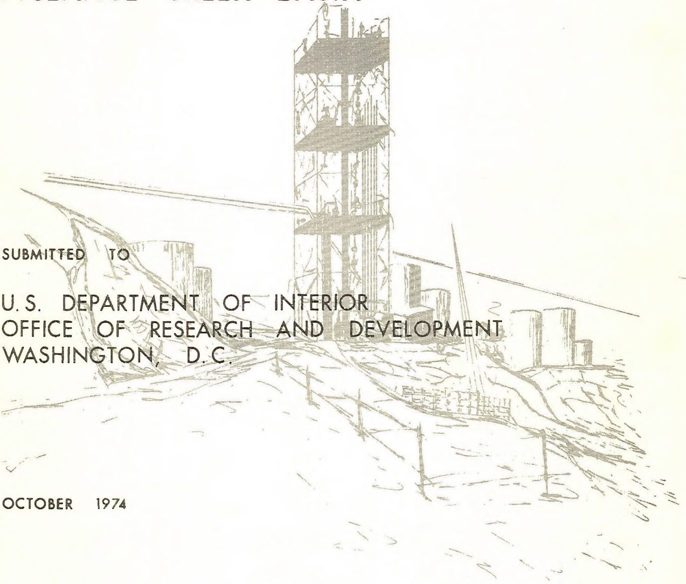
AIR QUALITY ASSESSMENT OF THE OIL SHALE DEVELOPMENT PROGRAM IN THE PICEANCE CREEK BASIN



SUBMITTED TO

U. S. DEPARTMENT OF INTERIOR
OFFICE OF RESEARCH AND DEVELOPMENT
WASHINGTON, D.C.

OCTOBER 1974

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OF THE

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IN THE

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BY

ENGINEERING-SCIENCE, INC.
MCLEAN, VIRGINIA

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CHAPTER I

INTRODUCTION

Engineering-Science Inc. (ES) was engaged to assess the potential impact on air quality of oil shale development to the year 1990 in the Piceance Creek Basin, Colorado. Since oil shale deposits were centered in the Piceance Basin, an analysis of accelerated development in this area was felt to reflect the environmental effects of development for other oil shale lands in adjoining Utah or Wyoming. This study represents an expansion and update of previous modeling efforts in which ES assisted the Department of Interior.[1, 2] Earlier, certain data bases could not be accurately defined and thus the projected impact on air quality had to be somewhat qualified. More accurate data had recently become available on potential emission rates for various retorting processes since the developers have advanced from prototype research projects to design for full-scale operating plants. Reportedly, some operators are securing permits to construct from Colorado state agencies; such permits require data on emission rates as well as potential impacts on air quality.

Demand for oil in the U.S. will determine, in part, the rate of development for oil shale facilities in the Piceance Basin. However, political, economic and environmental considerations also will affect the schedule for leasing federal lands and granting permits for producing oil. Considering all these variables, the Department of Interior estimated the range of potential development patterns for oil shale in the Piceance Basin (Table I-1). The range was described by three production patterns: Schedule 1, Schedule 2 and Schedule 3. Schedule 3 production rates total 2.5 million barrels of oil from the Colorado, Utah and Wyoming tracts per day. This estimate represents the maximum oil production that conceivably could be expected by the year 1990.

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1 Air Quality Analysis for the Oil Shale Development Program - Project Independence Blueprint, report by Engineering-Science, Inc., McLean, Va., June 1974.

2 Impact on Air Quality from Oil Shale Development, report by Engineering-Science, Inc., McLean, Va., to the Department of Interior, Oil Shale Task Group, January 5, 1973.

TABLE I-1

PROJECTED DEVELOPMENT PATTERNS FOR OIL SHALE
(thousands of barrels per day)

Year	Schedule 1			Schedule 2			Schedule 3		
	Colorado	Utah	Wyoming	Colorado	Utah	Wyoming	Colorado	Utah	Wyoming
1976									
1977									
1978				50			100		
1979				50			100		
1980	50						100	100	
1981				100			200		50
1982	100			100	100		200	50	50
1983	50			150	50		100		
1984		50		200		50	50	50	50
1985				50	50	50	100	50	
1986	50		50	100			200		
1987	50	50		100		50		150	50
1988	100			50	50		250		
1989	50	50		150			150	50	50
1990	50		50	50	50		250		
TOTAL	500	150	100	1,150	300	150	1,800	450	250

ES projected air quality levels under Schedule 1 and Schedule 3 developments thus providing an analysis of the upper and lower limits of the potential impact on air quality.

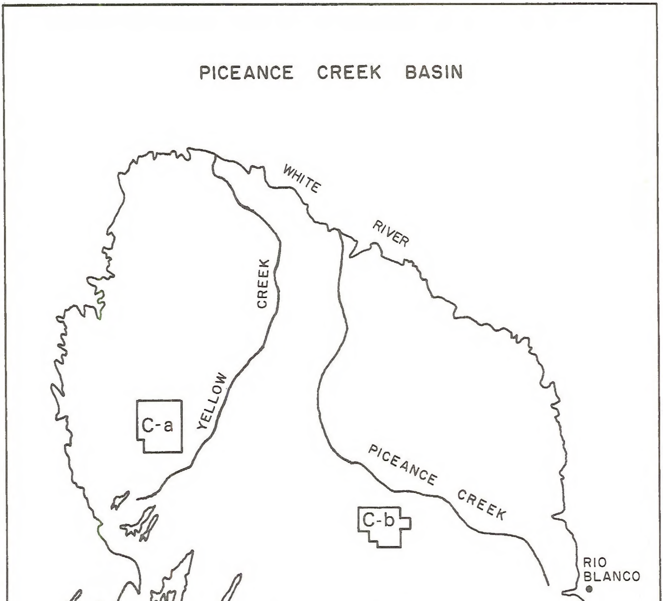
Data bases for this air quality assessment included:

- o Emission rates from the oil shale developers which included Colony Development Operation, Paraho Oil Shale Demonstration Inc., and TRW's conceptual design of the In-Situ process.
- o Meterological data from the Colony Development Operation, the Atomic Energy Commission's Rio Blanco Study, and the National Climatic Center in North Carolina.
- o Air quality data from the Colony Development Operation and the Colorado Department of Health.
- o Secondary developments from the Colorado West Area Council of Governments.
- o Development schedules and data on oil shale reserves from the U. S. Department of Interior.

Several techniques could be used to predict ambient air quality, but most investigators use atmospheric dispersion models. Such models work best when applied in simple terrain conditions. Complicated terrain features of the Piceance Basin made classical dispersion modeling very difficult. Valley conditions exist which produce up valley day time winds and nocturnal drainage winds. A significant portion of this study therefore addresses dispersion features of the valley winds and its ultimate impact on air quality.

Location of the processing plants was considered to play an important role in the potential cumulative impact on air quality in the Basin. Therefore the various oil shale processing plants, identified according to the type of retorting process and plant size, were located within an area generally identified as the boundaries of the Piceance Basin (Figure I-1). Guidance on potential location of these plants was provided by the Department of Interior. Plant size and retorting processes were related to available oil shale resources.

All oil shale processing schemes will have some fugitive dust problems associated with unpaved roadways, etc. when rock is transported from the mine to the crushers. Surface mining obviously will generate more fugitive dust than underground mines. Control measures do exist to minimixe fugitive dust losses. Appendix C discusses some of the causes of fugitive



ENGINEERING-SCIENCE, INC.

dust and the methods which operators may employ to reduce fugitive emissions. Emission estimates are included in Chapter II.

As oil shale plants go on line in the Piceance Basin, new towns and communities are expected to grow to support the industrial activity. Such secondary developments will produce additional pollution which is released to the atmosphere. For example, additional motor vehicles and new power plants will add new sources of carbon monoxide, oxides of nitrogen, particulate matter, and other contaminants. The air quality impact of the secondary induced developments was therefore identified on a meso-scale basis.

Projected air quality levels in this report were compared to Colorado and federal (EPA) ambient air quality standards (Table I-2). The objective development could proceed without violating either state or federal ambient air quality standards. The state standards which are likely to apply to the Piceance Basin in 1990 were Colorado's "designated area" standards.

All tasks involved in the completion of this study were completed by staff members of Engineering-Science, Inc. The report was intended to present an impartial and scientific evaluation of projected ambient air quality in the Piceance Basin. It was not intended to reflect or advocate and particular position or view of the authors.

TABLE I-2

FEDERAL AND COLORADO AMBIENT AIR QUALITY STANDARDS ($\mu g/m^3$)

POLLUTANT AVERAGING TIME	FEDERAL STANDARDS PRIMARY	FEDERAL STANDARDS SECONDARY	COLORADO STANDARDS NON-DESIGNATED AREA[f]	COLORADO STANDARDS DESIGNATED AREA[g] 1973	1976	1990
Particulate						
Annual Geometric Mean	75	60[c]	45	70	55	45
24 hr. Max.[a]	260	150	150	200	180	150
Sulfur Dioxide						
Annual Arithmetic Mean	80	60[e]	-	60	25	10
24 hr. Max.[a]	365	260[d,e]	15	300	150	55
3 hr. Max.[a]	-	1300	-	-	-	-
1 hr. Max.[b]	-	-	-	800	300	-
Oxidant						
1 hr. Max.[a]	160	160	-	98[h]		
8 hr. Max.[a]	-	-	-	59[h]		
Annual	-	-	-	20[h]		
Hydrocarbons						
3 hr. Max.[a]	160	160	-			
6-9 a.m. Morning average				6,560[h]		
1 hr.	-	-	-	3,280[h]		
8 hrs.	-	-	-	1,312[h]		
Carbon Monoxide						
Max. 8 hrs.	10,000	10,000	-	11,450[h]		
Max. 1 hr.	40,000	40,000	-	28,625[h]		
Annual	-	-	-	2,290[h]		
Nitrogen Oxides						
Annual Arithmetic Mean	100	100	-	-		

[a]Not to be exceeded more than once per year.

[b]Not to be exceeded more than once per month.

[c]As a guide to be used in assessing implementation plans for achieving the maximum 24-hour secondary standard.

[d]As a guide to be used in assessing implementation plans for achieving the arithmetic mean standard.

[e]EPA rescinded these standards September 14, 1973, Federal Register Vol. 38, No. 178.

[f]Non-designated areas are those which are presently very clean and which Colorado intends to maintain.

[g]Designated areas refer to areas on the eastern slope which already exceed the primary Federal Standards.

[h]Proposed for the Denver Air Quality Control Region.

CHAPTER II

EMISSIONS FROM OIL SHALE PROCESSING PLANTS

Engineering-Science contacted developers of various oil retort systems for current information on the expected atmospheric emissions from full-scale oil shale processing plants. The TOSCO II and the Paraho processes were the most developed of the retort systems available to the oil shale industry but emissions for five retort processes were identified. Colony Development Operation reportedly was filing permit applications with the Colorado Department of Health to construct a 50,000 bbl/day unit on Parachute Creek. As a result, fairly accurate information existed for TOSCO II retort process emissions. Development Engineering, Inc. (DEI) was in the process of engineering a full-scale demonstration unit of the Paraho process. In the Paraho process, the oil shale is heated directly by combustion gases and the gases are recycled thus leading to some reaction with the shale rock. At this time, the developers could only provide estimates of emissions from the full scale process. Estimates of emissions from other gas combustion processes have also been made.[3] TRW was in the conceptual design phase of developing an In-Situ process and had estimated emissions from an underground oil shale processing scheme. Likewise, the U. S. Bureau of Mines gas combustion process and the Union Oil retort process had been described and estimates had been made of emissions. The oil shale retorting processes and associated emissions are described in the ensuing discussion.

TOSCO II PROCESS

Engineering-Science reviewed estimated emissions of the TOSCO II process with its developers (Table II-1).[4] Emission rates were updated by Colony on August 20, 1974 but stack parameters were taken from their Environmental Impact Report.[5] Eight different unit operations were identified in the TOSCO II process. The TOSCO II process requires the rock to enter the pyrolysis operation in a rather fine form (less than

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3 Environmental Statement for the Prototype Oil Shale Leasing Program, U. S. Department of Interior, Washington, D. C., 1974.

4 Meeting with TOSCO officials in Golden, Colorado, July 1974.

5 An Environmental Impact Analysis for a Shale Oil Complex at Parachute Creek, Colorado, report by Colony Development Operation, Denver, Colorado, 1974.

TABLE II-1

AIR POLLUTION EMISSIONS FROM THE TOSCO II PROCESS[5]
(50,000 bbl/cd)

PROCESS	Emission Rates (tons/year)[a]				Total	Stack Parameters		
	SO_2	Particulate	NO_x	THC	Exhaust Flow (acfm)	Exit Temp (°F)	Radius (ft)	Height (ft)
Pyrolysis and Oil Recovery Unit								
Preheat Systems-6 stacks	2,873	526	3,460	1,314	1,272,000	130	4.6	275
Steam Superheaters-Ball	552	1,051	661	17	265,800	150	2.7	300
Moisturizing Systems-6 stacks	NG	1,183	NG	NG	226,400	184	2.7	50
Hydrogen Unit								
Reforming Furnaces-2 stacks	372	50	399	8	296,420	184	2.9	100
Gas Oil Hydrogenation Unit								
Reactor Heaters-2 stacks	88	9	105	3	21,000	900	1.2	100
Reboiler Heater	276	28	333	8	53,000	700	2.6	100
Naptha Hydrogenation Unit								
Reactor Heater	31	3	35	1	5,250	800	1.2	100
Sulfur Recovery Unit								
Sulfur Plants with common Tail Gas Plant	460	NG	NG	NG	64,900	125	2.0	250
Crushing and Conveying	NG	276	NG	NG	630,000	60	3.0	50
Delayed Coker								
Heater	307	31	368	9	42,000	350	(3.0)	200
Utilities	876	88	1,051	26	NG	NG	NG	NG
TOTAL	5,835	3,245	6,412	1,386				

[a]Data reflect Mode 1 operation, expected 2/3 of the time

one-half inch). Thus, primary and secondary crushing operations are required which generate particulates but not gaseous emissions. TOSCO designers offered various air pollution control strategies to comply with particulate emission standards. Colony Development Operation indicated that these procedures will be followed for minimizing emissions.

Sulfur in the form of hydrogen sulfide is liberated from shale oil rock in the pyrolysis and oil recovery unit. These gases are subsequently treated by the gas recovery and treating unit and sent to a sulfur recovery plant where elemental sulfur is recovered. H_2S which remains after the sulfur plant is incinerated and sent to a stack.

Hot gases from the ball heater preheat the shale before it enters the pyrolysis drum. During this process some sulfur is released from the shale in the form of H_2S and SO_2. These gases are also incinerated and then cleaned by a venturi scrubber before being released to the atmosphere through tall stacks.

Emissions in tons per year (Table II-1) were derived from a small demonstration unit and proportioned by Colony to reflect emissions from a 50,000 bbl/day plant. ES staff visited the pilot operations for this oil recovery scheme but the unit was not operating. Therefore, while emissions projected by Colony in Table II-1 appear to be reasonable, Engineering-Science can not attest to their validity. Developers of the TOSCO II process indicated that conservatism was used in estimating emissions. Colony provided ES with revised estimates of emissions and some stack parameters but stack heights were still being analyzed.[6] In this study, ES used stack parameters originally used by Colony.[7]

PARAHO PROCESS

Whereas the TOSCO II process pyrolysized kerogen in the rock by indirect heating, the Paraho retort uses direct combustion gases to obtain the required 900°F temperature. Figure II-1 is a schematic of the Paraho process. A gas recirculation system is used to reduce fuel requirements and take advantage of the heat value of the retort gas. Hydrogen sulfide is liberated when temperatures approach 900°F but shale oil vapors are sent to several condensors and an electrostatic precipitator to remove the

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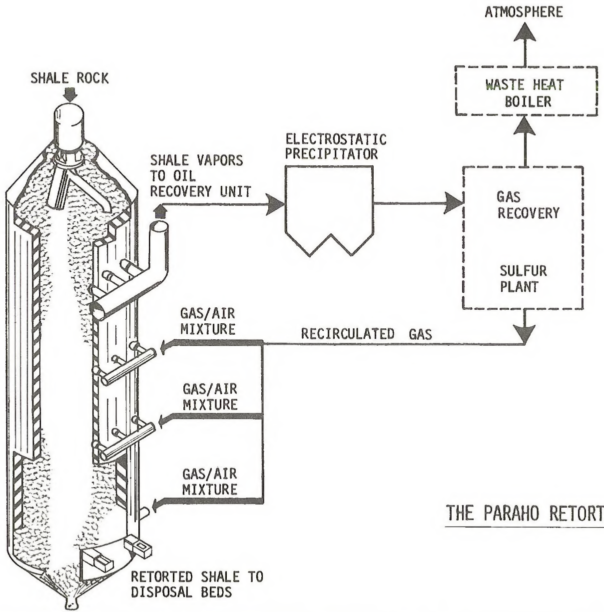
6 Personal communication with Warren Broman, letter of August 20, 1974.

7 Op.cit., the Colony study, note 5.

Figure II-1



THE PARAHO RETORT PROCESS

shale oil mist. Estimates of untreated gas constituents indicated hydrogen sulfide concentrations of less than 0.1 percent. This appears to be the lower sensitivity of the measurement instrument that was used in making the determination. Reportedly, the Paraho process is expected to have less (raw untreated) H_2S emissions than other gas combustion type retorts.[8] A large portion of the remaining noncondensible gases are returned to the retort as combustion gas. The rest of the process gas is sent to various process heaters or waste heat boilers. The proportion of gas to be recirculated was not defined so ES assumed 50% recirculation with exhaust gases cleaned to 500 ppm of SO_2.

Recirculated gases containing hydrogen sulfide are ignited and are oxidized to form sulfur dioxide. However, since the rock is mainly dolomite limestone, a large portion of the sulfur dioxide is absorbed by the rock and subsequently removed with the spent shale. In a sense then, the retort itself will act as a "scrubber" for potential sulfur dioxide emissions. Since there was no full-scale operation of the Paraho process, the effect of a large retort system on SO_2 removal had to be estimated. Table II-2 summarizes assumed control efficiencies and resultant emissions to the atmosphere.

Some differences exist in the size of rock used in the Paraho process and the TOSCO II process. The Paraho unit does not require crushed rock of 1/2 inch mesh as its feed mineral. Only primary and secondary crushing is required for the Paraho unit thus eliminating some of the dust caused by crushing, screening and material handling operations.

No data were available on any of the gas combustion retorts for oxides of nitrogen emissions. ES used a heat balance to determine the energy required to raise the temperature of air from about 250°F to 900°F (the pyrolysis temperature) at a flow rate of 375,000 scfm. The required heat input will be about 242×10^6 BTU/hr, about the same as an industrial boiler. EPA emission factors for boilers of this size average about 0.5 lb of $NO_x/10^6$ BTU. ES therefore applied this factor to the gas combustion retorts and estimated emissions of NO_x at 604 tons/year.

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8 Meeting with Edwin Piper of DEI, July 1974.

TABLE II-2

AIR POLLUTION EMISSIONS FROM THE PARAHO PROCESS[a]

(50,000 bbl/(cd)

POLLUTANT	EMISSIONS (tons/year) Uncontrolled	Controlled
Particulate		
Crushers[b,c]		
- primary	7,984	80[d]
- secondary	23,953	240[d]
		320
Sulfur Dioxide		
Retort	18,941	4,504[e]
Utilities	--	876[f]
		5,380
Nitrogen Oxides		
Retort	604	604
Utilities	1,051	1,051
		1,655
Carbon Monoxide[g]	363,422	3,634
Hydrocarbons[g]	233,455	2,534
Exhaust gas flow rate (scfm)	375,000	

[a]Estimated by Engineering-Science.

[b]Source: Compilation of Air Pollution Emission Factors, U. S. EPA, Publication No. AP-42, April 1973.

[c]Assuming a shale feed rate of 87,500 tons/day.

[d]Assumed control efficiency of 99%, typical of baghouses.

[e]Assumed 50% gas recirculation and exhaust gas cleaned to 500 ppm SO_2 (the Colorado emission standard).

[f]Estimated by Colony.

[g]Data for USBM Gas Combustion process.

OTHER GAS COMBUSTION RETORTS

The U. S. Bureau of Mines gas combustion process and the Union Oil retort processes are similar to the Paraho process. Both processes use direct heat to liberate oil from the shale rock. Table II-3 summarizes emissions from these processes. Air pollution emission estimates for untreated gases were made from pilot type operations. The units, like the Paraho, will include gas recirculation systems and waste heat boilers as part of the overall process. Operators were assumed to reduce emissions from these processes by more than 90 percent to meet Colorado emission standards (Table II-3).

IN-SITU PROCESS

At present the In-Situ process is far from being a viable full-scale oil shale production scheme for the Piceance Basin. Conceptually, the pyrolysis will take place underground with shale in place. Oil will drain to the base of the mine and later be pumped to the surface. Hot gases will pass through the shale rock, return by shaft to the surface, and go to oil and gas recovery units. Figure II-2 illustrates the In-Situ process and shows where gases emanate to the atmosphere. A large volume of air is needed in this retort process and a large amount of exhaust gas would be vented to the atmosphere.

Designers of the In-Situ plant indicate an inlet air requirement in excess of 4 million scfm.[9] Similarly, raw untreated exhaust gas flow for steady state operations is expected to be about 4.5×10^6 scfm for a 50,000 bbl/cd plant. Present design of the In-Situ plant calls for H_2S removal from the exhaust stream having a concentration of about 1,000 ppm H_2S (by volume). H_2S is an acidic gas which is commercially removed by a number of adsorption processes. Commercial H_2S systems generally used around petroleum refineries include the Claus, Shell's SCOT, the Wellman-Lord and the Beavon-Stretford processes. The USBM has been successful in removing low concentrations of H_2S but not in low pressure exhaust gas streams containing less than 0.1% or a throughput rate of 4,500,000 scfm. If H_2S removal is to be an integral part of the In-Situ plant, further advancement in H_2S technology may be required.

9 Modified In-Situ Oil Shale Plant, TRW Systems Report No. 26781-6002-Ru-00, prepared for the Interagency Oil Shale Task Force, Redondo Beach, CA, June 27, 1974.

TABLE II-3[a]

AIR POLLUTION EMISSIONS FROM DIRECT HEATING RETORT SYSTEMS (50,000 bbl/cd)[b]

POLLUTANT	EMISSIONS (tons/year)			
	Union Oil		Gas Combustion	
	Raw Shale Off-Gas[c]	Controlled	Raw Shale Off-Gas[c]	Controlled
Particulate		425		424
Sulfur Dioxide	19,119	955[d]	19,028	1,805[d]
Nitrogen Oxides	609	609	609	609
Carbon Monoxide	178,660	1,787[e]	363,422	3,634
Hydrocarbons	404,200	4,041[e]	253,455	2,534[e]
Exhaust gas flow rate (scfm)	378,472		376,736	

[a]Source: Reference 2.

[b]For emission rates for larger facilities, e.g., 100,000 and 150,000 bbl/cd multiply by 2 and 3 respectively.

[c]No air pollution control equipment.

[d]A 95% efficient sulfur recovery plant assumed.

[e]A 99% reduction assumed (burning in a waste heat boiler, turbine, etc.).

