand Triangle site can also be expected to be associated with high concentrations attributable to the low-level fugitive particulate emissions. We therefore selected for use in the short-term particulate concentrations the 5 days with the highest 24-hour average SO_2 concentrations calculated at Canyonlands for each of the four SO_2 sources in Table 2-1. Because the 5 "worst-case" days for each of the two Phase III stack sources were identical, this procedure yielded 15 days for use in the short-term particulate concentration calculations. These days are identified in Table 3-11. We used the particulate source inputs given in Section 2.1 and the hourly meteorological inputs for the days listed in Table 3-11 with the SHORTZ model to calculate hourly and 24-hour average particulate concentrations at the same receptors as used in the SHORTZ model "brute force" hourly SO_2 concentration calculations. Additionally, we used the particulate source inputs given in Section 2.1 and the climatological meteorological inputs discussed in Section 2.2 with the LONGZ model to calculate annual average particulate concentrations at these receptors. The SHORTZ/LONGZ models were executed in their flat terrain modes in the particulate concentration calculations for the reasons given above.

TABLE 3-11

IDENTIFICATION OF DAYS USED IN THE SHORTZ MODEL CALCULATIONS OF 24-HOUR AVERAGE PARTICULATE CONCENTRATIONS AT CANYONLANDS NATIONAL PARK

1975 Julian Day	Date	Hours
7	7 Jan 1975	0000-2300 MST
15	15 Jan 1975	0000-2300 MST
33	2 Feb 1975	0000-2300 MST
49	18 Feb 1975	0000-2300 MST
50	19 Feb 1975	0000-2300 MST
54	23 Feb 1975	0000-2300 MST
111	21 Apr 1975	0000-2300 MST
112	22 Apr 1975	0000-2300 MST
114	24 Apr 1975	0000-2300 MST
130	10 May 1975	0000-2300 MST
271	28 Sep 1975	0000-2300 MST
334	30 Nov 1975	0000-2300 MST
335	1 Dec 1975	0000-2300 MST
336	2 Dec 1975	0000-2300 MST
343	9 Dec 1975	0000-2300 MST

The results of the SO_2, particulate and NO_2 concentration calculations for Canyonlands National Park attributable to emissions from Phases III and IV of the proposed Tar Sand Triangle Project are summarized in Tables 3-12 and 3-13, respectively. Comparison of the concentrations listed in Tables 3-12 and 3-13 with the concentrations listed in Tables 3-1, 3-2, 3-6, 3-7 and 3-10 indicates that the air quality impact of emissions from the proposed sources at the Tar Sand Triangle site is much greater in the immediate vicinity of the site than at Canyonlands. In the case of the stack emissions, the reduction in air quality impact at Canyonlands is explained by the combination of dilution of the emission with increased downwind distance and the decreased importance of terrain effects as emissions tend to become uniformly mixed in the vertical within the surface mixing layer. Also, the elevations of the majority of the Canyonlands receptors are lower than the elevation of the Tar Sand Triangle site. In the case of the fugitive particulate emissions, the reduction in air quality impact at Canyonlands is explained by the combination of dilution of the emissions with increased downwind distance and depletion by gravitational settling and dry deposition.

Horseshoe Canyon (formerly known as Barrier Canyon) is a detached portion of Canyonlands National Park that is located west of the north end of Glen Canyon National Recreation Area (see Figure 1-1). Although the maximum ground-level pollutant concentrations in Canyonlands National Park attributable to emissions from sources at the Tar Sand Triangle site are calculated to occur in the main portion of the park (i.e., east of Glen Canyon), the maximum ground-level SO_2 concentrations at Horseshoe Canyon are of special interest to the NPS because of the unique petroglyphs that are contained in the canyon. Table 3-14 gives the magnitudes and locations of the maximum 3-hour, 24-hour and annual average ground-level SO_2 concentrations calculated by the SHORTZ model at Horseshoe Canyon for emissions from Phases III and IV of the Tar Sand Triangle Project.

TABLE 3-12

MAGNITUDES AND LOCATIONS OF MAXIMUM SHORT-TERM AND ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT CANYONLANDS NATIONAL PARK FOR PHASE III EMISSIONS

Pollutant	Averaging Time	Location		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boiler	Diesel Generators	Fugitives	Total
SO_2	3 Hours	12.11	067	1,997	2 Feb 75 (03-05 MST)	7.600	0.284	0.000	7.884
	24 Hours	12.11	067	1,997	2 Feb 75 (00-23 MST)	1.068	0.040	0.000	1.108
	Annual	12.11	067	1,997	--	0.095	0.003	0.000	0.098
Particulates	24 Hours	12.36	053	1,463	2 Feb 75 (00-23 MST)	0.213	0.102	0.133	0.447
	Annual	9.90	087	1,798	--	0.014	0.007	0.032	0.053
NO_2	Annual	12.11	067	1,997	--	0.051	0.053	0.000	0.103

TABLE 3-13

MAGNITUDES AND LOCATIONS OF MAXIMUM SHORT-TERM AND ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT CANYONLANDS NATIONAL PARK FOR PHASE IV EMISSIONS

Pollutant	Averaging Time	Location		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boilers	Furnaces	Fugitives	Total
SO_2	3 Hours	8.88	107	1,829	2 Dec 75 (15-17 MST)	195.427	0.413	0.000	195.840
	24 Hours	8.88	107	1,829	2 Dec 75 (00-23 MST)	25.490	0.054	0.000	25.544
	Annual	11.94	067	1,997	--	1.160	0.008	0.000	1.168
Particulates	24 Hours	11.54	132	1,640	2 Feb 75 (00-23 MST)	0.000	0.000	46.358	46.358
	Annual	9.74	093	1,844	--	0.127	0.118	10.798	11.043
NO_2	Annual	11.94	067	1,997	--	0.389	2.353	0.000	2.742

TABLE 3-14

MAGNITUDES AND LOCATIONS OF MAXIMUM SHORT-TERM AND ANNUAL AVERAGE GROUND-LEVEL SO_2 CONCENTRATIONS CALCULATED AT THE HORSESHOE CANYON UNIT OF CANYONLANDS NATIONAL PARK FOR PHASE III AND PHASE IV SO_2 EMISSIONS

Averaging Time	Location*		Elevation (m MSL)	Date (Hours)	Concentrations ($\mu g/m^3$)		
	Distance (km)	Azimuth Bearing (deg)			Boiler (Phase III) or Boilers (Phase IV)	Diesel Generators (Phase III) or Furnaces (Phase IV)	Total
(a) Phase III							
3 Hours	32.81	356	1,585	25 Aug 75 (00-02 MST)	1.063	0.040	1.103
24 Hours	32.81	356	1,585	25 Aug 75 (00-23 MST)	0.133	0.005	0.138
Annual	30.66	355	1,612	--	0.004	<0.001	0.004
(b) Phase IV							
3 Hours	29.76	353	1,622	30 Jan 75 (15-17 MST)	46.089	0.147	46.235
24 Hours	32.81	356	1,585	14 Apr 75 (00-23 MST)	6.076	0.016	6.091
Annual	30.66	355	1,612	--	0.139	0.001	0.140

* Locations are with respect to the Phase IV boilers stack.

3.3 CONCENTRATIONS AT DISTANCES OF MORE THAN 50 KILOMETERS

The two areas of major concern for the air quality impact of emissions from the proposed sources at the Tar Sand Triangle site that are more than 50 kilometers from the site are Capitol Reef and Arches National Parks. The nearest boundary of Capitol Reef is about 80 kilometers from the site, while the nearest boundary of Arches is about 65 kilometers from the site. The SHORTZ/LONGZ models are not strictly applicable at these long downwind distances because the two models do not address factors such as the spatial and temporal variations of wind fields, turbulent intensities and mixing depths. However, the SHORTZ/LONGZ models can be used as safe-sided screening models at these long downwind distances.

We used the SHORTZ model with the SO_2 source inputs given in Section 2.1 and the 1975 hourly meteorological inputs discussed in Section 2.2 to calculate, for each hour of the year, the hourly SO_2 concentrations at 23 receptors along the nearest boundary of Capitol Reef National Park and at 11 receptors along the nearest boundary of Arches National Park. The angular separation of these receptors, as measured from the Tar Sand Triangle site, was less than or equal to 6 degrees. We did not place any receptors on higher terrain internal to the two parks because emissions at the distances from the Tar Sand Triangle site to the two parks generally will be uniformly mixed in the vertical within the surface mixing layer. We then used the results of the SHORTZ model "brute force" hourly SO_2 concentration calculations with the POSTZ postprocessor program to determine, for each receptor, the maximum 3-hour and 24-hour average SO_2 concentrations as well as the annual average concentration. We scaled the calculated annual average SO_2 concentrations according to the ratios of NO_2 and SO_2 emission rates for the individual sources to obtain annual average NO_2 concentrations in the same manner that we obtained annual average NO_2 concentrations for Canyonlands National Park (see Section 3.2).

Approximately 70 percent of the fugitive particulate emissions estimated for Phase III and 99 percent of the fugitive particulate emissions estimated for Phase IV originate in the immediate vicinity of the Tar Sand Triangle site. The remainder of the fugitive particulate emissions are distributed over 80 kilometers of unpaved (Phase III) and paved (Phase IV) access roads. In general, these widespread roadway fugitive particulate emissions can be expected to settle out and be deposited within relatively short downwind distances, resulting in negligible air quality impacts at Capitol Reef and Arches. To obtain an estimate of the air quality impacts at Capitol Reef and Arches of fugitive particulate emissions from the onsite activities, we multiplied the maximum 24-hour and annual average concentrations calculated for the combined stack emissions of each phase by the ratio of the total onsite fugitive particulate emissions and the total stack SO_2 emissions. The resulting fugitive particulate concentration estimates are biased toward overestimation because this simple scaling of calculated concentrations does not account for the effects on particulate concentrations of depletion by gravitational settling and dry deposition. We obtained the contributions of the stack emissions to the maximum 24-hour and annual average particulate concentrations by scaling the results of the SO_2 concentration calculations in the same manner that we obtained annual average NO_2 concentrations. Table 3-15 summarizes the SO_2, particulate and NO_2 concentrations resulting from the Phase III emissions that we obtained for Capitol Reef and Arches National Parks following the procedures outlined above. Similarly, Table 3-16 summarizes the SO_2, particulate and NO_2 concentrations resulting from the Phase IV emissions that we obtained for Capitol Reef and Arches National Parks following the above procedures. Comparison of the concentrations in Tables 3-15 and 3-16 with the corresponding concentrations in Tables 3-12 and 3-13 shows that the air quality impact of emissions from the proposed Tar Sand Triangle Project will be significantly lower at Capitol Reef and Arches National Parks than at Canyonlands National Park.

