**Assessing the Air Pollution
Carrying Capacity of the
Northern Puget Sound
Region:
An Application of TAPAS**

September 1980

**Prepared for the
U.S. Department of Energy
Assistant Secretary for Environment
Office of Environmental Assessments
under Contract DE-AC06-76RLO 1830**

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ASSESSING THE AIR POLLUTION CARRYING CAPACITY
OF THE NORTHERN PUGET SOUND REGION:
AN APPLICATION OF TAPAS

September 1980

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EXECUTIVE SUMMARY

INTRODUCTION

The utility of traditional air quality diffusion models is limited in areas of complex topography. At the same time, the air quality constraints on facilities' siting, "carrying capacity"* requirements and land use planning alternatives may be particularly important in complex terrain. Such areas present a real challenge for the air quality modeler -- local topographic influences dominate the surface flow and dispersion potential patterns much of the time and these patterns can be expected to change drastically with a shift in the background flow conditions. The technique discussed in this report (the TAPAS system) was developed to provide valid information on the dispersion capability of the lower atmosphere in areas characterized by complex terrain features.

The northern Puget Sound region of Washington (U.S.A.) and British Columbia (Canada) was chosen as an ideal location in which to test the utility of the TAPAS system. The coastal areas of Washington and British Columbia are characterized by complex terrain. Data from the limited number of wind monitoring sites in the study area indicate the controlling influence that topographic features (including mountains, large and small islands and ocean passages) have on surface wind patterns. Under these conditions, ordinary diffusion modeling techniques using non-varying

*The term carrying capacity for air pollution is used here in the same manner as the range manager uses it to determine the number of animals to be permitted to graze on a certain pasture. Just as knowledge of the interaction of soils, plants and precipitation are the primary input to grazing capacity calculations, information on terrain, wind patterns and mixing depth are the inputs to determining air pollution carrying capacity.

wind speed and direction assumptions could not be expected to provide valid information on the air pollution "carrying capacity" of the region.

The northern Puget Sound is in a Class II air quality region. Air quality measurements indicate that the air in this region is fairly clean with respect to total suspended particulates. Short-term violations of federal and state ambient air quality standards for SO_2 , however, were recorded at several locations during 1975 and 1976, although the present SO_2 monitoring network is not adequate to provide detailed information about the spatial distribution of this pollutant (NWAPA, 1977). A study was undertaken to assess the air quality (SO_2) impacts associated with energy development in the region and to determine the constraints on energy development due to regulated limitations on the amount of air quality degradation allowable in the area. The northern Puget Sound region already contains a number of refinery and wharf locations which represent substantial sources of SO_2 emission. Projected expansion of these facilities, along with possible new energy development sites, provide a potential for significant air quality deterioration within the region.

MODEL DESCRIPTION

The Topographic Air Pollution Analysis System (TAPAS) consists of two major sections. The first part is a wind flow model (WINDS) which is capable of computing spatial and temporal variations in the low level wind field due to changes in topography, surface roughness and surface heating. Information about the study area is reduced to a system of grid points. Input for the flow model includes the prevailing

background flow (speed and direction) over the study area plus elevation, surface roughness and surface temperature information for each grid point. Output from the WINDS model consists of a series of maps of wind direction and speed (Figure 1) at each grid point, for each day and time. A mixing volume index, based primarily on wind speed and convergence or divergence of air parcels, is also calculated. This index provides information on the relative potential for pollutant accumulation at each grid cell location.

The second section of the TAPAS system combines the wind field output from WINDS, the mixing volume index array and the Pollutant Standards Index (PSI) (Thom and Ott, 1976) to determine the total emission from each grid cell that would result in selected ambient air quality levels over the entire study area. The resultant index, called the PI(π)-Matrix, contains no specific source information but provides an atmospheric constraint matrix (i.e. an array of contaminant "carrying capacity" values) for land use planning. An example of the PI-Matrix output is shown in Figure 2.

The modeling techniques used were developed by the Department of Earth Resources, Colorado State University; the Mountain Meteorology program of the Rocky Mountain Forest and Range Experiment Station (USFS); and Marlatt and Associates, Fort Collins, Colorado.

DATA ANALYSIS

Four days were selected for testing the model in the northern Puget Sound region. These days were dates on which high concentrations of sulfur dioxide or particulate matter were recorded in the northern Puget Sound region and represent meteorological conditions with background flow

Figure 2. PI(π)-Matrix For January 3, 1975 at 0300.

This figure illustrates the SO₂ emissions in each 2 km² grid cell which would result in ambient SO₂ concentrations of .4 ppm (Washington one hour ambient standard limitation) over the entire study area.

directions varying from 360° clockwise to 247° and background wind speeds ranging from 0.5 miles per hour to over 13 miles per hour in the study area.

Short-term PI-Matrices, representing instantaneous emission rate limitations to achieve ambient concentrations of 0.4 ppm SO_2 (Washington one hour ambient standards (PSAPCA, 1977)), were calculated at four hour intervals for each of the dates analyzed. In addition, a 24-hour PI-Matrix representing total emissions to achieve an ambient concentration of 0.1 ppm SO_2 (Washington 24-hour ambient standard (PSAPCA, 1977)), was calculated for each day simulated. An annual PI-Matrix was also calculated from the annual mixing volume index, based on annual wind rose data from Bellingham, Washington.

RESULTS

Table 1 shows a comparison of WINDS results to observed meteorology at 11 locations in the northern Puget Sound region for one of the four days analyzed. Due to rounding and grid point location discrepancies between the observed and simulated situations, the mean error figures, rather than errors at individual grid locations, were relied on most heavily in analyzing WINDS model performance. The table shows that the mean errors for the entire study area, and for a "core" area of approximately 3118 km^2 centered around the refinery and petrochemical developments near Ferndale and Anacortes, were generally within one meter per second or one compass point for this case. The standard deviation of error, used as a measure of spread in the simulation comparison, were also generally less than or equal to two compass points or two meters per second for this simulation. Similar comparisons were made for the other three days modeled.

Table 1. Comparison of WINDS Results With Observed Data -- January 3, 1975. The numbers represent amounts by which simulation differs from observed flow conditions. Units are compass points for direction (16-point compass; + for clockwise deviation, - for counterclockwise error) and meters per second for speed (+ for overprediction, - for underprediction).

Station Code	Time											
	0300		0700		1100		1500		1900		2300	
	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd
FARC	0	-3	0	-1	-1	0	0	-2	0	-3	+1	+2
FMRI	0	0	-1	-1	+1	0	-1	0	-1	+1	-1	-2
BELA	+1	-1	0	-3	0	0	0	0	+2	-3	+1	0
BELC	0	0	+2	0	+2	0	+2	+1	0	+1	+1	0
BELT	0	0	+1	0	+1	+1	+2	+1	+3	-1	0	0
AAVE*	+1	0	-1	-1	-1	-2	-1	-2	+1	-2	-4	0
BRIL	-1	+4	-7	0	+2	0	+1	-1	+1	+1	0	-3
WHID	0	-1	+2	+1	-1	-1	+1	+1	0	+1	0	+1
SMTH	+1	-2	0	-1	-	-	+1	-4	+1	-2	-	-
VICA	-1	+1	-2	+1	-1	0	-1	-3	0	-5	0	-3
VECH	0	-2	-1	0	+1	-2	-1	-2	0	-6	-1	-4
Mean Error												
All Stations	.09	-.36	-.64	-.45	.30	-.40	.27	-1.00	.64	-1.64	-.30	-.90
Standard Deviation												
of Error												
All Stations	.70	1.90	2.46	1.13	1.25	.97	1.19	1.73	1.12	2.50	1.49	1.97
Mean Error												
Core Area	.33	-.67	.17	-1.00	.33	-.17	.33	-.33	.83	-1.17	-.33	0.00
Standard Deviation												
of Error												
Core Area	.52	1.21	1.17	1.10	1.21	.98	1.37	1.37	1.47	1.83	1.97	1.26

Comparisons of observed meteorology and simulation predictions for the four days analyzed showed various degrees of accuracy in model performance under the differing meteorological situations encountered. This allowed the assessment of meteorological and grid size limitations to model use. The result is a set of guidelines detailing data requirements, area size limitations and methods of adjusting the WINDS model to fit individual situations.

The emission limitation (PI-Matrix) calculations were dealt with in two ways. Emission rates or amounts from each grid cell that would result in ambient SO_2 concentrations equal to Washington one hour or 24-hour standard limitations were calculated for each of the simulation periods. In addition, a core area total emission amount was calculated by assuming complete mixing and, therefore, uniform concentrations over the entire core area mixing volume. The individual grid cell rates represent conservative emission restrictions while the core area totals represent an upper limit to the SO_2 emissions that could be tolerated while maintaining acceptable levels of air quality.

An annual case was also calculated which shows emission limitations necessary under the most prevalent flow conditions to meet federal and state annual average SO_2 standards and Class II and Class III PSD increments. Table 2 shows annual emission constraints at grid cells representing the locations of present or proposed SO_2 point and area sources, along with 1976 NEDS (EPA-NEDS, 1977) estimates of actual SO_2 emissions at some of these locations. Table 3 shows core area total emission limitations, along with the NEDS 1976 total estimated point source emissions for the area.

Table 2. Annual Total Emissions of SO₂ That Would Result in Ambient Concentrations of 80, 60, 40 or 20 µg/m³ at Present or Projected Source Location Grid Cells. Emission estimates for current sources for 1976 are also listed (EPA, NEDS, 1976). Units are 10³ kilograms SO₂.

Source and Location	80µg/m ³	60µg/m ³	40µg/m ³	20µg/m ³	SO ₂ Emission Estimates 1976
Source A, Ferndale	101-125	76-94	51-62	25-31	5505
Source B, Ferndale	101-125	76-94	51-62	25-31	3821
Source C, Ferndale	101-125	76-94	51-62	25-31	4225
Source D, Ferndale	101-125	76-94	51-62	25-31	-
Source E, Ferndale	101-125	76-94	51-62	25-31	-
Source F, Ferndale	101-125	76-94	51-62	25-31	-
Source G, Ferndale	101-125	76-94	51-62	25-31	-
Source H, Bellingham	101-125	76-94	51-62	25-31	1124
Source I, Anacortes	76-100	57-75	39-50	18-24	12609
Source J, Anacortes	76-100	57-75	39-50	18-24	-
Source K, Anacortes	76-100	57-75	39-50	18-24	-
Bellingham	3235-4110	2432-3061	1628-2026	804-999	-
Anacortes	734-959	551-713	368-474	183-320	-

Table 3. Total Allowable Emissions Within Core Area on an Annual Basis to Achieve Ambient Concentrations of 80, 60, 40 and 20 $\mu\text{g}/\text{m}^3$ SO_2 . Units are 10^6 kilograms SO_2 .

SO_2 Concentration	Emission Total
80 $\mu\text{g}/\text{m}^3$	95.58
60 $\mu\text{g}/\text{m}^3$	71.68
40 $\mu\text{g}/\text{m}^3$	47.79
20 $\mu\text{g}/\text{m}^3$	23.89
1976 Point Source Estimated Emissions = 27.29 (total core area)	

CONCLUSION

The emission constraint analysis for the northern Puget Sound region indicated that total SO_2 emissions in the core area (on an annual basis) are less than half of the amount that could be tolerated in the entire core region while maintaining ambient concentrations within state and federal annual average limitations. However, comparison of source characteristics with source location and grid cell emission restrictions indicated that localized areas adjacent to the major point sources are already far in excess of the SO_2 "carrying capacity". This conclusion is supported by air quality monitoring data which indicate state standard violations at several receptor locations within the study area -- in some cases at points many grid cells "downwind" from the source of contaminant emission (NWAPA, 1977).

The annual maps of wind patterns and PI-Matrix values show areas of both good and poor dispersion characteristics under the most prevalent

flow conditions. Localized sites of excellent dispersion occur within the higher portions of Vancouver Island, the Olympic Peninsula and the foothills of the Cascades -- these generally coincide with areas with high wind speed predictions and probably represent exposed sites such as ridge top locations. Areas of reduced dispersion occur from Port Angeles west along the northern edge of the Olympic Peninsula, along the eastern edge of Vancouver Island and from the Bellingham Bay area south to Mt. Vernon and Camano Island and north along the edge of the higher terrain to the east.

The wind flow and emission constraint analyses performed for this study provide valuable information regarding the model's utility for subsequent analyses of a similar nature. Mixing volume index maps may be used to indicate areas of high and low "pollution potential" -- in effect, where to site or not site future emission sources. The PI-Matrix calculations could then be used to set allowable emission rates or amounts for each grid cell or, for clusters of grid cells, with reference to any standard of air quality desired. The TAPAS system may also prove useful in preparing attainment plans for areas where contaminant concentrations are currently in excess of standard limitations by defining levels to which emissions must be reduced to insure acceptable air quality at all locations.

Figure 1. Windfield Analysis of Northern Puget Sound Study Area
for January 3, 1975 at 0300 PST. Background flow input:
225.0 degrees at 5.0 meters per second.

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

CHAPTER I

INTRODUCTION

The Topographic Air Pollution Analysis System (TAPAS) has been developed for use as a land use planning and facilities siting tool. It can provide the information needed to determine regional and local land use constraints that may be necessary due to regulated limitations on air quality degradation. In this study, the TAPAS system has been used to determine the carrying capacity of a region with respect to sources of SO_2 ; to establish, in effect, the level of SO_2 emissions that can be tolerated within the study area while maintaining acceptable levels of air quality. "Acceptable" levels of SO_2 are those defined by the National Ambient Air Quality Standards and, for the region under study, standards of the State of Washington. These standards are shown in Table 1.

The purpose of this project was to test the performance of the TAPAS system in an area of complex terrain. The northern Puget Sound region of Washington was chosen for this analysis. The TAPAS system has been used to determine emission limitations that would be necessary to attain various regional air quality levels under annual average and "worst case" episodic conditions. Overall model performance and the utility of this technique for future analyses of a similar nature have been evaluated.

The magnitude of contaminant emissions that can be tolerated in any area is primarily determined by the character and frequency of relatively short-term episodes (hours to days) when prevailing meteorological conditions inhibit pollutant dispersal or otherwise interact with emissions to cause high groundlevel concentrations. Consequently, an

Table 1. Air Quality Standards for SO₂. Units are micrograms per cubic meter (µg/m³) and parts per million (ppm) (PSAPCA, 1977; PL 95-95, 1977).

	National Primary µg/m ³	ppm	National Secondary µg/m ³	ppm	Washington State µg/m ³	ppm
Annual Average	80*	.03*				.02*
24-Hour Average	365**	.14**				.10**
3-Hour Average			1300**	.50**	1300**	.50**
1-Hour Average						.25***
1-Hour Average						.40**

Prevention of Significant Deterioration
Incremental Standards (µg/m³)

	<u>Class I</u>	<u>Class II</u>	<u>Class III</u>
Annual Arithmetic Mean	2	20	40
24-Hour Average	5	91	182
3-Hour Average	25	512	700

* Never to be exceeded

** Not to be exceeded more than once per year

*** Not to be exceeded more than twice in seven days, once per year.

attempt was made to determine several synoptic conditions that were associated with high pollutant levels in the northern Puget Sound region and then to run the wind flow and air quality models for three to four specific days representative of these conditions. This information was then used to estimate the allowable SO₂ emissions for the area under similar meteorological conditions. Air quality and meteorological data from the northern Puget Sound area were collected to define needed input variables and to compare with the model results for validation.

Several area agencies (Northwest Air Pollution Association (NWAPA), Puget Sound Air Pollution Control Agency (PSAPCA) and representatives from Western Washington State College) were contacted in an effort to collect available air quality and meteorological data. While information specifically concerning the meteorological conditions most likely to be associated with episodes of poor air quality was not available, data concerning total suspended particulate (TSP) and SO₂ measurements taken in the region through 1975 and 1976 were obtained and are summarized in Tables 2 and 3. Particulates were monitored at the Lake Terrell Game Refuge and at the NWAPA office building in Mt. Vernon. The NWAPA SO₂ station network shows several monitoring locations within the study region and violations were recorded at four of the stations over the two year period. Monitoring locations for both TSP and SO₂ from which data were obtained are shown in Figure 1.

The air quality data indicate that the northern Puget Sound region is fairly clean with respect to particulates, but that SO₂ levels have occasionally exceeded standards at several locations. The highest levels of SO₂ and TSP recorded during 1975 and 1976 were assumed to be indicative of meteorological conditions that might cause periods of high pollutant

Table 2. Total Suspended Particulate Levels Measured at Mount Vernon and Lake Terrell in 1975 and 1976. Four highest days recorded for each year are shown, along with annual means for 1975 (units are micrograms per cubic meter) (NWAPA, 1977).*

Year	Mount Vernon		Lake Terrell	
	Date	Concentration ($\mu\text{g}/\text{m}^3$)	Date	Concentration ($\mu\text{g}/\text{m}^3$)
1975	January 24	128	February 5	78
	January 30	119	July 23	56
	February 5	115	June 11	45
	March 7	105	June 17	42
Annual			Annual	
		Arithmetic Mean 44.5		
		Geometric Mean 38.2		
			Arithmetic Mean 20.5	
			Geometric Mean 17.0	
1976	January 20	117	May 1	126
	February 6	116	April 28	55
	May 1	94	February 6	48
	October 22	88	July 24	44

*Applicable standards are $75 \mu\text{g}/\text{m}^3$, federal primary standard for annual geometric mean; $260 \mu\text{g}/\text{m}^3$, federal primary standard for 24-hour average; $60 \mu\text{g}/\text{m}^3$, federal secondary and Washington State standard for annual geometric mean; and $150 \mu\text{g}/\text{m}^3$, federal secondary and Washington State standard for 24-hour average concentration.