SCHEMATIC REPRESENTATION OF AN IN SITU RETORTING OPERATION

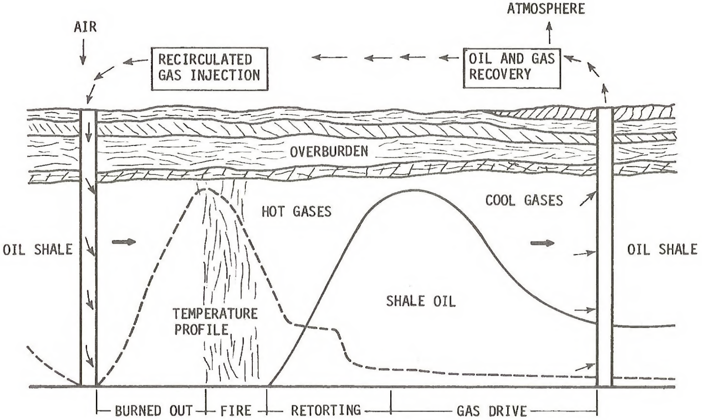

FIGURE II-2

The quantity of exhaust gas was projected to exceed 1,000,000 scfm assuming 75% recirculation for a 50,000 barrel per day plant. ES assumed hydrogen sulfide clean-up could be achieved, that the remaining H_2S would be incinerated to SO_2 and the final emission rate would meet the Colorado emission standard of 500 ppm of SO_2. Table II-4 summarizes emissions from the In-Situ plant.

SUMMARY OF PROCESS EMISSIONS

Presently, the TOSCO II and Paraho processes are forerunners in terms of those processes which will likely be used in the Piceance Basin. The Union Oil and Gas Combustion retort system may eventually evolve as viable retorting systems capable of producing 50,000 bbl/cd or more of shale oil. The In-Situ process is technologically undeveloped.

Emissions projected for each of the five processes may change significantly depending on the final processing schemes and production rates at each of the plant complexes (Table II-5). Similarities and differences obviously exist in projected emissions from the various retorting schemes. Particulate emissions from the TOSCO II process are higher than those from the other retorting systems because this process requires a finer rock feed to the retort. Emissions of sulfur dioxide from each of the systems will depend in part on the type of H_2S recovery system utilized. In addition, however, some of the gas combustion type retorts will include gas recirculation so some SO_2 will be absorbed by the shale rock and be included in the shale ash.

At present, little is known about potential nitrogen oxide emissions from oil shale retort systems since only the developers of the TOSCO II process have made estimates. Nitrogen oxides are formed in high temperature combustion processes such as commercial boilers but with pyrolysis temperatures at about 900°F, NO_x emissions are expected to be minimal.

Carbon monoxide will be generated by the retort processes because of the incomplete combustion that takes place during pyrolysis. However, carbon monoxide will be flared or sent to a waste heat boiler as a plant safety precaution.

Hydrocarbons generated by the retort systems will be recirculated in several of the retorting processes. Hydrocarbon emissions in the table refer to those emanating to the atmosphere. Most of these hydrocarbons

TABLE II-4

AIR POLLUTION EMISSIONS FROM THE MODIFIED IN-SITU OIL SHALE PROCESS (50,000 bbl/cd)

POLLUTANT	EMISSIONS (tons/year)	
	Uncontrolled	Controlled
Particulate		1,576
Sulfur Dioxide	70,714[b]	8,406[c]
Carbon Monoxide	28,734	72[d]
Nitrogen Oxides	2,256	2,256
Hydrocarbons	388,560	971[d]
Exhaust gas flow rate (scfm)	1,400,000	

[a]Source: References 3 and 9.

[b]Assumes no gas recirculation with all exhaust gas flared and vented to atmosphere.

[c]Assuming 75% gas recirculation and cleaning the remaining 25% to an SO_2 level of 500 ppm, the Colorado emission standard.

[d]25% gas recirculated incinerated with a 99% removal efficiency.

TABLE II-5

COMPARISON OF AIR POLLUTION EMISSIONS FROM OIL SHALE PROCESSING PLANTS

(50,000 bbl/cd)

POLLUTANT	EMISSIONS (tons/year)				
	TOSCO II	PARAHO	UNION OIL	GAS COMBUSTION	IN-SITU
Particulates	3,245	320	425	424	1,576
Sulfur Dioxide	5,835	5,380	955	1,805	8,406
Nitrogen Oxides	6,412	1,655	609	609	2,256
Carbon Monoxide	291[a]	3,634[b]	1,787	3,634[b]	72
Hydrocarbons	1,386	2,534[b]	4,041	2,534[b]	971
Exhaust gas flow rate (scfm)	265,800	375,000	378,472	376,736	1,400,000

[a]Source: Reference 6.

[b]Since certain emission data were incomplete, ES used emission rates of similar processes to complete the table.

are expected to be the methane-like hydrocarbons which include methane, ethane, propane, butane, etc. and are considered to be non-reactive type hydrocarbons.

FUGITIVE DUST EMISSIONS

The U. S. Environmental Protection Agency is currently developing estimated fugitive dust emissions from various sources but not discharged from a stack. Source categories include those for unpaved roads, agriculture (tilling), land development, residential-industrial-commercial construction, highway construction, quarrying-milling and tailings, aggregate storage, and cattle feed lots. Factors used in estimating emissions in this report are included in Appendix C (Table C-1). For this analysis, the parameter C, required in several of the equations, was assigned a value of 20. Such a C valve would be consistent with rainfall on the order of 16 inches per year and a potential evaporation rate on the order of 39 inches per year.[10] Appendix C lists control techniques that operators of oil shale plants may employ to minimize fugitive dust. Also included in Appendix C (Table C-2)are reductions that could be expected from utilizing the control strategies.

Fugitive dust emissions from surface mining operations are expected to be about one-half the emissions from various point source processes for a 100,000 bbl/cd TOSCO II plant. A total of about 3,000 tons per year could be generated from the surface mining operations unless controls are exercised. Emissions presented in the table refer to "uncontrolled" emissions. If operators follow the control techniques identified in Table C-2, emissions could be reduced by as much as eighty percent (Table II-6).

Potential fugitive dust emissions were not included in the particulate air quality projected in this report. The emission factors are very crude and could be in error; the Environmental Protection Agency has not officially published any such factors. No emission limits exist for fugitive dust except to employ various control techniques. These control techniques undoubtedly will improve greatly between now and 1990 to minimize such emissions.

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10 Op.cit. the DOI Impact Statement, Note 3, Page III-92.

TABLE II-6

POTENTIAL FUGITIVE DUST EMISSIONS[a]

Type of Mining Operation	Land Required (acres/year)		Particulate EMISSIONS (tons/year) Uncontrolled	Controlled
Surface Mine (100,000 bbl/cd)				
Mine development	50		133	
Overburden Disposal	1,000		2,660[b]	
Temporary Storage	150		60	
Permanent disposal processed shale	150		399	
Surface Facilities (5 miles of unpaved road, VMT 50 miles)	-		4	
Haulage from Mine (2 miles)			57	
		Total	3,313	663[c]
Underground Mine (50,000 bbl/cd)				
Mine development	10		27	
Permanent Disposal	75		200	
Surface Facilities (5 miles of unpaved roads; VMT 50 miles)	-		4	
		Total	231	46[c]
In-Situ Processing (50,000 bbl/cd)				
Surface Facilities (5 miles unpaved road; VMT 50 miles)	-		4	
		Total	4	1[c]

[a]Amick, Robert, S., et al, Fugitive Dust Emission Inventory Techniques, paper number 74-58 presented at the Air Pollution Control Assoc. meeting in Denver, Colorado, June 1974.

[b]Emissions from overburden disposal will likely be much less for the oil shale industry. Revegetation is planned for the disposal area. This will minimize fugitive losses from this source.

[c]Assuming an average of 80% control by applying various air pollution strategies to minimize particulate losses.

Undoubtedly, a sampler located adjacent to an unpaved roadway could show particulate concentrations in excess of ambient air quality standards. However, periodic inspections will be required by air pollution control officials to insure that proper control and maintenance programs are carried out in a fashion that will minimize fugitive emissions.

CHAPTER III

EMISSIONS FROM SECONDARY INDUCED DEVELOPMENTS

The development of an oil shale industry within the Piceance Basin will undoubtedly change the socio-economic profile of the area. A substantial population increase brings with it greater demands for goods and services, which in turn augments the impact on the area.

Represented in Table III-1 are the projected population estimates for the three-county area of Mesa, Rio Blanco and Garfield.[11] Three aspects of population growth are illustrated. Column A represents normal growth that would occur without oil shale development. A 3 percent annual growth rate is considered feasible until 1977, when, because of growth of the economy in the area, a 5 percent annual increase is assumed thereafter.

Column B represents the total population assuming a minimal development of the oil shale industry.

Column C represents growth of population under intensive oil shale development reaching upwards of one million barrels per day production.

Since three-fourths of the oil shale industry will most likely be located in Colorado, within a fifteen-year period a total population of 320,800 people could be realized under a Schedule 3 rate of development. This figure represents an additional 151,000 people over the normal population growth figure of 170,000.

Land area that would be suitable to accommodate the additional population is limited because of the extreme contour of the surface area in the three counties.

The greatest percentage of permanent housing, estimated at 45,000 units by 1990 (Table III-2) will be limited to areas suitable for development because of topographic and logistical limitations. The prime development areas would appear to be along the Colorado or White River Valleys depending upon the oil shale plant locations. For estimating the future air quality, all emissions from the secondary developments were assumed to be discharged within the boundaries of the Piceance Creek Basin. This would overestimate the actual emissions in the Basin and would likewise reflect higher estimates of ambient air quality. From the 1970 emission

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11 Communication with Department of Interior officials, September 1974.

TABLE III-1

POPULATION ESTIMATES FOR THREE COUNTY AREA[a]
(GARFIELD, MESA, RIO BLANCO)

A. NO OIL SHALE DEVELOPMENT[b]		B. SCHEDULE 1 OIL SHALE DEVELOPMENT		C. SCHEDULE 3 OIL SHALE DEVELOPMENT	
YEAR	TOTAL	YEAR	TOTAL	YEAR	TOTAL
1970[c]	73,900	1970	73,900	1970	73,900
1977	90,600	1977	91,800	1977	105,000
1980	104,900	1980	118,100	1980	153,700
1990	170,000	1990	231,000	1990	320,800

[a]Source: Reference 11.

[b]Population figures under no oil shale development reflect a 5% normal increase after 1977.

[c]Source: 1970 Census of Population, U. S. Department of Commerce, Washington, D. C., 1972.

TABLE III-2

TOTAL HOUSING DEMAND IN GARFIELD, MESA AND RIO BLANCO COUNTIES[a]

A. SCHEDULE 1 DEVELOPMENT			B. SCHEDULE 3 DEVELOPMENT		
Year	Site Housing	Temporary Housing	Year	Site Housing	Temporary Housing
1977	180	240	1977	3,900	1,300
1980	1,900	2,600	1970	13,400	4,500
1985	8,500	2,800	1985	25,300	18,400
1990	16,700	5,600	1990	41,300	13,800

[a]Source: Reference 11.

inventory which delineated emissions by various source categories,[12] summaries were prepared of existing emissions from point and area sources. Source categories included emissions from power plants, transportation type sources, residential home heating, commercial and institutional, refuse burning and agriculture burning.

To relate emissions in 1970 to 1990, ES assumed a proportional relationship between emissions and population. This population projection parameter can be applied fairly accurately since the number of vehicular emissions generally will increase as population increases. Furthermore, residential home heating emissions would be expected to increase proportionally as population increases unless fuels changed drastically. Thus, by knowing the emissions and population in 1970, future area emissions were calculated.

This methodology was felt to be accurate for particulates and sulfur dioxide. However, various federal emission regulations will affect the amount of carbon monoxide, hydrocarbons and nitorgen oxide emitted from automobiles in the next several years. To accommodate for this situation, the procedure outlined by the U. S. Environmental Protection Agency in a guideline document on adjusting emissions for carbon monoxide and hydrocarbons was followed.[13] The reference document suggested that a 47% reduction would occur in carbon monoxide emissions from heavy and medium duty vehicles (HDV and MDV) over the period 1970 to 1990. Light duty vehicles (cars) were expected to show a 92% reduction in carbon monoxide. The transportation mix assumed for the Piceance Valley was 20% HDV and MDV and 80% LDV. Thus, the carbon monoxide projections for 1990 were modified to reflect Federal emission regulations already adopted by EPA.

Projections of emissions for particulates, sulfur dioxide, carbon monoxide, hydrocarbons and nitrogen oxides in the Piceance Creek Basin were made for two levels of oil shale development including the null hypothesis of no oil shale development. The analysis included oil shale development for Schedule 1 (500,000 bbl/cd) and Schedule 3 (1,800,000 bbl/cd).

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12 Air Quality Implementation Plan for the State of Colorado, Colorado Department of Health, Denver, Colorado, January 26, 1972.

13 Guidelines for Designation of Air Quality Maintenance Areas, EPA, OAQPS, No. 1.2-016, Research Triangle Park, NC, January 11, 1974.

Emissions from secondary induced developments, even under Schedule 3 development patterns are a rather small portion of total emissions expected from development of the Basin. Secondary induced developments are expected to contribute only about 2,300 tons per year of particulate matter and 110 tons per day of sulfur dioxide. Even if population increases from 73,000 inhabitants in 1970 to a level of 323,700 with full development by 1990, emissions of auto exhaust contaminants are not expected to have a significant effect on air quality in Rio Blanco, Mesa and Garfield counties.

As a result of people moving into the area, additional electrical power will be required for the Rio Blanco, Garfield and Mesa County area. Presently one power plant on the White River northeast of the Basin provides much of the power for the communities of Meeker, Craig and Rio Blanco. However, new power plants may have to be erected in the Piceance Basin just to handle the incremental increases in electrical power required from these secondary induced developments. ES therefore assumed that electrical power needed to serve the secondary development would be generated in the Piceance Basin. Electrical requirements for the individual oil shale processing plants would be generated on site; emissions from such facilities were included in the various retorting plant emission inventories. Assuming a power consumption rate of 137 megawatt hours per month per 1,000 inhabitants and assuming the power is generated from shale oil with a sulfur-in-fuel content of 0.8 percent, the incremental emissions of various pollutants expected for 1975 and 1987 were calculated (Table III-3). The results of the 1970 emission inventory as reported for the three-county area were shown with the incremental emissions that will be generated as a result of population growth (Table III-4). Projections in Table III-4 reflect the development under Schedule 3 for the year 1990. These additional emissions were added to the total secondary induced emissions as reported in Table IV-1. Rather than assume that the power plant emissions would emanate at one specific location within the Basin, the emissions were proportioned to the oil shale processing plant emissions. Again, as with the impact of the secondary induced developments, such an approach should overstate the impact surrounding the oil shale processing plants.

TABLE III-3

AIR POLLUTION EMISSIONS DUE TO INCREASED POWER CONSUMPTION IN THE PICEANCE CREEK BASIN (tons/year)

POLLUTANT	EMISSIONS (tons/year) 1970[a]	Incremental Emissions[b,c] 1975	1990
Particulate	1,077	53	140
Sulfur Dioxide	1,649	836	2,228
Carbon Monoxide	104	20	53
Hydrocarbons	60	13	35
Nitrogen Oxides	1,822	690	1,840

[a] Air Quality Implementation Plan for State of Colorado, Colorado Department of Health, Denver Colorado, January 26, 1972. Data for Garfield, Rio Blanco and Mesa Counties.

[b] Using a power consumption rate of 137 megawatt-hours per month per 1000 inhabitants from Reference 11. Assumed power plants burn shale oil with 0.8% sulfur content.

[c] Compilation of Air Pollution Emission Factors, U.S. EPA, (Publication No. AP-42) Research Triangle Park, N. C., April 1973.

TABLE III-4

AIR POLLUTION EMISSIONS IN THE PICEANCE CREEK BASIN
DUE TO SECONDARY INDUCED DEVELOPMENTS[a]

POLLUTANT	1970 BASE	INCREASE IN AREA EMISSIONS (tons/year)[b]					
		WITHOUT OIL SHALE DEVELOPMENT		SCHEDULE 1		SCHEDULE 3	
		1975	1990	1975	1990	1975	1990
Particulates	2,011	600	1,200	600	1,600	600	2,300
Sulfur Dioxide	1,850	29	55	29	76	29	110
Carbon Monoxide[c]	51,427	38,500	19,000	38,500	26,400	38,500	38,200
Hydrocarbons[c]	9,273	5,700	2.700	5,700	3,700	5,700	5,400
Nitrogen Oxides	5,900	2,900	5,500	2,900	7,500	2,900	10,800

[a]Based on population projections in Table III-1. 1970 Colorado data used for area source emissions.

[b]Except for SO_2, emission projections were rounded to the nearest hundred tons/year.

[c]Source: Reference 13.

CHAPTER IV

TOTAL EMISSIONS IN THE PICEANCE BASIN IN 1990

Many uncertainties existed in projecting the type, size, and locations of oil processing plants that could be expected in the Piceance Creek Basin by 1990. As previously discussed, emissions vary with the type of retort system. Emissions also are proportional to plant size, and air quality at any point on the Piceance Creek Basin will depend on the location of each pollution source.

Department of Interior officials provided insight as to the possible locations of various size plants as well as to the retort systems that might be used in the Piceance Basin.[14] The largest plants are expected to be located on the western border of the Piceance Basin. Here, surface mining operations can be expected to support plant sizes in excess of 200,000 barrels per day under Schedule 3. Figure IV-1 illustrates the areas which would support various size plants in the Basin. These areas were designated from geological surveys of available oil shale resource and overburden.

A significant portion of the oil shale reserves which are readily accessible through either surface mining or underground mining operations were located near the geometric center of the Piceance Creek Basin. This area was denoted as maximum resource on Figure IV-1. With increasing distance from this reserve, resources and therefore plant sizes were expected to diminish in size. Department of Interior officials also identified those fringe areas to the north and east which were not suitable for any processing plants and would not likely support oil shale production. Lastly, D.O.I. officials indicated those areas to the southwest which were more acceptable to the In-Situ plants. For the Piceance Basin, In-Situ mining was expected to evolve 10 to 15 years after start-up of surface retorting plants. The In-Situ retorting plants would most likely be located on the southwest portion of the Piceance near the Cathedral Bluffs.

Two tracts have already been leased in the Piceance Basin. Tract C-a is located in the area capable of supporting a 200,000 barrel per day

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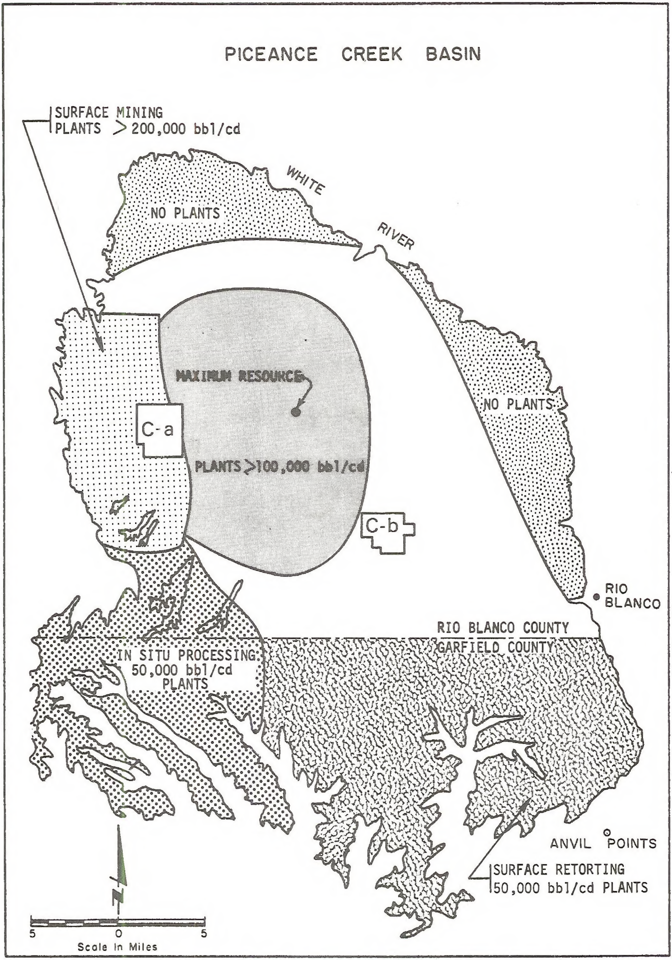
14 Meeting with John Donnell, Department of Interior, Denver Research Center, Denver, Colorado, July 1974.


PICEANCE CREEK BASIN
SURFACE MINING
PLANTS > 200,000 bbl/cd
WHITE
RIVER
NO PLANTS
MAXIMUM RESOURCE
C-a
PLANTS >100,000 bbl/cd
C-b
NO PLANTS
RIO
BLANCO
RIO BLANCO COUNTY
GARFIELD COUNTY
IN SITU PROCESSING
50,000 bbl/cd
PLANTS
ANVIL POINTS
SURFACE RETORTING
50,000 bbl/cd PLANTS
5
0
5
Scale In Miles

operation. Tract C-b is farther away to the southeast of the geometric center of the peak reserve. Projected plant capacity at C-b is 50,000 barrels per day.

The exact type of retorting process which would be used at any given tract had to be estimated. The tract C-a leasor was one of the cosponsors of the Paraho process so it was likely that the Paraho unit would be used on tract C-a. TOSCO was one of the co-owners of tract C-b so it was likely that the TOSCO II process would be used on tract C-b. It was possible, of course, that several different type retorting processes would evolve on a given tract. For example, some shale fines would be generated during primary crushing even for the Paraho process rock. Since the TOSCO II process is designed to use fines, one TOSCO II unit could possibly be used with several Paraho processes to compliment their retorting operations at any one plant site. Also a combination of retort systems was under consideration for the In-Situ plants where various surface retorts could be expected to handle the mined shale. Some underground mining would be necessary for the In-Situ plant as part of the preparation for in place retorting.

Considering the status of development for each of the retorting processes, Schedule 1 development (500,000 bbl/cd) assumed that three TOSCO II plants would produce 200,000 bbl/cd. In addition, three Paraho units would produce 200,000 bbl/cd; 1 Gas Combustion retort complex would produce 50,000 bbl/cd; and 1 In-Situ plant would produce 50,000 bbl/cd. Using this schedule of production and the emissions that had been tabulated for each process in Table II-5, emissions were projected for the oil shale industry by the year 1990 (Table IV-1). Schedule 3 development assumed four TOSCO II retort plants producing 750,000 bbl/cd; four Paraho units producing 700,000 bbl/cd; two Gas Combustion retort systems producing 200,000 bbl/cd and two In-Situ plants producing 150,000 bbl/cd. The combined production rate for Schedule 3 was 1,800,000 bbl/cd.

Emission summaries of the oil shale processing plants were then added to the other potential emissions expected in the Piceance Basin from secondary induced developments. Emissions from power generated for secondary development were assumed to be the same for both Schedule 1 and Schedule 3 oil shale development. This assumption would overstate total emissions from Schedule 1 development by a small amount.