3.4 ANNUAL SULFATE DEPOSITION

We used the ISCLT model with the SO_2 source inputs given in Table 2-1 in Section 2.1 and the climatological meteorological inputs given in

TABLE 3-15

MAGNITUDES AND LOCATIONS OF MAXIMUM SHORT-TERM AND ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT CAPITOL REEF AND ARCHES NATIONAL PARKS FOR PHASE III EMISSIONS

Pollutant	Averaging Time	Location		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boiler	Diesel Generators	Fugitives*	Total
(a) Capitol Reef National Park									
SO_2	3 Hours	83.30	268	1,829	18 Mar 75 (00-02 MST)	0.493	0.018	0.000	0.511
	24 Hours	83.64	271	1,737	17 May 75 (00-23 MST)	0.063	0.003	0.000	0.066
	Annual	80.38	249	1,829	--	0.002	<0.001	0.000	0.002
Particulates	24 Hours	83.64	271	1,737	17 May 75 (00-23 MST)	0.006	0.003	0.022	0.030
	Annual	80.38	249	1,829	--	<0.001	<0.001	<0.001	0.001
NO_2	Annual	80.38	249	1,829	--	0.001	0.001	0.000	0.003
(b) Arches National Park									
SO_2	3 Hours	77.28	032	1,524	25 Feb 75 (06-08 MST)	0.449	0.017	0.000	0.466
	24 Hours	83.23	027	1,585	23 Feb 75 (00-23 MST)	0.063	0.003	0.000	0.066
	Annual	70.69	046	1,433	--	0.003	<0.001	0.000	0.003

TABLE 3-15 (Continued)

Pollutant	Averaging Time	Location		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boiler	Diesel Generators	Fugitives*	Total
(a) Arches National Park (Continued)									
Particulates	24 Hours	83.23	027	1,585	23 Feb 75 (00-23 MST)	0.006	0.003	0.023	0.031
	Annual	79.07	048	1,524	--	0.001	0.001	0.002	0.002
NO_2	Annual	79.07	048	1,524	--	0.002	0.020	0.000	0.022

* Includes fugitive emissions from the active work area, but not from the unpaved access road.

TABLE 3-16

MAGNITUDES AND LOCATIONS OF MAXIMUM SHORT-TERM AND ANNUAL AVERAGE GROUND-LEVEL SO_2, PARTICULATE AND NO_2 CONCENTRATIONS CALCULATED AT CAPITOL REEF AND ARCHES NATIONAL PARKS FOR PHASE IV EMISSIONS

Pollutant	Averaging Time	Location		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boilers	Furnaces	Fugitives*	Total
(a) Capitol Reef National Park									
SO_2	3 Hours	86.38	230	1,554	25 Mar 75 (00-02 MST)	24.030	0.048	0.000	24.078
	24 Hours	86.38	230	1,554	25 Mar 75 (00-23 MST)	3.135	0.006	0.000	3.141
	Annual	79.81	254	1,890	--	0.067	<0.001	0.000	0.067
Particulates	24 Hours	86.38	230	1,554	25 Mar 75 (00-23 MST)	0.371	0.110	0.987	1.468
	Annual	79.81	254	1,890	--	0.008	0.005	0.021	0.034
NO_2	Annual	79.81	254	1,890	--	0.023	0.073	0.000	0.096
(b) Arches National Park									
SO_2	3 Hours	83.11	027	1,585	14 Apr 75 (21-23 MST)	34.570	0.072	0.000	34.642
	24 Hours	83.11	027	1,585	14 Apr 75 (00-23 MST)	5.773	0.012	0.000	5.785
	Annual	67.39	043	1,402	--	0.103	<0.001	0.000	0.103

TABLE 3-16 (Continued)

Pollutant	Averaging Time	Location		Elevation (m MSL)	Date (Hours)	Concentration ($\mu g/m^3$)			
		Distance (km)	Azimuth Bearing (deg)			Boilers	Furnaces	Fugitives*	Total
(a) Arches National Park (Continued)									
Particulates	24 Hours	83.11	027	1,585	14 Apr 75 (00-23 MST)	0.683	0.214	1.818	2.715
	Annual	67.39	043	1,402	--	0.013	0.008	0.033	0.053
NO_2	Annual	67.39	043	1,402	--	0.035	0.114	0.000	0.149

* Includes fugitive emissions from materials handling and storage, solid waste handling and disposal, and extraction zone sources, but not from the paved access road.

Section 2.2 and Appendix A to calculate annual sulfate (SO_4) dry deposition. As discussed in Section 1.3, we added a sulfate production term to the ISCLT model for use in the annual deposition calculations. On the basis of a literature survey of empirical SO_2-to-sulfate transformation rates, Bowers, Saterlie and Cramer (1979) estimated that the appropriate average psuedo-first-order transformation rate for SO_2 sources in rural Utah is between 0.3 and 0.7 percent per hour. We therefore assumed in the ISCLT model sulfate deposition calculations an average transformation rate of 0.5 percent per hour. Empirical sulfate removal rates have been estimated for use with models that parameterize dry deposition by the dry deposition velocity concept. However, no empirical sulfate removal rates have been established for use with a model such as the ISCLT model that parameterizes dry deposition by a surface reflection coefficient. We assumed in the sulfate dry deposition calculations that 20 percent of the sulfates that come in contact with the earth's surface are retained (deposited) at the surface. This assumption corresponds to an ISCLT model surface reflection coefficient of 0.8, which is normally assigned to particulates with a gravitational settling velocity of about 1 centimeter per second. Although there currently is no relationship between the ISCLT model's surface reflection coefficient and dry deposition velocities, we believe that a reflection coefficient for sulfates of 0.8 is conservative. We calculated sulfate dry deposition along each of the standard 22.5-degree wind-direction sectors at distances of 0.5, 1, 2, 3, 4, 5, 8, 10, 15, 20, 30, 40, 50, 80 and 100 kilometers. The origin of this polar receptor array was placed at the location of the stack for the furnaces of Phase I-V.

Figure 3-7 shows the calculated isopleths of annual sulfate dry deposition in milligrams per square meter attributable to the SO_2 emissions of Phase III. The corresponding sulfate dry deposition isopleth map for the Phase IV SO_2 emissions is shown in Figure 3-8. (One milligram per square meter is equal to 10^{-2} kilograms per hectare.) Two competing processes--dilution by atmospheric mixing and sulfate production--determine the location of the maximum sulfate deposition. If the SO_2 emissions are assumed to be immediately converted to sulfates as they exit the stacks, the location of