Table 3. Stations exceeding 3-hour average limit of 50 parts per hundred million SO_2 or 24-hour average limit of 10 parts per hundred million SO_2 in 1975 and 1976. Only the highest 3- or 24-hour average concentration is shown for each day. See Figure 1 for location of numbered stations. (NWAPA, 1977)

Year	Date	Location	Time Period	Concentration (pphm)
1975	January 3	30(Bellingham)	3 Hour	69
	January 8	30(Bellingham)	3 Hour	77
	December 4	30(Bellingham)	3 Hour	67
	January 6	25(Birch Bay)	24 Hour	11
	January 3	30(Bellingham)	24 Hour	21
	January 5	30(Bellingham)	24 Hour	11
	January 6	30(Bellingham)	24 Hour	19
	January 7	30(Bellingham)	24 Hour	11
	January 8	30(Bellingham)	24 Hour	21
	January 9	30(Bellingham)	24 Hour	21
	February 10	30(Bellingham)	24 Hour	12
	February 11	30(Bellingham)	24 Hour	14
	February 12	30(Bellingham)	24 Hour	40
	February 13	30(Bellingham)	24 Hour	12
	December 1	30(Bellingham)	24 Hour	18
	December 2	30(Bellingham)	24 Hour	18
	December 3	30(Bellingham)	24 Hour	18
1976	April 22	32(March Point)	3 Hour	74
	June 20	25(Birch Bay)	24 Hour	14
	June 21	25(Birch Bay)	24 Hour	11
	February 3	28(March Point)	24 Hour	13
	February 4	28(March Point)	24 Hour	18
	January 9	30(Bellingham)	24 Hour	11
	February 16	30(Bellingham)	24 Hour	16
	February 17	30(Bellingham)	24 Hour	11
	February 18	30(Bellingham)	24 Hour	15
	February 19	30(Bellingham)	24 Hour	11
	March 26	30(Bellingham)	24 Hour	12
	April 22	32(March Point)	24 Hour	18
	April 23	32(March Point)	24 Hour	18

Figure 1. Monitoring Locations for SO₂ and TSP Data (NWAPA, 1977).

concentrations at other times as well. Four days were chosen for the wind flow and air quality analyses based on the air quality data presented and the availability of meteorological data for the study area on the appropriate dates. These dates are January 24 and January 30, 1975 (showing the highest TSP concentrations for Mt. Vernon in the two years monitored) and January 3 and February 12, 1975 (when violations of SO₂ standards occurred at Bellingham). These four days also represent differing synoptic conditions (and associated background wind speed and direction) over the northern Puget Sound region.

To include the pertinent terrain features (including islands and ocean passages) that influence wind flow in the northern Puget Sound study area as originally described, the modeling area was enlarged to include the northern portions of the Olympic Peninsula, Washington; and the southern portion of Vancouver Island, British Columbia, Canada. The entire area is shown in Figure 2, along with the "core area" of interest, centered around Bellingham and the refinery and wharf developments near Ferndale and Anacortes. An enlarged view of this core region is shown in Figure 3.

Figure 2. Northern Puget Sound Study Area and "Core" Area of Interest.

Figure 3. Northern Puget Sound Region Showing Potential Petroleum Port and Refinery Development (Battelle Pacific Northwest Laboratories, 1977).

CHAPTER II
DATA COLLECTION

An inventory of major sources of SO₂ in the northern Puget Sound region is available from the National Emissions Data System files (NEDS). A list of these source locations and total SO₂ emissions for 1976 is shown in Table 4, along with the probable area sources of emission in the region.

Table 4. Major Sources of SO₂ in the Northern Puget Sound Area in 1976 (EPA-NEDS, 1977).

Source Number and Location	SO ₂ Emissions, 1976 (TPY)
Source 1, Port Angeles	2973
Source 2, Port Angeles	1269
Source 3, Port Townsend	1288
Source 4, Anacortes	8294
Source 5, Anacortes	5605
Source 6, Ferndale	6069
Source 7, Ferndale	4213
Source 8, Ferndale	4657
Source 9, Bellingham	1240
Source 10, Everett	1575
Source 11, Everett	1198
Source 12, Everett	21
<u>Area Sources</u>	
Port Angeles, Washington	Anacortes, Washington
Port Townsend, Washington	Oak Harbor, Washington
Everett, Washington	Victoria, British Columbia
Bellingham, Washington	

Meteorological data was collected from stations in the study area. These included locations with data on record with the National Climatic Center in Asheville, North Carolina and also a number of private data collection points operated by industries in the region. Table 5 is a list of all locations in the study area for which data were obtained. The station at Everett, which is just outside the modeled area, was used to check input for the wind flow model. A station at Quillayute, on the western side of the Olympic Peninsula, is also included. Upper air soundings were available for this location and were used to generate input for the wind flow model. Data for each of the four days used in the modeling effort are presented under each separate case later in this paper. The locations of the validation points are shown in Figure 4.

The four days chosen for analysis represent differing synoptic situations -- the one characteristic all have in common is that high pollutant concentrations occurred within the northern Puget Sound region on each of the four days. January 3, 1975 and February 12, 1975 were marked by violations of short-term SO_2 standards at Bellingham while January 24 and 30, 1975 showed the highest particulate levels (although within standard limitations) that were recorded over the two year period (1975-1976) at Mt. Vernon. Some relationships between synoptic meteorology and air quality are apparent from these four cases and their relationship to average meteorological conditions is also of interest.

The Washington coast is located approximately in the center of a zone of prevailing westerlies with local winds varying from northwest to southwest throughout most of the year. The seasonal cycle of winds on the Pacific Northwest coast is largely determined by the circulation about the northern Pacific high pressure area and the Aleutian low

Table 5. Locations From Which Meteorological Data
were Obtained for Model Validation.

Name and Location	Code
ARCO Refinery, Ferndale, Washington	FARC
Mobile Refinery, Ferndale, Washington	FMBL
Airport, Bellingham, Washington	BELA
Columbia Cement, Bellingham, Washington	BELC
PAMS Station, Bellingham, Washington	BELT
Shell Refinery, Anacortes, Washington	ASHL
Allied Chemical, Anacortes, Washington	AALC
Northwest Petrochemical, Anacortes, Washington	ANWP
Texaco Refinery, Anacortes, Washington	ATEX
Puget Sound Power and Light, Bacus Hill, Washington	BHIL
Naval Air Station, Whidbey Island, Washington	WHID
Coast Guard Light Station, Smith Island, Washington	SMTH
Medical-Dental Building, Everett, Washington	EVRT
Victoria Int'l. Airport, Vancouver Island, British Columbia	VICA
Gonzales Heights, Vancouver Island, Victoria, British Columbia	VICH
Pearson Aircraft, Port Angeles, Washington	PAPA
Coast Guard, Ediz Hook, Port Angeles, Washington	PACG
Quillayute Airport, Quillayute, Washington	QUIL

Figure 4. Locations From Which Meteorological Data Were Obtained for Model Validation.

pressure area. During summer the north Pacific high reaches its greatest development (approximately 1025 mb.) and is centered about 30-40°N and 150°W; the Aleutian low is weak during this period. The interaction of these pressure zones favors the development of summer winds generally from the northwest quadrant over the nearshore and coastal areas of Washington.

During winter the north Pacific high weakens and its center shifts about 10° southward while the Aleutian low intensifies. The resulting winds, frequently at gale force, approach the Washington coast from the southwest quadrant.

Extra-tropical cyclones occur most frequently in winter and the strongest winds are associated with the more intense winter storms moving east across the ocean. Depending upon the location of the center as it impinges on the coast, winds may be from northwest to southeasterly. In western Washington, circulation of air around the low centers approaching land results in a high frequency of strong southeasterly and southerly winds along the coast and strong easterly winds in the Strait of Juan de Fuca.

The barrier presented by the mountains of the coast range influences the general wind pattern, deflecting the winds so that they tend to align with the trend of the coast. In regions where the mountains are low, the deflecting effect is minimal and normal oceanic wind conditions prevail. The low level passages through the mountains at Hoquiam, Washington; the Strait of Juan de Fuca; and the Strait of Georgia show this pattern and influence the overall wind flow through the study area.

Table 6 shows the seasonal cycle of winds approaching the Washington coast, measured at the Umatilla Lightship located off Cape Alava of the Olympic Peninsula at $48^{\circ} 10.0' \text{ N}$, $124^{\circ} 50.0' \text{ W}$. The table shows resultant wind speed and direction (vector sum of all observations taken each month) and mean scalar speed over a five year period. Figures 5, 6 and 7 show January, July and annual surface wind roses at various locations in western Washington. The channeling effect of the Straits of Georgia and Juan de Fuca and the Hoquiam-Puget Sound passage are evident at several stations.

The air quality data collected for the years 1975 and 1976 show that short-term SO_2 violations in the study area occur most often in several day "episodes" during the winter period (i.e. January 3-9, 1975; February 10-13, 1975; December 1-4, 1975; February 16-19, 1976). The highest TSP levels recorded, on the other hand, show little discernable pattern, although the occurrence of several day episodes such as are seen in the SO_2 data would not be apparent here because measurements of particulate concentrations are only taken every fourth day.

Meteorological data were collected for the January 3-9 and the February 10-13, 1975 periods. Some similarity in synoptic conditions may be ascertained: data for both time periods show low pressure centers at the surface in the immediate vicinity of the study area or moving across the northern Puget Sound region, with associated fronts passing through the area under study. Low pressure systems were apparent at 850 mb. in the northwest quadrant relative to the study area with flow from the south, southwest or west. Flow at 700 and 500 mb. was from the northwest, west or southwest around the Aleutian low with an additional low pressure center at 700 mb. to the west of the study area on some occasions.

Table 6. Seasonal Cycle of Winds Along Washington Coast
for Five Year Period (1961-1965) (EPA, 1972).

Month	Resultant Direction (degrees)		Resultant Speed (knots)	Scalar Speed (knots)	Number of Observations
January	182	S	7	18	557
February	167	SSE	4	16	675
March	210	SW	3	14	693
April	208	SW	5	15	713
May	265	W	5	13	745
June	266	W	5	12	719
July	238	WSW	4	10	860
August	206	SW	2	7	925
September	179	S	2	8	900
October	167	SSE	8	13	923
November	161	SSE	9	16	898
December	168	SSE	9	17	930

Figure 5. Surface Wind Roses for Washington Stations - January. (Washington State University, 1972)

Figure 6. Surface Wind Roses for Washington Stations - July.
(Washington State University, 1972)

Figure 7. Surface Wind Roses for Washington Stations - Annual (Washington State University, 1972)

It would appear that a synoptic situation which is associated with high SO₂ concentrations in the study area is the passage of extra-tropical cyclones to the north or through the area and, in particular, a rapid succession of several cyclones passing through the region over the period of a few days. This situation is likely to be most common during the winter months.

The occurrence of SO₂ short-term standard violations during such periods may reflect the configuration of major SO₂ sources and SO₂ sampling locations in the region. Three-quarters of the violations recorded over the two year period were at the Bellingham locations and both episodes discussed (January 3-9 and February 10-13, 1975) showed violations at this location on each day. The presence of low pressure systems to the northwest of the study area at 850 mb. and to the north, northeast or northwest at the surface would bring prevailing flow over the northern Puget Sound region (at plume height) from the south to southwestern sector. Under such circumstances, the Bellingham location would be "downwind" from the refinery complexes at March Point (which represent major sources of SO₂ in the area) much of the time.

January 3, 1975 provides a good example of a typical wintertime situation. A low pressure center developed to the west of the study area at 850 mb. and moved eastward across the region through the period of analysis. Surface conditions show the development of a depression directly east of the study area during the simulation. Presumably, 24 hour SO₂ standard violations at Bellingham were primarily caused by flow conditions from the southern quadrant during the first part of the day. (More detailed discussions of meteorological conditions are given under each separate case in the appendices included with this paper.)

February 12 represents a similar situation with a strong low pressure system at the surface, 850 mb., 700 mb. and 500 mb. to the west of the study area. Flow was generally from the southwest at all levels, although the position of an occluded front through the study area complicated the surface flow situation. This pattern is also likely to occur during the winter months as extra-tropical cyclones develop in the Gulf of Alaska and move south and eastward.

The two days chosen for simulation on the basis of TSP measurements are quite different synoptically. January 24, 1975 was characterized by light winds with fairly high pressure conditions at the surface in northern Puget Sound. Flow at the upper levels was westerly around the Aleutian low. Stagnation conditions generally inhibit dispersion of pollutants and such uncharacteristically light wind speeds through the northern Puget Sound region would allow pollutant buildup in the study area. This situation would not be typical of the winter months and might be expected more frequently in summer.

January 30, 1975, in contrast, showed a more typical winter pattern with cyclones developing off the Pacific coast. This resulted in steady southeasterly flow at the surface over northern Puget Sound and southerly to southwesterly flow at upper levels. Winds were strong over much of the region and blowing dust may have contributed a significant portion of the TSP load measured on this occasion.

The four days chosen for analysis indicate that high pollutant concentrations may occur in the northern Puget Sound region under a variety of meteorological conditions. The rapid passage of extra-tropical cyclones that can occur during the winter months is apparently conducive to high SO_2 levels in some portions of the study area. This may reflect

source/receptor configuration to some extent. Stagnation conditions, though probably less common in the area, can occur and would tend to inhibit dispersion of any pollutants introduced into the atmosphere over northern Puget Sound. Conditions that offer a potential for pollutant concentration may also be accompanied by southeasterly flow over the region -- a fairly common occurrence during the winter period. The individual cases to be modeled show a variety of flow conditions with background directions 360.0° clockwise to 247.5° represented and wind speeds from 1 m/s to 6.5 m/s. Flow from the west to northwest, which would be a common summertime situation, is not represented. Each case reflects a situation where the meteorological conditions could interact with contaminant emissions in such a way that high groundlevel concentrations of pollutants would result.

CHAPTER III

MODEL DESCRIPTIONS

WINDS

The WINDS model is a simple one-layer model of atmospheric boundary layer flow that was developed for use in complex terrain. The model was derived through simplification of the fundamental Navier-Stokes flow equations. This simplification was gained by neglecting advection terms in the equations of motion and by assuming an impulse solution. Although the equations do not describe all flow characteristics, the resultant solution describes a diagnostic model of the vector flow field. Procedures for solving the equations involve serial approximations which superimpose a new physical effect on the previous solution. The first step in the solution is to transfer the large scale background wind into a terrain-induced modification of the throughflow. Next, thermal and frictional modification of the vorticity and divergence are introduced and superimposed on the terrain-induced flow. Finally, stream functions and velocity potentials are calculated so that the wind speed and direction can be defined at all interior points. The WINDS model is described more fully in a U. S. Forest Service technical paper (see Appendix A) (Fosberg, Marlatt and Krupnak, 1976) and a user's manual (Childs and Marlatt, 1978).

Input

An array of grid points, 54 rows by 72 columns, with a spacing of 2,032 meters between points was used to represent the study area. The major inputs required to run the WINDS model and the information sources used in this analysis to arrive at these inputs include:

1. ELEV - an array of elevations in meters at each grid point.

Elevations for this study were obtained from the TOPAS map tapes developed by the U. S. Army (Topographic Analysis System User's Guide, U.S.D.A. Forest Service, 1976), see Appendix B.

2. IVEG - an array containing types of vegetation growing at each grid point. This information was taken from U.S.G.S topographic maps (1:250,000 scale). Vegetation types used and associated roughness lengths are listed in Table 7. A map of vegetation types in the study area appears as Figure 9.

3. T70, T80, H70, H80 - temperatures and heights of upper level surfaces. T70 ($^{\circ}\text{K}$) is the temperature of the 700 mb. surface. T80 ($^{\circ}\text{K}$) is the temperature of the 850 mb. surface. H70 (m) is the height of the 700 mb. surface. H80 (m) is the height of the 850 mb. surface.

These variables were determined from upper atmosphere soundings taken from the Quillayute station in the northwestern section of the Olympic Peninsula and from upper air maps. Soundings and map readings are available at 12 hour intervals, at approximately 0300 PST and 1500 PST in the Puget Sound region.

The variables described are used to compute SIGMA, the lapse rate of the atmosphere over the study area and THETABR, the surface potential temperature. In conjunction with the elevation arrays, these variables are used to compute potential surface temperature ($^{\circ}\text{K}$) at each grid point (array THETA). The computed potential temperatures were used for all grid points with an elevation greater than zero (sea level). Surface

Code	Elevation (ft.)
Blank	0.0
.	.1-10.0
-	10.1-100.0
+	100.1-300.0
=	300.1-500.0
*	500.1-750.0
U	750.1-1000.0
\$	1000.1-1500.0
N	1500.1-2000.0
W	> 2000.0

Figure 8. Grid Point Elevations for the Northern Puget Sound Study Area.

Table 7. Vegetation Types, Associated Map Codes and Roughness Lengths Used for WINDS Model Input (Fosberg, Marlatt, Krupnak, 1976).

Vegetation Type	Map Code	Roughness Length (m)
Forest	F	2.80
Rough Water	R	0.10
Smooth or Protected Water	W	0.01
Thin Grass up to 50 cm High	G	0.05
Cultivated Fields	S	1.00
Towns	T	1.65
City or Urban Areas	V	2.00
Orchard	O	1.98
Industrial	I	1.65

Figure 9. Grid Point Vegetation Codes for Northern Puget Sound Study Area.

water temperatures were determined from information on average January and February temperatures for the northern Puget Sound area (Washington State University, 1972). A value of 282.16°K was used for all ocean surface grid points. The non-dimensional surface pressure array, PSTR, was also calculated from the above variables and the ELEV array.

4. ZHT (m) - vertical height of the air slab (6 meters used).
5. DEGRES (deg.) and SPD (m/sec.) - the background wind direction over the entire grid, based on a 16-point compass, and the speed of the prevailing background flow (m/sec.).

The WINDS model requires a single prevailing background flow as input. For most situations, however, it is impossible to realistically assume a single prevailing flow over the entire grid area as the flow field will have been channelized and perturbed by surrounding terrain features before it reaches the study area.

The northern Puget Sound region seen in Figure 10 shows three interconnected low level channels. These are Puget Sound to the southeast, the east-west oriented Strait of Juan de Fuca in the southwestern portion of the study area and the Strait of Georgia, filling the north-central portion of the area and oriented somewhat northwest-southeast. The interior of Vancouver Island, the Olympic Peninsula and the foothills of the Cascades on the eastern edge of the area surround the sea level passages with much higher terrain. Wind speed and direction at the study area boundary will depend on the direction from which winds approach the coast, coupled with the influence of channelization through the three low level passages. This can result in quite different prevailing background flow characteristics for various sections of the grid area. This situation is discussed further in Appendix C.