TABLE IV-1

TOTAL AIR POLLUTION EMISSIONS
IN THE PICEANCE BASIN EXPECTED BY 1990

POLLUTANT	EMISSIONS (ton/year)					
	SCHEDULE 1[a]			SCHEDULE 3[b]		
	OIL SHALE INDUSTRY	SECONDARY[c] DEVELOPMENT	TOTAL	OIL SHALE INDUSTRY	SECONDARY[c] DEVELOPMENT	TOTAL
Particulate						
Point and Area	16,260	1,740	18,000	59,583	2,440	62,023
Fugitive Losses[d]	2,080	-	-	8,228	-	-
Sulfur Dioxide	55,071	2,304	57,375	195,283	2,338	197,621
Carbon Monoxide	17,559	26,453	44,012	69,993	28,253	108,246
Nitrogen Oxides	35,123	9,340	44,473	128,554	10,835	139,389
Hydrocarbons	19,185	3,753	22,938	69,315	5,435	74,750

[a]Assuming 8 tracts would use the following retort systems:
3-TOSCO II plants for a total capacity of 200,000 bbl/cd; 3-Paraho's for 200,000.
1-USBM Gas Combustion for 50,000 bbl/cd and 1-In-Situ for 50,000 bbl/cd.

[b]Assuming 12 tracts would use the following retort systems: 4-TOSCO II plants for a total of 750,000 bbl/cd; 4-Paraho units for 700,000 bbl/cd; 2-Gas Combustion units for 200,000 bbl/cd and 2-In-Situ at 150,000 bbl/cd.

[c]Data is for the last year where projections had been made. Also includes emission expected from new power plants.

[d]Assuming two-thirds of the oil shale would be surface mined and one-third underground mined.

Total particulate emissions expected under Schedule 1 will be 18,000 tons per year excluding fugitive dust. Under Schedule 3, the total particulate emission is expected to be 62,023 tons per year. Note that 96% of the particulate emissions are emitted from the oil shale processing plants. Fugitive dust emissions in the Basin are expected to total 8,228 tons per year even with employment of good control technology.

Sulfur dioxide emissions expected for the Piceance Basin will total 57,375 tons per year under Schedule 1 and 197,621 under Schedule 3. Secondary induced developments will contribute only about one percent of the emissions for 1990. On the other hand, a significant portion of the CO and NO_x emissions will be the result of secondary induced transportation sources.

Hydrocarbon emissions will total 22,938 tons per year under Schedule 1 and 74,750 tons per year under the most optimistic development program.

Emphasis is placed on the application of the TOSCO II and the Paraho processes in this report. Very little difference in SO_2 emissions would occur if the TOSCO or the Paraho units were interchanged. However, approximately a 10-fold difference could be expected in particulate emissions.

After selecting the plant types and sizes that would make up the Schedule 1 and Schedule 3 levels of oil shale development, the plants had to be located in the Piceance Basin. Obviously, the location of the sources of pollution would play an important role in determining the impact on air quality. If all of the larger 200,000 bbl/cd processing complexes were located side by side, ground levels of air contaminants would be high. Furthermore, if two or more plants were located in the same valley where one up valley wind will carry the plumes to the up valley receptor, it is likely that the short-term standards would be exceeded. With this consideration in mind, the plant complexes were located in the Basin for the two production schedules. As described later, if the configuration resulted in unacceptable air quality levels, a different configuration was tried. The larger plants (>200,000 bbl/cd) in the western part of the Basin were spaced about 5 miles from one another prior to making dispersion estimates.

CHAPTER V

DISPERSION OF ATMOSPHERIC EMISSIONS IN THE PICEANCE BASIN

CLIMATOLOGY

The Piceance Creek Basin is located on the west slope of the Rocky Mountains between the Colorado and White Rivers. The watershed of the creek is approximately 30 by 30 miles, bordered on the south by the Roan Plateau, on the east by foothills of the Rockies and on the west by Cathedral Bluff. Elevations in the far reaches of the watershed are on the order of 8,000 to 9,000 feet. The Basin slopes generally to the north to the White River at an elevation of 5,500 to 6,000 feet. Beyond the White River, which flows westerly through a rather narrow passage north of Cathedral Bluff, are ridges and mountains up to 7,000 feet. The Basin is cut by many creeks and gulches leading into the Piceance.

The area has a pronounced dry continental climate characterized by large diurnal and seasonal temperature changes, low humidity, and abundant sunshine. While lying in the zone of prevailing westerlies, the whole of Western Colorado is practically surrounded by very high mountains which deflect the course of many migratory low pressure cells to the north or south. In consequence the sudden changes in weather usually experienced at this latitude are infrequent. In winter there is a tendency for persistent high pressure cells to form in the area which may remain for weeks at a time. These periods experience clear skies, light wind conditions and large diurnal changes in temperature.

During summer the weather is dominated by the large area of relatively low pressure associated with the hot continental effect. From the middle of July until September frequent thunderstorms occur. Days are warm and nights cool with generally light and changeable winds.

Tables V-1 and V-2 show some general climatological data for observation stations in the area. In addition is shown the estimated climatology for the 8,200 feet level on the Roan Plateau.

Although these climatological elements are important in understanding the weather in the vicinity of the proposed oil shale development, and indeed, have some direct effect in accelerating the physicochemical change and deposition of airborne material, the three most important parameters

TABLE V-1

SURFACE CLIMATOLOGICAL SUMMARY: TEMPERATURE (°F)

Station	Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Craig	Mean	17.2	21.8	30.8	42.5	51.4	59.3	66.5	64.8	56.6	45.5	31.0	22.6	42.5
	Mean Max.	32.9	37.0	44.5	57.6	68.3	77.9	86.1	83.8	76.3	63.6	46.7	37.1	59.3
	Mean Min.	1.5	6.7	16.9	27.3	34.6	40.7	46.9	45.8	37.0	27.4	15.3	8.2	25.7
	Highest	53	58	71	81	87	100	99	96	93	84	71	64	100
	Lowest	-40	-43	-24	- 2	14	21	31	28	17	9	-19	-31	-43
Little Hills	Mean	21.7	24.6	32.0	41.9	50.5	58.7	65.3	63.4	56.0	44.4	31.2	24.4	42.8
	Mean Max.	38.3	41.8	47.4	59.1	68.8	79.5	86.3	83.4	77.8	65.0	48.8	41.2	61.5
	Mean Min.	5.0	7.8	16.6	24.5	32.3	37.9	44.4	43.7	34.2	23.7	13.7	7.7	24.3
	Highest	60	64	70	80	87	97	98	98	95	91	68	69	98
	Lowest	-35	-32	-25	7	13	20	30	28	12	- 1	-27	-30	-35
Meeker	Mean	20.9	25.0	33.4	43.4	51.6	59.7	65.7	64.0	56.1	45.4	33.2	22.8	43.4
	Mean Max.	36.2	40.2	47.3	59.0	69.2	79.5	85.4	82.9	75.5	63.2	48.9	37.1	60.4
	Mean Min.	5.4	9.8	19.5	27.8	33.9	39.8	46.0	45.1	36.7	27.5	17.6	8.3	26.5
	Highest	61	63	72	86	93	102	103	99	94	86	73	65	103
	Lowest	-43	-38	-24	- 5	14	20	26	29	14	- 6	-25	-36	-43
Rangely	Mean	18.4	23.7	35.2	47.4	57.4	67.0	73.6	70.4	62.2	49.6	33.6	22.6	46.8
	Mean Max.	33.2	39.2	50.3	63.6	74.9	86.5	93.0	89.3	82.9	69.3	49.8	37.0	64.1
	Mean Min.													
	Highest	53	63	74	86	95	104	102	101	98	86	72	57	104
	Lowest	-37	-32	- 8	11	24	30	39	32	25	8	- 5	-20	-37
Roan Plateau 8200 ft.	Mean	18	19	25	37	48	60	66	65	58	43	28	20	41
	Mean Max.	26	29	33	44	56	65	73	72	66	50	36	27	48
	Mean Min.	11	10	18	30	42	55	61	58	35	35	20	13	34
	Highest	52	58	61	71	76	87	86	83	82	78	63	60	87
	Lowest	-18	-20	- 8	- 2	18	25	39	37	20	3	- 5	-18	-20

TABLE V-2

SURFACE CLIMATOLOGICAL SUMMARY: PRECIPITATION (in.)

Station	Parameter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Craig[15]	Mean Precip.	0.97	0.81	1.09	1.24	1.45	1.27	0.99	1.28	1.09	1.35	0.92	1.03	13.4
6285 ft.	Days ≥0.1	4	4	4	3	3	3	3	3	4	3	4	3	41
Hamilton[15]	Mean Precip.	1.52	1.35	1.95	1.63	1.63	1.30	1.36	1.25	1.42	1.52	1.36	1.58	17.8
6230 ft.	Days ≥0.1	6	6	6	6	7	7	5	6	7	7	7	6	53
	Mean Snowfall	19.7	21.9	18.8	7.6	1.2	trace	0	trace	trace	2.7	16.3	29.9	117.5
Little Hills[15]	Mean Precip.	.93	.85	1.20	1.28	1.01	0.92	1.09	1.71	0.88	1.19	0.93	0.85	12.8
6148 ft.	Days ≥0.1	3	4	4	3	4	2	3	4	4	3	4	3	41
Marvine[15]	Mean Precip	1.79	1.50	2.10	1.86	1.42	1.39	1.62	1.97	1.60	1.33	1.55	1.97	20.1
7343 ft.	Days ≥0.1	6	6	6	5	4	3	3	5	4	3	5	5	55
Meeker[15]	Mean Precip.	1.15	1.00	1.50	1.56	1.45	1.06	1.51	1.82	1.43	1.49	1.10	1.12	16.1
6242 ft.	Days ≥0.1	5	4	6	5	5	2	4	5	4	5	4	4	53
	Mean Snowfall	15.4	12.0	13.6	5.9	0.9	0.1	0	0	0.3	3.1	9.4	13.0	73.7
Rangely[15]	Mean Precip	0.73	0.84	0.81	0.62	0.76	0.52	0.49	1.28	0.76	0.76	0.51	0.68	8.7
5216 ft.	Days≥ 0.1	3	3	2	2	3	2	2	3	2	3	2	2	29
Roan Plateau[16] 8200 ft.	Mean Precip.	1.8	1.3	1.3	1.2	1.2	1.0	1.1	1.9	1.2	1.4	1.3	1.5	16.2

[15] Climatography of the United States. [16] Dames and Moore for Colony Development Operation, 1973.

for the practical determination of the behavior of the material are wind speed, wind direction and atmospheric stability.

WIND SPEED AND DIRECTION

Once airborne, the material moves with the local wind. In this area of prevailing westerlies the predominant direction of the gradient wind, that is, the wind that moves in response to the large scale pressure forces unaffected by surface friction, is from the south-southwest to west-northwest quadrant 65 percent of the time at an average speed of approximately 18 mph. Even with the strong persistence of the gradient winds as measured at near 10,000 feet at Grand Junction low downwind concentrations of an air pollutant would be expected because of the high speed of the wind and its large ventilating effect. Table V-3 shows the wind direction/wind speed distribution of the near 10,000 feet winds.

Unfortunately, the wind in which the plume from the oil recovery units is imbedded will vary considerably from the gradient wind, unless the effective height of release is well above the surface. These lower level winds result from topographic restrictions to flow and differential heating and cooling of the surface. During the night the lower level winds are downslope. In a large basin this movement results not only from outward radiation from the valley floor but also from the radiating side slopes which have cold air layers near the ground which flow down. From these downslope winds there develops the down valley wind. The downslope winds start shortly after sundown and reach the maximum extent during early morning.

During the period of a well-developed down valley wind a cellular circulation is set up with rising air in the middle of the valley and descending air along the slopes. This is illustrated schematically in Figure V-1. This phenomenon was carefully observed during smoke trails in a well-developed down valley wind in Alaska.[17] In these trials pronounced lifting of the smoke occurred at each point where a gulch or small tributary valley entered the main valley floor. This would have an important effect upon plume behavior in the Piceance Basin. A plume would tend to more nearly maintain a constant altitude rather than a constant height above the terrain.

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[17]Personal communication, J.K. Allison, Engineering-Science, Inc., 1974.

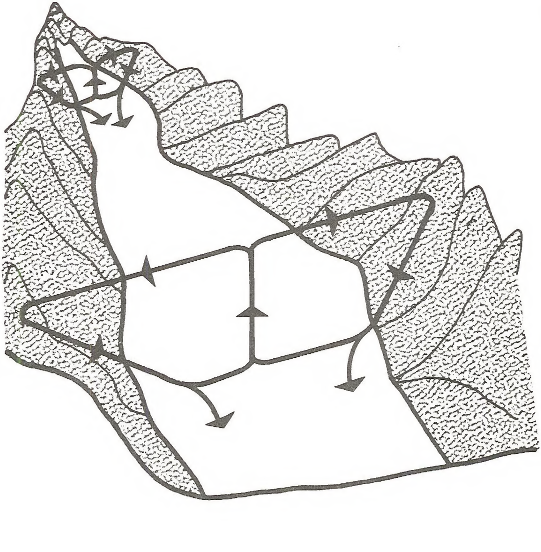
TABLE V-3

ANNUAL AVERAGE 700 mb WINDS (NEAR 10,000 FEET)

GRAND JUNCTION, COLORADO

Direction	Frequency (%)	Wind Speed (m/sec) Frequency (%)				
		Mean	0-4	5-9	10-14	15
N	6.1	6.4	30	54	13	3
NNE	4.9	5.7	37	54	7	2
NE	3.3	5.2	48	38	12	2
ENE	1.1	4.7	43	45	12	0
E	1.0	3.1	72	28	0	0
ESE	1.2	3.4	80	20	0	0
SE	0.9	4.7	75	0	24	0
SSE	1.3	4.1	63	37	0	0
S	4.3	8.1	27	44	17	9
SSW	9.9	9.6	19	39	30	16
SW	14.0	8.4	19	43	30	8
WSW	17.3	7.8	18	53	23	6
W	14.3	7.5	20	55	22	4
WNW	9.4	6.7	33	42	20	5
NW	6.4	6.7	32	51	12	5
NNW	4.7	5.1	51	36	8	2

TYPICAL NOCTURNAL FLOW



SOURCE: [18] Geiger, R., The Climate Near The Ground
Harvard University Press, Cambridge, Mass. 1959

Similar to the nocturnal downslope motion there is a daytime upslope wind. These up valley winds are not as consistent as the down valley winds and are of lower speed. Because of the orientation of the Basin and the prevailing gradient wind direction, the up valley is inhibited by the upper winds. However, during those times in which the plume is imbedded in an up valley wind very high ground concentrations of the air pollutant may result near the source. As the plume is carried farther up slope pronounced dilution will occur; the plume will be rapidly mixed with the gradient flow, dissipated, and carried away.

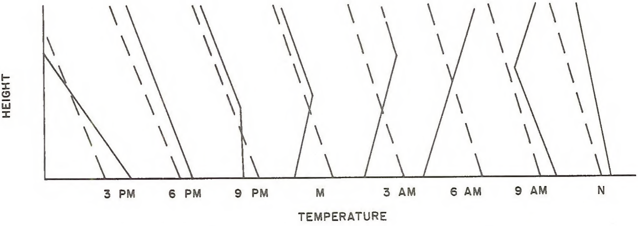
STABILITY

The stability of the atmosphere is the third meteorological parameter required to describe plume behavior. The stability and the induced effects upon horizontal and vertical fluctuations of the wind determine the horizontal and vertical dispersion of the airborne material. Wind speed, of course, is important in this respect, not only because of mechanically induced turbulence but also because of the functional relationship between the vertical gradients of wind speed and temperature.

When the temperature of free ambient air decreases with altitude at a superadiabatic rate (>0.01°C/m), typically during midday by heating of the ground surface, unstable conditions prevail, vertical currents are induced and good vertical mixing of the pollutants occurs. The more normal situation is a decrease of temperature with height between neutral conditions (0.01°C/m) and isothermal conditions, temperature constant with height. Under these conditions less pronounced but still significant vertical mixing occurs. Under inversion conditions, i.e., an increase of temperature with height, typically during early morning when the ground surface has been cooled by radiation, vertical mixing is inhibited. Such a surface inversion is accompanied by lighter winds and thus concentration levels are raised farther. After sunrise, as the sun begins to heat the surface, the lower part of the inversion may be removed, leaving an inversion aloft. Figure V-2 shows possible changes in the vertical temperature gradient during the course of the day. In each case, the dashed line is the neutral sounding or dry adiabatic sounding. At 3 P.M., an unstable condition is evident. By midnight, a surface inversion begins to form which is fully formed by 6 A.M., extending to some

FIGURE V-2

CHANGES IN VERTICAL TEMPERATURE GRADIENT DURING THE COURSE OF THE DAY



unknown level. By 9 A.M., the surface has warmed up leaving the inversion aloft, and by noon, the sounding is near neutral.

Pollutants released below an inversion will be trapped and inhibited from mixing to greater depths than the bottom of the stable layer. Pollutants released into or above an inversion will be prevented from mixing downward. Thus concentrations from a surface or low level source are increased by stability and ground level concentrations from a plume released sufficiently high are reduced by low stability. In the latter case short-term concentrations are highest in unstable conditions where the plume is brought rapidly down with little dilution or dispersion.

There can also exist an inversion or a stable layer aloft resulting from the dynamic effects of the earth's large scale circulation. These too, effectively limit the vertical extent to which a pollutant may be mixed. Holzworth[19] has calculated the height of this mixed layer for the morning and afternoon (minimum and maximum depths, respectively) for the four seasons. These data are given in Table V-4.

The meteorological input to the classic disperson model consists of a three-way joint frequency distribution of wind direction, wind speed, and stability class. The wind parameters are routinely observed and recorded

[19] Holzworth, George C., Mixing Heights, Wind Speeds, and Potential for Urban Air Pollution Throughout the Contiguous United States, AP-101, U.S. EPA, Research Triangle Park, NC, January 1972.

TABLE V-4

MEAN MIXING HEIGHTS (m)

	Morning	Afternoon
Winter	329	1,160
Spring	628	3,166
Summer	307	3,940
Fall	273	2,133
Annual	384	2,600

at National Weather Service first order stations and at many airports. The stability class, computed from routine observations of wind speed and net insolation, can be categorized as follows:

- o Stable, in which the lapse rate of temperature is less than adiabatic and the vertical dispersion of pollutants is inhibited.
- o Neutral, in which the lapse rate of temperature is equal to the adiabatic and the vertical dispersion of pollutants is indifferent.
- o Unstable, in which the lapse rate of temperature is greater than the adiabatic and the vertical dispersion of pollutants is supported.

These basic categories are usually divided into subclasses designated A through F in which A is the most unstable and F is the most stable. D is the neutral case. These three parameters, wind speed, wind direction, and stability class, are combined into the three-way joint frequency distribution of 16 wind directions, 6 wind speed classes and 6 stability classes. Each of the 576 combinations result in a unique concentration field which may be calculated.

The nearest meteorological observation station from which these data were available was the Grand Junction Airport approximately 60 miles south of the Piceance Basin, beyond the Roan Plateau in the Colorado River Valley. Because of the profound difference in topographical effects between the two locations it was not advisable to use Grand Junction stability wind rose data for the Piceance Basin.[20] However, stability data in Table V-5 were later used to synthesize a stability wind rose for the Piceance Basin.

<u>WIND REGIMES CONSIDERED FOR DISPERSION MODELS</u>

Some very valuable wind observations in the Basin were available from the Project Rio Blanco weather station network and from the Roan Plateau Station. See Figure V-3. These combined with knowledge of expected stability conditions in this kind of climate, a general inference which may be made from the upper level winds, good judgement, and care

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[20] The Dames and Moore study for Colony showed some correlation between the wind direction at Grand Junction and that at the Roan Plateau weather station. Little correlation was found in wind speed.

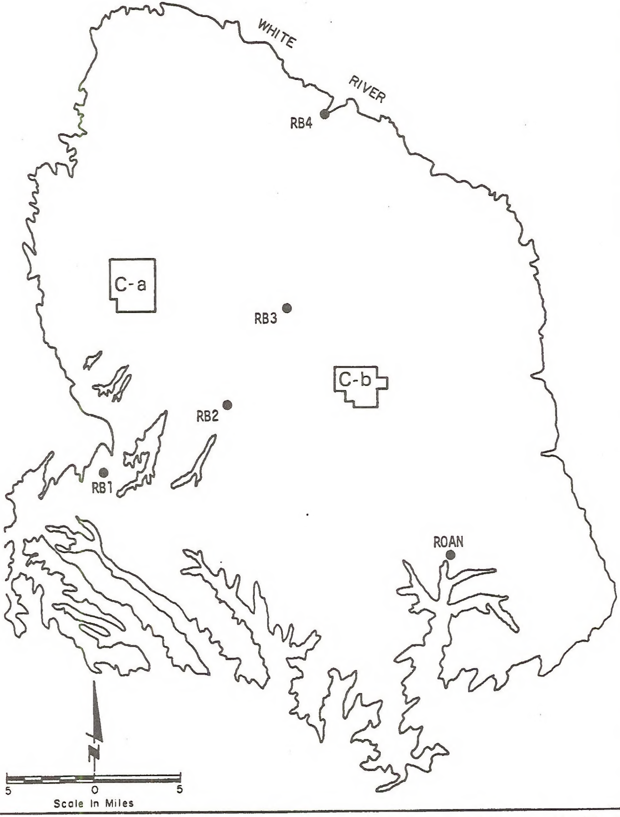
TABLE V-5

TWO-WAY DISTRIBUTIONS (%) OF METEROLOGICAL DATA FOR GRAND JUNCTION

	WIND SPEED (KNOTS)							AVERAGE	STABILITY CLASS					
	0-3	4-6	7-10	11-16	17-21	21	Total	WS	A	B	C	D	E	F
N	1.2	1.3	1.1	0.4	*	*	4.0	6.4	0.1	0.4	0.4	1.4	0.7	1.1
NNE	0.8	0.8	0.5	0.2	*	*	2.3	6.2	*	0.2	0.2	0.7	0.4	0.8
NE	1.2	1.0	0.6	0.2	0.1	*	3.1	5.8	0.1	0.2	0.2	0.8	0.6	1.3
ENE	2.0	2.2	0.6	0.2	*	*	5.0	5.0	0.1	0.2	0.2	0.9	0.8	3.0
E	2.2	2.1	0.8	0.3	*	*	5.4	5.1	*	0.2	0.2	1.1	1.0	2.8
ESE	3.2	5.5	7.1	3.8	0.3	*	19.9	7.9	0.1	0.7	1.2	7.4	5.3	5.3
SE	2.4	4.4	5.2	1.8	0.2	*	14.0	7.4	0.1	1.0	2.1	4.4	2.7	3.7
SSE	1.6	2.4	2.3	0.8	0.2	0.1	7.4	7.1	0.2	1.1	1.7	2.2	0.7	1.3
S	1.6	1.6	1.2	0.6	0.2	0.1	5.3	7.1	0.2	1.1	1.1	1.7	0.3	0.8
SSW	0.8	0.6	0.4	0.4	0.1	0.1	2.4	7.6	0.2	0.5	0.4	0.8	0.1	0.3
SW	0.9	0.7	0.4	0.4	0.2	*	2.6	7.5	0.2	0.6	0.4	0.9	0.1	0.4
WSW	0.9	0.8	0.4	0.3	0.1	*	2.5	6.2	0.2	0.7	0.4	0.7	0.2	0.4
W	1.2	1.3	1.0	0.5	0.2	0.1	4.3	7.0	0.2	0.9	0.9	1.3	0.2	0.6
WNW	2.3	2.9	2.9	1.4	0.3	0.1	9.9	7.3	0.3	1.6	2.3	3.6	0.7	1.3
NW	1.6	2.3	2.3	1.1	0.2	*	7.5	7.5	0.2	1.0	1.4	3.0	0.8	1.1
NNW	1.0	1.4	1.3	0.6	0.1		4.4	7.2	0.1	0.5	0.7	1.8	0.7	0.8
TOTAL	24.9	31.3	28.1	13.0	2.2	0.5	100.0	6.5	2.3	10.9	13.8	32.7	15.3	25.0
A	1.3	0.8	0.0	0.0	0.0	0.0								
B	5.3	3.7	2.0	0.0	0.0	0.0								
C	2.2	4.4	6.2	0.9	0.1	*								
D	2.5	4.9	10.8	12.0	2.1	0.5								
E	0.0	6.1	9.2	0.0	0.0	0.0								
F	13.4	11.4	0.0	0.0	0.0	0.0								

*less than 0.5%

LOCATION OF METEOROLOGICAL STATIONS



to be conservative will permit rather substantial and sound conclusions to be reached concerning plume behavior.