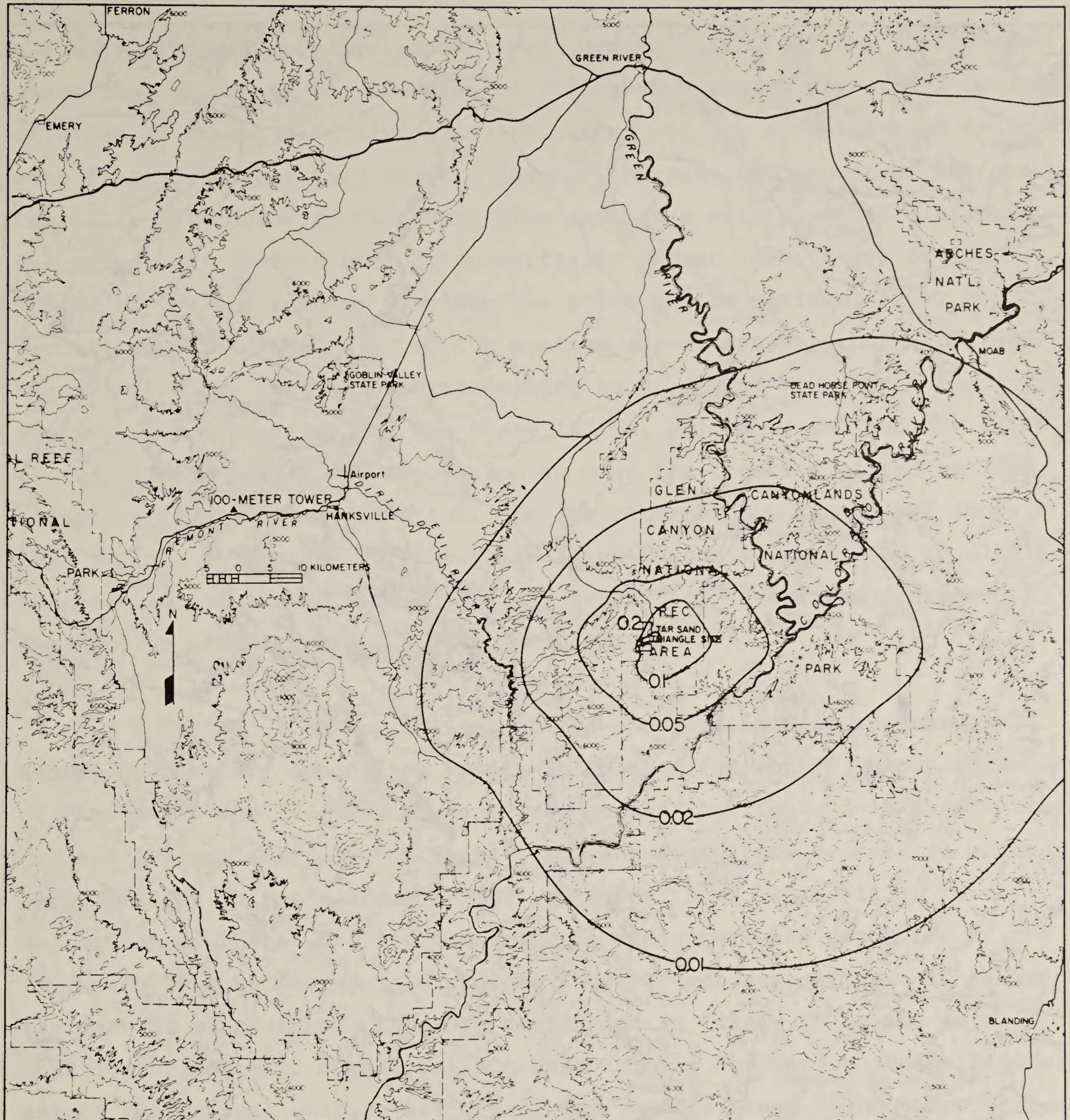

Figure 3-7. Calculated isopleths of annual sulfate dry deposition in milligrams per square meter attributable to the SO_2 emissions from Phase III of the proposed Tar Sand Triangle Project. (One milligram per square meter is equal to 10^{-2} kilograms per hectare.)

Figure 3-8. Calculated isopleths of annual sulfate dry deposition in milligrams per square meter attributable to the SO_2 emissions from Phase IV of the proposed Tar Sand Triangle Project. (One milligram per square meter is equal to 10^{-2} kilograms per hectare.)

the maximum annual average ground-level concentration for the stack emissions corresponds to the location of the maximum annual dry deposition, and dilution by atmospheric mixing causes the annual dry deposition to decrease with distance beyond this point. However, because the amount of sulfate increases with downwind transport time and hence with downwind distance, the effects of sulfate production partially offset the effects of atmospheric mixing and tend to displace the point of the maximum annual dry deposition beyond the point of the maximum annual average concentration. Figure 3-7 shows that atmospheric mixing is predicted to be more important than sulfate production for the Phase III SO_2 emissions so that the location of the maximum annual dry deposition is near the location of the maximum annual average SO_2 concentration. On the other hand, Figure 3-8 shows that sulfate production for the Phase IV emissions is predicted to displace the location of the maximum annual dry deposition beyond the distance to the maximum annual average SO_2 concentration.

Table 3-17 gives the magnitudes and locations of the maximum annual sulfate dry deposition values calculated for the SO_2 stack emissions of Phases III and IV. It should be recognized that Table 3-17 and Figures 3-7 and 3-8 probably underestimate total annual sulfate deposition because they consider only the dry component of deposition. In addition to dry deposition, sulfates are removed from the atmosphere and deposited at the surface by precipitation in a process known as wet deposition. In an arid region such as southern Utah, dry deposition is likely to be the major contributor to total annual sulfate deposition. However, the possibility exists that annual sulfate wet deposition in some areas of southern Utah is of the same magnitude as annual sulfate dry deposition. As a first approximation, the total (wet and dry) sulfate deposition for these areas can be obtained by doubling the dry deposition.

TABLE 3-17

MAGNITUDES AND LOCATIONS OF MAXIMUM ANNUAL DRY DEPOSITS OF SULFATES CALCULATED AT ANY POINT FOR PHASE III AND PHASE IV SO_2 EMISSIONS

Phase	Location*		Dry Deposition (mg/m^2)**		
	Distance (km)	Azimuth Bearing (deg)	Boiler (Phase III) or Boilers (Phase IV)	Diesel Generators (Phase III) or Furnaces (Phase IV)	Total
III	0.50	045	0.229	0.014	0.242
IV	4.00	270	6.058	0.013	6.071

* The locations are with respect to the stack for the Phase IV boilers.

** One milligram per square meter is equal to 10^{-2} kilograms per hectare.

SECTION 4

IDENTIFICATION OF THE MAJOR AREAS OF UNCERTAINTY IN THE MODEL CALCULATIONS

The principal areas of uncertainty affecting the accuracy of the concentrations calculated by the SHORTZ/LONGZ models and presented in this report are:

- The representativeness of the source inputs given in Section 2.1
- The representativeness of the meteorological inputs described in Section 2.2
- The accuracy of the SHORTZ/LONGZ models

There is at present insufficient information to define the exact locations and emissions characteristics of the pollutant sources that will be associated with Phases III and IV of the Tar Sand Triangle Project. We assume in this report that the emissions data provided to the H. E. Cramer Company by BLM, which were developed from the best available information, are representative. However, we point out that the maximum ground-level pollutant concentrations that will occur in the vicinity of the Tar Sand Triangle as a result of emissions from the Phase III and Phase IV sources will be uniquely determined by the combination of source characteristics (including locations), the topography and the local meteorological conditions. Thus, the calculated maximum concentrations, especially the maximum concentrations in the vicinity of the Tar Sand Triangle, should be considered specific to the source characteristics assumed in the model calculations. The calculated maximum concentrations are also likely to change if, at some time in the future, the model calculations are repeated for the same sources using more refined onsite meteorological data.

We used in the SHORTZ/LONGZ model calculations what we consider to be the most representative meteorological inputs currently available for the vicinity of the Tar Sand Triangle. The SHORTZ/LONGZ models are designed to use onsite meteorological measurements to the maximum extent possible so that the use of discrete stability categories can be avoided. The IPP Salt Wash tower wind, turbulence and temperature data were used as direct inputs to the SHORTZ/LONG models, which enabled us to avoid the use of stability categories in the model calculations. We consider the IPP tower winds to be reasonably representative of regional transport winds, although we recognize that they are not necessarily representative of the local winds affecting the initial transport and dispersion of emissions from the sources at the Tar Sand Triangle site. It follows that the concentrations calculated beyond the immediate vicinity of the Tar Sand Triangle, but within the range of applicability of the SHORTZ/LONGZ models, are likely to be more reliable than the concentrations calculated in the immediate vicinity of the Tar Sand Triangle. The most significant deficiency in the meteorological inputs is the lack of hourly mixing depth observations or estimates that are concurrent with the IPP tower hourly wind, turbulence and temperature measurements. We have no objective basis for assessing how this deficiency affects the accuracy of the concentrations calculated for the sources assumed in this study. However, because we believe the mixing depths assumed in the model calculations to be consistent with the other concurrent hourly meteorological inputs, we doubt that the uncertainties in the mixing depths introduced any systematic biases in the results of the model calculations.

It is not possible to demonstrate the accuracy of the SHORTZ/LONGZ model calculations for the hypothetical sources at the Tar Sand Triangle site by means of direct comparison of concurrent calculated and observed concentrations. However, on the basis of previous studies for EPA of SO_2 sources located in complex terrain, we can specify approximate confidence intervals for our model calculations for the stack emissions. Confidence intervals, in contrast to confidence limits which must satisfy strict statistical criteria, simply reflect the results of direct comparisons of model predictions with air quality observations without attempting to account for the effects of sample size and other limitations as must be done in the case of estimating confidence limits. In the cases where the plume from an isolated source was simultaneously detected by two or more SO_2 monitors (which allowed us to specify the wind direction at the plume height to within 1 or 2 degrees), the SHORTZ model yielded calculated hourly SO_2 concentrations that were, on the average, equal to the observed concentrations (see Cramer, et al., 1976). Individual calculated and observed hourly SO_2 concentrations differed by as much as a factor of two. To a large extent, we believe that the discrepancies between the individual calculated and observed hourly concentrations were caused by errors in the source and meteorological inputs and possibly in the air quality measurements. When unadjusted surface wind directions were used in the SHORTZ model calculations, the calculated maximum 3-hour and 24-hour average SO_2 concentrations were, on the average, within 20 percent of the observed values (see Section 8 of Cramer, et al., 1975). Finkelstein (1976) also compared the results of the short-term model calculations in the Cramer, et al. (1975) study with the results of wind-tunnel simulations of various sources in the Clairton area of Allegheny County and concluded that, "...the agreement between the two studies is surprisingly and reassuringly close." The LONGZ model has yielded calculated annual average SO_2 concentrations within 20 percent of the observed values at all monitors where the annual average SO_2 concentrations were above the accuracy and threshold of the SO_2 monitors (Cramer, et al., 1975). In cases where the annual average concentrations were below the threshold of the SO_2 monitors, the LONGZ model has yielded calculated annual average SO_2 concentrations that were within plus or minus one-half the accuracy and threshold of the SO_2 monitor (Cramer, et al., 1976 and Wilson, et al., 1977).

The most rigorous test of the SHORTZ model to date was the recent application of the model to the Westvaco data set (Bowers, et al., 1983). The 190-meter Westvaco Main Stack is located in a deep river valley with terrain elevations as much as 200 meters above the stack-top elevation within 1.5 kilometers of the stack. Data from nine SO_2 air quality monitors with elevations ranging from 26 to 195 meters above the stack top were used to evaluate the performance of the SHORTZ model and four other complex terrain dispersion models. The detailed onsite meteorological measurements enabled the direct development of all SHORTZ hourly meteorological inputs without recourse to the use of discrete stability categories to assign default values of model input parameters. Because of the extremely large and unique vertical wind-direction shears found at times in the onsite wind measurements, the Cramer, et al. (1972) wind shear term was added to the SHORTZ model's lateral dispersion coefficient equation for use in the model performance evaluation. At the three monitoring sites on elevated terrain at and beyond the distance to plume stabilization, the SHORTZ model was the only one of the five models evaluated that yielded unbiased predictions of the 25 highest 1-hour, 3-hour and 24-hour average SO_2 concentrations. For example, Figure 4-1 compares the cumulative frequency distributions of the 25 highest calculated and observed 24-hour average concentrations at Monitor 9, the monitor with the highest elevation above the stack top. On the other hand, the SHORTZ model showed a consistent bias toward overestimation at the six monitoring sites on elevated terrain within the distance to plume stabilization. This bias is illustrated by Figure 4-2, which compares the cumulative frequency distributions of the 25 highest calculated and observed 24-hour average concentrations at Monitor 3, the monitor nearest to the stack. The maximum ground-level concentrations calculated in this study by the SHORTZ/LONGZ models occurred at or beyond the distances to plume stabilization for the stack sources. Consequently, if it is assumed that the source and meteorological inputs used in the SHORTZ/LONGZ model calculations for the stacks at the Tar Sand Triangle site are representative, the results of the Westvaco model evaluation study indicate that the maximum concentrations calculated for the stack emissions should be unbiased.