Figure 10. Northern Puget Sound Region Showing Three Low Level Interconnecting Channels: Hoquiam-Puget Sound, Strait of Juan de Fuca, Strait of Georgia.

The capability to input observed wind data at any grid point provides some flexibility in dealing with a complex flow situation such as occurs in the study area. Required inputs are the x and y coordinates of the observed data points, the wind direction in degrees and speed in meters per second. The points are set to the observed data and then interpolated into the initial background wind field. Each point influences speed and direction out through a circular area with a radius of three grid points and with the observed data at the center.

To simulate the complex flow characteristics in the study area, a scatter of points in the northern section of Puget Sound and another set of points in the Strait of Juan de Fuca were used as "observed" data points. These were located so as to allow the user to define a trend in flow in either passage that would differ from the background speed and direction over the grid as a whole, without directly affecting any of the validation stations. The location of the points used are shown in Figure 11.

The Puget Sound points could be set either to the background flow or to a southeasterly flow direction of 135° , at any speed. Data points in Juan de Fuca Strait could be set to indicate an easterly flow (90°), a westerly flow (270°) or to the background speed and direction. These points were only used when the meteorological data collected indicated channelization in one passage or the other that differed significantly from the apparent background speed or direction over the rest of the grid. The station at Everett and, to a lesser extent, the stations at Smith and Whidbey Islands were used as indicators of flow from Puget Sound. The Victoria-Gonzales Heights station was examined with reference to wind flow characteristics in the Juan de Fuca region.

Figure 11. Location of "Observed" Data Points in the Northern Section of Puget Sound and Strait of Juan de Fuca.

The two Port Angeles stations are also located in the Strait of Juan de Fuca area but were excluded from the analyses. Examination of the data collected at these locations showed a large percentage of data missing. Another source (Jensen and Danard, 1975) indicates an apparent sheltering effect of surrounding land forms that may render at least one of the Port Angeles stations unrepresentative.

The problem remained of choosing a prevailing background speed and direction to input as the initial wind field over the entire grid. Most of the stations (including Quillayute) are located such that a strong influence of surrounding topography on the measured speeds and directions would be expected and is indeed apparent from the data collected. The locations least affected by local terrain and so most representative of prevailing flow conditions would appear to be at the refinery locations to the north of the grid area (FARC and FMBL stations), although complications can arise even here due to their location near the edge of the study area (see discussion of January 30, 1975 cases). An attempt to correlate the prevailing background flow with the 850 mb. level flow measured at Quillayute proved unsatisfactory. This station is located a considerable distance outside the study area and is on the other side of the Olympic Mountains, which block flow into the northern Puget Sound region from some directions at the 850 mb. level. Also, soundings are only available at 12 hour intervals (approximately 0315 PST and 1515 PST), while simulations were run for six periods on each of the four days chosen (0300, 0700, 1100, 1500, 1900 and 2300 hours PST).

The procedure used was to estimate a background flow based on a rough average of the core area stations, set the flow in Puget Sound and Juan de Fuca Strait as described above and simulate the windfield.

The errors in direction and speed for all stations were averaged and, on the basis of these average deviations, the initial background speed or direction adjusted and the simulation rerun. If necessary, this procedure was repeated to minimize the mean error over the entire grid area. The flows actually used were then compared to the observed conditions at the data station locations to see which matched most closely; in effect, to analyze what information would have provided the best approximation of measured flow if used in the WINDS model initially. This is discussed in more detail under each case simulation.

Output

Output from the WINDS model consists of a series of maps showing wind direction (based on a 16-point compass) and wind speed (meters/second) for each grid point for each day and time. A mixing volume index which describes the relative pollution potential of each grid cell, based primarily on wind speed and convergence or divergence of air parcels, is also calculated. The array of mixing volume indices calculated in the WINDS model is used as input to the TAPAS system (A Topographic Air Pollution Analysis System, Fosberg and Fox, 1977).

Topographic Air Pollution Analysis System (TAPAS)

The Topographic Air Pollution Analysis System (TAPAS) was developed from meteorological and air pollution dispersion models to allow the incorporation of air quality considerations into land use planning procedures. The windfield (calculated in WINDS) is combined with a dispersion model to determine a mixing volume which, in conjunction with

the Pollutant Standards Index, provides a means of determining total emissions at specified air quality levels. The resultant index, the PI (π)-Matrix, contains no source information but rather forms an atmospheric constraint matrix when applied to land use planning. Allowable emissions at each grid point are calculated for the PI(π) index matrix and the ambient air quality standards. (See more detailed discussion of the TAPAS system in Fosberg and Fox (1977) in Appendix D.)

Input

The major inputs to the TAPAS system include:

1. UD, UN

Arrays of wind speeds (m/s) at each grid point (from WINDS model) for day or night cases, respectively.

2. AINDXD, AINDXN

Mixing volume indices for each grid point (from WINDS model), day or night case. This index represents the volume that would be incorporated by a plume located within each computational grid cell. Basically, this is the air available for mixing the effluent. The theoretical development of this index is based on the Gaussian Plume model. The index, I, is defined as $\frac{\chi}{Q} \times 10^6$ where χ is the ambient pollutant concentration, Q is the pollutant emission rate and 10^6 is a scaling factor based on Turner's (1969) maximum value of $\chi \frac{u}{Q}$ from a groundlevel source with Class F stability, where u represents wind speed.

3. PSI

The Pollutant Standards Index (Ψ) (Thom and Ott, 1976) which is defined: $\Psi = a + b\left(\frac{\chi}{\chi_s}\right)$ where χ_s is the ambient air quality standard for a particular pollutant; a and b are constant scaling factors (set to 0 and 100, respectively, for the current analysis) and χ is the ambient concentration of the pollutant.

2. LCHIS, SCHIS

Long-term (> 3 hours) and short-term (3 hours or less) air quality standards for the effluent being analyzed. The standards considered under the TAPAS section of this study were federal and state annual average standards for SO_2 (.03 ppm ($80 \mu\text{g}/\text{m}^3$) and .02 ppm ($60 \mu\text{g}/\text{m}^3$), respectively), the Washington 24 hour average standards for SO_2 (.10 ppm ($260 \mu\text{g}/\text{m}^3$)), the state one hour average standard for SO_2 , not to be exceeded more than once per year (.40 ppm ($1047 \mu\text{g}/\text{m}^3$)) and federal incremental standards for Class II and Class III areas (.0076 and .015 ppm (20 and $40 \mu\text{g}/\text{m}^3$), respectively).

Output

The output from the TAPAS system is a PI-Matrix of the same dimensions as the mixing volume index. The PI-Matrix represents maximum allowable emissions in each grid cell that will insure that the standards are not exceeded. Two forms of the PI-Matrix are used, based on different averaging times:

1. For application to short-term standards, no longer than three hours, a short-term PI-Matrix is calculated. The π_s values, in dimensions of mass per unit time, represent total emission rates

which will result in air quality of a given Ψ value within each grid cell. For all the PI-Matrix calculations in this analysis, values of χ were set equal to χ_s in the Pollution Standards Index calculations. The short-term π_s value represents the instantaneous emission rate allowable.

2. For standards longer than three hours averaging time, a different PI-Index is calculated. The long-term index π_L is arrived at by using Gaussian dispersion to define a mixing cross-sectional area, and then using concepts similar to the box model (Fox, 1975) to compute the volume. The Gaussian form of the mixing volume index is transformed to a ventilated box model. The π_L index obtained is in units of mass. An emission rate must be multiplied by the length of time it is operating to give the allowable pollution loading for a given cell.

Two averaging periods were used to calculate long-term π_L matrix values. A 24 hour average value was calculated using a daytime situation (1500 PST) and a nighttime situation (0300 PST) for each day simulated. An annual PI-Matrix was calculated from the annual mixing volume index based on annual wind rose data from Bellingham.

CHAPTER IV

RESULTS

The results of the wind flow modeling and associated PI-Matrix values for each of the four days chosen are shown in the following section. For the wind flow analyses all input, observations, data points and resultant wind directions were rounded to the nearest 22.5° sector (16-point compass). Likewise, speeds were rounded to the nearest meter per second. Stations were located as nearly as possible on a topographic map (1:250,000 scale) and then assigned to the closest grid point. As some data stations only report wind direction to the nearest 45° and since all input, observations and output were rounded to the nearest compass point, a tolerance of $\pm$ one compass point (22.5°) was assumed for the simulation results. Thus, the wind flow directions were considered correctly modeled if the simulated value was within 22.5° of the direction reported (after rounding to the nearest compass point). Wind speeds were assumed correctly simulated if within $\pm$ one meter per second of the reported value.

The necessity of assigning each station a grid point location introduced some additional variance into the validation procedure. In several cases, the exact location of the site was uncertain enough that it could easily have been assigned to one of the other surrounding grid points. Since adjacent grid points often have different wind flows, the model may have, in some cases, correctly simulated the true wind flow at the station location even though the predicted value was more than one compass point or one meter per second different from the reported value. For this reason, the average deviations were relied on most heavily in evaluating WINDS model performance.

Appendix E, included with this report, contains more detailed information concerning the four case analyses. The appendix contains a description of the synoptic meteorology influencing the northern Puget Sound region during each period of analysis, along with sounding data from Quillayute, Washington. Observed and predicted wind flow conditions at data station localities are presented for each hour of the analyses. Wind flow modeling results for the entire northern Puget Sound region are summarized in wind flag maps and the PI-Matrix results are shown in a series of shaded maps.

WIND FLOW SIMULATION ANALYSES

Comparison tables for the wind flow analyses use the following conventions: notations are an indication of magnitude and direction that predicted winds err from observed wind data. Units are meters per second for wind speed and compass points (16-point compass) for direction. Positive (+) deviations for direction indicate error in a clockwise direction and negative (-) deviations indicate error in a counter-clockwise direction from the observed winds. Likewise, positive (+) deviations in wind speed indicate over-prediction and negative (-) notations indicate predicted wind speeds below recorded values.

The mean error between observed and simulated values of wind speed and direction and the standard deviations of error were calculated for each case. Mean and standard deviation values were calculated for all stations shown in the WINDS results tables and also for the stations in the "core" area only (FARC, FMBL, BELA, BELC, BELA, BELT and the Anacortes-March Point stations).

The mean error provides a point estimation of the overall accuracy with which wind flow conditions were simulated for a given time period. The standard deviation of error has been used as a measure of spread. These parameters facilitate comparison between simulation results for different time periods. As discussed previously, deviations of less than or equal to one compass point or one meter per second are within the tolerance units expected of the simulation due to time, grid point and rounding discrepancies between the collected data and the simulated situations. Unfortunately, the nature of the data precludes the estimation of a precise rejection region by standard statistical methods (i.e. non-normality of error distributions invalidate the matched pair t-test; ties and zero difference scores violate the assumptions of non-parametric procedures such as the Wilcoxon test, etc.). It is apparent, however, that small errors (≤ 1 -2 compass points or meters per second) are relatively uninformative while large discrepancies may provide useful information regarding model limitations or station anomalies. Since much of the data collected was used, at least indirectly, to generate input variables, the comparison of observed and simulated flow conditions at the 11 data locations does not represent a validation procedure but simply an analysis of how closely the observed situation could be simulated by the model.

The Allied Chemical station at March Point (AALC) was eliminated from the analysis as examination of the January 3 and February 12, 1975 meteorological data showed frequent large deviations from the other three nearby stations. Since these four stations (AALC, ASHL, ATEX and ANWP) are located at the same grid point for modeling purposes, the elimination of this station seemed justifiable. The three March Point stations were treated as one data point in the analyses by averaging the deviations of

the simulated wind flow at that grid location from the three observed values.

Table 8 is a summary of final input flows, temperature and pressure data used in the wind flow analyses. The speed and direction to which the "observed" data points were set is indicated under the Puget Sound and Juan de Fuca designations.

Tables 9, 13, 17 and 21 are comparisons of simulation results with the observed meteorological data. Deviations are recorded as compass points (16-point compass) and meters per second. "Core" area stations are FARC, FMBL, BELA, BELC, BELT and the Anacortes Stations (AAVE).

Tables 10, 14, 18 and 22 represent more detailed comparisons of WINDS results to the observed data. The fractions of the predicted values within a given number of compass points or meters per second of the observed values are shown for each hour simulated.

Tables 11, 15, 19 and 23 show analyses of observed versus predicted values for each station for each day simulated. Mean error values and the standard deviation of error are given -- units are compass points (16-point compass) for direction and meters per second for speed. Tables 12, 16, 20 and 24 are comparisons of the Ferndale station (FARC and FMBL) observations and the 850 mb. sounding data from Quillayute with the background direction and speed used in the analyses.

Table 8. Final Input Data Used in Wind Flow Simulation.
Units are degrees for direction, meters per
second for speed, °K for temperature and meters
for heights.

Time	Background		Puget Sound		Juan de Fuca		T70	T80	H70	H80
	Dir	Speed	Dir	Speed	Dir	Speed				
<u>January 3, 1975</u>										
0300	225.0	5.0	135.0	3.0	225.0	5.0	258.7	267.7	3003	1511
0700	157.5	3.0	135.0	2.0	270.0	2.0	260.1	268.5	2972	1464
1100	112.5	2.0	135.0	3.0	112.5	2.0	261.5	269.3	2940	1417
1500	67.5	3.5	135.0	4.0	67.5	3.5	262.9	270.1	2909	1390
1900	90.0	4.0	135.0	5.0	90.0	4.0	261.5	269.3	2878	1363
2300	22.5	4.0	135.0	8.5	22.5	4.0	260.1	268.5	2846	1336
<u>January 24, 1975</u>										
0300	180.0	3.0	180.0	3.0	180.0	3.0	267.6	270.2	3017	1496
0700	135.0	2.0	135.0	2.0	270.0	2.0	267.0	270.5	3010	1486
1100	157.5	2.0	135.0	2.0	270.0	2.0	266.4	270.8	3003	1476
1500	180.0	1.0	135.0	1.0	270.0	4.0	265.8	271.2	2996	1466
1900	225.0	1.0	225.0	1.0	270.0	3.5	264.3	270.5	2987	1464
2300	0.0	1.0	360.0	1.0	270.0	2.0	262.8	269.9	2978	1462

Table 8. Continued

Time	Background		Puget Sound		Juan de Fuca		T70	T80	H70	H80
	Dir	Speed	Dir	Speed	Dir	Speed				
<u>January 30, 1975</u>										
0300	112.5	4.0	135.0	6.0	90.0	7.0	258.6	266.8	2918	1427
0700	112.5	4.0	135.0	7.0	90.0	10.0	258.6	266.9	2944	1398
1100	112.5	5.5	135.0	6.5	90.0	16.0	258.6	267.0	2960	1369
1500	112.5	4.0	135.0	12.0	90.0	15.0	258.6	267.0	2840	1340
1900	112.5	6.5	135.0	6.5	90.0	20.0	259.1	267.4	2822	1319
2300	112.5	6.0	135.0	10.0	90.0	18.0	259.6	267.8	2804	1298
<u>February 12, 1975</u>										
0300	112.5	5.0	135.0	12.0	112.5	5.0	268.8	276.2	2777	1229
0700	157.5	6.0	135.0	11.0	90.0	2.0	266.4	274.4	2787	1249
1100	180.0	6.5	135.0	8.5	90.0	3.0	263.9	272.7	2797	1269
1500	247.5	5.5	247.5	5.5	270.0	13.0	261.4	271.0	2806	1290
1900	157.5	2.5	157.5	2.5	270.0	8.0	261.7	270.8	2821	1320
2300	157.5	1.5	135.0	1.5	270.0	4.0	262.0	270.5	2836	1320

Table 9. Comparison of Winds Results With Observed Data -- January 3, 1975.
Units are compass points (16 point compass) for direction and
meters per second for speed comparisons.

Station Code	Time									
	0300 Dir/Spd	0700 Dir/Spd	1100 Dir/Spd	1500 Dir/Spd	1900 Dir/Spd	2300 Dir/Spd				
FARC	0 -3	0 -1	-1 0	0 -2	0 -3	+1 +2				
FHBL	0 0	-1 -1	+1 0	-1 0	-1 +1	-1 -2				
BEIA	+1 -1	0 -3	0 0	0 0	+2 -3	+1 0				
BEIC	0 0	+2 0	+2 0	+2 +1	0 +1	+1 0				
BELT	0 0	+1 0	+1 +1	+2 +1	+3 -1	0 0				
AAVE*	+1 0	-1 -1	-1 -2	-1 -2	+1 -2	-4 0				
BHIL	-1 +4	-7 0	+2 0	+1 -1	+1 +1	0 -3				
WHID	0 -1	+2 +1	-1 -1	+1 +1	0 +1	0 +1				
SHYH	+1 -2	0 -1	- -	+1 -4	+1 -2	- -				
VICA	-1 +1	-2 +1	-1 0	-1 -3	0 -5	0 -3				
VICH	0 -2	-1 0	+1 -2	-1 -2	0 -6	-1 -4				
Mean Error All Stations	.09 -.36	-.64 -.45	.30 -.40	.27 -1.00	.64 -1.64	-.30 -.90				
Standard Deviation of Error All Stations	.70 1.90	2.46 1.13	1.25 .97	1.19 1.73	1.12 2.50	1.49 1.97				
Mean Error Core Area	.33 -.67	.17 -1.00	.33 -.17	.33 -.33	.83 -1.17	-.33 0.00				
Standard Deviation of Error Core Area	.52 1.21	1.17 1.10	1.21 .98	1.37 1.37	1.47 1.83	1.97 1.26				

Table 10. Fraction of the Predicted Values Within a Given Number of Compass Points or Meters per Second of Observed Values for January 3, 1975 Simulation.