As has been shown there are three principle wind regimes in which the plume may be imbedded.

- o Those in which the wind is primarily influenced by the gradient wind flow. This would occur during strong wind conditions or during the daytime, with strong insolation. These two conditions are conducive to high levels of mechanical and thermal turbulence, respectively, which in turn causes strong vertical currents in the lower atmosphere and the downward transport of momentum. Stability conditions C and D would be expected during the daytime and stability D at night.
- o Down valley nocturnal wind. This would occur at night with lighter winds aloft and a strong surface-based radiation inversion. Stability condition F would prevail.
- o Up valley daytime wind. This would occur during the daytime with rather light winds aloft. Stability A or B would be likely.

There will, of course, be wind directions and speeds which do not conform to any one of these three regimes. During period of transition from one to another variable winds will occur and when there is no influence by the upper winds, very light winds will occur during the transition from up to down valley and vice versa. However, these transient conditions will not increase the pollution levels at those locations most impacted by the three main regimes. In fact, they will tend to disperse the pollution more than would the steady wind directions expected under any of the three wind fields.

Gradient Wind Regime

Data requirements for the APSIM model (described later) include the three-way joint frequency distribution of wind speed, wind direction and stability and the average annual height of the mixed layer. Output from the model in this operating mode are the annual average ground level concentrations of pollution due to dispersion and dilution by the gradient wind. The gradient wind distribution assumed for the Piceance Basin was the 700 mb or near 10,000 foot level winds at Grand Junction. These data were presented earlier in Table V-3.

Stability category was calculated by a method involving surface wind speed, cloud cover and elevation of the sun. Although, as mentioned earlier, it was not advisable to consider Grand Junction wind data as representative of the Piceance Basin, the distribution of stability categories is probably very similar. The general climatology and consequently cloud cover are similar; differences in elevation of the sun are negligible. The surface wind speed at Grand Junction is judged to be somewhat less than at the operating sites in the Basin. This was shown to be the case for the Roan station and is to be expected for the sites, too, because of the increased elevation over Grand Junction. Use of the Grand Junction stability distribution is conservative in that the lower wind speeds give a higher frequency of A stability and consequently higher concentrations from elevated sources. The relative frequency of stability classes from the Grand Junction data are given in Table V-5.

The mean annual mixing height as given in Table V-4 is 1,492 m (384 m in the a.m. and 2600 in the p.m.). A conservative value of 1,400 m was later used in the predictive model.

Down Valley Nocturnal Wind Regime

The primary shortfall in knowledge is in the temporal and spatial extent of the down valley wind. Yet, it is under these conditions that the most severe air pollution situation may occur. Of particular concern is the lack of knowledge of the depth of this wind. Depth of down valley winds have been reported from a few to a few hundred meters. One of the most well-developed and consistent down slope wind, that of the Wisper Valley in Germany, has been measured at 150 meters. If this were the case in the Piceance Basin, a moderately high effective stack height (about 175 meters, typical of tall retort stacks) might loft the plume above the drainage flow.

Some evidence of the depth is gained from wind observation at RB1. See Figure V-3. This station at an elevation of 8,500 feet does not display the diurnal wind direction change that is expected with the valley wind regime and which is observed at RB2, RB3, and RB4. For comparison the data from RB1 is compared with that from RB2 at an elevation of near 7000 feet in Table V-6. As can be noted at RB2, there is an increase in downslope direction between mid-afternoon and late evening. Such is not the case at RB1. Preliminary analysis of the Roan Plateau data

TABLE V-6

COMPARISON OF WIND DATA AT RB1 AND RB2

Time	SON	DJF	MAM	JJA	ANNUAL AVERAGE
RB1 (Elevation 8,500 ft) Down Valley Winds (%)					
1200	50	70	46	33	50
1500	49	73	39	35	49
1800	46	70	36	34	47
2100	25	63	30	32	38
2400	38	65	26	42	43
0300	44	66	40	41	48
0600	43	61	32	38	44
0900	44	70	36	36	47
	42	67	36	36	46
RB2 (Elevation 7,000 ft) Down Valley Winds (%)					
1200	45	40	55	23	42
1500	54	42	50	35	45
1800	64	53	64	45	57
2100	80	56	75	74	71
2400	70	50	73	75	67
0300	74	52	70	76	68
0600	50	47	63	65	56
0900	43	58	44	16	40
	60	50	62	52	56

SON: September, October, November.
DJF: December, January, February.
MAM: March, April, May.
JJA: June, July, August.

(elevation 8200 feet) is inconclusive concerning the development of valley winds. For conservative purposes in this study, it was assumed that the down valley nocturnal wind was of sufficient depth to completely contain the plume.

Wind directions in the down valley drainage generally conform to the terrain gradient vector. This means that multiple plumes from different sources will tend to converge in the downwind direction. However, because of the extreme stability under drainage wind conditions little vertical spreading of the plume is to be expected. The general picture would be of the plumes fanning out horizontally, and meandering down the basin and merging at some distance from the sources. There would be some descent of the plumes but not as great as the terrain.

With a wind speed of 2.0 m/sec, equilibrium would be attained in about five hours with the slow transport of the pollutant down the valley at some elevation above the surface. In the morning, as the sun heated the valley floor and destroyed the inversion, this layer of pollutants would be mixed and fumigation of the valley would occur.

Data requirements for the fumigation model include the height and persistence of the mixed layer during fumigation and the mean valley wind speed fumigation. The mean wind speeds at station RB2, RB3 and RB4 during the period 0100 to 0700, representative of the pre-fumigation down valley wind, are given in Table V-7. A value of 4.8 mph (2.2 m/sec) was used in the model calculations.

At this wind speed, a plume rise of 74 m is expected. (Appendix A provides details of plume rise calculation methods.) With a 275 ft. (84 m) stack, effective stack height is 158 m. The thickness of the plume within the very stable layer can be estimated at 0.6 of the plume rise.[21] The polluted layer, at not a great distance from the source, extends from 136 m to 180 m above the surface. As the plume moves down the valley, there will be some rise in height relative to the surface. A conservative estimate would add 100 m to the plume height, and, as it reached the valley, the vertical extent would be from 236 m to 280 m above the surface. Multiple plumes released from different elevations would, of course, add to the thickness of the polluted layer as all plumes merged across

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[21] Graphs for Estimating Maximum Fumigative Concentrations, EPA, 1972.

TABLE V-7

AVERAGE WIND SPEED (MPH)
0100 TO 0700 - NIGHTIME

	RB2	RB3	RB4	Valley Average
July 70	5.1	4.2	2.3	3.9
August 70	5.4	4.4	1.9	3.9
September 70	5.6	5.9	3.5	5.0
October 70	5.4	4.9	2.2	4.2
November 70	6.3	6.6	3.5	5.5
December 70	6.2	5.6	2.6	4.8
January 71	7.0	7.2	5.0	6.4
February 71	5.2	5.8	2.8	4.6
March 71	6.1	5.8	3.5	5.1
April 71	5.0	5.1	3.3	4.5
Annual	5.7	5.6	3.1	4.8

the Basin. For this single source data input, it is assumed that fumigation starts when the inversion is removed to a level of 236 m and reaches maximum concentration values when it is removed to a level of 280 m.

The fumigation period is assumed to last three hours during which time the winds are relatively light and variable and no reduction in concentration due to ventilation occurs under the inversion. From Table V-4, the mean mixing height changes from 384 m to 2,600 m from morning to afternoon, a rate of change of 185 m/hour. At the beginning of fumigation, D' in the model formula is equal to 236 m; at the end of three hours, D' equals 791 m. The average value during the three hour period is 500 m. Similarly, the average height is 325 m during the first hour of fumigation.

Up Valley Daytime Wind Regime

Wind directions in the up valley regime also generally conform to the terrain. In this case, however, because of the divergence of the terrain gradient vector, plumes from separate sources do not tend to merge. Highest concentrations from any single complex would occur at short distance away before the air pollutants were mixed to greater heights and carried away.

Summary of Wind Regimes

Some estimate of the frequency of occurrence of each wind regime can be made from the wind data provided in the Rio Blanco study. It can be judged from these data that on 80 percent of the nights a true down valley wind develops with a surface based inversion resulting in fumigation of the valley in the morning, but with little ground level concentration before fumigation. The average duration of these conditions, down valley wind and fumigation, is 12 hours. True up valley winds occur 20 percent of the days with an average duration of six hours. The rest of the time, the surface winds are distributed in accordance with the gradient flow. These assumptions are very conservative in that they tend to congregate the plume axes in the up valley or down valley directions much more than would be indicated by the surface wind data or the upper air data alone.

On an annual basis, it was estimated that the frequency of occurrence of the three wind regimes is as follows:

Gradient Wind Regime	4,818 Hours
Down Valley Wind Regime	3,504 Hours
Up Valley Wind Regime	438 Hours
TOTAL HOURS/YEAR	8,760 Hours

CHAPTER VI

PROJECTED AIR QUALITY

DESCRIPTION OF THE MODELS

Three separate models were required for determining ground level pollution concentrations under the three wind regimes described in the previous chapter. Details of the first two models appear in Appendix A. The third model considers fumigation conditions resulting from down valley drainage at night with subsequent inversion break up and fumigation the next morning.

Up-Valley Wind Model

The APMAX dispersion model calculates the maximum ten-minute ground level concentration from a family of sources for each of the 576 possible combinations of wind speed, wind direction and stability using the classical Gaussian distribution parameters and downwind distance, and the generally accepted Briggs plume rise formula. This model is basically used for predicting short-term concentrations and would be very applicable to the up valley wind regimes which can be expected to occur only in the afternoon periods with good solar heating. By comparison of the frequency and duration of occurrence of each three-way weather combinations with the maximum concentration calculated from any weather combination, one can determine the maximum short-term concentration which could possibly occur for a given averaging time. Concentrations for 1 hour, 3 hours, or 24 hours are of course much less than the 10-minute concentration calculated by the model, since mean concentration decreases with averaging time by the one-fifth power. This results from the effect of longer waves in the turbulence spectrum spreading the plume over an increasing lateral area and thus decreasing the concentration at any one point.

Gradient Wind Model

The APSIM dispersion model is basically used to calculate the annual average ground level concentration. It can be used with a large number of point or area sources and uses the Gaussian distribution as described for the short-term model. Inputs to the model again include the three-way wind speed, wind direction and stability frequency distribution.

The computer program in this case calculates the concentration at all points in the receptor grid resulting from each combination of wind speed, wind direction and stability, weights the concentration in accordance with the frequency of occurrence, and sums over the grid.

Fumigation Model

The fumigation model assumes that during the night the plumes from all sources move down valley at a uniform wind speed under stability condition F, very stable, and remain aloft in a layer of uniform thickness. After equilibrium conditions are established, that is flow in and flow out are equal, the mean concentration in the polluted layer can be expressed as

$$\bar{C} = \frac{Q}{WD\bar{u}} \qquad \text{where}$$

$\bar{C}$ is the mean concentration (μg/m); Q is the mass emission rate (μg/sec); W is the width of the valley (m); D is the depth of the contaminated layer (m); and $\bar{u}$ is the mean wind speed (m/sec). Let W = 22,400 m (14 miles) the approximate width across the Piceance Basin near the confluence of the creek and the White River at 7,000 feet elevation. Now let the concentration of the pollutant be normally distributed in the crosswind direction with $\bar{C}$ as before and the standard deviation, σ_y = 3,733 m ($6\sigma_y$ = 22,400 m). The maximum concentration in the layer over the center of the basin is

$$C_L = \frac{Q}{\sqrt{2\pi}\,\sigma_y\, D\, \bar{u}}$$

$$C_L = \frac{Q \times 1.07 \times 10^{-4}}{D\, \bar{u}}$$

After the sun comes up the surface based inversion will start to be destroyed as illustrated earlier in Figure V-2. As the inversion continues to be destroyed and the low level mixed layer reaches the bottom of the polluted layer, fumigation of the valley floor will commence. Maximum fumigation and maximum ground level concentration will occur when the mixed layer reaches the top of the original polluted layer. In the

center of the valley this maximum concentration is

$$C_{max} = \frac{Q \times 1.07 \times 10^{-4}}{D' \overline{u}} \quad \text{where}$$

D' is the steady state height of the top of the polluted layer. As the height of the mixed layer increases above D' the mean concentration over the averaging time is

$$C = \frac{Q \times 1.07 \times 10^{-4}}{\overline{D}\ \overline{u}}$$

where $\overline{D}$ is the average mixing height during the period.

APPLICATION OF THE MODELS

In this investigation it was necessary to predict long-term and short-term concentrations in the Piceance Basin for all averaging times for which there were Federal and/or state standards. Short-term maximum concentrations for one-hour and-three hour durations were output directly by the APMAX program.

Long-term annual average concentration for any receptor point in the Basin was the sum of the annual averages at that point resulting from each of the three wind regimes described earlier times the frequency of occurrence of that wind regime. In the case of receptor points down valley from a source, the concentration value would result from a combination of the fumigation and the gradient wind regimes.

Sulfur dioxide was used as a tracer pollutant for conducting all analyses. Ground level concentrations of two other pollutants, suspended particulates and oxides of nitrogen were then proportioned to sulfur dioxide concentrations based on the relative emission rates.

There were no existing sources of air pollution in the Basin. Most of the property was federally owned and the principal use of the land was for grazing beef cattle. Natural background pollution levels were therefore assumed to be zero in the Piceance Creek Basin for all gaseous air contaminants. In the case of particulates, predicted concentrations of particulate matter from the oil shale development had to be added to the existing background levels of particulates expected for the area. Measurements had been made of suspended particulates at 5 stations near

the Piceance Basin (Table VI-1). For 1973, levels ranged from 14 to 67 $\mu g/m^3$ on an annual basis. The background levels in the Basin were represented best by the station at Rio Blanco since it is located on the eastern edge of the Basin. The other listed sampling stations are farther removed from the Basin and in addition reflect the impact of local pollution sources on suspended particulate on quality. In this report, background levels in the Basin were therefore assumed to be 14 $\mu g/m^3$.

To analyze the impact on air quality of shale oil development in the Piceance Basin, ES first considered the dispersion from a single large plant under each of the possible wind regimes. The maximum ground level conditions and the distance of this maximum from the plant was determined. This intelligence was then used to separate additional plants in such a way that their combined impact on air quality would prevent excessive and unnecessarily high pollution concentrations from occurring under the Schedule 1 or Schedule 3 levels of development.

AIR QUALITY WITH ONE PLANT

Figure VI-1 shows the sulfur dioxide concentration field calculated by the APSIM model for a 200,000 bbl/cd TOSCO II or Paraho retort system under the gradient wind regime. The two retort systems have roughly the same SO_2 emission rates and therefore the same impact on air quality. The point of maximum annual average concentration was 25 $\mu g/m^3$ located 4,500 feet northeast of the source. The mean plume axis extends in this direction in response to the predominantly southwesterly direction of the gradient wind. APSIM computer runs using the gradient winds are included in Appendix B.

Application of the APMAX program for up valley winds for the same 200,000 bbl/cd plant was tried for two wind speed classes, 2.23 mph (1.0 m/sec) and 5.75 mph (2.6 m/sec) (Appendix B). A maximum 10-minute concentration value of 1,710 $\mu g/m^3$ occurred with an east wind of 1.0 m/sec and stability A at a distance of approximately 2,600 feet from the source (x = 2,600, y = 200). Maximum 1-hour and 3-hour concentrations, for the same location and conditions, were calculated by the one-fifth power law resulting in:

$$\text{1-hour maximum} = \left(\frac{10}{60}\right)^{1/5} \times 1{,}710 = 1{,}195\ \mu g/m^3$$

$$\text{3-hour maximum} = \left(\frac{10}{180}\right)^{1/5} \times 1{,}710 = 959\ \mu g/m^3$$

TABLE VI-1

SUSPENDED PARTICULATE AMBIENT AIR QUALITY NEAR THE PICEANCE CREEK BASIN[a]

Station	CONCENTRATION - μg/m³ 1973 AGM[b]	1974 AAM[c]
Grand Valley	39	37
Meeker	56	45
Rangely	31	32
Rio Blanco[d]	14	7
Craig	67	98

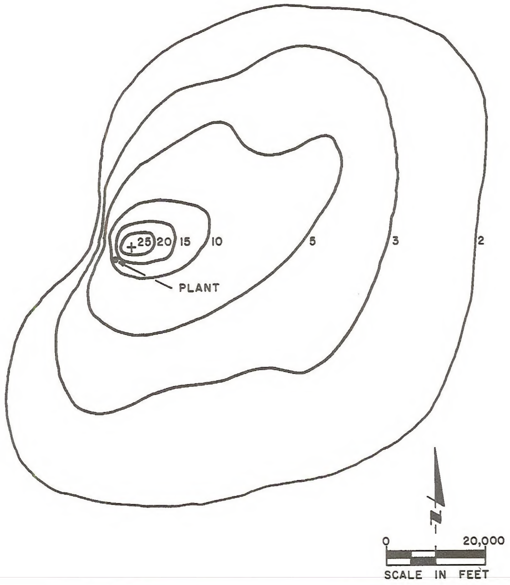
[a]Source: Colorado Department of Health, Air Quality Surveillance Section, July 1974.

[b]Annual geometric mean.

[c]Ordinarily reported as AGM, this is the annual arithmetic mean for two quarters of 1974.

[d]Rio Blanco is the closest station to the Piceance Basin. It is located on the extreme eastern boundary.

SULFUR DIOXIDE GROUND LEVEL CONCENTRATIONS ($\mu g/m^3$) ASSOCIATED WITH THE GRADIENT WINDS FOR A 200,000 bbl/cd TOSCO II OR PARAHO RETORT PROCESS



Application of the fumigation model for the same typical 200,000 bbl/cd plant having an emission rate of 23,340 tons/year ($Q = 6.73 \times 10^8$ µg/sec) gave the following results:

$$\text{10-minute maximum } C = \frac{6.73 \times 10^8 \times 1.07 \times 10^{-4}}{280 \times 2.2} = 117\ \mu g/m^3$$

$$\text{1-hour maximum } C = \frac{6.73 \times 10^8 \times 1.07 \times 10^{-4}}{325 \times 2.2} = 101\ \mu g/m^3$$

$$\text{3-hour maximum } C = \frac{6.73 \times 10^8 \times 1.07 \times 10^{-4}}{500 \times 2.2} = 65\ \mu g/m^3$$

As expected, the maximum short-term concentrations were predicted to occur with the up valley wind regime at the values given above, since stability A and light winds lead to high ground concentrations for short periods of time.

Annual average concentration at any location around one of the processing plants would be the sum of the weighted contributions from each of the three wind regimes. Maximum concentrations for a down valley receptor point would consist of the contribution from down valley winds with subsequent fumigation plus the contribution from the gradient wind regime:

876 hours @ 65 µg/m^3 = 56,940 µg hour/m^3
(3-hours per day for 80% of the days)

4,818 hours @ 25 µg/m^3 = <u>120,450 µg hour/m^3</u>

Total for the year -
(8,760 hours) 177,390 µg hour/m^3

The average annual concentration down valley of the plant would be 20.25 µg/m^3 (177,390/8,760).

For up valley recpetors, the annual average maximum would consist of contributions from the up valley wind flow and the gradient wind regime. The gradient wind regime's contribution to the up valley receptors is negligible as shown in Figure VI-1. Note the closeness of the isopleths and small concentrations to the west of the emission point. Contributions to the annual average from up valley winds were determined by further application of the one-fifth power law to convert the 10-minute maximum concentrations to expected 6-hour concentrations. It was earlier estimated that up valley winds occur 20% of the days in a year and last for

six hours each day. Therefore, ground level contributions from this wind regime would be:

$$0.20 \times 365 \times 6 \times \left(\frac{10}{360}\right)^{1/5} \times 1,710 = 365,771 \ \mu g \ hour/m^3$$

The average annual concentration up valley of the plant would be 41.8 $\mu g/m^3$.

This approach to determining the maximum annual average concentration is probably over-conservative since it assumes that the worst possible condition occurs each of the 73 days in which up valley winds develop. In actual fact, the up valley wind direction will vary somewhat from day to day and the speed will be greater than the 1.0 m/sec assumed. The Rio Blanco data for RB2 showed that the up valley wind direction varied over a 60° arc with an average speed of 6 mph. Calculations were made of the maximum annual average concentration using a stability A with the wind distributed equally over a 67 1/2° arc at 3 mph.

Under these assumptions, the average annual concentration would be 34 $\mu g/m^3$, slightly lower than the earlier calculation.

None of the methods discussed above lend themselves to estimating the maximum 24-hour concentration from the single 200,000 bbl/cd plant. Ordinarily, a location influenced by consistent diurnal wind direction variation does not have high 24-hour concentration levels since any one receptor is impacted by the single source for only part of the day. The assumed diurnal variation of the valley winds in the Piceance Basin, would result in moderate 24-hour values. For instance, in the fumigation case, the down valley concentration would be:

$$\frac{3}{24} \times 65 = 8 \ \mu g/m^3$$

Similarly, for the up valley wind regime, the 24-hour concentration would be:

$$\frac{6}{24} \times \left(\frac{10}{360}\right)^{1/5} \times 1,710 = 209 \ \mu g/m^3$$

However, neither of these values is likely to occur. The most probable 24-hour maximum will occur with an extended period of relatively strong, steady gradient winds during which time the valley winds are

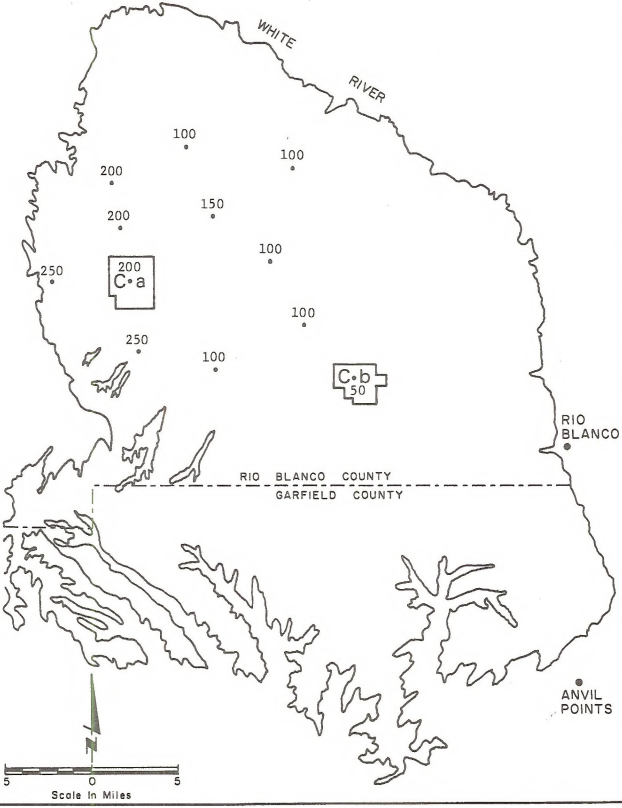
undeveloped. This would likely occur under stability condition D. The maximum 10-minute concentration under these conditions was calculated by the APMAX model at 505 $\mu g/m^3$ with a wind speed of 9.78 mph (4.4 m/sec). Appendix B contains the computer printout. If these weather conditions prevailed for 24 hours, the 24-hour ground level concentration would be 187 $\mu g/m^3$.