The accuracy of the particulate concentrations calculated by the SHORTZ/LONGZ models for emissions from the low-level fugitive sources at the Tar Sand Triangle site is more difficult to assess than the accuracy of the concentrations calculated for the stack emissions because there have been no verification studies of the SHORTZ/LONGZ models, updated to include the gravitational settling/dry deposition algorithms from the corresponding computer codes (ISCST/ISCLT) of the Industrial Source Complex (ISC) Dispersion Model (Bowers, Bjorklund and Cheney, 1979). The performance of the ISC

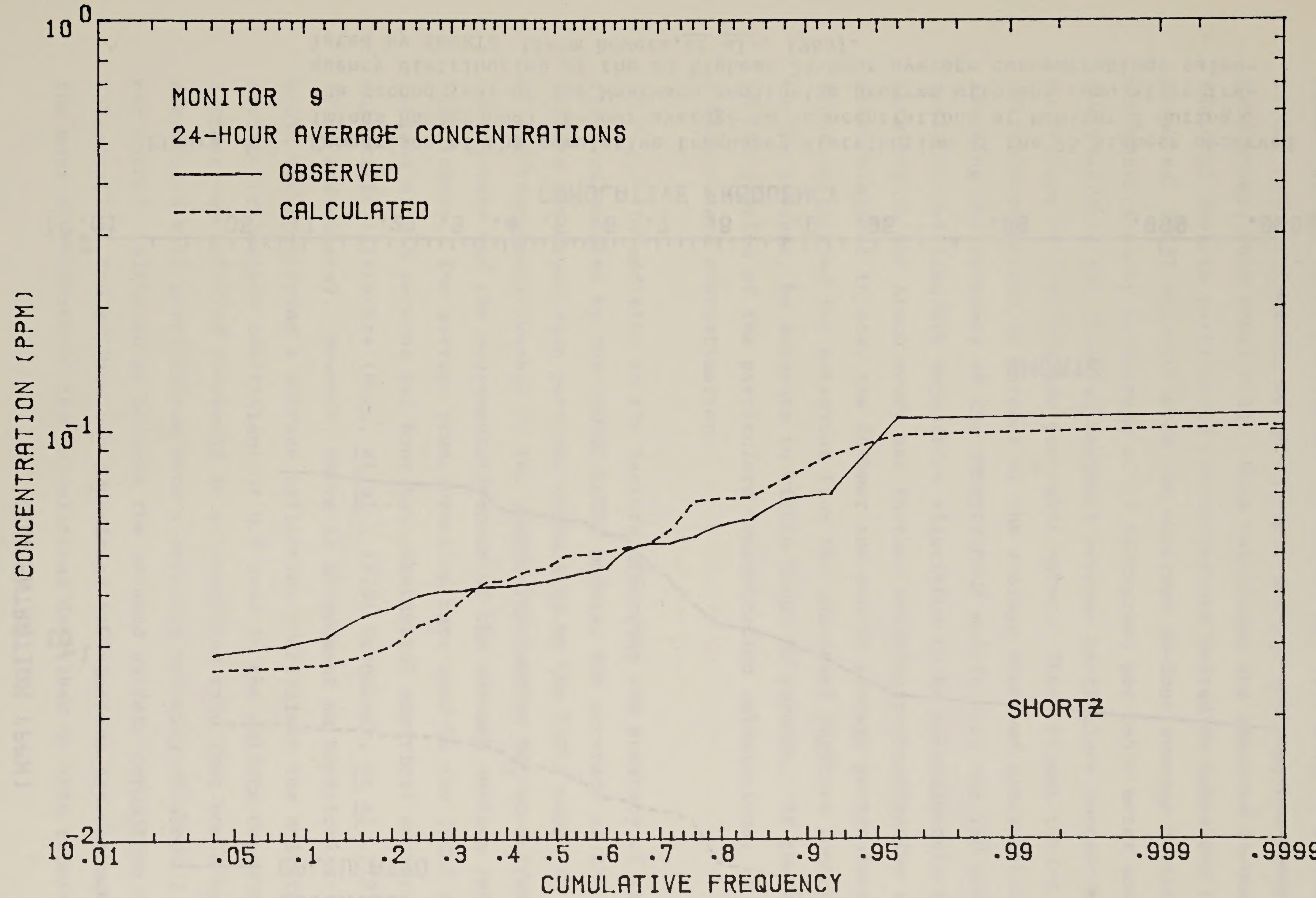

Figure 4-1. Comparison of the cumulative frequency distribution of the 25 highest observed (minus background) 24-hour average SO_2 concentrations at Monitor 9 during the second year of the Westvaco monitoring program with the cumulative frequency distribution of the 25 highest 24-hour average concentrations calculated by SHORTZ (from Bowers, et al., 1983).

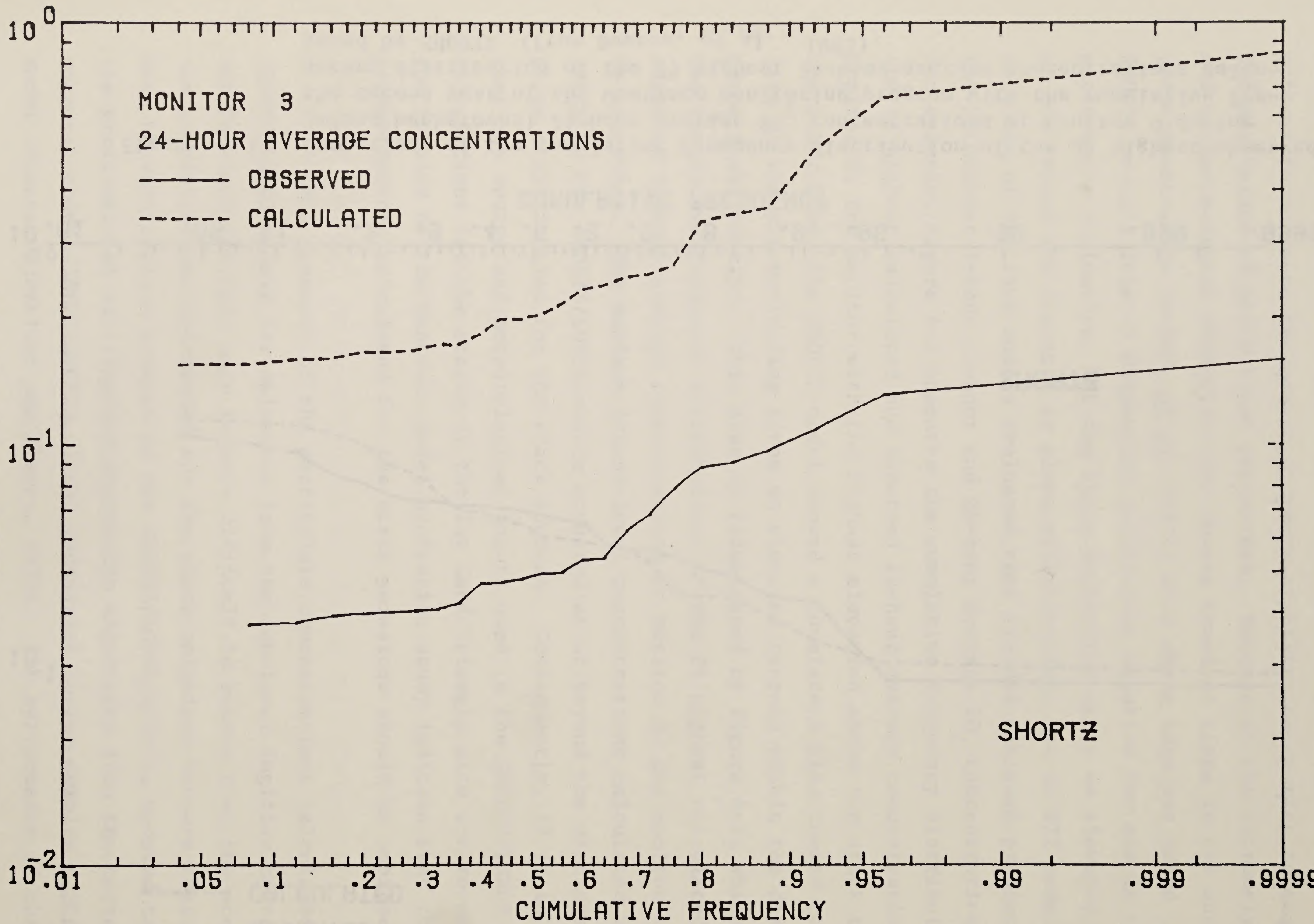

Figure 4-2. Comparison of the cumulative frequency distribution of the 25 highest observed (minus background) 24-hour average SO_2 concentrations at Monitor 3 during the second year of the Westvaco monitoring program with the cumulative frequency distribution of the 25 highest 24-hour average concentrations calculated by SHORTZ (from Bowers, et al., 1983).