	0300	0700	1100	1500	1900	2300
<u>All Stations</u>						
<u>±</u> 1 Compass Point	1.00	.64	.80	.82	.82	.90
<u>±</u> 2 Compass Points	1.00	.91	1.00	1.00	.91	.90
<u>±</u> 1 m/s	.64	.91	.80	.54	.45	.50
<u>±</u> 2 m/s	.82	.91	1.00	.82	.64	.70
<u>±</u> 3 m/s	.91	1.00	1.00	.91	.82	.90
<u>"Core" Stations</u>						
<u>±</u> 1 Compass Point	1.00	.83	.83	.67	.67	.83
<u>±</u> 2 Compass Points	1.00	1.00	1.00	1.00	.83	.83
<u>±</u> 1 m/s	.83	.83	.83	.67	.50	.67
<u>±</u> 2 m/s	.83	.83	1.00	1.00	.67	1.00
<u>±</u> 3 m/s	1.00	1.00	1.00	1.00	1.00	1.00

Table 11. Analysis of Simulation Accuracy for Each Station for All January 3, 1975 Cases. Units are compass points (16-point compass) and meters per second.

Station Code	Mean Error		Standard Deviation of Error	
	Direction	Speed	Direction	Speed
FARC	0.00	-1.17	.63	1.94
FMBL	-.50	-.33	.84	1.03
BELA	.67	-1.17	.82	1.47
BELC	1.17	.33	.98	.52
BELT	1.17	.17	1.17	.75
AAVE	-.83	-1.17	1.83	.98
BHIL	-.67	.17	3.27	2.32
WHID	.33	.33	1.03	1.03
SMTH	.75	-2.25	.50	1.26
VICA	-.83	-1.50	.75	2.51
VICH	-.33	-2.67	.82	2.07

Table 12. Comparison of Ferndale Stations and 850 mb. Wind Flow From Quillayute Soundings with Background Flow Used as Final Input to WINDS Model (Jan. 3, 1975 Simulation). Units are degrees and meters per second.

	0300		0700		1100		1500		1900		2300	
	Dir/Spd		Dir/Spd		Dir/Spd		Dir/Spd		Dir/Spd		Dir/Spd	
Background Flow WINDS	225	5.0	158	3.0	113	2.0	68	2.0	90	4.0	23	4.0
FARC Obs.	225	8.0	158	4.0	135	2.0	68	6.0	90	7.0	360	3.0
FMBL Obs.	225	6.0	180	5.0	113	2.0	90	3.0	113	3.0	45	6.0
QUIL 850 mb. Observation	225	14.0	-	-	-	-	140	41.0	-	-	-	-

Table 13. Comparison of Winds Results With Observed Data -- January 24, 1975.
Units are compass points (16-point compass) for direction and
meters per second for speed comparisons.

Station Code	Time											
	0300		0700		1100		1500		1900		2300	
	Dir/Spd		Dir/Spd		Dir/Spd		Dir/Spd		Dir/Spd		Dir/Spd	
FARC	-1	-1	-2	-2	-1	-1	0	0	-	+2	+3	-3
FMBL	0	+1	-1	0	0	+1	+1	+1	-	+2	0	-2
BELA	-1	-2	0	0	0	-1	-1	-2	+1	0	-	+1
BELC	+1	+1	+5	+2	0	+1	-2	+1	-	+2	-1	0
BELT	+1	+2	+4	+1	0	+2	-	+2	-1	+1	-	+1
AAVE*	+2	0	0	-1	+1	-1	+2	0	0	0	0	+1
BHIL	-4	+1	+2	+1	+2	-1	+4	0	-3	+1	0	0
WHID	+1	+2	+2	0	+2	0	+1	0	+1	0	-	+2
SMTH	0	-2	+1	-1	-	-	-	+1	0	-2	-	-
VICA	-1	-3	-	+2	-5	0	-5	-1	-3	-1	+3	0
VICH	-2	-2	0	-2	0	+1	+1	-1	-1	0	-1	0
Mean Error												
All Stations	-.36	-.27	1.10	0.00	-.10	.10	.11	.09	-.75	.45	.57	0.00
Standard Deviation												
of Error												
All Stations	1.69	1.79	2.18	1.41	1.97	1.10	2.57	1.14	1.58	1.29	1.72	1.49
Mean Error												
Core Area	.33	.17	1.00	0.00	0.00	.17	0.00	.33	0.00	1.17	.50	-.33
Standard Deviation												
of Error												
Core Area	1.21	1.47	2.83	1.41	.63	1.33	1.58	1.37	1.00	.98	1.73	1.75

*AAVE represents the average of ASHL, ANWP and ATEX results.

Table 14. Fraction of the Predicted Values Within a Given Number of Compass Points or Meters per Second of Observed Values for January 24, 1975 Simulation.

	0300	0700	1100	1500	1900	2300
<u>All Stations</u>						
<u>+ 1</u> Compass Point	.73	.50	.70	.56	.75	.71
<u>+ 2</u> Compass Points	.91	.80	.90	.78	.75	.71
<u>+ 1</u> m/s	.45	.64	.90	.82	.64	.70
<u>+ 2</u> m/s	.91	1.00	1.00	1.00	1.00	.90
<u>+ 3</u> m/s	1.00	1.00	1.00	1.00	1.00	1.00
<u>"Core" Stations</u>						
<u>+ 1</u> Compass Point	.83	.50	1.00	.60	1.00	.75
<u>+ 2</u> Compass Points	1.00	.67	1.00	1.00	1.00	.75
<u>+ 1</u> m/s	.67	.67	.83	.67	.50	.67
<u>+ 2</u> m/s	1.00	1.00	1.00	1.00	1.00	.83
<u>+ 3</u> m/s	1.00	1.00	1.00	1.00	1.00	1.00

Table 15. Analysis of Simulation Accuracy for Each Station for All January 24, 1975 Cases.

Station Code	Mean Error		Standard Deviation of Error	
	Direction	Speed	Direction	Speed
FARC	-.20	0.83	1.92	1.72
FMBL	0.00	.50	.71	1.38
BELA	-.20	0.67	.84	1.21
BELC	.60	1.17	2.70	.75
BELT	1.60	1.50	1.52	.55
AAVE	.83	-.17	.98	.75
BHIL	.17	.33	3.13	.82
WHID	1.40	.67	.55	1.03
SMTH	0.00	-1.00	1.41	1.00
VICA	-1.60	-.50	2.97	1.64
VICH	-.50	-.67	1.05	1.21

Table 16. Comparison of Ferndale Stations and 850 mb. Wind Flow From Quillayute Soundings with Background Flow Used as Final Input to WINDS Model (Jan. 24, 1975 Simulation). Direction rounded to nearest compass point (16-point compass).

	0300	0700	1100	1500	1900	2300
	Dir/Spd	Dir/Spd	Dir/Spd	Dir/Spd	Dir/Spd	Dir/Spd
Background Flow WINDS	180 3.0	135 2.0	158 2.0	180 1.0	275 1.0	0 1.0
FARC Obs.	203 4.0	180 4.0	180 3.0	180 2.0	Calm	293 4.0
FMBL Obs.	180 3.0	180 3.0	180 2.0	180 1.0	Calm	315 3.0
QUIL 850 mb. Observation	243 9.0	- -	- -	315 9.0	- -	- -

Table 17. Comparison of Winds Results With Observed Data -- January 30, 1975.
Units are compass points (16-point compass) for direction and
meters per second for speed comparisons.

Station Code	Time											
	0300		0700		1100		1500		1900		2300	
	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd
FARC	+1	-1	+1	0	+1	0	+1	0	+1	+1	+1	-2
FNBL	0	+1	0	0	0	+1	0	0	0	0	+1	-1
BELA	+4	-1	+3	+1	+4	-1	+5	+1	+1	-1	+4	+2
BELC	-	-	-	-	-	-	-	-	-	-	-	-
BELT	+4	+1	+3	+1	+5	+1	0	+1	+1	0	-1	+2
AAVE*	-1	0	-1	-2	-2	-1	-1	-2	0	+3	+1	+3
BHLL	+2	0	+2	0	+1	+2	+2	+2	+1	+4	+1	+3
WHID	+1	0	+1	0	+1	-1	0	0	+1	+2	+1	0
SMTH	0	-3	0	-5	-	-	0	-2	+1	-6	-	-
VICA	0	0	-2	-4	-1	-6	-1	-7	-1	-2	0	-3
VICH	-2	-2	-2	-2	-2	-2	-2	-7	0	-6	-2	-5
Mean Error												
All Stations	.90	-.50	.50	-1.10	.78	-.78	.40	-1.40	.50	-.50	.67	-.11
Standard Deviation												
of Error												
All Stations	1.97	1.27	1.84	2.08	2.44	2.33	1.96	3.20	.71	3.41	1.66	2.85
Mean Error												
Core Area	1.60	0.00	1.20	0.00	1.60	0.00	1.00	0.00	.60	.60	1.20	.80
Standard Deviation												
of Error												
Core Area	2.03	1.00	1.79	1.22	2.88	1.00	2.34	1.22	.55	1.52	1.79	2.17

*AAVE represents the average of ASHL, ANWP and ATEX results.

Table 18. Fraction of the Predicted Values Within a Given Number of
Compass Points or Meters per Second of Observed Values
for January 30, 1975 Simulation.

	0300	0700	1100	1500	1900	2300
<u>All Stations</u>						
<u>+ 1</u> Compass Point	.60	.50	.55	.70	1.00	.78
<u>+ 2</u> Compass Points	.80	.80	.78	.90	1.00	.89
<u>+ 1</u> m/s	.80	.60	.67	.50	.40	.22
<u>+ 2</u> m/s	.90	.80	.89	.80	.60	.56
<u>+ 3</u> m/s	1.00	.80	.89	.80	.70	.89
<u>"Core" Stations</u>						
<u>+ 1</u> Compass Point	.60	.60	.40	.80	1.00	.80
<u>+ 2</u> Compass Points	.60	.60	.60	.80	1.00	.80
<u>+ 1</u> m/s	1.00	.80	1.00	.80	.80	.20
<u>+ 2</u> m/s	1.00	1.00	1.00	1.00	.80	.80
<u>+ 3</u> m/s	1.00	1.00	1.00	1.00	1.00	1.00

Table 19. Analysis of Simulation Accuracy for Each Station for All January 30, 1975 Cases.

Station Code	Mean Error		Standard Deviation of Error	
	Direction	Speed	Direction	Speed
FARC	1.00	-.33	0.00	1.03
FMBL	.17	.17	.41	.75
BELA	3.50	.17	1.38	1.33
BELC	-	-	-	-
BELT	2.00	1.00	2.37	.63
AAVE	-.67	.17	1.03	2.32
BHIL	1.50	1.83	.55	1.60
WHID	.83	.17	.41	.98
SMTH	.25	-4.00	.50	1.83
VICA	-.83	-3.67	.75	2.58
VICH	-1.67	-4.00	.82	2.28

Table 20. Comparison of Ferndale Stations with 850 mb. Wind Flow From Quillayute Soundings with Background Flow Used as Final Input to WINDS Model (Jan. 30, 1975 Simulation). Direction rounded to nearest compass point (16-point compass).

	0300		0700		1100		1500		1900		2300	
	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd
Background Flow WINDS	112	4.0	112	4.0	112	5.5	112	4.0	112	6.5	112	6.0
FARC Obs.	90	5.0	90	4.0	90	6.0	90	4.0	90	6.0	90	8.0
FMBL Obs.	112	3.0	112	4.0	112	4.0	112	4.0	112	6.0	90	7.0
QUIL 850 mb. Observation	205	8.0	-	-	-	-	170	18.0	-	-	-	-

Table 21. Comparison of Winds Results With Observed Data -- February 12, 1975.
Units are compass points (16-point compass) for direction and meters
per second for speed comparisons.

Station Code	Time											
	0300		0700		1100		1500		1900		2300	
	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd	Dir	Spd
FARC	-	-	-	-	-4	0	-6	-1	+6	-3	+7	0
FMBL	-	+5	-3	+1	0	+1	-1	+3	0	0	0	+1
BELA	+5	0	0	-1	0	0	+1	-2	-1	-1	-1	0
BELC	0	0	+1	-1	+1	-1	+1	+2	0	+1	+1	0
BELT	+5	+1	+1	-2	+1	-1	+1	+2	0	+1	-	+2
AAVE*	-2	-4	0	-1	0	-2	-1	-2	0	0	+1	-3
BHIL	+1	-8	+3	-5	+1	-6	+1	-2	+4	-1	+4	-5
WHID	0	0	-1	0	0	-1	-1	0	-	+2	0	+1
SMTH	0	-2	0	+1	-	-	-1	-2	-5	-1	-	-
VICA	-7	+1	-	+6	+1	+2	+1	-7	-2	+1	-6	-2
VICH	-1	-6	+5	+2	-1	-4	+1	-2	-1	-2	-1	-5
Mean Error												
All Stations	.11	-1.30	.67	1.40	-.10	-1.20	-.36	-1.00	.10	-.27	.56	-1.10
Standard Deviation												
of Error												
All Stations	3.62	3.80	2.29	2.46	1.52	2.35	2.11	2.76	3.03	1.49	3.57	2.51
Mean Error												
Core Area	2.00	.40	-.20	-.80	-.33	-.50	-.83	.33	.83	-.33	1.60	0.00
Standard Deviation												
of Error												
Core Area	3.56	3.21	1.64	1.10	1.86	1.05	2.71	2.25	2.56	1.51	3.13	1.67

*AAVE represents the average of ASHL, ANWP and ATEX results.

Table 22. Fraction of the Predicted Values Within a Given Number of Compass Points or Meters per Second of Observed Values for February 12, 1975 Simulation.

	0300	0700	1100	1500	1900	2300
<u>All Stations</u>						
<u>±</u> 1 Compass Point	.56	.67	1.00	.91	.60	.67
<u>±</u> 2 Compass Points	.67	.67	1.00	.91	.80	.67
<u>±</u> 1 m/s	.50	.60	.60	.18	.73	.50
<u>±</u> 2 m/s	.60	.80	.80	.82	.91	.70
<u>±</u> 3 m/s	.60	.80	.80	.91	1.00	.80
<u>"Core" Stations</u>						
<u>±</u> 1 Compass Point	.25	.80	.83	.83	.83	.80
<u>±</u> 2 Compass Points	.50	.80	.83	.83	.83	.80
<u>±</u> 1 m/s	.60	.80	.83	.18	.83	.67
<u>±</u> 2 m/s	.60	1.00	1.00	.83	.83	.83
<u>±</u> 3 m/s	.60	1.00	1.00	1.00	1.00	1.00

Table 23. Analysis of Simulation Accuracy for Each Station for All February 12, 1975 Cases.

Station Code	Mean Error		Standard Deviation of Error	
	Direction	Speed	Direction	Speed
FARC	.75	-1.00	6.70	1.41
FMBL	-8.00	1.83	1.30	1.83
BELA	.67	-.67	2.25	.82
BELC	.67	.17	.52	1.17
BELT	1.60	.50	1.95	1.64
AAVE	-.33	-2.00	1.03	1.41
BHIL	2.33	-4.50	1.51	2.59
WHID	-.40	.33	.55	1.03
SMTH	-1.50	-1.00	2.38	1.41
VICA	-2.60	-.20	3.78	4.89
VICH	.33	-2.83	2.42	2.85

Table 24. Comparison of Ferndale Stations and 850 mb. Wind Flow From Quillayute Soundings with Background Flow Used as Final Input to WINDS Model (Feb. 12, 1975 Simulation). Direction rounded to nearest compass point (16-point compass).

	0300 Dir/Spd	0700 Dir/Spd	1100 Dir/Spd	1500 Dir/Spd	1900 Dir/Spd	2300 Dir/Spd
Background Flow WINDS	112 5.0	157 6.0	180 6.5	247 5.5	157 2.5	157 1.5
FARC Obs.	90 5.0	100 4.0	90 6.0	100 4.0	90 6.0	80 8.0
FMBL Obs.	110 3.0	110 4.0	110 4.0	110 4.0	110 6.0	100 7.0
QUIL 850 mb. Observation	220 6.0	- -	- -	245 9.0	- -	- -

January 3, 1975

The comparison tables (Tables 9, 10 and 11) show a fairly accurate simulation of the observed meteorology for January 3, 1975. The largest mean error occurred with the wind speed simulation at 1900 hours -- the underprediction of velocity evident here was influenced by large discrepancies at the two Victoria locations (VICA and VICH). The station analysis shows that the VICH and SMTH sites observed higher wind velocities than predicted for all the January 3 cases and VICA speeds were underpredicted during the final three hours. The station analysis also indicates that estimates of wind direction at the BHIL station were the least reliable (largest standard deviation) and that the accuracy of wind speed calculations at this station was also variable.

The background flow directions used (Table 12) shifted counterclockwise through the 24 hours simulated, following the trend in direction indicated by the 850 mb. sounding data. The differences between the 850 mb. data and the inputs used, however, are not consistent enough to have made the 850 mb. direction a good indicator of background flow over the entire grid. Likewise, the wind velocities at 850 mb. show little relation to the surface patterns evident from the data collected.

The Ferndale stations, on the other hand, would have been fairly good indicators of background flow on January 3, 1975. One station or the other showed the same direction as was used for the background flow for each case except 2300 PST, and the remaining station differed by no more than one compass point from the input direction. For the exception, 2300 PST, the input direction used (22.5°) lay between the directions indicated by FARC and FMBL (360° and 45° , respectively). Similarly, one station or the other was always within one meter per second of the

inputs used. Since the predicted wind speeds averaged slightly below the observed values for all the January 3 cases, using an average of FARC and FMBL observations for wind speed inputs, rather than the inputs actually used, would most likely have resulted in similar or improved overall model performance for the January 3 cases.

January 24, 1975

As with the January 3 cases, the overall simulation of observed conditions was reasonably accurate, although the direction errors exhibited a higher degree of variance in the January 24 simulation. Some difficulties were encountered in reproducing observed wind directions on January 24 due to the low wind velocities (2 m/s or less) encountered over much of the simulation period. The lack of a dominating background flow means that local thermal influences and small scale perturbations in flow become important, introducing a fair amount of random deviation into the observed flow characteristics. This, in turn, means that any individual observation is more difficult to duplicate in the simulation modeling than would be so under conditions of stronger flow. The large number of calm observations on January 24 adds to the wind speed prediction error figures as the WINDS model rarely, if ever, estimates such a low wind speed ($\leq .1$ m/s) that a zero wind speed prediction results.