PROJECTED AIR QUALITY UNDER SCHEDULE 3

Using the concentration projections that were made earlier for the 200,000 bbl/cd TOSCO or Paraho retort plant, it was possible to project ambient air quality at some future time when 12 processing plants would be operational. The Schedule 3 developments, as depicted in Table I-1, calls for a total production rate of 1,800,000 bbl/cd for the Basin. The TOSCO II retort system was used for expected SO_2 emissions in the Piceance Creek Basin since this process emits slightly more than the other gas combustion processes yet slightly less than the In-Situ retorting plant. Thus, the SO_2 emissions using 12 TOSCO plants having a combined capacity of 1,800,000 bbl/cd would total 210,060 tons/year of SO_2. By comparison, using the various splits of retorting systems as described in Table II-6 and including emissions from secondary induced developments, the total projected SO_2 was 197,621 tons/year.

Because of terrain and weather features and the variable location of potential oil shale plants, the annual average concentration cannot be directly proportioned from the 200,000 bbl/cd annual maximums to 1990 with 1.8×10^6 bbl/cd production. In the case of one 200,000 bbl/cd unit, the annual maximum occurred up valley with 41.8 $\mu g/m^3$. No additive effect of such concentrations will be expected up valley when 12 plants are operating in the Basin so long as they are reasonably separated. However, as plumes from the 12 plants meander down slope during the night, an additive effect will likely be noted down valley. For one 200,000 bbl/cd plant the maximum 3-hour concentration down valley was 65 $\mu g/m^3$. For 1,800,000 bbl/cd, the projected 3-hour maximum as a result of the fumigation would be 585 $\mu g/m^3$ (65 x 200,000/1,800,000). This fumigation model assumes that plumes from all sources converge at some point down valley. Figure VI-2 illustrates possible locations for various size plants in the Piceance Creek Basin determined by ES with guidance by Department of Interior officials.

SOURCE LOCATIONS OF OIL SHALE PROCESSING PLANTS
SCHEDULE 3
(1,000 bbl/cd)



The maximum annual average concentration in the Basin that would be expected from the gradient wind model will occur somewhere in the vicinity of the cluster of 200,000 and 250,000 bbl/cd plants in the western region of the Piceance Creek Basin. (Figure VI-2). Assuming the source locations identified in Figure VI-2, the APSIM model predicted an annual gradient wind maximum of 44 $\mu g/m^3$ located about 6 miles north of tract C-a.

The annual average concentration expected in the Basin would be a combination of concentrations due to these two wind regimes:

Fumigation:

876 hours @ 585 $\mu g/m^3$ = 512,460 μg hours/m^3
(80% of 365 days at 3 hours/day)

Gradient Wind:

4,818 hours of 44 $\mu g/m^3$ = 211,992 μg hours/m^3

Total for year (8,760 hours) = 724,452 μg hours/m^3

The average annual concentration down in the valley would therefore be 82 $\mu g/m^3$.

The maximum 24-hour concentration of SO_2 for 1990 would be 261 $\mu g/m^3$ occurring a few times each year with up valley winds from a 250,000 bbl/cd plant. This maximum would occur about 2.5 miles from the plant under stability classification D. The 24-hour maximum which would result from the several hours of down valley wind flow and subsequent fumigation would be 72 $\mu g/m^3$.

The maximum 3-hour SO_2 concentration would be 1,199 $\mu g/m^3$. This condition would occur up valley of a 250,000 bbl/cd plant under stability classification A and a wind speed of 2.23 mph. The distance to the point of maximum would be about 1/2 mile up valley from that size plant. Such short-term concentrations are very localized and would not be additive because of the up valley wind and terrain.

The maximum 1-hour concentration of SO_2 would be 1,494 $\mu g/m^3$. This maximum also would occur about 1/2 mile up valley from a 250,000 bbl/cd plant under stability classification A and light winds.

PROJECTED AIR QUALITY UNDER SCHEDULE 1

Under Schedule 1 development a total of 500,000 bbl/cd of oil would be produced from 8 different plants. The limiting Colorado SO_2 standard

would be the 10 $\mu g/m^3$ such as designated for 1980 in the developed eastern parts of the state. This ambient standard would limit the size of the oil processing plants and the total capacity of the shale processing industry which could be located in the Basin. For example, plants as large as 100,000 bbl/cd would not be able to locate in the Piceance Creek Basin without exceeding the Colorado 10 $\mu g/m^3$ ambient standard. A 50,000 bbl/cd TOSCO retort plant would result in 5.1 $\mu g/m^3$, while one 100,000 bbl/cd plant would result in an annual average concentration of 10.2 $\mu g/m^3$ (applying the three wind regimes discussed earlier).

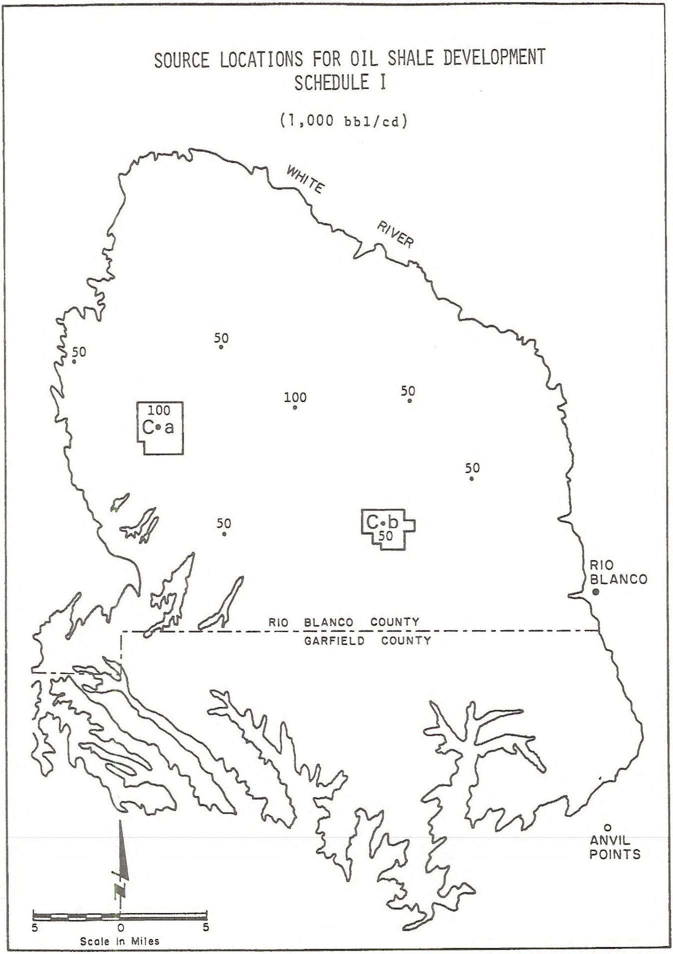
Larger oil shale retort plants could not be used in the Piceance Creek Basin and still maintain Colorado standards. A few 50,000 bbl/cd plants could be scattered in the Basin and the Colorado annual ambient air quality standard of 10 $\mu g/m^3$ could still be met. Total oil shale production that could be placed in the Basin and not exceed the Colorado standards would be limited to somewhere between 200,000 and 250,000 bbl/cd. Four 50,000 bbl/cd plants in the Basin would result in a maximum annual SO_2 concentration of 9.9 $\mu g/m^3$.

If oil shale development were to continue past the allowable Colorado standards to the 500,000 bbl/cd production anticipated under Schedule 1, a very small impact will be noted on air quality. The maximum annual average SO_2 concentration was calculated at 23 $\mu g/m^3$. The 3-hour maximum SO_2 would be 480 $\mu g/m^3$. The 24-hour SO_2 maximum was predicted at 104 $\mu g/m^3$. Figure VI-3 illustrates plant locations.

OTHER CONTAMINANTS

Particulate concentrations were proportioned to the SO_2 predictions based on the amount of emissions for each pollutant. Such an approach assumes that all of the particulate matter was emitted under the same conditions as the sulfur dioxide. Some particulates may be emitted from lower stacks and would result in slightly higher groundline concentrations. Under Schedule 3 development, the annual average particulate concentration was predicted at 23 $\mu g/m^3$, the maximum for the entire Piceance Creek Basin. Assuming a background level of 14 $\mu g/m^3$ (the value reported for measurements made in 1973 for Rio Blanco) the future particulate concentration would be 37 $\mu g/m$.

The maximum 24-hour particulate concentration will be 77 $\mu g/m^3$. No natural background concentration has been added to the predicted particulate


SOURCE LOCATIONS FOR OIL SHALE DEVELOPMENT
SCHEDULE I
(1,000 bbl/cd)
WHITE
RIVER
50
50
100
50
100
C•a
50
50
C•b
50
RIO
BLANCO
RIO BLANCO COUNTY
GARFIELD COUNTY
ANVIL
POINTS
N
5
0
5
Scale In Miles

level for 1990 for this short-term averaging period. The particulate concentration expected for a 500,000 bbl/cd industry under Schedule 1 development was computed at 24 $\mu g/m^3$. The 24-hour maximum was predicted at 31 $\mu g/m^3$.

Carbon monoxide and hydrocarbon predictions were also made for the Piceance Creek Basin. These contaminants are ordinarily classified as transportation pollutants. As a result, standards have been set which limit degradation over the rush-hour. The maximum 1-hour CO concentration predicted for the Basin was 815 $\mu g/m^3$ for Schedule 3 development and 231 $\mu g/m^3$ for Schedule 1 (200,000 bbl/cd). The 8-hour concentrations were 538 $\mu g/m^3$ and 152 $\mu g/m^3$ for the same development schedules. The projected values were about 1/40th of the standard. The HC emission from the retort systems consist mainly of non-reactive (methane-like) hydrocarbons[22]. ES assumed that 10% of the hydrocarbons emitted from the processing plants would be reactive HC. The 3-hour (6 to 9 A.M.) concentration predicted for the Piceance Creek Basin was 45 $\mu g/m^3$ under Schedule 3 development and 10 $\mu g/m^3$ under Schedule 1 development. No federal standards exist for HC. However, the EPA has set a 'guide' for HC concentrations in order to assess the attainment of the oxidant standard. Since the HC concentrations are well below the federal guide (160 $\mu g/m^3$, 6 to 9 A.M. maximum), oil shale development will not interfere with the attainment of the oxidant standard.

DISCUSSION OF RESULTS

A comparison of the calculated results with ambient air quality standards of the Environmental Protection Agency shows that full-scale oil shale development in the Piceance Creek Basin can be planned and carried out without violating EPA's standards. It is clear that oil shale development would be severely limited if the SO^2 Colorado standard for designated areas were applied to the Piceance Basin or if Colorado were to classify the Area I or II under the EPA's proposed non-degradation rules.

Throughout this analysis, conservative assumptions were used so that if estimates were not completely accurate, the potential impact on air quality would be overstated rather than understated. Also, the

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[22]Op.cit., the DOI Impact Statement, Note 3, pages I-18 to I-40.

results would more likely indicate those subject areas where more scientific analyses should be conducted or where potential future problems might arise. Predicted pollution levels will closely approach the EPA standards for certain contaminants under the emission rates, meteorology, and stack conditions assumed in this investigation.

Some of the more important of these assumptions and comparisons are highlighted in the following discussion.

Stack heights used in this study were the best estimates of the operators and ranged between 200 and 275 feet with most sulfur dioxide being emitted at about 250 feet. If stack heights were raised to 500 feet, SO_2 groundline concentration for Schedule 3 development would be 67 $\mu g/m^3$ annual average maximum. On the other hand, if stack heights of the processing plants averaged only 125 feet, the maximum annual average SO_2 concentration would be 125 $\mu g/m^3$. Taller stacks obviously would reduce ground level concentrations. Furthermore, if processing plants were located near the top of the ridges and tall stacks were used, it is possible that the plume would break through the valley wind regimes and would be diluted and dispersed by the gradient wind. If this were the case, no valley fumigation would occur and the high release height would minimize annual groundline concentrations to a level of about 15 $\mu g/m^3$, several kilometers from the Basin. Further field studies could define the extent and depth of the valley wind regimes.

Maximum 3-hour concentrations were calculated by the APMAX model to occur under stability conditions A with light winds. This is presumed to most likely result from the daytime up valley wind regime. Under these conditions, a substantial plume rise would be expected. About 200 meters for the 1 m/sec wind speed was used in the calculations. Current dispersion technology does not permit consideration of vertical wind shear in modeling. Yet, it is in this mountainous country that frictional effects of the surface roughness would most likely lead to large values of wind shear. This is hinted at in the Rio Blanco report in which a comparison of statistical values of surface wind and 10,000 foot winds showed large variations. The result of the high plume rise and large wind shear would be to disperse and dilute the plume much more that is predicted by the model. In most cases of the up valley wind model, the plume would be affected and ground level concentrations greatly reduced

from those predicted. In other cases, the plume would be bent back in the down valley direction and not affect ground level concentrations at all. Subjectively, it is believed that under unstable conditions ground level concentrations both for the maximum short period and for the contributions to annual averages at any receptor site will be small outside the immediate area of the source.

In this analysis, the one-fifth power law was used to estimate 24-hour concentrations. The method assumes mean wind speed and direction constant over the 24-hour averaging period. In order for the valley wind to be coupled with the gradient wind in the Piceance Basin rather strong winds aloft are required, probably greater than the 9.78 mph used in the calculations. In addition, a substantial cloud cover would be required to prevent surface cooling and a resulting surface inversion. Such conditions of strong winds and cloudiness are indicative of a well-developed cyclonic circulation, which under most circumstances would have appreciable movement during a 24-hour period. During this movement, the mean wind direction would change either clockwise or counter-clockwise depending upon the location of the center of the low pressure cell. This would result in further lateral dilution of the concentration not accounted for by the one-fifth power law and reduced maximum 24-hour concentrations.

Undoubtedly, the most serious pollution problem on an annual basis will result from the morning fumigation of the valley floor by the layer of air contaminants that collects overnight. This is the condition to be expected on most nights with the light down valley winds developing near sunset and a surface based inversion by early morning. Plume behavior under these conditions is poorly understood. The Eulerian wind statistics available for the Basin add little insight into the Lagrangian nature of the plume behavior. There is little evidence to show that the material within the plume is normally distributed; in fact, visual observations of plumes under these conditions indicate otherwise with the very sharp edge of the plume noted. It is only over a rather long averaging period, in which the meander of the plume as a whole has had sufficient time to be effective, that the normal distribution is approached. It will be necessary to acquire extensive meteorological data and some estimate of plume characteristics by smoke trials or tracer studies before a complete understanding is possible.

While emissions from secondary induced developments were added to those emissions for oil shale processing plants, no computer projection was made for suspended particulate air quality resulting solely from fugitive dust sources. Obviously, a sampling device placed adjacent to an unpaved road or strip mining operation would result in high concentrations of particulate matter. In one EPA study[23] of fugitive emissions from unpaved roads, vehicles passing a nearby sampling receptor resulted in extremely high one-hour concentrations. It is anticipated that such situations will be limited to extremely localized problems. Because of the size distribution of the fugitive dusts, a large portion will likely settle out within a few hundred meters of the source. However, receptor points outside the operators property line which are influenced primarily by fugitive dust sources should meet ambient air quality standards. To maintain the standards oil shale operators will have to exercise precautions and implement control measures such as paving roads, immediate revegetation, etc.

On June 11, 1973, in a tie vote before the U.S. Supreme Court, all state implementation plans were disapproved in that they failed to provide for the prevention of significant deterioration of air quality in those areas where air quality was better than the national standards. EPA was then forced to promulgate proposed rulemaking on non-degradation on July 16, 1973. After hearings and a year of review, EPA proposed air quality increments for areas Classified as I and II on August 27, 1974. The Class I regions were areas such as parks where little or no development would occur; Class II regions were to allow controlled development, and; Class III regions would be urban areas where the national ambient air quality standards would apply. The proposed increments are shown below:

Pollutant	Class I ($\mu g/m^3$)	Class II ($\mu g/m^3$)
Particulate matter:		
Annual geometric mean	5	10
24-hour maximum	10	30
Sulfur dioxide:		
Annual arithmatic mean	2	15
24-hour maximum	5	100
3-hour maximum	25	700

[23] Development of Emission Factors for Fugitive Dust Sources, U.S. EPA, Publication No. EPA 450/3-74-037, Research Triangle Park, NC., June 1974.

If the Piceance Creek Basin were classified as a Class I area, the oil shale industry could not be developed. Not even one 50,000 bbl/cd plant could meet such limitations especially the SO_2 limit which would be more restrictive than the particulate increment. If the Basin were classified as a Class II area, annual SO_2 concentrations would be limited to an incremental degradation of 15 $\mu g/m^3$. This would limit oil shale production to three 100,000 bbl/cd plants. The annual average SO_2 concentration would be 17 $\mu g/m^3$, which is slightly more than the incremental standard. If the maximum plant size were limited to 50,000 bbl/cd, seven plants (for a combined capacity of 350,000 bbl/cd) could be located in the Piceance Basin. The annual average SO_2 concentration for 350,000 bbl/cd would be 14 $\mu g/m^3$.

On the other hand, if the Piceance Basin were classified as a Class III area, Schedule 3 development could be completed and still maintain the national ambient air quality standards.

CHAPTER VII

SUMMARY AND CONCLUSIONS

1. The purpose of this investigation was to determine the potential impact on air quality of oil shale development in the Piceance Creek Basin of Colorado. The study evaluated the impact of emissions of sulfur dioxide particulate matter, nitrogen dioxide, hydrocarbons and carbon monoxide. It considered two levels of oil shale development: Schedule 1 and Schedule 3. It considered point source emissions from the oil shale processing plants as well as fugitive dust from the excavation, crushing, handling, and storage of the oil shale rock. It also considered air pollutant emissions from the induced secondary development such as motor vehicles, home heating, and power plants.

2. Emission data were obtained from the developers and operators of the proposed oil shale plants, from the Department of Interior, from Environmental Protection Agency emission factors and from staff estimates. Meteorological data were obtained from the Atomic Energy Commission, Department of Commerce, and Colony Development Operation. However, available meteorological data were not adequate for describing important diffusion parameters in the Piceance Creek Basin. Engineering-Science, Inc. thus systhesized an appropriate wind flow pattern and frequency distribution. The synthesized wind patterns were used to calculate dilution and dispersion of released air contaminants.

3. The three wind regimes which were used in the dispersion models were: down valley with fumigation, up valley, and the gradient wind. After estimating the frequency of each occurrence, classical dispersion models were used to compute long-term (annual avarage) and short-term (24-hour, 3-hour, 1-hour) ground level concentrations.

4. Results of the investigation showed that oil shale development would be severely limited (200,000 bbl/cd) unless a change is made in the 1980 Colorado sulfur dioxide ambient air quality standard (10 $\mu g/m^3$). Full-scale development of the Piceance Creek Basin to the production level postulated in Schedule 3 (1,800,000 bbl/cd) can be planned and carried out without violating the ambient air quality standard of the U. S. Environmental Protection Agency.

5. The projected air quality levels for both Schedule 1 and Schedule 3 development are compared with Federal and Colorado standards in Table VII-1.

6. The EPA is in the process of evaluating significant degradation. No Federal or state standards exist which quantitatively define non-degradation. If the proposed EPA Class II incremental limits for SO_2 and particulate matter are adopted, oil shale production in the Piceance Creek Basin would be limited to about 350,000 bbl/cd.

TABLE VII-1

SUMMARY OF PROJECTED AIR QUALITY IN THE PICEANCE BASIN ($\mu g/m^3$)

POLLUTANT	PROJECTED AIR QUALITY			AMBIENT STANDARDS	
	SCHEDULE 1[a]		SCHEDULE 3		
	500,000 bbl/cd	200,000 bbl/cd[a]	1,800,000 bbl/cd	FEDERAL	COLORADO
Sulfur Dioxide					
Annual Average	23	9.9	82[b]	80	10[c]
24-hour Maximum	104	52	261	365	55[c]
3-hour Maximum	480	240	1,199	1,300	--
1-hour Maximum	597	299	1,494	--	300[d]
Particulate Matter					
Annual Average	24	18	37	75	45
24-hour Maximum	31[e]	16[e]	77[e]	150	150
Nitrogen Oxides					
Annual Average	16	7	47	100	--
Carbon Monoxide					
8-hour Maximum	304	152	538	10,000	--
1-hour Maximum	462	231	815	40,000	--
Non-Methane Hydrocarbons					
3-hour Maximum	20	10	45	160	--

[a] Schedule 1 estimates a production rate of 500,000 bbl/cd. A production rate of 200,000 bbl/cd is the maximum allowable oil shale production that would still maintain Colorado standards.

[b] If only four 200,000+ bbl/cd plants instead of five were located in the western part of the Basin but the total remained the same, the annual SO_2 concentration would be 78 $\mu g/m^3$.

[c] A 1980 standard.

[d] A 1976 standard.

[e] The annual average background level is 14 $\mu g/m^3$. This was not added to the short-term 24-hour estimate.

APPENDIX A

MODEL DESCRIPTIONS

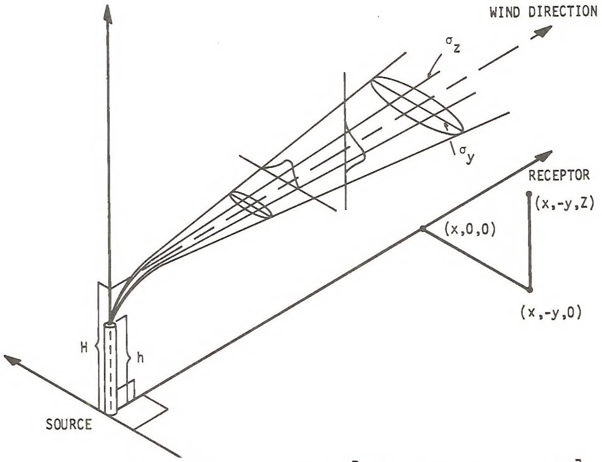
MODEL DESCRIPTION

For years, investigators have successfully used meteorological data and mass emission rates in mathematical dispersion models to predict downwind concentrations of pollutants. Such modelling has shown moderate success under simple conditions, that is, flat terrain, uniform winds, and neutral atmospheric conditions. However, even with a constant rate of emission, ground level concentrations may show instantaneous variations by a factor of 1000 because of atmospheric fluctuations such as gusty winds, inversions, and mountainous terrain. In all instances, the role of meteorology is of paramount importance in assessing the impact of any source. Once the material is in the air, meteorological conditions determine its fate. It is transported and diluted by air motion, it undergoes physical and chemical change such as hydration or photochemical reaction and it may take a hand in things itself by having sufficiently high settling velocity to fall out. Ultimately, it reaches a receptor. If the nature and concentration of the airborne material is such that it is harmful to human, vegetable, or animal life, or is a nuisance, then the situation of air pollution exists. If there are no sensitive receptors in its path or if it is sufficiently diluted or transformed before it reaches the receptor, it will be neither harmful or a nuisance. This last point is often neglected. The atmosphere has a tremendous self-cleansing capability. If this were not so, the air quality of the entire world would have long since been incapable of supporting life.