Model for low-level particulate emissions was evaluated by Bowers, *et al.* (1982) using emissions, meteorological and air quality data from the Armco Middletown, Ohio Steel Mill. When calculated and observed 24-hour and seasonal average particulate concentrations paired in space and time were compared, ISCST overpredicted the observed 24-hour average particulate concentrations by an average of 12 micrograms per cubic meter and ISCLT overpredicted the observed seasonal average particulate concentrations by an average of 4 micrograms per cubic meter. These biases toward overestimation were within 20 percent of the average observed concentrations. Assuming the accuracy of the SHORTZ/LONGZ models with the ISC Model's gravitational settling/dry deposition algorithms to be approximately the same as obtained in the Armco study and further assuming representative source and meteorological inputs, the 24-hour and annual average particulate concentrations calculated for emissions from the low-level fugitive sources should, on the average, be accurate to within about 20 percent. If there is a bias in the results of the particulate concentration calculations, it is probably a bias toward overestimation.

In addition to the factors affecting the accuracy of the concentrations calculated by the SHORTZ/LONGZ models, the accuracy of the annual sulfate dry deposition patterns calculated by the ISCLT model is affected by the representativeness of the psuedo-first-order SO_2-to-sulfate transformation rate and the representativeness of the assumed surface reflection coefficient. The average transformation rate used in the ISCLT model calculations of 0.5 percent per hour has substantial empirical support in the scientific literature (Hegg, *et al.*, 1976; Ursenbach, *et al.*, 1977; Davis, 1977; and others). However, there is at present no empirical or theoretical basis for specifying a surface reflection coefficient for sulfates. The surface reflection coefficient of 0.8 used in the sulfate deposition calculations was selected to result in a deposition rate that would normally be associated with particulates with a settling velocity of about 1 centimeter per second. Although we believe the assumed sulfate deposition rate to be conservative, the sulfate dry deposition calculations are without question the most speculative of the calculations described in this report.

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APPENDIX A
ANNUAL WIND SUMMARIES

Table A-1 lists the 1975 annual joint frequency of occurrence of wind-speed and wind-direction categories at the 100-meter level of the Intermountain Power Project (IPP) Salt Wash tower, classified according to four time-of-day categories (night, morning, afternoon and evening). Similarly, Table A-2 lists the 1975 annual joint frequency of occurrence of wind-speed and wind-direction categories at the 100-meter level of the IPP tower, classified according to the six Pasquill stability categories. The procedures used to develop the wind summaries contained in Tables A-1 and A-2 are discussed in detail in Section 2.2 in the main body of the report. Table A-1 was used in the LONGZ model annual concentration calculations and Table A-2 was used in the ISCLT model annual sulfate dry deposition calculations.

TABLE A-1

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE NIGHT TIME-OF-DAY CATEGORY

	WIND SPEED (M/SEC)						
DIRECTION	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	.0104	.0082	.0064	.0027	.0018	.0012	.0308
NNE	.0062	.0068	.0027	.0028	.0009	0.0000	.0195
NE	.0035	.0044	.0026	.0008	.0003	0.0000	.0115
ENE	.0031	.0045	.0013	.0008	0.0000	0.0000	.0097
E	.0028	.0030	.0010	.0004	0.0000	0.0000	.0072
ESE	.0027	.0017	.0009	.0006	.0001	0.0000	.0061
SE	.0035	.0015	.0010	.0001	0.0000	0.0000	.0062
SSE	.0024	.0021	.0006	.0001	0.0000	0.0000	.0053
S	.0048	.0030	.0023	.0012	.0012	.0009	.0133
SSW	.0071	.0066	.0054	.0075	.0052	.0037	.0354
SW	.0089	.0187	.0148	.0064	.0035	.0036	.0559
WSW	.0128	.0228	.0263	.0104	.0017	.0003	.0742
W	.0183	.0276	.0119	.0066	.0012	.0004	.0658
WNW	.0182	.0134	.0031	.0031	.0015	.0008	.0401
NW	.0161	.0111	.0036	.0040	.0037	.0032	.0417
NNW	.0133	.0086	.0039	.0055	.0052	.0015	.0380
TOTAL	.1340	.1439	.0879	.0531	.0262	.0156	.4606

TABLE A-1 (CONTINUED)

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE MORNING TIME-OF-DAY CATEGORY

	WIND SPEED (M/SEC)						
DIRECTION	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	.0046	.0054	.0013	.0018	.0006	.0005	.0143
NNE	.0040	.0037	.0008	.0005	.0001	.0001	.0093
NE	.0040	.0036	.0008	0.0000	.0001	0.0000	.0085
ENE	.0035	.0028	.0012	.0001	0.0000	0.0000	.0076
E	.0018	.0019	.0004	0.0000	0.0000	0.0000	.0041
ESE	.0015	.0024	.0005	0.0000	0.0000	0.0000	.0045
SE	.0023	.0018	0.0000	0.0000	0.0000	0.0000	.0041
SSE	.0028	.0023	.0001	.0001	0.0000	0.0000	.0054
S	.0032	.0021	.0005	.0008	.0014	.0015	.0095
SSW	.0030	.0031	.0004	.0017	.0022	.0030	.0133
SW	.0053	.0058	.0031	.0022	.0004	.0015	.0183
WSW	.0045	.0053	.0040	.0010	.0006	.0006	.0161
W	.0080	.0041	.0018	.0005	.0004	.0003	.0151
WNW	.0052	.0027	.0008	.0019	.0005	.0001	.0112
NW	.0053	.0024	.0010	.0021	.0013	.0009	.0130
NNW	.0049	.0019	.0009	.0012	.0006	.0004	.0099
TOTAL	.0639	.0515	.0175	.0139	.0084	.0090	.1643

TABLE A-1 (CONTINUED)

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE AFTERNOON TIME-OF-DAY CATEGORY

	WIND SPEED (M/SEC)						
DIRECTION	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	.0013	.0022	.0019	.0018	.0008	.0010	.0090
NNE	.0012	.0035	.0021	.0006	.0005	.0001	.0080
NE	.0008	.0044	.0019	.0013	.0006	0.0000	.0090
ENE	.0014	.0059	.0031	.0009	.0004	0.0000	.0117
E	.0013	.0084	.0044	.0009	0.0000	.0001	.0151
ESE	.0018	.0070	.0052	.0012	0.0000	0.0000	.0151
SE	.0019	.0052	.0041	.0013	.0001	.0001	.0128
SSE	.0026	.0071	.0039	.0006	0.0000	0.0000	.0142
S	.0021	.0045	.0026	.0034	.0028	.0031	.0184
SSW	.0022	.0044	.0015	.0059	.0080	.0110	.0330
SW	.0036	.0048	.0032	.0049	.0059	.0089	.0313
WSW	.0026	.0050	.0028	.0015	.0009	.0014	.0143
W	.0026	.0040	.0024	.0032	.0010	.0021	.0153
WNW	.0017	.0035	.0018	.0028	.0018	.0014	.0130
NW	.0006	.0032	.0018	.0036	.0019	.0043	.0155
NNW	.0015	.0031	.0018	.0026	.0022	.0028	.0140
TOTAL	.0291	.0760	.0446	.0366	.0271	.0363	.2497

TABLE A-1 (CONTINUED)

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE EVENING TIME-OF-DAY CATEGORY

	WIND SPEED (M/SEC)						
DIRECTION	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	.0008	.0012	.0014	.0021	.0009	.0004	.0067
NNE	.0010	.0022	.0009	.0015	.0006	.0001	.0064
NE	.0013	.0021	.0013	.0008	.0003	.0001	.0058
ENE	.0014	.0018	.0012	.0005	.0003	0.0000	.0052
E	.0017	.0031	.0010	.0003	.0001	0.0000	.0062
ESE	.0008	.0021	.0012	.0004	0.0000	0.0000	.0044
SE	.0006	.0008	.0023	.0009	0.0000	0.0000	.0046
SSE	.0012	.0009	.0005	.0005	0.0000	0.0000	.0031
S	.0024	.0001	.0013	.0018	.0015	.0001	.0073
SSW	.0010	.0014	.0017	.0046	.0035	.0015	.0138
SW	.0024	.0024	.0026	.0039	.0014	.0023	.0151
WSW	.0023	.0013	.0018	.0034	.0006	.0008	.0102
W	.0017	.0013	.0022	.0019	.0005	.0008	.0084
WNW	.0024	.0014	.0008	.0012	.0006	.0005	.0070
NW	.0014	.0009	.0010	.0015	.0012	.0019	.0080
NNW	.0017	.0013	.0019	.0037	.0026	.0021	.0133
TOTAL	.0242	.0242	.0231	.0290	.0142	.0107	.1254

TABLE A-2

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE PASQUILL A STABILITY CATEGORY

	WIND SPEED (M/SEC)						
DIRECTION	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	.0001	.0017	.0004	.0003	.0001	0.0000	.0026
NNE	.0001	.0015	.0003	0.0000	0.0000	0.0000	.0019
NE	0.0000	.0026	.0012	0.0000	0.0000	0.0000	.0037
ENE	0.0000	.0023	.0012	.0004	.0001	0.0000	.0040
E	0.0000	.0040	.0017	0.0000	0.0000	0.0000	.0057
ESE	0.0000	.0034	.0021	0.0000	0.0000	0.0000	.0054
SE	0.0000	.0022	.0018	.0004	0.0000	0.0000	.0044
SSE	.0001	.0039	.0010	0.0000	0.0000	0.0000	.0050
S	0.0000	.0021	.0008	.0005	0.0000	0.0000	.0034
SSW	0.0000	.0017	.0005	.0005	.0001	0.0000	.0028
SW	.0001	.0026	.0017	.0004	.0004	0.0000	.0052
WSW	.0001	.0027	.0008	.0003	0.0000	0.0000	.0039
W	.0001	.0022	.0006	.0001	0.0000	0.0000	.0031
WNW	.0003	.0018	.0005	.0001	0.0000	.0001	.0028
NW	.0001	.0015	.0004	.0001	.0001	0.0000	.0023
NNW	.0001	.0017	.0005	0.0000	0.0000	.0001	.0024
TOTAL	.0013	.0378	.0153	.0031	.0009	.0003	.0586