The mean error figures in the station analysis table (Table 15) indicate that none of the stations were consistently misrepresented by the model -- the errors are instead distributed in either direction from the observed values, resulting in fairly large standard deviations for some locations but small mean error figures. Stations at BELC, BHIL and VICA were particularly variable with respect to direction errors.

The 850 mb. flow measurements from Quillayute do not show a predictable relationship to the input values used and would not have made effective estimators of the flow prevailing over the northern Puget Sound study area. The flow directions measured at FMBL are closest to the input values -- at 0700 and 2300 PST the observations were two compass points different from the input direction, while the discrepancy was one compass point or less for the other three hours where comparison was possible (1900 PST observations at both FARC and FMBL were calm). FMBL observations also closely approximate the input wind speeds -- within one meter per second for all cases but 2300 PST, when the difference was two meters per second.

The meteorological data collected for January 24, 1975 (Table B6 in Appendix B) shows a significant amount of variation from hour to hour at each station and also between stations at each time period, particularly during the latter half of the day. With this situation, the background flow direction used is really a compromise figure, an average of the directions indicated at the various station locations. Consequently, the input flow characteristics do not match observed conditions at any one location consistently. Under conditions of light and/or variable wind speeds and directions, even fairly "open" stations like FARC and FMBL make relatively unreliable indicators of prevailing flow over the entire grid area, if indeed a prevailing flow can be defined under such conditions.

January 30, 1975

The simulations of the January 30, 1975 cases show a significant amount of disagreement with measured conditions at some of the observation stations. Difficulties were encountered due to the fact that meteorological conditions over the entire grid area were not really at a "sub-synoptic" level. Synoptic conditions remained fairly uniform throughout the day, with surface level flow over the study area from an easterly to southeasterly direction, toward the depression centered off the west coast of Washington. The grid area is large enough, however, that observed prevailing flow differed by one or two compass points between the northern portions of the study area and the southern boundary. Thus, measured flow direction at the northernmost station (FARC) was regularly one compass point counterclockwise from the simulated value, while the Anacortes and Victoria stations erred in the opposite direction (a "compromise" input direction of 112.5° was used as prevailing flow over the entire grid for all cases).

The two Bellingham stations for which meteorological observations were obtained show north to northeasterly flow much of the day, while the prevailing background flow over the rest of the grid appears more southeasterly. The wind flow simulation predicted directions for these stations more in line with the overall pattern, resulting in large directional error statistics for these stations.

SMTH, VICA and VICH were consistently under-predicted with respect to wind velocity. Wind speeds as high as 18 m/s were recorded at VICH and SMTH during several of the simulation periods. Velocities in excess of the background flow were input at the "observation" points in Puget Sound and the Strait of Juan de Fuca in an attempt to duplicate the

strong winds apparent in the straits on January 30. It should be noted that wind speeds predicted by the model are somewhat more conservative than the range seen in the data collected from the northern Puget Sound area -- calm situations are not duplicated and the highest wind speeds are under-predicted to some extent. Under-prediction of extreme wind speeds is also, in part, due to the fact that input winds were chosen to err towards slower speeds to insure that the air quality information was conservative.

Comparison of the Ferndale stations (FARC and FMBL) to the input background flow once again shows good correlation with respect to both direction and wind speed. FMBL is the better choice for wind direction estimation here, while the two stations appear equally useful in formulating input speeds. The 850 mb. data show a more consistent relation to input direction than was seen in either of the days simulated previously but are still less useful predictors than the surface observations at Ferndale.

February 12, 1975

February 12, 1975 again presented a situation where the conditions to be modeled were not on a "sub-synoptic" scale and, consequently, were very difficult to duplicate. An occluded front lay across the northern Puget Sound region during the entire simulation period and, from the meteorological observations, appears to have intersected the surface of the study area around the Ferndale stations in the northern section of the grid. The result was a very complex situation with erratic speed and direction observations at any particular station over the course of the 24 hour simulation and quite different "background"

flows apparent over various portions of the grid at any one time. The FARC station, apparently lying to the north of the frontal region, had observed wind directions up to 180° different from the nearest stations to the south and was, for the most part, ignored in formulating input data for the simulation cases.

The comparison tables (Tables 21 and 22) show reasonably good mean error values for most of the cases but large standard deviations. This indicates the background flow used was really a compromise, with the errors in direction and speed at different locations cancelling out to produce a small mean error. The station analysis shows a similar effect with significant mean errors and fairly large standard deviations at many of the stations for the February 12 simulations. The FARC station shows particularly large deviations between predicted and observed wind direction values.

Because of the synoptic situation in the vicinity of the Ferndale locations, neither station is a good indicator of overall background flow. Similarly, the 850 mb. sounding data have little relationship to the background flows input for the individual cases.

AIR QUALITY EMISSION LIMITATION ANALYSES

PI-Matrix calculations expressing air quality constraints on pollutant emissions are also presented. Maps of the PI-Matrix results for the entire study area are included in Appendix B. A one hour standard of .40 ppm ($1047 \mu\text{g}/\text{m}^3$) SO_2 (not to be exceeded more than once per year (PSAPCA, 1977)) was used in calculating allowable emissions for each hour simulated. A 24 hour PI-Matrix was also calculated using a standard of .10 ppm ($260 \mu\text{g}/\text{m}^3$) (not to be exceeded more than once per year (PSAPCA, 1977)). The

0300 and 1500 PST runs for each day were used to represent night and day situations, respectively, to calculate the long-term PI-Matrices.

Tables showing emission restrictions at particular locations for each case simulated are presented in this section. These grid locations correspond to existing or projected source locations in the core area, including the largest area sources of contaminants (see Figure 3). Table 25 is a list of the locations used and the corresponding grid coordinates. Figure 12 is a map of the grid points indicated as source locations.

Table 25. Major SO₂ Source Grid Locations for Northern Puget Sound Study Area.

Source	Grid Coordinates (row,column)
Source A, Ferndale	10,48
Source B, Ferndale	9,47
Source C, Ferndale	7,46
Source D, Ferndale	8,46
Source E, Ferndale	11,47
Source F, Ferndale	8,45
Source G, Ferndale	9,46
Source H, Bellingham	13,54
Source I, Anacortes	28,52
Source J, Anacortes	28,53
Source K, Anacortes	29,53
Bellingham	12-17,53-58
Anacortes	27-29,49-51

Figure 12. Location of Major SO_2 Sources
for Northern Puget Sound.
(See Table 25)

Tables showing total emissions allowable for each case simulated in the core area as a whole (3118 km²) are also included. These tables were computed by adding together the allowable emissions at each grid cell in the core area. They represent emissions into the available mixing volume over the entire core area that could be tolerated under conditions of complete mixing and, consequently, uniform concentration over the region as a whole.

Daily Cases

Tables 26, 27, 28 and 29 show hourly emission rates that would result in SO₂ concentrations equal to the standard limitations at the locations corresponding to proposed or existing pollutant sources. These tables also show the total pollutant mass that would need to be emitted over the 24-hour period represented to maintain an ambient concentration equivalent to the 24-hour standard limit. The Bellingham area emission figures are for a total of 36 grid cells (approximately 148 km²) and the City of Anacortes represents a nine grid cell area (approximately 37 km²).

Tables 30, 31, 32 and 33 show the total emissions into the core area mixing volume which would result in ambient concentrations of SO₂ equal to indicated standard limitations if complete mixing and, therefore, uniform concentrations were attained.

Table 26. Emission Strength That Would Result in Ambient SO₂ Concentrations Equal to Short and Long Term Standard Limitations (.40 ppm and .10 ppm, respectively) at Locations Indicated -- January 3, 1975 Simulation. Units are grams per second for hourly cases and kilograms for 24-hour cases.

Source	0300	0700	1100	1500	1900	2300	24-Hour
Source A, Ferndale	30-59	<30	<30	30-59	30-59	30-59	20.30-20.39
Source B, Ferndale	30-59	30-59	<30	<30	<30	30-59	20.30-20.39
Source C, Ferndale	30-59	<30	<30	<30	30-59	30-59	20.30-20.39
Source D, Ferndale	30-59	<30	<30	<30	<30	<30	20.30-20.39
Source E, Ferndale	30-59	<30	<30	<30	30-59	<30	20.30-20.39
Source F, Ferndale	30-59	<30	<30	<30	<30	30-59	20.30-20.39
Source G, Ferndale	30-59	<30	<30	<30	<30	30-59	20.30-20.39
Source H, Bellingham	30-59	<30	<30	<30	<30	30-59	20.30-20.39
Source I, Anacortes	30-59	<30	<30	<30	30-59	30-59	20.30-20.39
Source J, Anacortes	30-59	<30	<30	<30	30-59	30-59	20.30-20.39
Source K, Anacortes	30-59	<30	<30	30-59	30-59	30-59	20.30-20.39
Bellingham	1140-2184	270-1314	90-1134	300-1344	300-1344	1110-2214	730.90-734.46
Anacortes	210-471	60-321	30-291	150-411	210-471	270-531	182.60-183.49

Table 27. Emission Strength That Would Result in Ambient SO₂ Concentrations Equal to Short and Long Term Standard Limitations (.40 ppm and .10 ppm, respectively) at Locations Indicated -- January 24, 1975 Simulation. Units are grams per second for hourly cases and kilograms for 24-hour cases.

Source	0300	0700	1100	1500	1900	2300	24-Hour
Source A, Ferndale	30-59	<30	<30	<30	<30	<30	20.30-20.39
Source B, Ferndale	30-59	<30	<30	<30	<30	<30	20.30-20.39
Source C, Ferndale	30-59	<30	<30	<30	<30	<30	20.30-20.39
Source D, Ferndale	30-59	<30	<30	<30	<30	<30	20.30-20.39
Source E, Ferndale	30-59	<30	<30	<30	<30	<30	20.30-20.39
Source F, Ferndale	30-59	<30	<30	<30	<30	<30	20.30-20.39
Source G, Ferndale	<30	<30	<30	<30	<30	<30	20.30-20.39
Source H, Bellingham	30-59	<30	<30	<30	<30	<30	20.30-20.39
Source I, Anacortes	<30	<30	<30	<30	<30	<30	20.30-20.39
Source J, Anacortes	<30	<30	<30	<30	<30	<30	20.30-20.39
Source K, Anacortes	<30	<30	<30	<30	<30	<30	20.30-20.39
Bellingham	720-1677	90-1134	180-1224	60-1104	90-1134	120-1164	730.90-734.46
Anacortes	0-300	0-234	0-234	0-234	0-234	0-234	182.60-183.49

Table 28. Emission Strength That Would Result in Ambient SO₂ Concentrations Equal to Short and Long Term Standard Limitations (.40 ppm and .10 ppm, respectively) at Locations Indicated -- January 30, 1975 Simulation. Units are grams per second for hourly cases and kilograms for 24-hour cases.

Source	0300	0700	1100	1500	1900	2300	24-Hour
Source A, Ferndale	30-59	30-59	30-59	30-59	30-59	30-59	20.30-20.39
Source B, Ferndale	30-59	30-59	30-59	30-59	30-59	30-59	20.30-20.39
Source C, Ferndale	30-59	30-59	30-59	30-59	30-59	30-50	20.30-20.39
Source D, Ferndale	<30	<30	30-59	<30	30-59	30-59	20.30-20.39
Source E, Ferndale	30-59	30-59	30-59	30-59	30-59	30-59	20.30-20.39
Source F, Ferndale	30-59	30-59	30-59	30-59	30-59	30-59	20.30-20.39
Source G, Ferndale	<30	<30	30-59	<30	30-59	30-59	20.30-20.39
Source H, Bellingham	<30	<30	30-59	<30	30-59	30-59	20.30-20.39
Source I, Anacortes	30-59	30-59	30-59	30-59	30-59	30-59	20.30-20.39
Source J, Anacortes	30-59	30-59	30-59	30-59	30-59	30-59	20.30-20.39
Source K, Anacortes	30-59	30-59	30-59	30-59	30-59	30-59	20.30-20.39
Bellingham	270-1314	270-1314	900-1944	270-1314	1260-2304	1110-2154	710.80-714.27
Anacortes	180-441	180-441	300-561	180-441	360-621	330-591	182.60-183.49

Table 29. Emission Strength That Would Result in Ambient SO₂ Concentrations Equal to Short and Long Term Standard Limitations (.40 ppm and .10 ppm, respectively) at Locations Indicated -- February 12, 1975 Simulation. Units are grams per second for hourly cases and kilograms for 24-hour cases.

Source	0300	0700	1100	1500	1900	2300	24-Hour
Source A, Ferndale	30-59	30-59	60-89	30-59	<30	<30	20.30-20.39
Source B, Ferndale	30-59	30-59	60-89	30-59	<30	<30	20.30-20.39
Source C, Ferndale	30-59	30-59	30-59	30-59	<30	<30	20.30-20.39
Source D, Ferndale	30-59	30-59	60-89	30-59	<30	<30	20.30-20.39
Source E, Ferndale	30-59	30-59	60-89	30-59	<30	<30	20.30-20.39
Source F, Ferndale	30-59	30-59	60-89	30-59	<30	<30	20.30-20.39
Source G, Ferndale	30-59	30-59	60-89	30-59	<30	<30	20.30-20.39
Source H, Bellingham	30-59	30-59	60-89	30-59	<30	<30	20.30-20.39
Source I, Anacortes	30-59	30-59	30-59	30-59	<30	<30	20.30-20.39
Source J, Anacortes	30-59	30-59	30-59	30-59	<30	<30	20.30-20.39
Source K, Anacortes	30-59	30-59	30-59	30-59	<30	<30	20.30-20.39
Bellingham	720-1764	1320-2364	1860-2904	1110-2154	210-1254	60-1104	730.90-734.46
Anacortes	270-531	270-531	300-561	270-531	0-261	0-261	182.60-183.49

Table 30. Emission Rate or Total Emission Into Core Area Mixing Volume That Would Result in Ambient Concentrations Equal to Standard Limitations (.40 ppm SO₂, 1-Hour standard; .10 ppm SO₂, 24-Hour standard) for January 3, 1975 Simulation. Units are kilograms per second for each hourly case and kilograms for 24-Hour simulation.

Time	Emission Rate (kg/s) or Emission (kg)
0300	42.4
0700	27.7
1100	18.9
1500	28.7
1900	31.8
2300	34.6
24 Hour	19,054.9

Table 31. Emission Rate or Total Emission Into Core Area Mixing Volume That Would Result in Ambient Concentrations Equal to Standard Limitations (.40 ppm SO₂, 1-Hour standard; .10 ppm SO₂, 24-Hour standard) for January 24, 1975 Simulation. Units are kilograms per second for each hourly case and kilograms for 24-Hour simulation.

Time	Emission Rate (kg/s) or Emission (kg)
0300	28.7
0700	19.7
1100	20.6
1500	14.1
1900	13.7
2300	13.0
24 Hour	19,055.0

Table 32. Emission Rate or Total Emission Into Core Area Mixing Volume That Would Result in Ambient Concentrations Equal to Standard Limitations (.40 ppm SO₂, 1-Hour standard; .10 ppm SO₂, 24-Hour standard) for January 30, 1975 Simulation. Units are kilograms per second for each hourly case and kilograms for 24-hour simulation.

Time	Emission Rate (kg/s) or Emission (kg) _o .
0300	32.4
0700	32.4
1100	42.9
1500	32.4
1900	50.1
2300	46.6
24 Hour	19,054.1

Table 33. Emission Rate or Total Emission Into Core Area Mixing Volume That Would Result in Ambient Concentrations Equal to Standard Limitations (.40 ppm SO₂, 1-Hour standard; .10 ppm SO₂, 24-Hour standard) for February 12, 1975 Simulation. Units are kilograms per second for each hourly case and kilograms for 24-hour simulation.

Time	Emission Rate (kg/s) or Emission (kg)
0300	39.8
0700	51.3
1100	56.8
1500	45.2
1900	24.2
2300	17.1
24-Hour	19,054.9

In general, the hours or days simulated with low wind speed inputs (i.e. 0700 or 1100 PST, January 3; much of January 24, etc.) show more severe restrictions on pollutant emissions than periods of increased ventilation. The long-term (24-hour) PI-Matrices (Appendix B) show areas of lower pollution potential in the upland areas west of Bellingham, the higher interior portions of Vancouver Island and the section of the Olympic Peninsula included in the analysis, and over some of the San Juan Islands, with higher potential for pollutant buildup over flat terrain and ocean areas. These pollution potential patterns generally correspond to wind speed variations seen in the wind flow modeling results -- high wind speeds at scattered upland locations (i.e. exposed ridges, etc.) with lower wind speeds, similar to the background flow inputs, in areas of less complex terrain.

Emission restrictions for all the January 24 cases are more severe than on January 3, 1975. This can be attributed to the fact that wind speeds were generally lower on January 24; pollutants would consequently disperse more slowly than under conditions similar to the January 3 cases and the potential for pollution accumulation over the grid area as a whole is therefore greater. Conversely, emission are less constrained for the January 30 cases due to the greater wind velocities relative to either of the previous days. Higher wind speeds increase ventilation, causing pollutants to disperse more efficiently, thereby reducing the pollution potential.

The February 12 cases show less restrictive emission strengths during the early part of the day than during the last two simulation periods. This corresponds to a change in the background wind flow velocity used as input; between 5 and 6.5 m/s early in the day and 1.5 to 2.5 m/s for the 1900 and 2300 PST cases.

The variation in pollution potential and emission limitations with meteorology is evident from the source location summary tables (Tables 26, 27, 28 and 29). Emission rates at the indicated grid locations are generally less than 60 g/s for the January 3 cases, consistently less than 30 g/s for most of January 24, generally between 30 and 60 g/s on January 30 and as high as 90 g/s during the first part of February 12, dropping to under 30 g/s during the last two time periods of that day. The longer-term (24-hour) calculation smooths out these time period fluctuations such that the daily total emission for individual source location grid cells is always between 20,300 and 20,390 grams. The area source figures show similar patterns between the various cases.