The science of mathematically modelling emissions at elevated sources and their final impact at ground level is an established art which originated with O.G. Sutton (1933). The dispersion technique which ES utilized in the preparation of this report was developed by D. Bruce Turner, EPA Research meteorologist; it was based on Sutton's original effort. This technique was published in the Federal Register (August 14, 1971) by EPA as a means of estimating ground line concentrations for gaseous pollutants. The Air Pollution Control Department of ES previously computerized Turner's dispersion model some five years ago and has successfully predicted ground level concentrations using emission parameters and meteorological data under simple conditions.

Fundamentally, the ES/Turner dispersion model is based on the plume being normally distributed about its centerline (Gaussian distribution) where the highest concentrations occur. Figure A-1 is the classical view of this dispersion pattern from an elevated point source. The dispersion equation is shown on the same figure to illustrate the specific input parameters to the model. In applying this model

DISPERSION PATTERN AND EQUATION



$$X_{x,y,z,H} = \frac{Q_m}{2\pi U \sigma_y \sigma_z} \left[\exp - \frac{1}{2} \left(\frac{y}{\sigma_y} \right)^2 \right] \left\{ \exp \left[- \frac{1}{2} \left(\frac{z - H}{\sigma_z} \right)^2 \right] + r \exp \left[- \frac{1}{2} \left(\frac{z + H}{\sigma_z} \right)^2 \right] \right\}$$

where $X_{x,y,z}$ = concentration, gms/m^3 and commonly converted to µg/m^3

Q_m = emission rate, gms/sec

x,y,z = downwind locations, meters

U = wind speed, meters/second

H = effective stack height = f (h + bouyancy)

h = stack height

σ_y, σ_z = std. horizontal and vertical deviation, meters (depends on atmospheric stability classification A, B,.....F wind speed and distance downwind)

r = reflectivity of surface

the Holland or the Briggs plume rise equation may be used to determine effective stack height. The Holland plume rise equation (developed in 1953) provides slightly lower release heights than other equations. (With a lower release height, higher ground level concentrations are predicted, thus allowing some conservatism into our estimates). The Briggs (1971) equation is currently recommended by EPA officials.

Assumptions of the ES/Turner Long Term Dispersion Model

There is very little difference in any of the presently published air quality dispersion models. All of the models assume some form of concial dispersion pattern and make assumptions about the terrain and secondary atmospheric reactions which help reduce the number of input parameters. Frequently, investigators tailor a model to their local conditions by measuring air quality and then applying correction factors to different portions of the dispersion equation. One of the other publicized dispersion models of the EPA is entitled AQDM. ES at one time had made a comparison of the annual averages of each of these computer models and found consistent/similar predictions. The ES/Turner model entitled APSIM was used to estimate long term concentrations for this study. Each model has unique advantages. The EPA's AQDM was designed and meant to be used for larger regional (metropolitan) areas while APSIM was intended to evaluate multiple point sources in non-metropolitan areas.

One of the key assumptions that is made when modeling various gases is that no secondary reactions take place from the time the pollutant is released until the time it reaches a receptor. SO_2 and particulate matter meet this criteria. Some of the oxides of nitrogen will change after a few hours in the air, especially in the presence of sunlight. ES uses APSIM to model NO_x and assumes no change of state. At best, these modeled results will indicate potential problems for annual average NO_x concentrations. Not much change is expected with reactive pollutants in a 3-hour period.*

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* This is strictly true 8-10 kilometers from a source. Little or no change occurs as reactive type pollutants travel this distance.

The emission and stack configuration parameters described earlier were used in the model to estimate annual average ground level concentrations of hydrocarbons. Other inputs to the model included the mixing depth, atmospheric stability, wind speed and wind direction. These parameters were dependent on actual weather conditions for the specific area and for a specific time frame. Samples of the many printouts from the computer runs involving various source and weather combinations follow. Approximately 2 million calculations were required for each source involving a 21 x 21 grid system. Computer runs were made which generally had no more than 2,000 feet between each grid mark (horizontal and vertical) in order to assure that the maximum concentration would not be missed. In the area of the anticipated maximum, the grid was reduced to 1000 ft. x 1000 ft.

Short Term Concentrations

Short term concentrations refer to an averaging period on the order of an hour, 3 hours, or 24 hours. Turner and others have indicated that calculated 10-minute concentrations decay for longer averaging times based on the 1/5th power law. For making short term predictions, the ES dispersion model entitled APMAX was used to predict 10-minute ground level concentrations for multiple point sources over a large study area. An EPA model existed for calculating short term concentrations but was not as flexible and would require an exhaustive search to locate the point of maximum concentration. EPA's PTMTP uses a maximum of 30 receptors. APMAX uses 441 receptors in its study field. ES had made a comparison of these programs before and found nearly identical results in predicting the short term concentrations.

To extrapolate to a predicted 3-hour concentration from the 10-minute concentration (which is equivalent to eighteen 10-minute sectors), the concentration is given by the following equation:

$$Conc_{3\text{-}hr} = Conc_{10\ min.} \times (10\ min/180\ min)^{1/5}$$

APMAX was used to estimate the 10-minute concentrations for all combinations of wind directions, wind speeds, and stability and included major point source inputs from as far away as 15 miles for these short term concentration predictions. Next a check is made with the STAR relative frequencies to obtain the maximum concentrations for a specific averaging period that could occur for an area.

Plume Rise

All plume rise formulae consider the rise due to two effects: momentum and buoyancy. The momentum term depends upon physical stack parameters, exit velocity and diameter, and the buoyancy term upon heat parameters, heat emission rate or the difference between effluent and ambient air temperature. This immediately leads to a model of the form:

$$\Delta h = C_1 \frac{V_s d}{U} + C_2 \frac{Q_h^{C_3}}{u^{C_4}}$$

where Δh = plume rise

V_s = effluent exit velocity

d = stack diameter

Q_h = heat emission rate

u = wind speed

C = fitted constants

There are over one hundred such formulae and probably 50 papers published reviewing and analyzing their accuracy and applicability. Without exception, the investigators have concluded that none predict plume rise accurately under all meteorological conditions.

The EPA/AQDM originally utilized the Holland plume rise equation. In 1969, the Holland equation was in fact the preferred equation of the meteorological fraternity. Since, then, however, Briggs published his (latest) equation in 1971 and provided supporting data to establish the validity of the estimates provided by his equation. The Holland formula is now known to greatly underpredict plume rise while the Briggs formula is believed to be most accurate under most conditions. Briggs concluded from dimensional analysis that:

$$\Delta h = \left[\frac{12.17 F_m x}{u^2} + \frac{12.17 F x^2}{2u^3} \right]^{1/3}$$

F_m is the momentum term and F is the buoyant term. x is downwind distance and since its value is squared in the buoyancy term this effect will dominate beyond $x > 3\ h_s$, the actual stack height. Briggs concluded that momentum rise could be ignored, a conservative assumption, and found a best fit constant.

$$\Delta h = \frac{1.6F^{1/3}x^{2/3}}{u}$$

F is the flux of bouyant force/$\pi\rho_a$. ρ_a is the density of the ambient air. Force flux is equal to mass flux times the acceleration.

Therefore:

$$F = \frac{1}{\pi\rho_a}\left(\pi r^2 V_s \rho_e\right)\left(g\,\frac{T_s - T_a}{T_s}\right)$$

where ρ_e is the density of the effluent, g is gravity force, and T_s and T_a are stack and ambient temperature. If $\rho_e = \rho_a$, another conservative assumption,

$$F = gr^2 V_s \quad \frac{T_s - T_a}{T_s}$$

The Briggs formula above predicts plume rise within a short distance downwind from the stack. As the distance increases, ambient air is entrained into the plume and under stable conditions a deceleration of the plume is exerted. This force is defined by, $S = \frac{g}{T_a}\ \frac{\partial\theta}{\partial z}$,

where $\frac{\partial\theta}{\partial z}$ is the lapse rate of the potential temperature

$g = 9.8\ \text{msec}^{-1}$

$T_a = 293^{o}K$, the mean annual temperature for most of the U. S.

$\frac{\partial\theta}{\partial z} = 1.75^{o}K\ \ (100\ m)^{-1}$, a moderately stable lapse rate

$$S = \frac{9.8}{293} \times \frac{1.75}{100} = 5.85 \times 10^{-4}\ \sec^{-2}$$

Briggs estimated the maximum rise under stable conditions as

$$\Delta h = 2.9\ \ \frac{F}{uS}^{\quad 1/3}$$

Using the value of S calculated above, and the formula for F, we arrive at the plume rise equation in stable conditions (E and F):

$$\Delta h = 74.2\left[\frac{V_s r^2}{u}\quad \frac{T_s - T_a}{T_s}\right]^{1/3}$$

Typical values might be:

$$V_s = 16.8 \text{ msec}^{-1}$$
$$r = 0.46 \text{ m}$$
$$u = 6.0 \text{ msec}^{-1}$$
$$T_s = 839^{o}K$$
$$T_a = 292^{o}K$$
$$\Delta h = 54 \text{ m}$$

For very low winds an even greater plume rise would be expected

$$\Delta h = 5.0 \ \frac{F^{1/4}}{S^{3/8}}$$

Under the above conditions this would result in a plume rise of 178 m. We have elected not to use this low wind speed estimate of plume rise because of our desire to be conservative. Higher values for the effective stack height will result in lower ground line concentrations when using the dispersion equations.

In neutral and unstable conditions, ambient air is again entrained into the plume but does not exert a retarding force. The plume continues to rise until it is dominated by atmospheric turbulence. Briggs estimated a conservative approximation

$$\Delta h = 1.6 \ \frac{F^{1/3}}{u} \left(3x^*\right)^{2/3}$$

where $x^* = 2.16\ F^{2/5} h_s^{3/5}$. Empirical modifications to this formula recommended by EPA[1] have been used in this study

$$\Delta h = 1.6 \ \frac{F^{1/3}}{u} \left(3.5x^*\right)^{2/3}$$

where $x^* = 14\ F^{5/8},\ F \leq 55$

$x^* = 34\ F^{2/5},\ F \leq 55$

The EPA modifications follow:

If the momentum term F is simplified to

$$F = 9.8\ r^2\ V_s \left(\frac{T_s - T_a}{T_s}\right)$$

---

1 Personal correspondence with Joseph Tikvart, EPA, North Carolina, November 28, 1973.

the Concawe #2 formula gave the best results. However, for the Argonne data, where the stacks were of small diameter, the Briggs was the best formula. The underprediction of the Holland formula is evident. In view of the known preference for the Briggs formula by AEC,[3] the approval of this formula by EPA, the results of the Moses survey, and a growing acceptance of the Briggs formula as the most accurate, it is believed that its use in this study is warranted.

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3 "Meteorology and Atomic Energy," U.S. Atomic Energy Commission, Washington, D. C., July 1968.

$$= 2.45 \, d^2 \, V_s \left(\frac{T_s - T_a}{T_s} \right) \qquad r = \frac{d}{2}$$

and, if $$ABRG = d^2 \, V_s \left(\frac{T_s - T_a}{T_s} \right)$$

$$F = 2.45 \, ABRG$$

then

$$\Delta hu = 1.6(2.45 \, ABRG)^{1/3} \left| 3.5 \, (14) \, (2.45 \, ABRG)^{5/8} \right|^{2/3}$$

this reduces to:

$$\Delta hu = 42 \, ABRG^{0.75}$$

Similarly for the case of $F > 55$,

$$\Delta hu = 66.3 \, ABRG^{0.6}$$

These equations are used in the EPA/AQDM.

One simplifying assumption has been made in incorporating the Briggs plume rise equation into the model by the EPA. The stable conditions (E and F) are calculated with this latter equation instead of having two routines for plume rise (one for stable and one for all other conditions). As a result of this assumption, a conservative estimate in ground concentrations (from a lower plume height) will be calculated.*

For the same typical values as above:

$F = 22.7 \text{ m}^4 \text{ sec}^{-3}$

$x^* = 98.5$

$\Delta h = 37 \text{ m}$

Briggs' unmodified formula results in $\Delta h = 34$ m for a 76.2 m stack.

Moses[2], et al, made a comprehensive survey of the accuracy and suitability of some sixteen plume rise formulae. The results of this survey are repeated in part in Table A -1. It appears that for all stations combined,

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*This is strictly true only if the wind speed is greater than 3.5 meters per second. However, under lower wind speeds, the plume rise is ordinarily high and will not show that much of a difference.

2 Harry Moses and Martin R. Kraimer, Paper No. 71-61, APCA Annual Meeting Atlantic City, 1971.

TABLE A-1. COMPARISON OF PLUME RISE FORMULAS

MEAN RATIOS OF OBSERVED TO CALCULATED PLUME RISE VALUES

Formula	Argonne I & II			Duisberg, Gernsheim & Harwell			Lakeview & TVA-Gallatin, Paradise, Widows Creek			Bringfelt			All Stations Combined		
	Unstable & Neutral	Stable	All	Unstable & Neutral	Stable	All	Unstable & Neutral	Stable	All	Unstable & Neutral	Stable	All	Unstable & Neutral	Stable	All
1. Holland	5.87	3.98	5.33	2.34	2.59	2.37	1.00	.60	.95	2.02	2.10	2.04	2.99	3.05	3.00
2. Stumke	2.68	1.65	2.39	.74	.74	.74	.77	.43	.73	.62	.87	.67	1.18	1.14	1.17
3. Concawe #1	2.74	1.78	2.46	.74	.76	.74	.75	.44	.71	.60	.72	.62	1.19	1.20	1.19
4. Concawe #2	1.67	1.07	1.50	.68	.71	.69	.82	.48	.78	.53	.65	.56	.91	.85	.90
5. Lucas, Moore, and Spurr	.18	.11	.16	.28	.29	.28	.57	.32	.54	.21	.25	.21	.28	.21	.27
6. Rauch	.54	.33	.48	.80	.84	.81	1.64	.93	1.56	.60	.71	.62	.81	.60	.78
7. Stone & Clark	.23	.14	.20	.30	.32	.31	.58	.33	.55	.24	.28	.25	.31	.23	.30
8. Bryant-Davidson	7.44	3.66	6.36	6.80	6.51	6.76	3.34	1.79	3.15	6.05	4.34	5.72	6.55	4.72	6.25
9. ASME Momentum Sources	8.18	4.02	6.99	8.91	8.09	8.81	4.30	2.33	4.06	8.04	6.01	7.64	8.23	5.68	7.80
10. ASME Neutral and Unstable	27.63	12.78	23.38	1.22	1.41	1.24	.29	.17	.28	1.27	.67	1.15	7.17	6.46	7.05
11. ASME Stable		.76	.76		.70	.70		.92	.92		.89	.89		.76	.76
12. Moses & Carson All Data	2.66	1.63	2.36	1.12	1.18	1.13	1.27	.70	1.20	.87	.98	.89	1.47	1.34	1.45
13. Moses & Carson Unstable	.89	.54	.79	.46	.48	.46	.48	.27	.46	.36	.39	.36	.56	.48	.54
14. Moses & Carson Neutral	2.37	1.44	2.10	1.06	1.11	1.06	1.17	.65	1.11	.82	.92	.84	1.35	1.22	1.33
15. Moses & Carson Stable	5.03	3.09	4.47	1.55	1.66	1.57	1.90	1.05	1.79	1.23	1.42	1.26	2.36	2.26	2.34
16. Briggs	.66	1.57	.92	.83	.95	.84	.74	.72	.74	.67	.88	.71	.77	1.21	.84
17. Csanady	16.58	7.67	14.02	.73	.84	.74	.17	.10	.17	.76	.40	.69	4.30	3.87	4.23
Observed Rise (M) Mean	9	7	8	40	37	40	198	160	193	30	53	35	48	33	45
Standard Dev.	7	5	7	19	15	19	107	106	107	28	40	32	63	48	61
No. of Cases	117	47	164	311	41	352	51	7	58	33	8	41	512	103	615

APPENDIX B

COMPUTER RUNS

ENGINEERING-SCIENCE, INC.
WASHINGTON,D.C.

DISPERSION CALCULATIONS FOR
SO2 ANALYSIS *TOSCO II RETORT 200,000BBL/DAY --REVISED EMISSION DATA 700MB WIND

BRIGGS (1971) PLUME RISE EQ. USED FOR POINT SOURCES

NOTE:

Program name - APSIM

These 4 runs illustrate the gradient wind concentration (based on the 700 mb wind) for one 200,000 bbl/cd plant. The same locations and receptor locations are with respect to an arbitrarily chosen cartesian coordinate system having an orgin at the pyrolysis and oil recovery stack (x = 0 ft., y = 0 ft.). Three emission sources defined the total emissions from an oil shale complex. The 4 runs computed the concentration isopleths for the four quadrants surrounding the plant. The grid spacing was 2,000 ft.

STUDY AREA EMISSION SUMMARY

SOURCE ID	EMISSION RATE (GM/SEC)	SOURCE LOCATION (FT) X	Y	Z	STACK HEIGHT (FT)	EXIT VEL. (FPS)	EXIT TEMP (F)	STACK RADIUS (FT)	AREA EMISSIONS (SQ. MILE)	LINE SOURCE DESCRIPTIONS (FT) X1	Y1	X2	Y2
PYR&OIL	447.44	0.	0.	0.	275.	50.	130.	5.					
S PLANT	88.32	400.	200.	0.	250.	86.	125.	2.					
UTILITIES	136.24	0.	800.	0.	200.	50.	250.	3.					

AVERAGE CONCENTRATIONS (UG/M3)

AT 0. FT.

Y-CORD (FEET) \ X-CORD	0.	2000.	4000.	6000.	8000.	10000.	12000.	14000.	16000.	18000.	20000.	22000.	24000.	26000.	28000.	30000.	32000.	34000.	36000.	38000.	40000.
40000.	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3	3	3	3
38000.	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	4	3	3	3	3	3
36000.	1	1	1	1	2	2	2	2	2	2	2	2	3	3	4	3	3	3	3	3	3
34000.	2	2	2	2	2	2	3	2	2	2	2	3	5	4	4	3	3	3	3	3	3
32000.	2	2	2	2	3	3	3	3	3	3	3	3	4	4	4	4	4	3	3	3	3
30000.	2	2	2	2	3	3	3	3	3	3	3	4	4	4	4	4	4	4	3	3	3
28000.	2	2	2	3	3	3	3	3	3	3	4	5	4	4	4	4	4	4	4	3	4
26000.	2	2	2	3	3	3	3	3	3	4	5	5	5	4	4	4	4	4	4	4	4
24000.	2	2	2	3	4	4	4	4	4	5	5	5	5	5	4	4	4	4	4	4	5
22000.	2	2	3	4	4	4	4	5	6	6	5	5	5	5	4	4	4	5	5	5	5
20000.	2	2	3	4	4	4	5	6	6	6	6	5	5	5	5	5	5	6	5	5	5
18000.	2	2	4	5	5	5	6	7	7	6	6	6	6	6	6	6	6	6	5	5	5
16000.	3	3	5	6	6	6	8	8	7	7	7	7	7	7	7	7	6	6	5	5	5
14000.	3	4	6	6	6	8	8	8	8	7	7	8	8	7	7	7	6	6	6	5	5
12000.	3	5	3	8	9	10	9	9	8	9	9	8	8	8	7	7	6	6	6	5	5
10000.	4	6	10	10	12	11	10	10	10	10	9	9	8	8	7	7	6	6	6	5	5
8000.	5	9	10	13	13	13	13	13	11	10	10	9	8	8	7	7	6	6	5	5	4
6000.	5	12	15	17	17	17	14	13	12	10	9	9	8	7	6	6	5	5	5	5	5
4000.	6	16	21	22	19	17	15	13	11	10	9	8	7	7	6	6	6	5	5	5	4
2000.	4	21	25	22	19	16	13	12	10	9	8	8	7	7	6	6	5	5	5	4	4
0.	0	15	20	19	17	15	13	11	10	9	8	8	7	6	6	6	5	5	5	4	4

AVERAGE CONCENTRATIONS (UG/M3)

AT 0. FT.

Y-CORD (FEET) \ X-CORD	-40000.	-38000.	-36000.	-34000.	-32000.	-30000.	-28000.	-26000.	-24000.	-22000.	-20000.	-18000.	-16000.	-14000.	-12000.	-10000.	-8000.	-6000.	-4000.	-2000.	0.
0.	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	1	1	0
-2000.	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	3	5	8
-4000.	1	1	1	1	1	1	1	1	1	1	2	2	2	2	1	1	2	4	6	9	11
-6000.	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	4	5	7	10	12
-8000.	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	4	4	5	8	9	11
-10000.	0	0	0	0	0	0	0	0	0	0	1	1	1	2	3	4	4	6	7	8	10
-12000.	0	0	0	0	0	0	0	0	0	0	1	1	2	3	3	3	4	6	6	7	8
-14000.	0	0	0	0	0	0	0	0	0	1	1	2	2	3	3	3	5	5	6	6	7
-16000.	0	0	0	0	0	0	0	1	1	1	2	2	2	2	3	4	4	5	5	6	6
-18000.	0	0	0	0	0	0	1	1	1	2	2	2	2	2	3	4	4	4	4	5	5
-20000.	0	0	0	0	0	1	1	1	1	2	2	2	2	2	3	4	4	4	4	5	5
-22000.	0	0	0	1	1	1	1	1	2	2	2	2	2	3	3	3	3	3	4	4	4
-24000.	0	0	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	4	4	4
-26000.	0	0	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	3	3
-28000.	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	3	3	3	3	3	3
-30000.	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3
-32000.	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	3	3	3
-34000.	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	3	2	3
-36000.	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2
-38000.	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2
-40000.	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2

Y-CORD (FEET) X-CORD

AVERAGE CONCENTRATIONS (UG/M3)

AT 0. FT.

Y-CORD (FEET) \ X-CORD	0.	2000.	4000.	6000.	8000.	10000.	12000.	14000.	16000.	18000.	20000.	22000.	24000.	26000.	28000.	30000.	32000.	34000.	36000.	38000.	40000.
0.	0	13	23	24	22	19	16	14	13	11	10	9	8	7	7	6	6	5	5	5	4
-2000.	7	11	16	17	16	15	14	13	12	11	10	9	8	7	7	6	6	5	5	5	4
-4000.	10	10	11	12	13	12	11	10	9	8	8	7	7	7	6	6	6	5	5	5	4
-6000.	10	9	10	10	10	11	10	9	8	8	7	6	6	6	5	5	5	5	4	4	4
-8000.	9	8	9	9	9	8	9	9	8	7	6	6	5	5	5	4	4	4	4	4	3
-10000.	8	8	9	9	9	7	6	6	7	7	6	6	5	5	5	4	4	4	3	3	3
-12000.	7	7	6	6	6	6	6	5	5	5	5	5	5	5	4	4	4	4	3	3	3
-14000.	6	6	5	6	5	5	5	5	4	4	4	4	5	4	4	4	4	3	3	3	3
-16000.	6	5	5	5	5	5	5	5	4	4	4	4	4	4	4	4	4	3	3	3	3
-18000.	5	5	4	4	4	4	4	4	4	4	3	3	3	3	3	3	4	3	3	3	3
-20000.	4	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3
-22000.	4	4	4	4	4	4	3	3	3	3	3	3	3	2	2	2	2	2	3	3	3
-24000.	4	4	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
-26000.	3	3	3	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2
-28000.	3	3	3	3	3	3	3	3	2	2	2	3	2	2	2	2	2	2	2	2	2
-30000.	3	3	3	3	2	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2
-32000.	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
-34000.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
-36000.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
-38000.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1
-40000.	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1

AVERAGE CONCENTRATIONS (UG/M3)

AT 0. FT.