TABLE A-2 (CONTINUED)

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE PASQUILL B STABILITY CATEGORY

DIRECTION	WIND SPEED (M/SEC) 0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	0.0000	.0008	.0004	.0001	0.0000	0.0000	.0013
NNE	0.0000	.0009	.0004	.0001	.0001	0.0000	.0015
NE	0.0000	.0009	.0001	.0003	0.0000	0.0000	.0013
ENE	.0001	.0015	.0006	.0003	.0003	0.0000	.0028
E	0.0000	.0024	.0005	.0005	0.0000	0.0000	.0035
ESE	0.0000	.0022	.0005	.0001	0.0000	0.0000	.0028
SE	0.0000	.0010	.0005	.0001	0.0000	0.0000	.0017
SSE	0.0000	.0015	.0003	0.0000	0.0000	0.0000	.0018
S	0.0000	.0013	.0004	.0009	0.0000	.0001	.0027
SSW	.0001	.0015	.0001	.0008	.0003	.0001	.0030
SW	0.0000	.0010	.0005	.0006	.0001	0.0000	.0023
WSW	.0001	.0021	.0012	.0001	0.0000	.0001	.0036
W	.0001	.0009	.0010	.0001	.0001	0.0000	.0023
WNW	0.0000	.0009	.0001	.0004	.0001	0.0000	.0015
NW	0.0000	.0008	.0004	.0004	.0001	.0001	.0018
NNW	0.0000	.0005	.0001	.0003	0.0000	0.0000	.0009
TOTAL	.0005	.0204	.0072	.0052	.0012	.0005	.0349

TABLE A-2 (CONTINUED)

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE PASQUILL C STABILITY CATEGORY

	WIND SPEED (M/SEC)						
DIRECTION	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	0.0000	.0019	.0010	.0005	.0006	.0006	.0048
NNE	.0001	.0021	.0009	.0001	.0003	.0001	.0036
NE	.0001	.0018	.0003	0.0000	.0001	0.0000	.0023
ENE	.0001	.0023	.0008	0.0000	0.0000	0.0000	.0032
E	.0001	.0019	.0008	.0001	.0001	0.0000	.0031
ESE	0.0000	.0031	.0013	.0003	0.0000	0.0000	.0046
SE	.0001	.0027	.0006	.0004	0.0000	0.0000	.0039
SSE	.0001	.0026	.0009	.0005	0.0000	0.0000	.0041
S	.0001	.0019	.0005	.0013	.0004	0.0000	.0043
SSW	0.0000	.0021	.0004	.0014	.0012	.0005	.0055
SW	0.0000	.0028	.0013	.0009	.0009	.0012	.0071
WSW	0.0000	.0022	.0019	.0009	.0003	.0003	.0055
W	0.0000	.0022	.0017	.0013	.0005	.0013	.0070
WNW	0.0000	.0018	.0009	.0006	.0003	.0001	.0037
NW	0.0000	.0021	.0010	.0009	.0003	.0006	.0049
NNW	0.0000	.0019	.0009	.0012	.0003	.0003	.0045
TOTAL	.0009	.0354	.0152	.0104	.0052	.0050	.0722

TABLE A-2 (CONTINUED)

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE PASQUILL D STABILITY CATEGORY

	WIND SPEED (M/SEC)						
DIRECTION	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	0.0000	.0054	.0027	.0046	.0012	.0018	.0157
NNE	0.0000	.0052	.0021	.0008	.0008	0.0000	.0088
NE	.0001	.0048	.0021	.0004	.0009	0.0000	.0082
ENE	0.0000	.0044	.0021	.0009	.0003	0.0000	.0076
E	.0001	.0043	.0026	.0004	0.0000	.0001	.0075
ESE	0.0000	.0024	.0021	.0012	.0001	0.0000	.0058
SE	0.0000	.0021	.0024	.0012	.0001	.0001	.0059
SSE	0.0000	.0028	.0021	.0005	0.0000	0.0000	.0054
S	0.0000	.0019	.0030	.0021	.0022	.0009	.0101
SSW	.0001	.0037	.0021	.0079	.0063	.0080	.0281
SW	.0005	.0089	.0092	.0072	.0067	.0095	.0420
WSW	.0001	.0090	.0101	.0072	.0018	.0022	.0304
W	.0001	.0117	.0055	.0062	.0014	.0019	.0269
WNW	.0001	.0059	.0027	.0041	.0012	.0009	.0150
NW	.0003	.0050	.0027	.0032	.0023	.0041	.0177
NNW	.0001	.0045	.0026	.0044	.0026	.0036	.0178
TOTAL	.0017	.0821	.0558	.0522	.0278	.0333	.2529

TABLE A-2 (CONTINUED)

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE PASQUILL E STABILITY CATEGORY

	WIND SPEED (M/SEC)						
DIRECTION	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	.0001	.0053	.0039	.0026	.0022	.0006	.0147
NNE	0.0000	.0045	.0019	.0039	.0010	.0003	.0116
NE	.0003	.0031	.0026	.0021	.0001	.0001	.0082
ENE	0.0000	.0034	.0017	.0006	0.0000	0.0000	.0057
E	0.0000	.0030	.0012	.0005	0.0000	0.0000	.0046
ESE	0.0000	.0015	.0015	.0006	0.0000	0.0000	.0037
SE	.0001	.0010	.0018	.0003	0.0000	0.0000	.0032
SSE	.0001	.0010	.0009	.0003	0.0000	0.0000	.0023
S	0.0000	.0014	.0017	.0021	.0041	.0046	.0139
SSW	0.0000	.0045	.0044	.0073	.0086	.0103	.0352
SW	.0008	.0113	.0077	.0072	.0028	.0053	.0352
WSW	.0005	.0112	.0122	.0055	.0018	.0005	.0318
W	.0005	.0130	.0067	.0040	.0010	.0003	.0255
WNW	.0001	.0068	.0015	.0031	.0028	.0017	.0161
NW	.0003	.0054	.0017	.0053	.0048	.0054	.0228
NNW	.0005	.0041	.0030	.0063	.0072	.0028	.0240
TOTAL	.0034	.0807	.0544	.0517	.0366	.0320	.2587

TABLE A-2 (CONTINUED)

ANNUAL JOINT FREQUENCY OF OCCURRENCE OF WIND SPEED AND WIND DIRECTION CATEGORIES FOR THE PASQUILL F STABILITY CATEGORY

	WIND SPEED (M/SEC)						
DIRECTION	0.0-1.5	1.6-3.0	3.1-5.1	5.2-8.2	8.3-10.8	>10.8	TOTAL
N	.0169	.0019	.0027	.0003	0.0000	0.0000	.0218
NNE	.0122	.0021	.0009	.0006	0.0000	0.0000	.0159
NE	.0090	.0013	.0004	.0001	.0001	0.0000	.0110
ENE	.0094	.0012	.0004	.0001	0.0000	0.0000	.0111
E	.0072	.0008	.0001	0.0000	0.0000	0.0000	.0081
ESE	.0068	.0005	.0003	0.0000	0.0000	0.0000	.0076
SE	.0080	.0003	.0003	0.0000	0.0000	0.0000	.0085
SSE	.0088	.0005	0.0000	.0001	0.0000	0.0000	.0094
S	.0124	.0010	.0004	.0003	.0003	0.0000	.0143
SSW	.0130	.0019	.0015	.0018	.0023	.0003	.0209
SW	.0189	.0050	.0034	.0010	.0003	.0004	.0290
WSW	.0211	.0072	.0088	.0023	0.0000	0.0000	.0394
W	.0295	.0070	.0027	.0005	0.0000	0.0000	.0397
WNW	.0267	.0037	.0006	.0006	.0001	0.0000	.0318
NW	.0228	.0028	.0013	.0013	.0005	0.0000	.0287
NNW	.0204	.0022	.0014	.0009	.0005	0.0000	.0254
TOTAL	.2432	.0394	.0251	.0101	.0041	.0006	.3226

APPENDIX B

HOURLY METEOROLOGICAL INPUTS FOR THE "WORST-CASE" SHORT-TERM PERIODS

Tables I through IV in the Executive Summary and the corresponding tables in Sections 3.2 and 3.3 in the main body of the report give the dates and hours of the 3-hour and 24-hour periods with the maximum ground-level SO_2 and particulate concentrations calculated by the SHORTZ model for emissions from Phases III and IV of the proposed Tar Sand Triangle Project. The hourly meteorological inputs for the various "worst-case" 3-hour and 24-hour periods are listed in chronological order in Tables B-1 and B-2, respectively. The procedures used to develop the hourly meteorological inputs are discussed in detail in Section 2.2 in the main body of the report.