Annual Case

The WINDS model and TAPAS system were also used to calculate emission constraints on an annual basis. Annual wind rose data from Bellingham was used for the annual situation (Figure 7). The average speed (5.5 m/s) indicated by the Bellingham data was used to generate wind speed and direction arrays for background flow over the northern Puget Sound region from eight directions (N, NE, E, SE, S, SW, W and NW). Mixing volume index arrays associated with each of the eight situations described above were also calculated -- these indices express the relative "pollution potential" at each grid cell. Emissions into the atmosphere over the study area would tend to concentrate in areas where stagnation or convergence would occur under the input flow conditions -- hence, these locations have a high potential for pollutant buildup. Further information about wind flow conditions and pollution potential

arrays associated with each of the eight situations may be found in Appendix B.

An annual pollution potential (mixing volume index) array was generated by weighting the index values associated with each input flow direction according to the percentage of annual flow occurring from that direction (as indicated by the Bellingham wind rose data) and averaging the eight cases. Four PI-Matrix arrays were calculated using the annual mixing volume index. The PI-Matrices represent emission restrictions necessary on an annual basis to achieve concentrations of 80, 60, 40 and 20 $\mu\text{g}/\text{m}^3$ (.03, .02, .015 and .0076 ppm) SO_2 . These figures represent federal annual average standards for SO_2 , Washington annual average standards and federal incremental (PSD) SO_2 standards for Class III and Class II areas, respectively. The annual PI-Matrix maps appear as Figures 13 through 16.

The annual PI-Matrices were calculated as an emission rate and are indicative of the allowable source strength assuming a 24 hour a day, 365 day per year operation. These have been converted to total mass allowable on a yearly basis. Table 34 shows annual emission constraints at the grid cells representing present or future point source locations and for the two area source locations (Anacortes and Bellingham). Also included are the 1976 NEDS estimates of pollutant emission for the major point sources in the study area. Table 35 shows core area total emission limitations for the annual case.

The mixing volume indices generated for the eight background flow directions show that relative pollution potential at any particular grid location depends upon the direction of flow occurring (mixing volume index maps are included in Appendix B). Different areas of the grid will be sheltered from strong flow under each different background

EMISSION RESTRICTION CODES:

CODE:	Blank	-	+	x	*	#	S	N	M
EMISSION RATE (kg X 10 ³):	<4	4-10	11-17	18-24	25-31	32-38	39-45	46-52	53-59

Figure 13. Combined PI(π)-Matrix for the Annual Case;
 SO_2 Standards are $20 \mu\text{g}/\text{m}^3$.

EMISSION RESTRICTION CODES:

CODE:	Blank	-	+	*	#	\$	%	^	~
EMISSION RATE (kg X 10 ³):	<15	15-26	27-38	39-50	51-62	63-74	75-86	87-98	99-110

Figure 14. Combined PI(π)-Matrix for the Annual Case;
 SO_2 Standards are $40 \mu\text{g}/\text{m}^3$.

EMISSION RESTRICTION VALUES:

CLASS:	Blank	-	+	-	+	0	S	M	N	
EMISSION RATE (kg x 10 ³):	<19	19-37	38-56	57-75	76-94	95-113	114-132	133-151	152-170	>170

Figure 15. Combined PI(π)-Matrix for the Annual Case;
 SO_2 Standards are $60 \mu\text{g}/\text{m}^3$.

EMISSION RESTRICTION CODES:

CODE:	Blank	.	-	+	+	+	+	+	+	+
EMISSION RATE (kg x 10 ³):	<25	26-50	51-75	76-100	101-125	126-150	151-175	176-200	201-225	>225

Figure 16. Combined PI(π)-Matrix for the Annual Case;
 SO_2 Standards are $80 \mu\text{g}/\text{m}^3$.

Table 34. Annual Total Emissions of SO₂ That Would Result in Ambient Concentrations of 80, 60, 40 or 20 µg/m³ at Present or Projected Source Location Grid Cells. Emission estimates for current sources for 1976 are also listed (EPA, NEDS, 1976). Units are 10³ kilograms SO₂.

Source and Location	80µg/m ³	60µg/m ³	40µg/m ³	20µg/m ³	SO ₂ Emission Estimates 1976
Source A, Ferndale	101-125	76-94	51-62	25-31	5505
Source B, Ferndale	101-125	76-94	51-62	25-31	3821
Source C, Ferndale	101-125	76-94	51-62	25-31	4225
Source D, Ferndale	101-125	76-94	51-62	25-31	-
Source E, Ferndale	101-125	76-94	51-62	25-31	-
Source F, Ferndale	101-125	76-94	51-62	25-31	-
Source G, Ferndale	101-125	76-94	51-62	25-31	-
Source H, Bellingham	101-125	76-94	51-62	25-31	1124
Source I, Anacortes	76-100	57-75	39-50	18-24	12609
Source J, Anacortes	76-100	57-75	39-50	18-24	-
Source K, Anacortes	76-100	57-75	39-50	18-24	-
Bellingham	3235-4110	2432-3061	1628-2026	804-999	-
Anacortes	734-959	551-713	368-474	183-320	-

Table 35. Total Allowable Emissions Within Core Area on an Annual Basis to Achieve Ambient Concentrations of 80, 60, 40 and 20 $\mu\text{g}/\text{m}^3$ SO_2 . Units are 10^6 kilograms SO_2 .

SO_2 Concentration	Emission Total
80 $\mu\text{g}/\text{m}^3$	95.58
60 $\mu\text{g}/\text{m}^3$	71.68
40 $\mu\text{g}/\text{m}^3$	47.79
20 $\mu\text{g}/\text{m}^3$	23.89
1976 Point Source Estimated Emissions = 27.29 (total core area)	

direction. Consequently, a particular location may have a high potential for pollutant buildup under some short-term episodes but will be relatively free from high contaminant concentrations under other situations.

The annual index shows the areas with poor dispersion characteristics under the most prevalent flow conditions. The PI-Matrix maps translate this average pollution potential into emission restriction numbers for each grid cell for the various air quality standard limitations. In general, areas with good ventilation occur at scattered locations within the upland areas on Vancouver Island, the Olympic Peninsula and in the foothills of the Cascades in the eastern portions of the study area. These areas correspond to localized windy sites such as ridge top locations. Areas of reduced dispersion occur from Port Angeles west along the northern edge of the Olympic Peninsula, along the eastern edge of Vancouver Island and from the Bellingham Bay area south to Mt. Vernon and Camano Island and north along the edge of the higher terrain to the west.

Table 34 shows that in 1976 the estimated emissions of SO_2 at the major point source locations were in excess of the emission constraints

indicated by the TAPAS system. This coincides with air quality monitoring data which indicate occasional violations of SO_2 standards in the northern Puget Sound region. However, the emission rate indicated for each location represents emissions into the mixing volume above a single 2 km^2 grid cell on an instantaneous basis -- dispersion outside this volume is not taken into account. Since pollutants emitted into the northern Puget Sound airshed will normally disperse over a fairly large area, the core area totals are perhaps more appropriate figures for comparison. The total 1976 SO_2 load from major point sources in the core area ($27.29 \times 10^6 \text{ kg}$) represents approximately 28 percent of the total emission load that could be tolerated without exceeding federal primary annual average SO_2 standards or 38 percent of the total load that would result in ambient air quality equal to Washington State annual average SO_2 standards. Since these figures assume complete mixing and uniform concentrations over the entire core area mixing volume they represent upper limits to emission loads that could be tolerated while maintaining acceptable levels of air quality.

The standards that may be of particular interest in reference to new industrial development in the northern Puget Sound region are the federal incremental standards for Class II and Class III areas (PSD). These represent allowable increments of SO_2 that may be added to baseline concentrations, provided that these additional emissions do not result in violations of ambient air quality standards. The emission levels representing these incremental amounts are shown in Tables 34 and 35 under concentrations of $40 \text{ } \mu\text{g}/\text{m}^3$ (Class III) and $20 \text{ } \mu\text{g}/\text{m}^3$ (Class II). As before, the individual grid cell restrictions are conservative while the core area totals represent upper limits to the tolerable emissions.

DISCUSSION OF RESULTS

Wind Flow Simulation

Some of the difficulties encountered in simulating wind flow patterns in the northern Puget Sound region were detailed in previous sections of this report. Channelization of flow coming into the grid presents a problem which can be partially dealt with by setting some grid locations to the observed or inferred flow direction or speed. The wind flow maps (Appendix B) show a somewhat awkward transition of the affected regions into the background flow conditions -- however, the overall result was a more effective duplication of observed conditions than was possible using a single flow as initial conditions over the entire grid.

Other problems encountered related to the size of the region modeled. The wind flow simulation model is designed to handle sub-synoptic level situations where a single, characteristic prevailing flow can be used to model the entire grid area. The January 30, 1975 cases provided a situation where background flow was easterly in the northern grid sections but southeasterly along the southern grid boundary. The compromise direction used resulted in consistent direction errors at both extremes. The February 12, 1975 cases showed another synoptic level complication -- this time a frontal region passing through the grid area. The wind speed and direction shifts associated with the presence of a front are impossible to duplicate with a simple flow model and any input flow chosen would thus be characteristic of only a portion of the affected area.

Light wind speed and variable wind direction conditions also proved difficult to duplicate in terms of direction, although the wind speeds

were simulated with reasonable accuracy (January 24, 1975 cases). For pollution potential analyses, the wind speed at each grid cell is a major determinant of mixing volume -- hence, when the wind flow model is used for this purpose, discrepancies in flow direction that occur under light wind conditions are relatively less important than the wind speed prediction accuracies. Wind speeds at some locations will be regularly over-predicted under similar conditions due to the infrequent occurrence of zero wind speed predictions. This is in contrast to strong wind situations where the wind speeds extremes will be under-predicted.

In general, the simplest situations were the ones most successfully duplicated. January 3, 1975 represented a relatively uncomplicated situation and was reproduced fairly well. January 24, 1975 was well simulated with respect to wind speed but direction variances were greater than in the January 3 cases. The January 30, 1975 cases show still more variation in prediction errors -- several portions of the grid (Bellingham area stations and Smith and Vancouver Islands locations) are consistently in error in either speed or direction estimates. The tendency of the model to under-predict extreme wind speeds is noticeable in several of the January 30 cases. February 12, 1975 proved a nearly impossible situation to duplicate -- wind patterns in various portions of the northern Puget Sound region differed from one another to such an extent that the entire study area could not be modeled as a single situation with much accuracy.

The station analyses show a few stations where simulation errors were regularly encountered. Three of the stations (SMTH, VICA and VICH) were consistently under-predicted with respect to wind speed. These three stations showed the highest wind speeds of any locations and are

apparently well exposed sites subject to windy conditions under certain meteorological situations. VICH and VICA (and to a lesser extent, SMTH) were also quite variable in speed prediction errors, with relatively high standard deviations overall. The wind flow model also proved to be a poor predictor of the BHIL station observations and showed large standard deviations over the four days simulated with respect to both speed and direction at this location.

The validation situation was somewhat artificial in that the wind flow model simulates a smoothed approximation of the actual terrain -- information is entered at 2 km intervals and smaller scale features which may influence actual wind patterns at station locations may be missed entirely by the grid point network. This was undoubtedly the case at several of the validation points and probably accounts for many of the discrepancies between simulated and observed flow conditions. Because of the simplification of the terrain represented by the grid point network, the wind flow and TAPAS predictions are more useful to identify clusters of grid cells where particular air quality constraints are necessary rather than single points.

Comparison of input flows utilized with the 850 mb. sounding data from Quillayute show the Quillayute data to be unrepresentative of flow situations in the study area. This is not surprising since the Quillayute station is located some distance from the study area, on the other side of a major mountain range. Unfortunately, it is the nearest location for which upper air data are available. In such a situation, temperature and pressure data needed to define T70, T80, H70 and H80 input variables can be taken from an upper air station adjacent to the study area but wind flow inputs should be derived from a location within the

area to be modeled (preferably toward the center of the grid area). The FARC and FMBL stations were, in most cases, representative of the prevailing background flow estimates used. The lack of similarity between observations at these two locations and most of the other stations indicates that "open" locations, relatively free from local topographic influences, are necessary to estimate prevailing flow conditions for model input.

TAPAS Results

The hourly PI-Matrix results for each of the four days simulated show little difference in overall pollution potential among the present or projected source locations. The expansion of the averaging period to 24 hours involves calculating the allowable emissions based on Gaussian dispersion and ventilated box model concepts. The net result in this analysis was that day to day differences in meteorology were "smoothed" for the individual grid cell locations and the 24 hour emission totals were the same for each of the source grid points and for each of the four days simulated. The 24 hour emission totals also tend to be more restrictive than the instantaneous emission rates since the acceptable average concentration over a 24 hour period is less than could be tolerated for a shorter time (i.e. .10 ppm versus .40 ppm). Differences in meteorology resulted in various levels of constraint for each hour and day over the core area as a whole. In general, periods with slower input wind velocities resulted in lower allowable emission rates and day-to-day differences tended to disappear over the longer averaging period (24 hours).

The annual average PI-Matrices indicate that currently operating point sources emit pollutants at a greater rate than the effluent can be

dispersed to acceptable levels of air quality at the source location, under average meteorological conditions. Most of the SO_2 emitted into the northern Puget Sound airshed comes from these large point sources. With such a source configuration, annual standard violations could be expected in the vicinity of the contaminant sources even when the total emission into the core area mixing volume is within the constraints indicated by the TAPAS system. This situation will occur because complete and uniform mixing over the entire core area is unlikely, especially with most of the pollutant emissions coming from a few locations. The effective mixing volume available for dilution is therefore considerably reduced from that used in the core area total calculations. Short-term standard violations may also be expected in the area immediately "down-wind" from the major emitters under episodes of reduced dispersion. This situation is currently applicable to the northern Puget Sound region -- total SO_2 emissions in the core area are apparently below the upper limits defined by the TAPAS system but short-term standard violations do occur under some meteorological conditions in the vicinity of the "overloaded" grid cells.

In contrast, the individual grid cell emission levels may be considered a conservative "lower level" for pollutant emission constraints. The short-term PI-Matrices represent maximum allowable emission rates under episodic conditions. The four days simulated some of the differing meteorological conditions under which high groundlevel concentrations of pollutants can result -- allowable emission rates vary from one grid cell to another and depend upon the conditions of prevailing flow. The short-term PI-Matrix constraints are particularly applicable to the type of situation that occurred on January 24, 1975 (light wind conditions

and poor dispersion) since contaminants emitted into the northern Puget Sound airshed under such conditions will tend to disperse from the points of emission at a fairly slow rate. Emission rate constraints are therefore more restrictive over most of the January 24, 1975 simulations than for the other three sets of meteorological conditions modeled.

CHAPTER V

SUMMARY AND CONCLUSIONS

The wind flow simulation analyses performed for this study provided valuable information regarding the model's utility for subsequent analyses of a similar nature. In using the WINDS model to simulate wind flow patterns, the following points should be addressed:

- 1) Upper air data at some location within or near the study area is needed to define pressure and temperature profiles during the simulation period.
- 2) If a particular situation is to be modeled, wind flow data must be obtained from some location within the study area which is relatively free from local topographic influences to provide critical background flow estimates. The data station used would preferably be near the center of the area to be analyzed.
- 3) In any area of complex terrain as large as the study area used for this report, prior channelization of flow entering the grid area must be considered. Inferred flow tendencies that differ in either speed or direction from the estimated prevailing background flow may have to be input at some of the grid locations.
- 4) The grid size used for this analysis (110 km by 146 km) is probably as large an area as can be successfully modeled with this procedure under many meteorological conditions. For instance, the January 30, 1975 and February 12, 1975 cases were not entirely "sub-synoptic" situations, which reduced simulation accuracy over parts of the grid area.

- 5) In complex terrain, a smaller grid scale would have picked up more of the local topographic features that influence flow at some of the station locations.

The TAPAS system was used to identify areas with high or low relative pollution potential under average meteorological conditions. The relative potential for contaminant accumulation was also identified for each grid cell under eight different directions of flow that occur with varying frequency in the northern Puget Sound region. Such information could be of use in siting studies for potential industrial development in the northern Puget Sound region.

Estimates of allowable emission rates or total mass emitted at each grid cell location were also calculated for a variety of meteorological conditions. These rates or amounts indicate pollutant emissions that would result in ambient concentrations equal to the Washington State one hour standard of 0.4 ppm SO₂ or to the 24-hour standard of .10 ppm SO₂ (not to be exceeded more than once per year (PSAPCA, 1977)). The simulated flow conditions represent episodes of poor dispersion or other meteorological situations that have a demonstrated potential to interact with contaminant emissions in such a way that high groundlevel concentrations could result.

Emission limitations necessary to meet annual average SO₂ standard limitations at each grid cell were also calculated. The emission rates and summed total yearly emission amounts are related to federal and state ambient SO₂ concentration restrictions as well as to the increments of air quality degradation allowable under federal Class II and Class III PSD standards.

The "carrying capacity" of the entire northern Puget Sound core area may be defined in reference to either federal or state ambient air quality standards or to the federal PSD standards. Short-term "episodic" carrying capacity figures are represented by the core area totals under the various hours or days simulated. Annual carrying capacities for the entire core area are approximately 96 million kilograms per year under federal annual SO₂ standards or 72 million kilograms per year under the equivalent state limitations. Incremental limits for Class II standards are 24 million kilograms per year and Class III conditions allow 48 million kilograms per year.

These estimates are necessarily upper limits to the emissions that could be tolerated in the northern Puget Sound region since topographic considerations and the configuration of major sources result in a much smaller effective mixing volume than is indicated above. Consequently, although major SO₂ sources currently operating in the core area released less than half of the 72 million kilograms indicated above with respect to state annual SO₂ standards in 1976, comparison of source characteristics with source location and cell emission restrictions indicates that several areas of the northern Puget Sound region are already far in excess of the SO₂ "carrying capacity". This conclusion is supported by air quality monitoring data which indicate state standard violations at several receptor locations within the study area -- in some cases at points many grid cells "downwind" from the source of contaminant emissions.

The results indicate that siting of future SO₂ emission sources should be made in reference to the location of major sources already present. A larger effective "carrying capacity" for SO₂ emissions would be obtained for the northern Puget Sound region if the points of

emission were more evenly dispersed throughout the study area. Analysis of current or projected source locations with conventional air quality modeling techniques may indicate how many grid cells are at or above the SO_2 carrying capacity, under annual or episodic conditions, due to advection of pollutants emitted by the major sources into the adjacent grid cell space. Future sources should be sited away from these air spaces which are currently at or above carrying capacity. If possible, future industrial development should be sited in areas with the least potential for pollutant concentration as indicated by the mixing volume index maps (Appendix B).