Y-CORD (FEET) \ X-CORD	-40000.	-38000.	-36000.	-34000.	-32000.	-30000.	-28000.	-26000.	-24000.	-22000.	-20000.	-18000.	-16000.	-14000.	-12000.	-10000.	-8000.	-6000.	-4000.	-2000.	0.
40000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
38000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1
36000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
34000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
32000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
30000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2
28000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2
26000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2
24000.	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	2	2	2
22000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	2
20000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	2	3
18000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	3	3
16000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	3	3
14000.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	2	3	4
12000.	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	3	5
10000.	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	3	6
8000.	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	3	7
6000.	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	2	3	7
4000.	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	1	2	7
2000.	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	2	2	2	1	3
0.	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	1	1	0

STUDY AREA EMISSION SUMMARY

SOURCE ID	EMISSION RATE (GM/SEC)	SOURCE LOCATION (FT) X	Y	Z	STACK HEIGHT (FT)	EXIT VEL. (FPS)	EXIT TEMP (F)	STACK RADIUS (FT)
PYREOIL	447.44	0.	0.	0.	275.	50.	130.	5.
S PLANT	88.32	400.	200.	0.	250.	86.	125.	2.
UTILITIES	136.24	0.	800.	0.	200.	50.	250.	3.

BRIGGS (1971) PLUME RISE EQUATION USED.

NOTE:

Program name - APMAX

This run illustrates the short term 10-minute concentration from one 200,000 bbl/cd plant. A similar cartesian coordinate system is used to identify source and receptor locations. However, the grid spacing was 1,000 ft.

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON, D.C.

CISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT EXAMINED FOR EARLY MORNING FUMIGATION
STUDY AREA (FEET)
X 0. TO 20000.
Y 0. TO 20000.
WIND SPEED = 2.23MPH
MIXING DEPTH = 1400.0 METERS

STABILITY

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	0	20000	0	0	20000	0	C	20000	0	0	20000	0	0	20000	0	0	20000	0
NNE	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
NE	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
ENE	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
E	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
ESE	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
SE	5	0	2000	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
SSE	410	0	2000	55	0	3000	0	20000	0	0	20000	0	0	20000	0	0	20000	0
S	1636	0	3000	994	0	7000	759	0	13000	148	0	20000	204	0	20000	2	0	20000
SSW	1523	1000	3000	954	3000	7000	761	5000	12000	159	8000	19000	231	8000	20000	2	8000	19000
SW	1680	2000	2000	980	5000	5000	754	9000	9000	211	20000	20000	378	20000	20000	12	20000	20000
WSW	1334	3000	1000	946	7000	3000	747	12000	5000	160	20000	8000	222	20000	9000	2	20000	8000
W	1546	3000	0	953	7000	0	737	13000	0	153	20000	0	190	20000	0	2	20000	0
WNW	543	2000	0	66	4000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
NW	32	2000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
NNW	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON, D.C.

DISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT EXAMINED FOR EARLY MORNING FUMIGATION
STUDY AREA (FEET)
X 0. TO 20000.
Y 0. TO 20000.
WIND SPEED = 5.75MPH
MIXING DEPTH = 1400.0 METERS

S T A B I L I T Y

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	0	20000	0	0	20000	0	C	20000	0	0	20000	0	0	20000	0	0	20000	0
NNE	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
NE	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
ENE	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
E	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
ESE	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
SE	15	0	1000	0	20000	0	0	20000	0	0	20000	0	0	20000	0	0	20000	0
SSE	424	0	2000	112	0	2000	6	2000	3000	0	20000	0	0	20000	0	0	20000	0
S	1373	0	2000	1149	0	4000	963	0	7000	489	0	19000	224	0	20000	7	0	20000
SSW	1342	1000	2000	957	2000	5000	934	3000	7000	486	7000	17000	238	8000	20000	9	8000	20000
SW	1009	2000	2000	1074	3000	3000	918	5000	5000	481	14000	14000	309	20000	20000	28	20000	20000
WSW	1388	2000	1000	1005	4000	2000	896	7000	3000	477	19000	8000	223	19000	8000	9	20000	9000
W	1416	2000	0	1024	4000	0	868	7000	0	467	20000	0	204	20000	0	6	20000	0
WNW	699	2000	0	233	3000	0	26	3000	0	0	20000	0	0	20000	0	0	20000	0
NW	179	1000	0	2	2000	0	C	20000	0	0	20000	0	0	20000	0	0	20000	0
NNW	5	1000	0	0	20000	0	C	20000	0	0	20000	0	0	20000	0	0	20000	0

END OF PROGRAM. NO FURTHER SUMMARIES COMPUTED.

STUDY AREA EMISSION SUMMARY

SOURCE ID	EMISSION RATE (GM/SEC)	SOURCE LOCATION (FT) X	Y	Z	STACK HEIGHT (FT)	EXIT VEL. (FPS)	EXIT TEMP (F)	STACK RADIUS (FT)
PYR&OIL	447.44	0.	0.	0.	275.	50.	130.	5.
S PLANT	88.32	400.	200.	0.	250.	86.	125.	2.
UTILITIES	136.24	0.	800.	0.	200.	50.	250.	3.

BRIGGS (1971) PLUME RISE EQUATION USED.

NOTE:

Program name - APMAX

This run illustrates the short term 10-minute concentration expected around one 200,000 bbl/cd plant. The gird spacing was 200 ft. in order to precisely define the maximum.

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON, D.C.

DISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT EXAMINED FOR EARLY MORNING FUMIGATION
STUDY AREA (FEET)
X 0. TO 4000.
Y 0. TO 4000.
WIND SPEED = 2.23MPH
MIXING DEPTH = 1400.0 METERS

STABILITY

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
NNE	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
NE	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
ENE	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
E	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
ESE	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
SE	6	0	1600	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
SSE	424	0	2200	56	0	3200	0	4000	0	0	4000	0	0	4000	0	0	4000	0
S	1636	0	3000	524	200	4000	83	400	4000	0	4000	0	0	4000	0	0	4000	0
SSW	1645	1000	2600	647	1800	4000	117	2000	4000	0	4000	0	0	4000	0	0	4000	0
SW	1680	2000	2000	933	4000	4000	235	4000	4000	0	4000	0	0	4000	0	0	4000	0
WSW	1690	2400	1000	670	4000	1800	95	4000	1800	0	4000	0	0	4000	0	0	4000	0
W	1710	2600	200	569	4000	200	64	4000	200	0	4000	0	0	4000	0	0	4000	0
WNW	689	2400	0	66	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
NW	33	1800	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
NNW	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON,D.C.

CISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT EXAMINED FOR EARLY MORNING FUMIGATION
STUDY AREA (FEET)
X 0. TO 4000.
Y 0. TO 4000.
WIND SPEED = 5.75MPH
MIXING DEPTH = 1400.0 METERS

STABILITY

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
NNE	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
NE	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
ENE	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
E	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
ESE	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
SE	24	0	1200	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
SSE	451	0	1800	115	0	2200	6	0	2400	0	4000	0	0	4000	0	0	4000	0
S	1456	0	2200	1149	0	4000	448	200	4000	12	400	4000	0	4000	0	0	4000	0
SSW	1438	800	2000	1125	1600	3800	555	1800	4000	19	2000	4000	0	4000	0	0	4000	0
SW	1440	1400	1400	1084	2800	3000	831	4000	4000	53	4000	4000	0	4000	0	0	4000	0
WSW	1472	1800	800	1068	3600	1600	556	4000	1800	14	4000	1800	0	4000	0	0	4000	0
W	1447	2000	200	1059	4000	200	455	4000	200	8	4000	200	0	4000	0	0	4000	0
WNW	735	1800	0	251	2600	0	27	3400	0	0	4000	0	0	4000	0	0	4000	0
NW	203	1200	0	6	1400	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0
NNW	11	600	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0	0	4000	0

ENO OF PROGRAM. NO FURTHER SUMMARIES CCMPUTED.

ENGINEERING-SCIENCE, INC.
WASHINGTON, D.C.

CISPERSION CALCULATIONS FOR
SO2 ANALYSIS *TOSCO 200,000BBL/DAY RETORT* UPWIND STAB=A,WIND=WSW,W,WNW AT 3MPH

BRIGGS (1971) PLUME RISE EQ. USED FOR PCINT SCURCES

NOTE:

Program name - APSIM

This run illustrates the effect of an up valley wind varying over a 67 1/2° arc (WSW, W, WNW) at 3 mph from one 200,000 bbl/cd plant. Although the wind is shown blowing out of the west, identical concentrations are expected if the wind were out of the east, like the up valley wind of the Piceance Creek Basin.

STUDY AREA EMISSION SUMMARY

SOURCE ID	EMISSION RATE (GM/SEC)	SOURCE LOCATION (FT) X	Y	Z	STACK HEIGHT (FT)	EXIT VEL. (FPS)	EXIT TEMP (F)	STACK RADIUS (FT)	AREA EMISSIONS (SQ. MILE)	LINE SOURCE DESCRIPTIONS (FT) X1	Y1	X2	Y2
PYR&OIL	447.44	0.	0.	0.	275.	50.	130.	5.					
S PLANT	88.32	400.	200.	0.	250.	86.	125.	2.					
UTILITIES	136.24	0.	800.	0.	200.	50.	250.	3.					

AVERAGE CONCENTRATIONS (UG/M3)

AT 0. FT.

Y-CORD (FEET) \ X-CORD	0.	1000.	2000.	3000.	4000.	5000.	6000.	7000.	8000.	9000.	10000.	11000.	12000.	13000.	14000.	15000.	16000.	17000.	18000.	19000.	20000.
10000.	0	0	0	0	0	0	0	0	1	3	6	9	12	16	19	21	23	24	25	26	26
9000.	0	0	0	0	0	0	0	1	3	7	11	15	19	22	25	26	28	28	29	29	28
8000.	0	0	0	0	0	0	1	4	8	13	18	23	27	29	31	32	32	32	32	31	31
7000.	0	0	0	0	0	2	5	10	16	23	28	32	35	36	37	37	36	35	35	34	33
6000.	0	0	0	0	1	7	20	21	30	36	40	42	43	43	42	41	40	38	37	35	34
5000.	0	0	0	1	8	26	47	50	48	50	51	51	50	48	46	44	42	40	38	37	35
4000.	0	0	0	10	36	67	89	100	68	64	61	58	55	52	49	46	44	42	39	37	36
3000.	0	0	18	66	107	132	138	134	90	74	68	63	59	55	51	48	45	42	40	38	36
2000.	0	1	183	269	211	196	177	157	121	79	72	65	60	55	51	48	45	42	40	38	36
1000.	0	1	632	569	298	229	192	165	144	81	72	65	60	55	51	48	45	42	40	37	36
0.	0	1	681	640	318	231	192	165	144	82	72	65	60	55	51	48	45	42	40	37	35
-1000.	0	1	441	462	271	221	189	163	144	81	72	65	60	55	51	48	45	42	40	38	36
-2000.	0	0	73	165	170	174	164	150	109	78	71	65	60	55	51	48	45	42	40	38	36
-3000.	0	0	3	31	73	105	119	122	81	70	66	62	58	54	50	47	45	42	40	38	36
-4000.	0	0	0	3	21	48	71	81	60	59	58	56	53	51	48	46	43	41	39	37	36
-5000.	0	0	0	0	4	16	34	35	40	45	47	48	47	46	45	43	41	40	38	36	35
-6000.	0	0	0	0	0	4	13	16	24	31	35	38	40	40	40	39	38	37	36	35	33
-7000.	0	0	0	0	0	1	3	7	13	19	24	29	32	34	34	35	35	34	34	33	32
-8000.	0	0	0	0	0	0	0	2	6	10	15	20	23	26	28	30	30	31	31	30	30
-9000.	0	0	0	0	0	0	0	0	2	5	8	12	16	19	22	24	26	27	27	27	27
-10000.	0	0	0	0	0	0	0	0	1	2	4	7	10	13	16	19	21	22	24	24	25

STUDY AREA EMISSION SUMMARY

SOURCE ID	EMISSION RATE (GM/SEC)	SOURCE LOCATION (FT) X	Y	Z	STACK HEIGHT (FT)	EXIT VEL. (FPS)	EXIT TEMP (F)	STACK RADIUS (FT)
PYRSOIL	447.44	0.	0.	0.	275.	50.	130.	5.
S PLANT	88.32	400.	200.	0.	250.	86.	125.	2.
UTILITIES	136.24	0.	800.	0.	200.	50.	250.	3.

BRIGGS (1971) PLUME RISE EQUATION USED.

NOTE:

Program name - APMAX

This run shows the results of the short term 10-minute predictions which were used for estimating the 24-hour maximum concentrations. The grid spacing was 2,000 ft. in order to study the area about 2 miles downwind from a source. The wind directions are not important for this particular analysis. The results were intended to indicate maximum down wind concentration independent of direction. Six wind speeds were analyzed.

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON,D.C.

DISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT***24-HOUR MAX OF GRADIENT WIND REGIME
STUDY AREA (FEET)
X 0. TO 20000.
Y -10000. TO 10000.
WIND SPEED = 2.23MPH
MIXING DEPTH = 1400.0 METERS

STABILITY

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	1458	0	-3000	975	0	-6000	691	0	-10000	40	0	-10000	13	0	-10000	0	20000	-10000
NNE	394	0	-2000	56	0	-3000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
NE	4	0	-1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ENE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
E	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ESE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SE	5	0	2000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SSE	410	0	2000	55	0	3000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
S	1636	0	3000	994	0	7000	670	0	10000	35	0	10000	8	0	10000	0	20000	-10000
SSW	1523	1000	3000	964	3000	7000	708	4000	10000	43	5000	10000	12	4000	10000	0	20000	-10000
SW	1680	2000	2000	980	5000	5000	754	9000	9000	96	10000	10000	61	10000	10000	0	20000	-10000
WSW	1334	3000	1000	946	7000	3000	747	12000	5000	160	20000	8000	222	20000	9000	2	20000	8000
W	1546	3000	0	953	7000	0	737	13000	0	153	20000	0	190	20000	0	2	20000	0
WNW	1440	3000	-1000	953	6000	-2000	739	13000	-5000	169	20000	-8000	244	20000	-8000	3	20000	-8000
NW	1551	2000	-2000	949	5000	-5000	740	9000	-9000	104	11000	-10000	82	11000	-10000	0	20000	-10000
NNW	1528	1000	-2000	935	3000	-7000	691	4000	-10000	56	5000	-10000	20	5000	-10000	0	20000	-10000

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON, D.C.

DISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT***24-HOUR MAX OF GRADIENT WIND REGIME
STUDY AREA (FEET)
X 0. TO 20000.
Y -10000. TO 10000.
WIND SPEED = 5.75MPH
MIXING DEPTH = 1400.0 METERS

STABILITY

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	1415	0	-2000	1092	0	-4000	940	0	-7000	302	0	-10000	36	0	-10000	0	20000	-10000
NNE	384	0	-1000	114	0	-2000	6	1000	-2000	0	20000	-10000	0	20000	-10000	0	20000	-10000
NE	23	0	-1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ENE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
E	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ESE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SE	15	0	1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SSE	424	0	2000	112	0	2000	6	2000	3000	0	20000	-10000	0	20000	-10000	0	20000	-10000
S	1373	0	2000	1149	0	4000	963	0	7000	276	0	10000	24	0	10000	0	20000	-10000
SSW	1342	1000	2000	967	2000	5000	934	3000	7000	307	4000	10000	33	4000	10000	0	20000	-10000
SW	1009	2000	2000	1074	3000	3000	918	5000	5000	426	10000	10000	97	10000	10000	0	20000	-10000
WSW	1388	2000	1000	1005	4000	2000	896	7000	3000	477	19000	8000	223	19000	8000	9	20000	9000
W	1416	2000	0	1024	4000	0	868	7000	0	467	20000	0	204	20000	0	6	20000	0
WNW	1118	2000	-1000	980	3000	-1000	850	8000	-3000	476	20000	-8000	243	20000	-8000	11	20000	-8000
NW	854	2000	-2000	1018	3000	-3000	883	5000	-5000	416	10000	-10000	113	11000	-10000	1	11000	-10000
NNW	1285	1000	-2000	1006	2000	-4000	919	3000	-7000	307	4000	-9000	38	5000	-10000	0	20000	-10000

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON, D.C.

DISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT***24-HOUR MAX OF GRADIENT WIND REGIME
STUDY AREA (FEET)
X 0. TO 20000.
Y -10000. TO 10000.
WIND SPEED = 9.78MPH
MIXING DEPTH = 1400.0 METERS

STABILITY

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	1031	0	-2000	993	0	-3000	880	0	-5000	473	0	-10000	46	0	-10000	0	20000	-10000
NNE	339	0	-1000	106	0	-2000	10	1000	-2000	0	20000	-10000	0	20000	-10000	0	20000	-10000
NE	22	0	-1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ENE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
E	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ESE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SE	29	0	1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SSE	342	0	2000	121	0	2000	9	1000	2000	0	20000	-10000	0	20000	-10000	0	20000	-10000
S	1212	0	2000	1030	0	3000	903	0	6000	465	0	10000	34	0	10000	0	20000	-10000
SSW	974	1000	2000	943	1000	3000	886	2000	5000	476	4000	10000	44	4000	10000	0	20000	-10000
SW	869	1000	1000	899	2000	2000	836	4000	4000	505	10000	10000	102	10000	10000	1	10000	10000
WSW	969	2000	1000	769	3000	1000	776	5000	2000	498	14000	6000	195	19000	8000	14	20000	9000
W	1064	2000	0	882	3000	0	776	6000	0	480	15000	0	181	20000	0	9	20000	0
WNW	773	2000	-1000	924	3000	-1000	794	5000	-2000	496	13000	-5000	208	20000	-8000	16	20000	-8000
NW	944	1000	-1000	877	2000	-2000	798	4000	-4000	491	10000	-10000	111	11000	-10000	3	11000	-10000
NNW	870	1000	-2000	837	1000	-2000	816	2000	-5000	468	4000	-9000	45	4000	-9000	0	20000	-10000

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON,D.C.

DISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT***24-HOUR MAX OF GRADIENT WIND REGIME
STUDY AREA (FEET)
X 0. TO 20000.
Y -10000. TO 10000.
WIND SPEED = 15.53MPH
MIXING DEPTH = 1400.0 METERS

S T A B I L I T Y

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	714	0	-2000	786	0	-3000	738	0	-4000	476	0	-10000	50	0	-10000	0	20000	-10000
NNE	273	0	-1000	86	0	-2000	11	0	-2000	0	20000	-10000	0	20000	-10000	0	20000	-10000
NE	18	0	-1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ENE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
E	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ESE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SE	31	0	1000	1	0	1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SSE	260	0	2000	105	0	2000	12	1000	2000	0	20000	-10000	0	20000	-10000	0	20000	-10000
S	948	0	2000	882	0	3000	781	0	5000	482	0	10000	39	0	10000	0	20000	-10000
SSW	676	1000	2000	781	1000	3000	735	2000	5000	473	4000	10000	49	4000	10000	0	20000	-10000
SW	803	1000	1000	760	2000	2000	669	4000	4000	453	8000	8000	96	10000	10000	2	10000	10000
WSW	657	2000	1000	626	2000	1000	632	5000	2000	435	12000	5000	162	19000	8000	17	20000	9000
W	745	2000	0	713	3000	0	641	5000	0	425	12000	0	151	20000	0	11	20000	0
WNW	522	2000	-1000	719	3000	-1000	645	5000	-2000	439	10000	-4000	170	20000	-8000	19	20000	-8000
NW	829	1000	-1000	728	2000	-2000	638	3000	-3000	438	8000	-8000	100	11000	-10000	5	11000	-10000
NNW	583	1000	-2000	771	1000	-2000	689	2000	-4000	467	4000	-9000	48	4000	-9000	0	20000	-10000

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON, D.C.

DISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT***24-HOUR MAX OF GRADIENT WIND REGIME
STUDY AREA (FEET)
X 0. TO 20000.
Y -10000. TO 10000.
WIND SPEED = 21.86MPH
MIXING DEPTH = 1400.0 METERS

S T A B I L I T Y

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	528	0	-2000	651	0	-2000	628	0	-4000	417	0	-10000	50	0	-10000	0	20000	-10000
NNE	225	0	-1000	77	0	-1000	9	1000	-2000	0	20000	-10000	0	20000	-10000	0	20000	-10000
NE	14	0	-1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ENE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
E	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ESE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SE	28	0	1000	1	0	1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SSE	203	0	2000	88	0	2000	11	1000	2000	0	20000	-10000	0	20000	-10000	0	20000	-10000
S	746	0	2000	716	0	3000	660	0	4000	427	0	10000	41	0	10000	0	20000	-10000
SSW	501	1000	2000	625	1000	3000	589	2000	5000	411	4000	10000	49	4000	10000	0	20000	-10000
SW	675	1000	1000	615	2000	2000	565	3000	3000	388	7000	7000	88	10000	10000	3	10000	10000
WSW	482	2000	1000	548	2000	1000	504	4000	2000	376	9000	4000	136	19000	8000	18	20000	9000
W	555	2000	0	566	3000	0	518	5000	0	362	11000	0	128	20000	0	12	20000	0
WNW	382	2000	-1000	560	3000	-1000	513	5000	-2000	378	10000	-4000	141	20000	-8000	20	20000	-8000
NW	683	1000	-1000	584	2000	-2000	540	3000	-3000	375	7000	-7000	88	11000	-10000	6	11000	-10000
NNW	425	1000	-2000	652	1000	-2000	562	2000	-4000	408	4000	-9000	48	4000	-9000	0	20000	-10000

MAXIMUM 10-MINUTE GROUNDLINE CONCENTRATIONS

ENGINEERING-SCIENCE, INC.
WASHINGTON,D.C.