TABLE B-1

HOURLY METEOROLOGICAL INPUTS FOR THE "WORST CASE" 3-HOUR PERIODS

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				30 JANUARY 1975				
15	1	1.61	628	272.3	0.000	.778	.0615	.0880
16	13	1.21	710	272.4	0.000	.528	.0544	.0778
17	334	1.01	563	271.8	.030	.342	.0347	.0496
				2 FEBRUARY 1975				
3	265	2.19	55	266.3	.020	0.00	.0692	.0990
4	314	2.06	55	266.3	.020	0.00	.0245	.0351
5	231	2.95	55	265.9	.020	0.00	.0497	.0710
				25 FEBRUARY 1975				
6	212	1.16	116	267.2	.030	0.00	.0225	.0321
7	309	1.00	116	267.2	.030	0.00	.0167	.0239
8	255	1.01	182	269.1	0.000	0.00	.0500	.0716
				18 MARCH 1975				
0	153	1.92	125	274.2	.020	.010	.0249	.0356
1	194	1.16	125	274.1	.030	0.00	.0210	.0300
2	87	1.16	125	273.8	.030	0.00	.0231	.0330
				25 MARCH 1975				
0	21	3.71	240	280.8	.010	.156	.0181	.0258
1	50	1.34	240	280.7	.030	0.00	.0231	.0330
2	97	1.88	240	280.2	.020	0.00	.0267	.0382
				14 APRIL 1975				
21	212	2.82	331	284.3	.020	.156	.0618	.0883
22	207	1.25	331	282.3	.030	0.00	.0184	.0264
23	178	1.01	331	281.5	.030	0.00	.0181	.0258

TABLE B-1 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				18 JULY 1975				
3	259	12.96	429	295.8	0.000	.722	.0488	.0698
4	260	6.26	429	294.2	0.000	.354	.0464	.0663
5	259	8.49	429	294.2	0.000	.339	.0305	.0436
				25 AUGUST 1975				
0	25	1.43	200	295.8	.030	.204	.1666	.2382
1	99	3.62	200	293.8	.010	.285	.0838	.1199
2	264	1.48	200	292.7	.030	.041	.1358	.1943
				27 SEPTEMBER 1975				
19	337	10.73	823	296.7	0.000	.160	.0341	.0487
20	337	8.54	180	294.7	0.000	.198	.0215	.0307
21	336	9.43	180	293.4	0.000	.224	.0211	.0302
				2 DECEMBER 1975				
15	123	1.01	644	275.5	0.000	.090	.1644	.2351
16	76	1.01	710	275.4	.030	.118	.0774	.1107
17	252	1.01	503	274.7	.030	0.00	.0837	.1197

TABLE B-2

HOURLY METEOROLOGICAL INPUTS FOR THE "WORST CASE" 24-HOUR PERIODS

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				2 FEBRUARY 1975				
0	315	1.61	55	268.3	.020	0.00	.0251	.0360
1	285	1.01	55	268.7	.030	0.00	.0488	.0698
2	219	2.32	55	268.0	.020	0.00	.0521	.0745
3	265	2.19	55	266.3	.020	0.00	.0692	.0990
4	314	2.06	55	266.3	.020	0.00	.0245	.0351
5	231	2.95	55	265.9	.020	0.00	.0497	.0710
6	221	4.25	55	265.1	.010	0.00	.0569	.0813
7	282	2.15	55	264.9	.020	0.00	.0129	.0185
8	245	1.01	55	266.2	.030	0.00	.0376	.0538
9	239	2.06	204	268.3	.010	0.00	.0513	.0733
10	243	1.03	354	271.1	0.000	0.00	.1063	.1520
11	257	1.01	503	273.2	0.000	0.00	.1268	.1813
12	15	1.61	653	274.5	.010	0.00	.0967	.1382
13	28	2.06	802	275.8	0.000	0.00	.1555	.2224
14	32	2.46	951	276.5	0.000	0.00	.0582	.0833
15	30	2.82	1101	276.8	0.000	0.00	.0445	.0637
16	34	2.37	1250	276.6	0.000	0.00	.0336	.0480
17	17	3.53	951	275.3	.005	0.00	.0395	.0565
18	4	3.49	653	273.9	.005	0.00	.0366	.0524
19	14	1.03	354	273.2	.030	0.00	.0100	.0143
20	313	1.00	55	271.3	.030	0.00	.0123	.0176
21	199	1.01	55	270.6	.030	0.00	.0217	.0311
22	164	1.01	55	270.2	.030	0.00	.0161	.0230
23	232	1.01	55	269.2	.030	0.00	.0207	.0297

TABLE B-2 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				23 FEBRUARY 1975				
0	331	5.27	125	270.7	0.000	.085	.0154	.0220
1	336	3.67	125	270.2	.010	.150	.0520	.0744
2	249	1.92	125	268.8	.020	.054	.0186	.0265
3	204	3.80	125	267.3	.010	.467	.0269	.0384
4	196	2.06	125	266.8	.020	.384	.0510	.0730
5	207	1.01	125	265.6	.030	0.00	.0204	.0291
6	293	1.01	125	265.3	.030	0.00	.0304	.0435
7	228	1.01	125	264.6	.030	0.00	.0516	.0738
8	260	1.01	190	265.8	0.000	0.00	.0364	.0520
9	9	2.19	255	269.6	.010	.348	.0820	.1173
10	342	1.43	320	272.6	0.000	.074	.1418	.2028
11	318	1.30	385	273.6	0.000	.101	.1385	.1981
12	244	1.03	450	274.8	0.000	0.00	.1534	.2194
13	199	1.48	515	275.7	0.000	0.00	.1057	.1511
14	219	1.88	580	276.3	0.000	0.00	.0987	.1412
15	194	1.01	645	276.9	0.000	0.00	.1357	.1941
16	219	1.34	710	277.3	0.000	.062	.1034	.1478
17	198	1.03	556	277.1	.030	.158	.0408	.0583
18	204	1.88	403	275.7	.020	.262	.0394	.0564
19	245	1.21	249	274.9	.030	.201	.0454	.0649
20	213	1.43	96	273.2	.030	.275	.0293	.0419
21	208	2.46	96	271.9	.020	.278	.0193	.0276
22	224	2.64	96	270.8	.020	.540	.0242	.0346
23	237	2.01	96	270.2	.020	.808	.0528	.0756

TABLE B-2 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				25 MARCH 1975				
0	21	3.71	240	280.8	.010	.156	.0181	.0258
1	50	1.34	240	280.7	.030	0.00	.0231	.0330
2	97	1.88	240	280.2	.020	0.00	.0267	.0382
3	39	2.68	240	279.6	.020	.097	.0142	.0202
4	74	1.65	240	279.4	.020	0.00	.0256	.0367
5	172	3.40	240	279.9	.010	.268	.0579	.0827
6	185	3.71	240	282.8	.010	.220	.0582	.0833
7	191	8.54	516	282.6	0.000	.217	.0359	.0513
8	190	11.04	792	282.7	0.000	.142	.0387	.0553
9	196	5.95	1068	282.9	0.000	.128	.0422	.0604
10	180	8.45	1344	283.0	0.000	.083	.0492	.0703
11	182	9.70	1620	283.0	0.000	.093	.0493	.0705
12	123	5.72	1896	268.3	0.000	.082	.0266	.0380
13	MISSING DATA - NOT INCLUDED IN AVERAGES							
14	171	8.27	2448	279.4	0.000	.080	.0920	.1316
15	210	10.68	2724	287.0	0.000	.069	.0526	.0752
16	220	14.48	3000	286.6	0.000	.092	.0450	.0644
17	221	15.42	2524	283.2	0.000	.088	.0478	.0684
18	236	10.01	2049	280.2	0.000	.100	.0491	.0702
19	217	12.69	1573	279.9	0.000	.101	.0450	.0644
20	209	11.00	1098	278.6	0.000	.110	.0411	.0588
21	212	10.50	622	278.6	0.000	.133	.0439	.0628
22	212	13.86	622	278.6	0.000	.126	.0438	.0627
23	218	10.91	622	278.2	0.000	.157	.0503	.0719

TABLE B-2 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				14 APRIL 1975				
0	262	3.71	125	279.4	.010	.472	.0583	.0834
1	268	2.28	125	277.8	.020	.084	.0266	.0380
2	251	2.99	125	277.4	.020	.464	.0932	.1333
3	263	2.64	125	276.7	.020	.409	.0480	.0686
4	179	1.48	125	275.9	.030	.013	.0209	.0298
5	156	1.21	125	275.2	.030	0.00	.0109	.0155
6	148	1.12	125	275.2	.030	0.00	.0156	.0223
7	240	1.01	413	275.2	0.000	0.00	.1745	.2356
8	216	2.68	700	277.1	.010	.380	.0635	.0908
9	199	4.07	988	279.3	.005	.357	.0779	.1114
10	MISSING DATA - NOT INCLUDED IN AVERAGES							
11	MISSING DATA - NOT INCLUDED IN AVERAGES							
12	MISSING DATA - NOT INCLUDED IN AVERAGES							
13	MISSING DATA - NOT INCLUDED IN AVERAGES							
14	MISSING DATA - NOT INCLUDED IN AVERAGES							
15	MISSING DATA - NOT INCLUDED IN AVERAGES							
16	199	10.55	3000	286.7	0.000	.070	.0417	.0597
17	201	9.07	2466	286.7	0.000	.098	.0420	.0600
18	217	8.94	1933	287.0	0.000	.094	.0448	.0641
19	236	6.39	1399	286.2	0.000	.114	.0450	.0644
20	218	4.74	865	285.2	.005	.186	.0399	.0571
21	212	2.82	331	284.3	.020	.156	.0618	.0883
22	207	1.25	331	282.3	.030	0.00	.0184	.0264
23	178	1.01	331	281.5	.030	0.00	.0181	.0258

TABLE B-2 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				15-16 APRIL 1975				
14	218	9.43	2466	288.3	0.000	.079	.0448	.0641
15	219	9.52	2733	289.6	0.000	.068	.0443	.0634
16	205	7.82	3000	289.8	0.000	.076	.0432	.0618
17	219	8.72	2503	290.8	0.000	.062	.0432	.0618
18	212	8.54	2007	290.9	0.000	.094	.0422	.0604
19	208	9.07	1510	290.3	0.000	.137	.0367	.0525
20	208	7.33	1013	288.6	0.000	.256	.0236	.0337
21	214	7.46	516	287.4	0.000	.250	.0254	.0363
22	215	7.29	516	286.4	0.000	.217	.0201	.0288
23	212	8.54	516	286.2	0.000	.198	.0269	.0384
0	213	9.61	516	286.3	0.000	.183	.0337	.0482
1	226	10.73	516	286.3	0.000	.132	.0384	.0550
2	226	11.58	516	286.1	0.000	.130	.0409	.0585
3	212	6.35	516	284.1	0.000	.148	.0159	.0227
4	208	4.43	516	283.4	.010	.126	.0131	.0187
5	220	4.20	516	282.2	.010	.442	.0489	.0700
6	214	4.25	516	280.5	.010	.747	.1277	.1826
7	207	7.02	765	280.9	0.000	.506	.1180	.1688
8	200	9.03	1013	283.0	0.000	0.00	.0488	.0698
9	207	7.96	1261	285.4	0.000	.069	.0453	.0648
10	215	12.74	1510	286.4	0.000	.082	.0454	.0649
11	217	13.37	1758	287.2	0.000	.071	.0478	.0684
12	218	13.81	2007	287.7	0.000	.075	.0477	.0682
13	223	13.86	2255	287.4	0.000	.055	.0467	.0668