Alternatively, the TAPAS results may be used to indicate the amounts by which current emission levels must be reduced to insure acceptable air quality at all locations within the northern Puget Sound region. Future sources of SO_2 emission could be limited to the emission rates or total emission amounts the location can tolerate under average annual and episodic meteorological conditions. The mass of SO_2 currently entering grid cell locations due to advection from upwind sources must also be considered.

The TAPAS system may also be used for land use planning considerations in other locations. The accuracy of the mixing volume and, hence, emission constraint estimates will depend upon the accuracy of wind flow modeling achievable, as explained above. Mixing volume index maps may be used to indicate areas of relative "pollution potential" and a smaller grid scale may be used in studies requiring finer spatial resolution. The PI-Matrix calculations may then be used to set allowable emission rates or amounts for each grid cell or for clusters of grid cells with reference to any standard of air quality desired. The TAPAS

system may also prove useful in preparing attainment plans for areas where contaminant concentrations are currently in excess of standard limitations, by defining levels to which emissions must be reduced to insure acceptable air quality at all locations.

CHAPTER VI

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APPENDIX A

Estimating Airflow Patterns Over Complex Terrain

Estimating Airflow Patterns Over Complex Terrain

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Estimating Airflow Patterns Over Complex Terrain

Michael A. Fosberg, William E. Marlatt,
and Lawrence Krupnak

Introduction

Land managers are increasingly faced with problems requiring quantitative estimates of air-flow patterns over complex terrain. Use of the wind information may range from potential air quality analysis for land use planning to predicting spread of actual wildfires. Areas in which such analysis is required are typically mountainous. Nearly always, evaluation is severely hampered by a single problem—lack of data, particularly wind data.

For these reasons, a method of determining boundary layer flow patterns is needed as an alternative to expensive data networks.

Boundary layer flow over complex terrain cannot currently be numerically modeled with complete fluid and thermodynamic equations. Accuracy and quantity of the initial data fields required for complete solution only shift the problem back to need for expensive data networks (Fosberg 1967, 1969). While these costs and efforts may be worthwhile in special locations and for specific problems, flexibility in geographic location and timeliness of solutions are sacrificed. We feel that an alternative procedure is required for wind pattern analysis which provides geographic flexibility and does not require sophisticated, expensive data networks. Such solutions cannot include all atmospheric processes, however. The governing equations must be simplified and some important effects must be represented by parameterized analogs.

A model of this type is based on tradeoffs between simplified solutions and preservation of realistic results. Several models of thermal and terrain-induced perturbation of near-ground flow have been developed recently. Anderson (1971)

and Lantz⁴ developed single layer models of two-dimensional potential flow over terrain features. Anderson (1971), Fosberg et al. (1972), and Fosberg⁵ examined the thermally driven flow disturbances. These studies were all based on the philosophical argument that major simplification of the equations was acceptable, and that the disturbed flow field could be superimposed on a mean flow field. While superficially attractive, these preliminary models did not evaluate the consequences of the simplifications, nor did they provide quantitative arguments supporting neglect of specific processes.

Each of the models describes a single layer of finite depth, depicts a quasi-horizontal slab, and treats body forces as an impulse acceleration. The models also require the flow to be statically stable, either as an incompressible fluid or through the hydrostatic assumption. Superposition of disturbed flows on the mean flow also implies limitations on the processes that can be modeled. Impulse accelerations tacitly imply that a model is intended as a diagnostic tool rather than a time-dependent predictive model. Also, these models generally neglect or highly linearize the advection terms in the dynamic equations.

The highly idealized treatment of the advection term is probably the most serious of the assumptions. Justification is provided partially by examination of the energy integrals in Fos-

⁴Lantz, R. B. 1972. Application of a three dimensional numerical model to air pollution calculations. Preprint of paper presented at 65th Annu. Meet., Air Pollution Control Assoc., Miami Beach, Fla., June 18-22, 22 p.

⁵Fosberg, Michael A. (in press). New technology for determining atmospheric influence on smoke concentrations. Proc. Int. Symp. on Air Quality and Smoke from Urban and For. Fires, 1973. 11 p.

berg's (1967, 1969) analysis of flow over single ridges. Conversion of potential energy to kinetic energy dominates the kinetic energy budget. The advective redistribution of kinetic energy and the viscous dissipation are about an order of magnitude smaller. While these energy budget comparisons do not fully justify neglect of the advective processes, they do show that the assumption does not invalidate the models, but only restricts interpretation of the results.

In general, this class of airflow models excludes the small-scale physical situations in which transient or highly interactive processes such as gravity waves or unstable thermal convection dominate the flow field. Also, because of the restrictions imposed on the advection terms, downwind wake effects are not properly represented.

Use of these simplified models—rather than complex and complete solutions or as a substitute for extensive field studies—becomes attractive when extensive data are not available, or in land use planning where alternatives may be great, the time span for planning short, and the accuracy or costs of more physically precise solutions and studies unwarranted.

The model described in this paper is intended to meet these applied objectives. This model is based on simplified solutions of the complete equations. It is philosophically identical to the preliminary models, but combines more of the physical processes.

Structure of the Model

The mathematical model is based on the terrain-induced flow processes derived by Anderson (1971) and the thermally induced flows described by Fosberg et al. (1972). In addition, the frictional terms are included in the model. Anderson's model was based only on a form of the divergence equation, while the Fosberg et al. (1972) model was based only on the vorticity equation. The model developed here is developed from both equations.

The advection terms were neglected in both previous equations. The consequences of this assumption are that the equations were simplified at the expense of losing a complete physical description of the dynamic processes. Thermally, frictionally and terrain-induced flows were superimposed on a background potential flow across the computational boundaries. Each of these disturbances was assumed to take place only within the computational area. Superposition of disturbances on the background flow, after ne-

glecting advection terms, is physically analogous to an impulse acceleration. The diagnostic nature of the model was achieved by allowing the impulse to act over a small, finite time interval defined by phase velocities of disturbances. Flow following the ground surface was obtained by a coordinate transform. A rigid upper surface above the terrain was assumed in order to define the top of the atmospheric slab.

Procedures for solving the equations involve serial approximations which superimpose a new physical effect on the previous solution. The first step in the solution was to transfer the large-scale background wind into a terrain-induced modification of the throughflow. This step provided a local throughflow wind.

Next, thermal and frictional modification of the vorticity and divergence were introduced. These changes were superimposed on the terrain-induced flow. Finally, stream functions and velocity potentials were calculated so that the wind-speed and direction could be defined at all interior points.

Throughflow Representation

Total airflow through the computation field was required to satisfy conservation of mass. Since the lower surface of the layer was mountainous, provisions had to be made for local channeling and deflection. Throughflow characteristics were calculated from the steady-state mass continuity equation as outlined by Anderson (1971). Vertical integration and use of the anelastic approximation permitted local velocities to be approximated from the overall wind field and terrain features. The steady-state continuity equation is:⁶

$$\nabla \cdot \rho \mathbf{v} = - \frac{\partial (\rho w)}{\partial z}$$

In this equation, ∇ is the horizontal gradient operator, ρ is density, $\mathbf{v}$ is the velocity vector, and w is the vertical motion, positive upward.

Vector coordinates used in the mathematics are west to east in the x direction, south to north in the y direction, and vertically as z .

The anelastic approximation, where kinematic influences on density are negligible compared to thermodynamic influences, was first applied to the equation:

$$\overline{\rho} \nabla \cdot \mathbf{v} = - \frac{\partial (\rho w)}{\partial z}$$

⁶See appendix for a complete description of notations used in the equations.

Bars over a variable indicate a mean value for the slab. The equation was then integrated over the depth of the layer between the ground (h) and the top of the slab (H).

$$\overline{\rho} \int_h^H \nabla \cdot \tilde{\mathbf{v}} \, dz = - \int_h^H \frac{\partial (\rho w)}{\partial z}$$

Horizontal divergence was defined as $\delta = \nabla \cdot \tilde{\mathbf{v}}$ so that the integral equation was solved as:

$$\overline{\rho} \, \overline{\delta} \, (H-h) = -\rho w(H) + \rho w(h)$$

through the mean value theorem. A rigid lid was assumed, so $\rho w(H)$ became zero. Vertical motion near the ground was assumed to be dominated by orographic lifting. The horizontal divergence of the mean wind field then became:

$$\overline{\delta} = \frac{\rho}{\overline{\rho}} \tilde{\mathbf{v}} \cdot \frac{\nabla h}{(H-h)} \quad (1)$$

Terrain modification of the large-scale flow could then be calculated from the channeling and deflection of this flow, and could provide a first approximation of the local wind.

Thermal and Frictional Influences

Modification of the wind field produced by thermal acceleration and retardation required invoking the assumptions associated with the advection terms of the complete equations. Frictional influences were included as spatial variations of idealized and parameterized solutions relating surface characteristics to the wind profile. The fundamental procedure was to: (1) derive the complete divergence and vorticity equations, (2) judiciously neglect the advective terms, (3) allow full influence of the thermal terms, and (4) utilize classic frictional solutions.

The procedure required for inclusion of these body forces was to define the thermal and frictional solutions in terms of the Navier-Stokes equations. The first step was to express the divergence equation utilizing these assumptions. Divergence was obtained through:

$$\nabla \cdot \frac{d\tilde{\mathbf{v}}}{dt} = \frac{\partial \delta}{\partial t} = \nabla \cdot (-c_p \nabla \theta \tilde{\mathbf{p}}_*) + \nabla \cdot (K \nabla^2 \tilde{\mathbf{v}})$$

where θ is the potential temperature, p_* is the pressure variable defined as $p_* = T/\theta$, and K is the turbulent viscosity. The friction term was simplified to:

$$\nabla \cdot K \left(\frac{\partial^2 \tilde{\mathbf{v}}}{\partial z^2} \right) = K \left(\frac{\partial^3 u}{\partial x \partial z^2} + \frac{\partial^3 v}{\partial y \partial z^2} \right)$$

since the horizontal dissipation terms are small compared to the vertical terms when expressed in finite-difference mesoscale models. A parameterized form of the dissipation was obtained from the logarithmic wind profile near the ground. The wind profile for an adiabatic surface layer (Sutton 1953) is:

$$\frac{\partial u}{\partial z} = \frac{u_*}{kz^2} \quad \text{and} \quad \frac{\partial v}{\partial z} = \frac{v_*}{kz^2} \quad (2)$$

where u_* and v_* are the friction velocities and k is the von Karman constant. These two functions were differentiated with respect to z to produce the second derivative. The terms

$$\frac{\partial^2 u}{\partial z^2} = -\frac{u_*}{kz^2} \quad \text{and} \quad \frac{\partial^2 v}{\partial z^2} = -\frac{v_*}{kz^2}$$

were then substituted into the divergence equation. The divergence equation then became:

$$\begin{aligned} \frac{\partial \delta}{\partial t} = & -c_p \nabla^2 \theta \tilde{\mathbf{p}}_* - c_p \nabla \theta \cdot \nabla \tilde{\mathbf{p}}_* \\ & - \frac{K}{kz^2} \left(\frac{\partial u_*}{\partial x} + \frac{\partial v_*}{\partial y} \right) \end{aligned} \quad (3)$$

Friction velocity was obtained by integrating the wind profile equation for fully rough surfaces. The friction velocities are then:

$$u_* = \frac{|\tilde{u}| k}{\ln \left(\frac{Z + z_o}{z_o} \right)} \quad (4a)$$

$$v_* = \frac{|\tilde{v}| k}{\ln \left(\frac{Z + z_o}{z_o} \right)} \quad (4b)$$

where z_o is the surface roughness length and Z is the height of the wind above ground.

Rotational flow characteristics were introduced through the vorticity equation. Using the same assumptions for this derivation as were

used in the development of the divergence equation, the vorticity equation became:

$$k \cdot \nabla x \frac{dv}{dt} = \frac{\partial \zeta}{\partial t} = -c_p \frac{\partial(\Theta, p_*)}{\partial(x, y)} \quad (5)$$

$$-(\zeta + f) \delta - \frac{K}{kZ^2} \left(\frac{\partial v_*}{\partial x} - \frac{\partial u_*}{\partial y} \right)$$

The divergence and vorticity equations are time-dependent and therefore must be integrated. Divergence was integrated directly through the mean value theorem over an arbitrary time interval. Since little is known about the rate of change of divergence, a square wave impulse of interval Δt_δ was assumed. The integrating time factor then became $\frac{1}{2}\Delta t_\delta$ when the magnitude of the acceleration was assumed to be $\frac{1}{2}$ the observed or maximum value. Divergence was then:

$$\partial = \frac{1}{2}\Delta t_\delta \left[-c_p \nabla^2 p_* - c_p \nabla \Theta \cdot \nabla p_* - \frac{K}{kZ^2} \left(\frac{\partial u_*}{\partial x} + \frac{\partial v_*}{\partial y} \right) \right] + \delta \quad (6)$$

Given this solution, the vorticity equation became the ordinary differential equation of:

$$\frac{\partial \zeta}{\partial t} + \zeta \delta = -c_p \frac{\partial(\Theta, p_*)}{\partial(x, y)} - f \delta - \frac{K}{kZ^2} \left(\frac{\partial v_*}{\partial x} + \frac{\partial u_*}{\partial y} \right)$$

The solution is:

$$\zeta = e^{-f\delta dt} \int \left[-c_p \frac{\partial(\Theta, p_*)}{\partial(x, y)} - f \delta - \frac{K}{kZ^2} \left(\frac{\partial v_*}{\partial x} - \frac{\partial u_*}{\partial y} \right) \right] \exp(f\delta dt) dt + c e^{-f\delta dt}$$

Again, an impulse of finite time interval Δt_ζ was assumed, so that the mean value integration gave:

$$\zeta = \exp(-\frac{1}{2}\delta \Delta t_\zeta) \frac{1}{2}\Delta t_\zeta$$

$$\left[-c_p \frac{\partial(\Theta, p_*)}{\partial(x, y)} - f \delta - \frac{K}{kZ^2} \left(\frac{\partial v_*}{\partial x} - \frac{\partial u_*}{\partial y} \right) \right]$$

$$\exp(\frac{1}{2}\delta \Delta t_\zeta) + c e^{-\delta \Delta t_\zeta / 2}$$

The arbitrary time intervals for the divergence and vorticity were defined in terms of phase velocities. Because a rigid lid was used as an upper boundary for the calculation and an anelastic approximation was used for compressibility, the phase velocity for divergence was taken as the speed of sound. This gave a time interval of:

$$\Delta t_\delta = \frac{\text{sec } \Delta}{300 \text{ m}}$$

where Δ is the minimum distance between computational points. Phase velocities for vorticity were taken to be the large-scale windspeed, so that the time interval for vorticity was:

$$\Delta t_\zeta = \frac{\Delta}{(u^2 + v^2)^{1/2}}$$

For typical distances of 1 to 10 km between computational points and windspeeds of 1 to 10 m per second, the time interval is of the order of 1,000 seconds. Divergence at the mesoscale is typically 10^{-5} to 10^{-3} per second. These magnitudes suggested the exponential term in the vorticity equation should be approximately one, except under condition of light winds and large grid spacing. The constant of integration was then taken to be the large-scale flow vorticity. The vorticity then became:

$$\zeta = \frac{1}{2}\Delta t_\zeta \left[-c_p \frac{\partial(\Theta, p_*)}{\partial(x, y)} - f \delta - \frac{K}{kZ^2} \left(\frac{\partial v_*}{\partial x} - \frac{\partial u_*}{\partial y} \right) \right] + \zeta_0 \quad (7)$$

Equations (1) and (6) for the frictionally, thermally and terrain-induced flow deviations on divergence, and equation (7) for the frictionally and thermally induced flow deviations on rotation, were then used to calculate the wind components.

Calculation of Local Winds

Wind components of the flow were calculated in the area by superimposing the terrain, frictional, and thermal deviations on the large-scale wind. The wind deviations were obtained by separating the flow into an irrotational divergent component and a nondivergent rotational component. The divergent flow was described with a velocity potential and the rotational component with a stream function. The deviation velocity was then:

$$\underline{v} = \underline{kx} \nabla \psi + \nabla \phi$$

where ψ is the stream function and ϕ is the velocity potential. The vorticity is:

$$\zeta = \underline{k} \cdot \nabla \times \underline{v} = \underline{k} \cdot \nabla \times \underline{kx} \nabla \psi + \underline{k} \cdot \nabla \times \nabla \phi = \nabla^2 \psi \quad (8)$$

and the divergence is:

$$\delta = \nabla \cdot \underline{v} = \nabla \cdot \underline{kx} \nabla \psi + \nabla \cdot \nabla \phi = \nabla^2 \phi \quad (9)$$

Since the vorticity and divergence were known from equations (1), (6), and (7), the stream function and velocity potential could be obtained from a numerical solution of the elliptical differential equations (8) and (9). Decomposing the velocity into the west-east component and the south-north component, and superimposing the background flow, the velocities are:

$$u = u_o + \frac{\partial \phi}{\partial x} - \frac{\partial \psi}{\partial y} \quad (10a)$$

and

$$v = v_o + \frac{\partial \phi}{\partial y} + \frac{\partial \psi}{\partial x} \quad (10b)$$

where u_o and v_o are the background velocities.

Flow Near the Ground Surface

Airflow along the terrain surface is of much more interest in fire or air-quality studies than flow at some fixed elevation. Since the equations require calculations to be made on a flat horizontal surface, transformations from the horizontal plane to the terrain surface are necessary.

Data required by the model are observed at a fixed height above the ground (generally between 1 and 3 m) so the transforms chosen were to restructure the observed data to a flat surface locally, and then to consider the model as being

composed of a series of adjacent horizontal surfaces, each of slightly different elevation based on the elevation of the local terrain. The coordinate transform required expressing the derivations of the variables observed on the terrain surface as though they were along a horizontal surface. If vertical variations of the variables are known, the transform for any quantity, S , is then:

$$\left(\frac{\partial S}{\partial x} \right)_E = \left(\frac{\partial S}{\partial x} \right)_T - \frac{\partial S}{\partial z} \frac{\partial h}{\partial x} \bigg|_T$$

where the unsatisfied parentheses indicate derivations taken along either constant elevation or along the terrain surface.