DISPERSION CALCULATIONS FOR:
APMAX FOR SO2** ONE 200,000BBL/DAY PLANT***24-HOUR MAX OF GRADIENT WIND REGIME
STUDY AREA (FEET)
X 0. TO 20000.
Y -10000. TO 10000.
WIND SPEED = 25.00MPH
MIXING DEPTH = 1400.0 METERS

S T A B I L I T Y

	A			B			C			D			E			F		
WIND	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC	UG/M3	X-LOC	Y-LOC
N	474	0	-1000	606	0	-2000	579	0	-4000	391	0	-9000	49	0	-10000	1	0	-10000
NNE	207	0	-1000	72	0	-1000	9	1000	-2000	0	20000	-10000	0	20000	-10000	0	20000	-10000
NE	13	0	-1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ENE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
E	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
ESE	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SE	27	0	1000	1	0	1000	0	20000	-10000	0	20000	-10000	0	20000	-10000	0	20000	-10000
SSE	183	0	2000	81	0	2000	11	1000	2000	0	20000	-10000	0	20000	-10000	0	20000	-10000
S	672	0	2000	651	0	3000	615	0	4000	400	0	9000	41	0	10000	0	20000	-10000
SSW	444	1000	2000	565	1000	3000	533	2000	5000	381	4000	10000	48	4000	10000	0	20000	-10000
SW	620	1000	1000	559	2000	2000	520	3000	3000	362	7000	7000	84	10000	10000	3	10000	10000
WSW	426	2000	1000	510	2000	1000	462	4000	2000	350	9000	4000	126	19000	8000	18	20000	9000
W	492	2000	0	511	3000	0	479	4000	0	335	11000	0	119	20000	0	12	20000	0
WNW	337	2000	-1000	503	3000	-1000	463	5000	-2000	350	10000	-4000	131	20000	-8000	20	20000	-8000
NW	623	1000	-1000	529	2000	-2000	497	3000	-3000	349	7000	-7000	84	11000	-10000	6	11000	-10000
NNW	375	1000	-2000	600	1000	-2000	512	2000	-4000	380	4000	-9000	48	4000	-9000	0	20000	-10000

END OF PROGRAM. NO FURTHER SUMMARIES COMPUTED.

ENGINEERING-SCIENCE, INC.
WASHINGTCN,D.C.

DISPERSION CALCULATIONS FOR
TOSCO II RETORT *SO2 ANALYSIS *700 MB WIND *REVISED EMISSIONS *3@200&2@250KBBL/D

BRIGGS (1971) PLUME RISE EQ. USED FOR POINT SOURCES

NOTE:

Program name - APSIM

These results illustrate the combined concentrations expected from three 200,000 bbl/cd and two 200,000 bbl/cd plants. The area under investigation was the western part of the Basin. Obviously the highest concentrations were expected in this area. The grid spacing used was 2,000 ft.

STUDY AREA EMISSION SUMMARY

SOURCE ID	EMISSION RATE (GM/SEC)	SOURCE LOCATION (FT) X	Y	Z	STACK HEIGHT (FT)	EXIT VEL. (FPS)	EXIT TEMP (F)	STACK RADIUS (FT)	AREA EMISSIONS (SQ. MILE)	LINE SOURCE DESCRIPTIONS (FT) X1	Y1	X2	Y2
PYR&OIL	447.44	0.	0.	0.	275.	50.	130.	5.					
S PLANT	88.32	400.	200.	0.	250.	86.	125.	2.					
UTILITIES	136.24	0.	800.	0.	200.	50.	250.	3.					
PYR&OIL	447.44	-27000.	-14000.	0.	275.	50.	130.	5.					
S PLANT	88.32	-26600.	-13800.	0.	250.	86.	125.	2.					
UTILITIES	136.24	-27000.	-13200.	0.	200.	50.	250.	3.					
PYR&OIL	447.44	-27000.	30000.	0.	275.	50.	130.	5.					
S PLANT	88.32	-26600.	30200.	0.	250.	86.	125.	2.					
UTILITIES	136.24	-27000.	30800.	0.	200.	50.	250.	3.					
PYR&OIL *	559.30	0.	33000.	0.	275.	50.	130.	5.					
S PLANT *	110.40	400.	33200.	0.	250.	86.	125.	2.					
UTILITIES*	170.30	0.	33800.	0.	200.	50.	250.	3.					
PYR&OIL *	559.30	5000.	-33000.	0.	275.	50.	130.	5.					
S PLANT *	110.40	5400.	-32800.	0.	250.	86.	125.	2.					
UTILITIES*	170.30	5000.	-32200.	0.	200.	50.	250.	3.					

AVERAGE CONCENTRATIONS (UG/M3)

AT 0. FT.

Y-CORD (FEET) \ X-CORD	-20000.	-18000.	-16000.	-14000.	-12000.	-10000.	-8000.	-6000.	-4000.	-2000.	0.	2000.	4000.	6000.	8000.	10000.	12000.	14000.	16000.	18000.	20000.
40000.	15	17	16	16	17	17	16	16	16	16	20	26	28	31	30	31	30	28	27	25	24
38000.	25	24	23	23	23	22	21	21	20	21	25	33	38	36	35	34	32	29	27	25	23
36000.	26	27	27	26	25	23	22	22	21	21	25	40	42	41	38	35	32	29	26	24	23
34000.	34	32	30	27	25	23	22	22	22	20	17	43	44	39	36	33	30	27	25	23	22
32000.	32	28	26	24	23	21	21	21	21	20	20	29	34	34	33	32	29	27	25	24	23
30000.	29	27	25	24	23	21	21	21	24	26	29	29	28	30	29	27	25	24	23	23	23
28000.	25	23	23	22	21	21	21	23	23	27	28	25	26	26	27	27	25	23	22	22	22
26000.	24	24	24	21	21	21	22	22	24	24	28	26	24	25	24	24	24	23	22	22	22
24000.	16	17	18	19	19	20	19	19	22	22	25	24	23	25	24	22	21	22	22	23	22
22000.	16	17	17	19	19	19	19	20	20	22	24	23	23	23	24	22	21	21	22	22	22
20000.	16	18	19	18	19	19	19	20	20	22	23	22	22	22	22	22	20	21	21	21	21
18000.	17	18	19	18	18	17	19	19	20	22	22	22	22	23	22	21	22	22	21	21	21
16000.	15	16	15	16	16	17	17	18	19	22	22	22	23	23	23	22	23	23	22	21	21
14000.	15	15	15	16	16	16	17	18	18	21	22	22	24	23	23	23	23	22	22	22	22
12000.	15	15	15	15	16	17	17	18	18	20	21	22	25	25	26	25	24	23	24	24	24
10000.	15	15	15	16	16	17	17	18	18	20	21	23	26	27	29	26	25	25	26	26	24
8000.	15	15	16	16	17	18	18	18	19	19	22	26	27	30	30	28	28	28	26	25	24
6000.	16	16	17	17	18	19	18	18	19	20	23	30	32	35	35	32	29	28	27	26	24
4000.	16	17	17	19	19	19	19	18	18	19	24	34	39	39	36	32	29	28	26	25	24
2000.	17	17	19	20	20	19	19	19	20	19	23	40	43	39	34	31	28	27	25	24	23
0.	18	19	20	21	20	20	19	20	21	20	19	34	38	36	32	30	27	26	25	23	22

ENGINEERING-SCIENCE, INC.
WASHINGTON, D.C.

DISPERSION CALCULATIONS FOR
TOSCO II RETORT *SO2 ANALYSIS *700 MB WIND *REVISED EMISSIONS *2@200&2@250KBBL/D

BRIGGS (1971) PLUME RISE EQ. USED FOR POINT SOURCES

NOTE:

Project name - APSIM

This run illustrates the concentration for two 200,000 bbl/cd and two 250,000 bbl/cd plants in the western part of the Basin.

STUDY AREA EMISSION SUMMARY

SOURCE ID	EMISSION RATE (GM/SEC)	SOURCE LOCATION (FT) X	Y	Z	STACK HEIGHT (FT)	EXIT VEL. (FPS)	EXIT TEMP (F)	STACK RADIUS (FT)	AREA EMISSIONS (SQ. MILE)	LINE SOURCE DESCRIPTIONS (FT) X1	Y1	X2	Y2
PYR&OIL	447.44	0.	0.	0.	275.	50.	130.	5.					
S PLANT	88.32	400.	200.	0.	250.	86.	125.	2.					
UTILITIES	136.24	0.	800.	0.	200.	50.	250.	3.					
PYR&OIL	447.44	-27000.	0.	0.	275.	50.	130.	5.					
S PLANT	88.32	-26600.	200.	0.	250.	86.	125.	2.					
UTILITIES	136.24	-27000.	800.	0.	200.	50.	250.	3.					
PYR&OIL *	559.30	-27000.	32000.	0.	275.	50.	130.	5.					
S PLANT *	110.40	-26600.	32200.	0.	250.	86.	125.	2.					
UTILITIES*	170.30	-27000.	32800.	0.	200.	50.	250.	3.					
PYR&OIL *	559.30	0.	-30000.	0.	275.	50.	130.	5.					
S PLANT *	110.40	400.	-29800.	0.	250.	86.	125.	2.					
UTILITIES*	170.30	0.	-29200.	0.	200.	50.	250.	3.					

AVERAGE CONCENTRATIONS (UG/M3)

AT 0. FT.

Y-CORD (FEET) \ X-CORD	-30000.	-28000.	-26000.	-24000.	-22000.	-20000.	-18000.	-16000.	-14000.	-12000.	-10000.	-8000.	-6000.	-4000.	-2000.	0.	2000.	4000.	6000.	8000.	10000.
40000.	6	9	11	19	21	21	21	21	21	20	19	18	18	17	16	16	15	15	15	14	14
38000.	9	12	17	24	29	28	28	27	25	23	22	21	20	19	18	18	17	16	15	14	15
36000.	6	8	19	29	29	31	29	27	24	22	20	19	18	18	17	17	17	16	16	15	15
34000.	7	6	21	37	35	31	27	24	22	20	18	17	16	16	16	16	15	15	15	14	14
32000.	7	5	7	30	30	28	25	23	21	19	18	17	17	17	17	16	15	15	15	15	15
30000.	10	14	14	20	22	22	21	20	20	19	18	17	17	18	17	16	16	15	15	15	15
28000.	12	17	19	19	18	20	20	18	17	16	16	16	17	17	17	16	16	16	16	16	16
26000.	13	15	17	17	17	16	17	17	17	16	16	16	16	16	15	15	15	15	15	15	15
24000.	13	14	15	15	16	15	15	14	15	16	16	16	16	16	15	15	14	14	15	16	15
22000.	12	14	14	13	14	15	15	15	14	15	17	16	16	16	16	15	15	15	16	16	17
20000.	12	14	14	13	15	15	15	14	14	16	15	16	16	16	16	16	16	17	18	17	17
18000.	11	13	13	13	15	15	15	16	16	16	16	15	15	16	17	17	17	18	18	17	17
16000.	11	14	14	15	15	15	15	16	17	16	16	15	15	16	17	18	19	20	19	19	19
14000.	10	13	13	15	17	16	17	18	18	17	16	16	16	17	18	18	18	20	20	19	21
12000.	10	13	13	16	17	17	19	19	18	18	17	18	18	17	18	19	19	21	21	22	23
10000.	11	13	14	13	18	20	21	20	19	19	20	19	19	18	19	20	22	23	24	25	24
8000.	11	14	15	21	22	23	22	22	22	21	20	19	19	19	18	21	24	24	26	25	25
6000.	7	10	14	20	23	23	23	22	20	19	18	17	17	16	16	18	24	27	29	29	29
4000.	7	9	17	25	25	27	25	23	21	19	18	17	17	16	16	20	29	33	34	31	29
2000.	7	7	19	31	29	26	23	20	18	17	16	15	15	15	14	16	33	36	33	31	28
0.	6	6	7	25	25	23	21	19	18	16	15	15	14	14	14	12	27	32	31	29	27

ENGINEERING-SCIENCE, INC.
WASHINGTON,D.C.

DISPERSION CALCULATIONS FOR
*SO2 ANALYSIS *700 MB WIND *REVISED EMISSIONS *3@200&2@250KBBL/D *STACK = 500 FT

BRIGGS (1971) PLUME RISE EQ. USED FOR POINT SOURCES

NOTE:

Program name - APSIM

This run illustrates the effect of raising stack heights to 500 feet for three 200,000 bbl/cd plants and two 250,000 bbl/cd plants in the western part of the Basin.

STUDY AREA EMISSION SUMMARY

SOURCE ID	EMISSION RATE (GM/SEC)	SOURCE LOCATION (FT) X	Y	Z	STACK HEIGHT (FT)	EXIT VEL. (FPS)	EXIT TEMP (F)	STACK RADIUS (FT)	AREA EMISSIONS (SQ. MILE)	LINE SOURCE DESCRIPTIONS (FT) X1	Y1	X2	Y2
FYR&OIL	447.44	0.	0.	0.	500.	50.	130.	5.					
S PLANT	88.32	400.	200.	0.	500.	86.	125.	2.					
UTILITIES	136.24	0.	800.	0.	500.	50.	250.	3.					
FYR&OIL	447.44	-27000.	-14000.	0.	500.	50.	130.	5.					
S PLANT	88.32	-26600.	-13800.	0.	500.	86.	125.	2.					
UTILITIES	136.24	-27000.	-13200.	0.	500.	50.	250.	3.					
FYR&OIL	447.44	-27000.	30000.	0.	500.	50.	130.	5.					
S PLANT	88.32	-26600.	30200.	0.	500.	86.	125.	2.					
UTILITIES	136.24	-27000.	30800.	0.	500.	50.	250.	3.					
FYR&OIL *	559.30	0.	33000.	0.	500.	50.	130.	5.					
S PLANT *	110.40	400.	33200.	0.	500.	86.	125.	2.					
UTILITIES*	170.30	0.	33800.	0.	500.	50.	250.	3.					
FYR&OIL *	559.30	5000.	-33000.	0.	500.	50.	130.	5.					
S PLANT *	110.40	5400.	-32800.	0.	500.	86.	125.	2.					
UTILITIES*	170.30	5000.	-32200.	0.	500.	50.	250.	3.					

AVERAGE CONCENTRATIONS (UG/M3)

AT 0. FT.

Y-CORD (FEET) \ X-CORD	-20000.	-18000.	-16000.	-14000.	-12000.	-10000.	-8000.	-6000.	-4000.	-2000.	0.	2000.	4000.	6000.	8000.	10000.	12000.	14000.	16000.	18000.	20000.
40000.	5	6	6	6	6	6	6	6	6	7	8	9	10	11	11	11	11	11	11	10	10
38000.	10	9	9	9	9	9	9	9	9	9	10	11	12	13	13	12	12	11	11	10	10
36000.	10	10	10	10	10	9	9	9	9	8	8	12	14	15	14	13	12	11	10	10	10
34000.	13	12	11	10	10	9	9	9	9	8	7	11	14	14	13	12	11	11	10	10	10
32000.	12	10	10	9	9	9	9	9	9	8	7	9	12	13	13	12	11	11	10	10	10
30000.	11	10	10	9	9	9	9	9	10	9	10	10	10	11	11	11	10	10	10	10	10
28000.	9	9	9	9	8	8	9	10	9	10	10	10	10	10	10	11	10	9	9	9	9
26000.	10	9	9	8	8	8	9	9	9	10	10	10	10	10	10	10	9	9	9	9	10
24000.	6	7	7	8	8	8	8	8	8	9	9	9	9	9	9	9	9	9	9	10	10
22000.	6	7	7	7	8	8	7	8	8	9	9	9	9	9	9	9	8	9	9	9	10
20000.	7	7	8	7	7	8	7	8	8	9	9	9	9	9	9	9	8	9	9	9	9
18000.	7	8	8	8	7	7	7	8	8	9	9	9	9	9	9	8	9	9	9	9	9
16000.	6	7	7	7	7	7	7	7	8	9	9	9	9	9	9	9	9	9	9	9	9
14000.	6	6	6	6	6	7	7	7	8	8	9	9	9	9	9	9	9	9	9	9	10
12000.	6	6	6	6	7	7	7	8	8	8	9	9	10	10	10	10	10	10	10	10	10
10000.	6	6	6	6	7	7	7	8	8	8	9	9	10	10	11	10	10	10	11	11	10
8000.	6	6	7	7	7	7	8	8	8	8	9	10	10	11	11	10	11	11	11	11	10
6000.	6	7	7	7	8	8	8	8	8	8	9	11	12	12	12	11	11	11	11	11	10
4000.	6	7	7	8	8	8	8	8	8	8	9	12	13	14	13	12	11	11	11	10	10
2000.	7	7	8	8	8	8	8	8	8	8	8	12	15	15	13	11	11	11	10	10	10
0.	7	7	8	8	8	8	8	8	9	8	8	10	13	14	12	11	11	10	10	10	10

ENGINEERING-SCIENCE, INC.
WASHINGTON,D.C.

DISPERSION CALCULATIONS FOR
*SO2 ANALYSIS *700 MB WIND *REVISED EMISSIONS *3@200&2@250KBBL/D *STACK = 125 FT

BRIGGS (1971) PLUME RISE EQ. USED FOR POINT SOURCES

NOTE:

Program name - APSIM

This run illustrates the effect of lowering stack heights to 125 feet for three 200,000 bbl/cd plants and two 250,000 bbl/cd plants in the western part of the Basin.

STUDY AREA EMISSION SUMMARY

SOURCE ID	EMISSION RATE (GM/SEC)	SOURCE LOCATION (FT) X	Y	Z	STACK HEIGHT (FT)	EXIT VEL. (FPS)	EXIT TEMP (F)	STACK RADIUS (FT)	AREA EMISSIONS (SQ. MILE)	LINE SOURCE DESCRIPTIONS (FT) X1	Y1	X2	Y2
PYR&OIL	447.44	0.	0.	0.	125.	50.	130.	5.					
S PLANT	88.32	400.	200.	0.	125.	86.	125.	2.					
UTILITIES	136.24	0.	800.	0.	125.	50.	250.	3.					
PYR&OIL	447.44	-27000.	-14000.	0.	125.	50.	130.	5.					
S PLANT	88.32	-26600.	-13800.	0.	125.	86.	125.	2.					
UTILITIES	136.24	-27000.	-13200.	0.	125.	50.	250.	3.					
PYR&OIL	447.44	-27000.	30000.	0.	125.	50.	130.	5.					
S PLANT	88.32	-26600.	30200.	0.	125.	86.	125.	2.					
UTILITIES	136.24	-27000.	30800.	0.	125.	50.	250.	3.					
PYR&OIL *	559.30	0.	33000.	0.	125.	50.	130.	5.					
S PLANT *	110.40	400.	33200.	0.	125.	86.	125.	2.					
UTILITIES*	170.30	0.	33800.	0.	125.	50.	250.	3.					
PYR&OIL *	559.30	5000.	-33000.	0.	125.	50.	130.	5.					
S PLANT *	110.40	5400.	-32800.	0.	125.	86.	125.	2.					
UTILITIES*	170.30	5000.	-32200.	0.	125.	50.	250.	3.					

AVERAGE CONCENTRATIONS (UG/M3)

AT 0. FT.

Y-CORD (FEET) \ X-CORD	-20000.	-18000.	-16000.	-14000.	-12000.	-10000.	-8000.	-6000.	-4000.	-2000.	0.	2000.	4000.	6000.	8000.	10000.	12000.	14000.	16000.	18000.	20000.
40000.	29	33	32	31	32	34	31	31	31	32	42	55	57	64	60	59	59	55	52	48	46
38000.	49	45	43	42	42	41	39	38	38	39	52	78	89	77	71	66	61	55	51	47	44
36000.	52	51	50	48	46	43	42	41	40	40	55	103	106	90	78	69	63	56	51	48	46
34000.	68	63	58	51	48	44	42	41	41	39	39	121	109	89	75	66	59	52	47	44	42
32000.	67	56	49	44	41	39	38	38	38	39	46	72	79	75	69	63	56	50	47	44	42
30000.	60	53	48	45	42	40	39	39	46	52	67	70	63	65	57	52	48	45	43	42	42
28000.	51	46	44	42	40	39	40	44	46	56	64	57	59	52	53	53	47	44	41	40	40
26000.	47	46	44	41	39	40	42	42	46	49	59	55	48	50	47	46	46	45	42	41	42
24000.	31	32	33	34	35	35	35	36	41	43	50	48	45	47	44	42	40	41	43	45	43
22000.	30	31	32	34	35	35	34	37	38	41	45	44	43	45	46	41	39	38	40	42	42
20000.	30	34	34	33	34	36	35	36	38	42	42	41	41	42	42	42	39	39	40	39	39
18000.	32	33	33	33	32	32	35	35	36	42	41	41	43	43	42	40	42	42	40	39	38
16000.	28	28	29	29	30	31	32	34	36	43	41	40	43	44	42	41	45	44	41	40	39
14000.	27	27	27	28	29	30	32	33	34	40	41	42	45	45	43	44	44	43	42	41	42
12000.	28	28	27	28	30	31	32	33	33	37	39	41	48	48	48	48	46	44	47	46	48
10000.	28	28	28	29	30	32	33	33	34	37	41	45	51	53	58	51	49	49	51	52	45
8000.	28	29	29	30	31	33	34	34	35	36	43	51	54	59	57	56	55	56	49	47	47
6000.	30	30	32	33	35	35	35	34	36	37	47	62	66	74	72	67	55	53	51	48	46
4000.	30	31	33	35	36	35	35	34	35	36	50	80	98	94	72	62	56	53	50	47	45
2000.	32	33	35	37	37	36	36	36	37	37	52	98	99	85	71	60	54	51	48	45	44
0.	34	35	39	39	38	37	37	37	40	39	35	90	88	77	66	59	52	49	46	44	41

APPENDIX C

FUGITIVE DUST

Table C-1. EMISSION FACTORS AND SOURCE PARAMETERS

Source Category	Source Parameters	Emission Factor Information Emission Factor (Uncontrolled)
Unpaved roads	Vehicle miles traveled (VMT)=miles of unpaved road x average daily traffic	$[2.15 + \frac{C}{80} \times 1.55]$ lbs/vehicle mile
Agriculture	Soil type Crop type Acreage by crop type Climatic conditions	E_s=(0.025) IKCL'V', where E_s=suspended particulate fraction of wind erosion losses off tilled fields tons/acre/year I =Soil erodibility, tons/acre/year K =Surface roughness factor, dimensionless C =Climatic factor, (dimensionless) L'=Unsheltered field width factor, dimensionless V'=Vegetative cover factor, dimensionless
Land development	Acreage developed	9 lbs/mile/ft. of access width x C (Climatic factor, dimensionless)
Residential, industrial, & commercial construction	Acreage under construction	0.8 ton/acre/month of construction
Highway construction	Miles of highway under construction	1.12 ton/acre/month of construction
Quarrying, mining & tailings	Acres of tailings, waste, and storage	0.133 C ton/acre/year
Aggregate storage	Tons of aggregate stored	0.005 ton/ton/yr. - sand 0.00075 ton/ton/yr. - gravel

Table C-2. CONTROL TECHNIQUES FOR FUGITIVE DUST SOURCE

Source	Control Method	Control Efficiency
Unpaved roads	Paving and right of way improvement	85%
	Surface treatment with penetration chemicals	50%
	Soil stabilization chemicals worked into the roadbed	50%
	Speed control	25 mph-25% 20 mph-35% 15 mph-40%
Construction activity	Watering	50%
	Chemical stabilization of completed cuts and fills	80%
	Treatment of temporary access and haul roads on or adjacent to site	50%
	Minimal exposure periods (controlled by permit; good practice with watering or chemical stabilization)	
Argiculture	Continuous cropping	25%
	Limited irrigation of fallow fields	20%
	Windbreaks	5%
	Inter-row plantings of grain on widely-spaced row crops	15%
	Stubble, crop residue, or mulch left on fields after harvest for wind protection	10%
	Spray-on chemical stabilization	40%
Tailings pile	Chemical stabilization	80%
	Vegetation	65%
	Combined chemical-vegetative stabilization	90%
Aggregate storage	Continuous spray of chemical on material going to storage piles	90%
	Watering of haul roads and storage areas	50%
	Treatment of haul roads and traffic areas	50%
	Watering (sprinklers or truck)	80%

Form 1279–3
(June 1984)

BORROWER

Air quality asse
the oil shale

DATE LOANED	BORROWER

USDI – BLM