TABLE B-2 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				20 APRIL 1975				
0	328	7.06	474	277.7	0.000	.153	.0369	.0527
1	265	3.67	474	277.7	.010	.143	.0323	.0463
2	242	3.67	474	277.2	.010	.027	.0256	.0367
3	239	3.75	474	276.9	.010	.043	.0269	.0384
4	239	3.89	474	276.5	.010	.053	.0283	.0405
5	244	3.84	474	276.5	.010	.037	.0309	.0442
6	250	3.71	474	275.4	.010	.296	.0392	.0560
7	244	3.13	689	276.0	.005	.314	.0724	.1035
8	234	3.62	904	278.1	.005	.096	.0549	.0785
9	229	2.50	1119	280.4	.010	0.00	.0520	.0744
10	240	1.25	1334	282.3	0.000	0.00	.1274	.1822
11	216	1.74	1549	283.9	0.000	0.00	.1570	.2244
12	257	1.92	1765	285.2	0.000	0.00	.1418	.2028
13	128	2.01	1980	286.2	0.000	.010	.1776	.2539
14	202	2.01	2195	287.0	0.000	0.00	.1197	.1712
15	153	2.01	2410	287.7	0.000	0.00	.1507	.2155
16	249	1.83	2625	288.2	0.000	0.00	.1251	.1789
17	232	2.06	2125	288.6	0.000	.019	.0992	.1419
18	150	2.01	1625	288.4	.020	0.00	.0698	.0998
19	116	3.13	1125	287.8	.005	.053	.0375	.0536
20	124	3.49	625	286.8	.005	.239	.0227	.0325
21	141	3.26	125	285.7	.010	.358	.0885	.1265
22	240	1.01	125	284.9	.030	0.00	.0330	.0471
23	326	2.24	125	282.3	.020	.108	.0419	.0599

TABLE B-2 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				3-4 MAY 1975				
14	207	11.53	2477	293.7	0.000	0.00	.0466	.0667
15	213	12.01	2739	294.1	0.000	0.00	.0461	.0660
16	208	11.95	3000	294.5	0.000	0.00	.0459	.0656
17	200	11.10	2525	294.7	0.000	0.00	.0449	.0642
18	209	12.70	2050	294.6	0.000	0.00	.0416	.0595
19	212	12.16	1575	294.0	0.000	0.00	.0414	.0592
20	201	8.64	1100	292.4	0.000	0.00	.0301	.0431
21	189	8.86	625	291.3	0.000	0.00	.0256	.0367
22	202	7.16	625	290.1	0.000	0.00	.0292	.0417
23	203	8.78	625	290.1	0.000	0.00	.0247	.0353
0	207	10.13	625	290.1	0.000	0.00	.0330	.0471
1	201	9.99	625	288.8	0.000	0.00	.0267	.0382
2	208	8.93	625	288.1	0.000	0.00	.0338	.0483
3	210	8.93	625	288.1	0.000	0.00	.0409	.0585
4	210	8.17	625	287.9	0.000	0.00	.0476	.0681
5	214	12.54	625	288.3	0.000	0.00	.0424	.0606
6	210	8.77	841	287.9	0.000	0.00	.0436	.0623
7	208	8.29	1057	287.9	0.000	0.00	.0430	.0614
8	203	8.02	1273	287.9	0.000	0.00	.0477	.0682
9	199	11.26	1489	288.2	0.000	0.00	.0494	.0707
10	197	11.79	1705	288.7	0.000	0.00	.0469	.0670
11	199	13.65	1920	290.2	0.000	0.00	.0460	.0658
12	205	15.88	2136	291.2	0.000	0.00	.0450	.0644
13	204	13.81	2352	291.1	0.000	0.00	.0482	.0689

TABLE B-2 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				17 MAY 1975				
0	90	1.92	125	286.3	.020	.934	.0366	.0524
1	90	1.34	125	285.8	.030	0.00	.0427	.0611
2	90	1.12	125	285.2	.030	0.00	.0207	.0297
3	330	1.01	125	284.9	.030	0.00	.0293	.0419
4	360	2.68	125	283.6	.020	.079	.0319	.0456
5	345	1.83	125	283.0	.020	.136	.0366	.0524
6	240	2.06	380	283.6	.010	.362	.0769	.1100
7	225	1.52	634	284.7	0.000	.054	.0867	.1239
8	330	1.21	889	286.9	0.000	0.00	.0976	.1396
9	240	1.25	1143	288.3	0.000	0.00	.1221	.1745
10	135	1.56	1398	289.1	0.000	0.00	.1306	.1868
11	165	2.68	1652	290.3	0.000	.079	.2002	.2862
12	180	2.99	1907	291.3	0.000	0.00	.1269	.1815
13	167	2.55	2161	292.4	0.000	.057	.1605	.2295
14	170	2.59	2416	293.0	0.000	0.00	.1221	.1745
15	301	1.74	2670	296.2	0.000	0.00	.1079	.1543
16	272	2.32	2925	296.3	0.000	0.00	.0887	.1269
17		MISSING DATA - NOT INCLUDED IN AVERAGES						
18		MISSING DATA - NOT INCLUDED IN AVERAGES						
19	213	8.58	1245	294.6	0.000	.099	.0439	.0628
20	221	8.09	685	293.1	0.000	.121	.0436	.0623
21	244	5.68	125	292.4	0.000	.126	.0438	.0627
22	231	3.26	125	291.7	.010	.115	.0227	.0325
23	204	3.22	125	290.5	.010	.195	.0970	.1388

TABLE B-2 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
25 AUGUST 1975								
0	25	1.43	200	295.8	.030	.204	.1666	.2382
1	99	3.62	200	293.8	.010	.285	.0838	.1199
2	264	1.48	200	292.7	.030	.041	.1358	.1943
3	177	1.01	200	289.8	.030	0.00	.0373	.0534
4	177	1.01	200	288.5	.030	0.00	.0254	.0363
5	245	3.67	200	289.3	.010	.467	.1113	.1592
6	267	3.53	200	289.3	.010	.536	.1028	.1470
7	244	4.83	535	288.4	.005	.635	.1611	.2304
8	257	4.69	870	286.4	.005	.699	.0851	.1216
9	40	1.39	1205	288.6	0.000	.060	.1235	.1766
10	227	2.24	1540	292.1	.010	.018	.0918	.1312
11	220	1.39	1875	294.8	0.000	.014	.1812	.2592
12	319	2.32	2210	296.7	0.000	.073	.1760	.2517
13	87	2.41	2545	298.3	0.000	.060	.2522	.3606
14	22	1.92	2880	301.3	0.000	0.00	.2874	.4110
15	8	1.97	3215	302.6	0.000	0.00	.3232	.4622
16	13	1.97	3550	303.2	0.000	.020	.2152	.3077
17	223	2.06	2865	303.6	0.000	.050	.2933	.4194
18	85	3.04	2180	303.6	.020	.033	.2203	.3150
19	88	2.55	1495	302.7	.020	.057	.0829	.1185
20	279	6.35	810	300.5	0.000	.166	.0975	.1395
21	356	5.99	125	298.6	0.000	.168	.0322	.0461
22	4	4.60	125	298.1	.010	.078	.0377	.0539
23	38	2.15	125	296.8	.020	.048	.0659	.0942

TABLE B-2 (CONTINUED)

HOUR (MST)	WIND DIR. (DEG)	WIND SPEED (MPS)	MIXING DEPTH (M)	AMB. TEMP (DEG K)	POT. TEMP (DEG K/M)	WIND EXP.	STD DEV. EL ANGLE (RAD)	STD DEV. AZ ANGLE (RAD)
				2 DECEMBER 1975				
0	282	1.01	112	267.6	.030	0.00	.0621	.0888
1	343	1.01	112	266.3	.030	0.00	.1014	.1450
2	269	2.77	112	265.7	.020	.562	.1224	.1751
3	334	1.01	112	265.3	.030	0.00	.1007	.1440
4	274	3.22	112	265.0	.010	.711	.1050	.1501
5	275	2.15	112	264.2	.020	.380	.1333	.1906
6	22	2.19	112	263.7	.020	.292	.0487	.0696
7	297	1.39	112	263.5	.030	.261	.0854	.1222
8	287	1.21	178	263.3	0.000	.109	.0776	.1110
9	314	1.01	245	265.4	0.000	.556	.1291	.1847
10	13	1.01	311	268.7	0.000	0.00	.1822	.2606
11	242	1.25	378	271.8	0.000	.125	.1152	.1648
12	MISSING DATA - NOT INCLUDED IN AVERAGES							
13	137	1.01	511	274.7	0.000	.079	.3005	.4297
14	170	1.01	577	275.6	0.000	0.00	.1970	.2817
15	123	1.01	644	275.5	0.000	.090	.1644	.2351
16	76	1.01	710	275.4	.030	.118	.0774	.1107
17	252	1.01	503	274.7	.030	0.00	.0837	.1197
18	287	1.01	296	273.1	.030	0.00	.0472	.0675
19	320	1.01	89	271.3	.030	0.00	.0217	.0311
20	327	1.01	89	270.5	.030	0.00	.0406	.0581
21	286	2.01	89	269.1	.020	.331	.0464	.0663
22	267	3.22	89	268.4	.010	.778	.0818	.1169
23	287	1.43	89	267.9	.030	.426	.1561	.2232

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