Second derivations were obtained similarly as:

$$\begin{aligned} \left(\frac{\partial^2 S}{\partial x^2} \right)_E &= -2 \frac{\partial^2 S}{\partial x \partial z} \frac{\partial h}{\partial z} - \frac{\partial S}{\partial z} \frac{\partial^2 h}{\partial x^2} \\ &+ \left(\frac{\partial h}{\partial x} \right)^2 \frac{\partial^2 S}{\partial z^2} \end{aligned}$$

The higher order terms involving derivatives of the terrain are small compared to the linear term. Six separate derivatives of the thermal characteristics are required by the vorticity and divergence equations. These are the first derivative of potential temperature and pressure, and the second derivative of pressure in the cardinal directions.

Vertical variations of these thermodynamic variables are required. These were obtained first for potential temperature through static stability for a hydrostatically balanced atmosphere as:

$$\left(\frac{\partial \theta}{\partial x} \right)_E = \left(\frac{\partial \theta}{\partial x} \right)_T - \theta \sigma \frac{\partial h}{\partial x} \bigg|_T \quad (11a)$$

$$\left(\frac{\partial \theta}{\partial y} \right)_E = \left(\frac{\partial \theta}{\partial y} \right)_T - \theta \sigma \frac{\partial h}{\partial y} \bigg|_T \quad (11b)$$

where $\sigma = \frac{1}{\theta} \frac{\partial \theta}{\partial z}$.

Vertical decrease of pressure was represented by hydrostatic equilibrium:

$$\frac{\partial p_*}{\partial z} = - \frac{g}{c_p \theta}$$

Utilizing these relationships, the pressure derivatives are:

$$\left(\frac{\partial p_*}{\partial x}\right)_E = \left(\frac{\partial p_*}{\partial x}\right)_T + \frac{g}{c_p \Theta} \left(\frac{\partial h}{\partial x}\right)_T \quad (11c)$$

$$\left(\frac{\partial p_*}{\partial y}\right)_E = \left(\frac{\partial p_*}{\partial y}\right)_T + \frac{g}{c_p \Theta} \left(\frac{\partial h}{\partial y}\right)_T \quad (11d)$$

$$\left(\frac{\partial^2 p_*}{\partial x^2}\right)_E = \left(\frac{\partial^2 p_*}{\partial x^2}\right)_T - 2 \frac{g}{c_p \Theta^2} \frac{\partial h}{\partial x} \frac{\partial \Theta}{\partial x} \quad (11e)$$

$$\left(\frac{\partial^2 p_*}{\partial y^2}\right)_E = \left(\frac{\partial^2 p_*}{\partial y^2}\right)_T - 2 \frac{g}{c_p \Theta^2} \frac{\partial h}{\partial y} \frac{\partial \Theta}{\partial y} \quad (11f)$$

Horizontal derivatives of the friction velocities remain unchanged, since the model is designed for use in the constant flux layer where they are constant in the vertical. This shallow layer assumption then gives:

$$\left(\frac{\partial u_*}{\partial x}\right)_E = \left(\frac{\partial u_*}{\partial x}\right)_T \quad (11g)$$

$$\left(\frac{\partial u_*}{\partial y}\right)_E = \left(\frac{\partial u_*}{\partial y}\right)_T \quad (11h)$$

$$\left(\frac{\partial v_*}{\partial x}\right)_E = \left(\frac{\partial v_*}{\partial x}\right)_T \quad (11i)$$

$$\left(\frac{\partial v_*}{\partial y}\right)_E = \left(\frac{\partial v_*}{\partial y}\right)_T \quad (11j)$$

These linear coordinate transforms neglect the small changes in the grid spacing due to slope distances projected to the horizontal grid.

Data Requirements and Solution Procedure

Specific data required by the model are temperature, pressure, elevation, and roughness length of the underlying surface for all computational points. Temperature and pressure data are transformed thermodynamically to model variables by:

$$\Theta = \frac{T}{p_*} \quad (12)$$

and

$$p_* = \left(\frac{p}{p_o}\right)^{\frac{R}{c_p}} = \left(\frac{p}{p_o}\right)^{0.2857} \quad (13)$$

where p_o is a reference pressure and T is expressed in an absolute temperature scale. While any consistent set of units may be used, the appendix list of symbols gives constants only in metric units.

Roughness lengths are a reasonably constant value describing the height at which the mean wind flow is zero. These values are conveniently describable to acceptable accuracy by classifying the surface into such categories as (but not limited to) grass, brush, boulder field, and so forth. These data are tabulated in numerous texts (Sutton 1953, Priestley 1959, and Sellers 1965); a sample listing is provided in table 1 for convenience and completeness.

Table 1.--Relationship between surface roughness and surface features

Classification of underlying surface	Typical value of roughness length (z.)
	cm
Mud flats, ice	0.001 (Sutton 1953)
Smooth snow	0.005 (Priestley 1959)
Snow, prairie	0.01 "
Thin grass up to 50 cm high	5 (Sutton 1953)
Thick grass up to 50 cm high	9 "
Wheat	22 (Sellers 1965)
City	165 "
Orchard	198 "
Fir forest	283 "

Since the model was designed for use in moderately small areas of finite size, several single-valued coefficients are required to complete the model. Most important of these are the static stability and the large-scale wind direction and windspeed. The large-scale winds were specified as the geostrophic wind. Less important coefficients are the eddy viscosity, the latitude (if the geographic scale of a particular solution is large so that the earth's rotation is important), and the large-scale vorticity (if strong curvature exists in the large-scale flow).

Wind patterns are calculated from a sequence of approximations, each refining the previous step by introducing a more refined physical process, and superimposing the refinement on the previous solution. The first step was to transfer the large-scale background wind into a major terrain-induced modification of the throughflow. This step provided a local throughflow wind.

First, the divergence was calculated through equation (1) for a smoothed terrain. This smoothed terrain was obtained by averaging the four surrounding points with each computational point; the rigid lid was placed well above the terrain in this step. Second, the terrain-induced vorticity was calculated by equation (7) with the thermal and frictional terms neglected. Once these vorticities and divergences were calculated, they were transformed to stream functions and velocity potentials through numerical solutions of equations (8) and (9), and subsequently resolved into velocities by equation (10). These first approximations to the wind field represented the influences of the large terrain feature on the throughflow.

The second level of approximation involved recalculating the terrain-induced divergence for a shallow layer. Divergence was calculated by equation (1) for the actual terrain.

The next step required using the large-scale terrain flow to calculate the friction velocities by equations (4a and 4b) and making the coordinate transforms of equation (11). These intermediate steps provided the input to the final level of approximation.

Friction terms, defined by the friction velocity, and the spatial derivations of temperature and pressure after the coordinate transform were included in the solution of equation (6) for divergence and of equation (7) for vorticity. Background divergence came from the second level of approximation, and the background vorticity came from the divergence and vorticity as in the first step through numerical solutions of equations (8) and (9). Velocity components were then calculated

through equation (10), where the background velocities were defined by the first step.

Evaluation of the Model

Validation

There are several philosophies of model validation, each designed to accomplish specific objectives. Because this model is intended for use in applied meteorology, we have chosen to use actual data sets from mountain mesoscale studies to validate the wind field estimates. In adopting this approach, we have imposed a severe test since the model is limited in spatial resolution by computational filtering to approximately four times the grid distance, while the validation data have small-scale spatial resolutions defined by nearby terrain or vegetation and sensor response characteristics. Also, calculated winds represent an average wind over an area defined by the grid mesh. Such a test is desirable, however, because it defines operational uncertainty rather than model potential, and represents actual resolution attainable.

Seven data sets were used in the model validation. Six came from studies conducted by Cramer⁷ in the Oregon Cascade Mountains. One data set came from central California (Fosberg and Schroeder 1966). All seven depict daytime conditions: five for midafternoon, and two for morning. One morning case occurred under overcast skies and rain. The other six occurred with strong solar heating. Background winds ranged from 2 to 5 m per second. The Oregon winds were calculated on a 6 km square grid, the California case on a 16 km square grid. Air temperatures were extrapolated to grid points from the field network weather stations.

Evaluation of the errors in both windspeed (fig. 1) and wind direction (fig. 2) demonstrates the utility of the model. The root mean square windspeed error was 2.0 m per second. Forty-five percent of the calculated windspeeds fell within 1 m per second of the observed wind, and 75 percent fell within 2 m per second. These comparisons were made over an observed range of 0.5 to 10.5 m per second. Observed wind directions were reported on a 16-point compass basis. Therefore, the error analysis is presented as a compass-point error rather than a more precise evaluation

⁷We thank Owen P. Cramer of the U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon for unqualified use of original data for the model validation and for permission to reproduce unpublished results in this paper.

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Figure 1.—Comparison of calculated and observed windspeeds. Bold diagonal line defines perfect fit. Forty-five percent of predictions fall within 1 m sec⁻¹ of the observed windspeed and 75 percent fall within 2 m sec⁻¹.

Figure 2.—Comparison of calculated and observed wind direction. Comparison is on a 16-point compass basis. Sixty percent of calculated directions fall within 11 degrees and 92 percent fall within 22 degrees of observed directions.

of angle. The root mean square direction error was 1.9 points. Sixty percent of the calculated directions fell within 1 compass point of the observed direction, and 92 percent fell within a 2-point envelope of the observed direction. Observed directions were from all compass points except for the east and northeast sections.

Models of this type implicitly require a number of specifiable coefficients which tune the model to particular geographic regions. While we have attempted to specify these coefficients through physical arguments, some are still at the discretion of the user. The integration coefficients were totally predetermined. The rigid lid coefficients for potential flow were selected through several criteria. The first was that the terrain could not penetrate the rigid lid. The second was based on a large number of solutions where the lid was systematically varied until a high level of sensitivity was reached. Lid height is based on elevation differences across the grid field. The user guidelines in the climatology section of this paper describe the techniques for determining layer thickness. They are cited here because the consequences are reflected in the error analysis.

Flow Patterns

Each of the seven cases showed similar dynamic processes (table 2). Thermally and terrain-produced divergence dominated the dynamics of the flow. Divergence-generated flow perturbations were 2.5 to 4.3 times as large as vortically generated deviations. Vortex flow accounted for 11 to 24 percent of total kinetic energy, while 32 to 69 percent was accounted for by the potential flow. Strongest local wind energetics were ob-

served under conditions of light background winds and strong surface heating. As background winds increased, or the solar heating decreased, the local winds became a weaker component and less important in the total kinetic energy budget. Tests of background windspeeds for several hypothetical cases beyond the range of data used in validation show that at 0.5 m per second, the wind patterns are controlled completely by the thermal patterns. At 10 m per second, thermal control vanished and terrain influences were weak.

Mesoscale flow characteristics are best illustrated through a detailed examination of one of the case studies. The area is in the Oregon Cascades, south of Mt. Hood, north of Mt. Jefferson, and runs from the Willamette Valley across the crest of the Cascade Range to the edge of the eastern Oregon plateau. The mountains are penetrated by a major drainage on the west side, the Clackamas River. The particular case selected, August 8, 1963 at 1600 PST, was chosen as representing a typical or intermediate situation. The synoptic weather pattern was characterized by a weak upper-level, high-pressure area, and west to west-north-west geostrophic surface flow over the Cascades. Details of the observation and analysis procedures were presented in Cramer (1972) and Cramer and Lynott (1961, 1970). Discussion here is limited to resultant computations and estimation of the wind field from the analysis. Only salient features of Cramer's analysis are presented here for completeness.

Cramer's data analysis of temperature and 850 mb surface heights were interpolated to 6-km grid points. These data were converted to potential temperature and normalized station pressures for each grid point. Terrain elevation at each grid point was interpolated from a topographic map.

Table 2.--Relationship between flow energetics and weather features

Date	Location	Time	Flow energy accounted for by:		Ratio of irrotational energy to rotational energy	Geostrophic windspeed	Weather features
			Irrotational energy	Rotational energy			
		LST					
			percent			m per second	
1963							
Aug. 8	Oregon	0700	60.4	24.3	2.5	2.5	Strong morning heating
Aug. 8		1600	55.1	19.8	2.8	2.5	Strong afternoon heating
Aug. 19		0700	34.2	9.1	3.8	4.9	Weak morning heating-- extensive clouds and rain
Sept. 4		1600	31.5	10.7	2.9	4.9	Strong afternoon heating
Sept. 5		1600	42.7	15.7	2.7	3.5	Strong afternoon heating
Sept. 12		1300	68.5	20.7	3.3	2.5	Strong afternoon heating
1962							
Aug. 15	Calif.	1400	42.3	9.9	4.3	3.0	Strong afternoon heating

The underlying surface was almost exclusively characterized by conifer forest, so the roughness length was taken as a constant 283 cm.

Temperature distribution (fig. 3) over this terrain generally showed a slight decrease with elevation. West-facing slopes were warmer than east-facing slopes. The major river valley was much warmer than surrounding areas, and provided strong local temperature gradients. In general, the area east of the Cascades was warmest as a result of morning heating and topographic blocking of cool marine air flowing off the Pacific Ocean.

Height of the 850 mb pressure surface (fig. 4) generally reflected the high-pressure area over northwest Oregon. Surface heating of the mountain slopes produced the "thermal low" frequently observed along the West Coast. This "thermal low" appeared as a mesoscale low-pressure area through the higher terrain and modified the large-scale pressure pattern.

These observed data were transformed to the thermodynamic variables of potential temperature and normalized nondimensional surface pressure used in the model equations. The 850 mb surface height was reduced to the terrain surface through the hydrostatic equation using the static stability from the Salem, Oregon rawinsonde observation. Once this pressure calculation was made, the potential temperatures were calculated with these pressures and the interpolated temperatures.

Since the dynamic influences due to pressure gradients are completely reflected in the 850 mb pressure surface height, only the potential temperature patterns will be described here (fig. 5). Potential temperature showed a highly organized pattern. Higher elevations had higher potential temperatures. Valleys where cooler marine air could penetrate from the coast were clearly marked by low potential temperature. East-slope highlands had highest potential temperatures.

These observed fields of temperature and pressure were used to calculate the fundamental kinematic characteristics of divergence and vorticity. Divergence patterns were strongly correlated with terrain. Even small topographic features such as narrow ridges and valleys stand out in the divergence patterns (fig. 6). Flow divergence was confined to lowlands and valley bottoms. Convergence zones were on ridgetops and followed the terrain contours. Gentle slopes and large continuous upland areas on the east slopes typically had weak gradients. Magnitudes of the divergence were typically $\pm 10^{-3}$ per second. The convergence areas in regions of rugged terrain were much smaller than divergence areas, and maximum values were two to three times as in-

tense as the compensating divergent areas. The intense gradients generated in the rugged terrain were most noticeable between the Clackamas River valley and the surrounding ridges. Areas of moderately changing terrain had divergent and convergent patterns of roughly equal area and intensity.

Vorticity patterns (fig. 7) did not show either the response to small terrain features or the large magnitude found in the divergence fields. Vorticity was typically $\pm 10^{-6}$ per second with the strongest areas only $\pm 10^{-4}$ per second. Ridgetops tended to have anticyclonic relative vorticity of 10^{-4} per second while valley bottoms had cyclonic vorticities of -10^{-4} per second. Areas with slowly changing elevation did not show a consistent terrain-vorticity correlation. In general, vorticity tended to have a much longer wave length than divergence. The only generalizations we can make about the patterns are that major ridges tend to favor anticyclonic vorticity, while lowlands and major valleys tend to favor cyclonic vorticity. This characteristic was probably due to the dominant influence of the divergence in flow properties.

Resultant wind fields (fig. 8) showed strong topographic and thermal control of the wind patterns. Airflow in the Clackamas River valley and the other two west-slope watersheds penetrating into the Cascades showed strong topographic channeling up the rivers and the influence of slope winds angling away from the valley axis. West-slope areas away from these major drainages generally showed upslope flow, even on the lee sides. Strongest winds were calculated on high ridgetops and at the heads of canyons as they reached the highlands. Lee effects were most noticeable along the eastern slope. Winds flowing across the ridge in the northeast portion of the area were reduced from 5 m per second to 1 m per second by the upslope influences on the lee side. Strong, thermally driven winds were calculated in the south-central and southeastern portion of the area, where prevailing winds were reduced and influences of the penetrating west-slope canyons were negligible. Those variables which had greatest impact on model reliability were determined by sensitivity analysis. Both processes and variables were systematically excluded and error analysis conducted on all seven cases. This analysis indicated that frictional influences and the vorticity equation affected the resultant wind field only slightly. Terrain and thermal influences totally dominated the calculations. Neglect of either created large errors in the wind field in the test cases. Further analysis of these processes indicated that pressure variation could be excluded with introduction of a small error, but that

Figure 3.—Temperature field for 1600 PST, August 8, 1963. Temperatures are in degrees k; warmest areas are on the east slopes of the Cascade Mountains.

Figure 4.—Height of 350 mb surface for 1600 PST, August 8, 1963. Height is in meters above m.s.l. Thermal trough is oriented southwest to northeast.

Figure 5.—Distribution of potential temperature for 1600 PST, August 8, 1963. Temperatures are in degrees k. Inversion of marine air into the mountains is confined to the Clackamas River valley.

Figure 6.—Horizontal divergence field for 1600 PST, August 8, 1963. (Units are 10^{-5}sec^{-1} .) Strongest gradients of divergence are between the west side drainages and the surrounding ridges.

Figure 7.—Vertical component of vorticity for 1600 PST, August 8, 1963. (Units are 10^{-5}sec^{-1} .) Anticyclonic vorticity is on ridgetops and cyclonic vorticity is in valleys.

Figure 8.—Calculated and observed wind field for 1600 PST, August 8, 1963. Arrows indicate direction of wind. Speeds are given by sum of barbs and pennants on arrow tails. Pennants indicate 5 m sec^{-1} ; a full barb, 2 m sec^{-1} ; a half barb, 1 m sec^{-1} . Calculated wind field is in red; observed wind field is in black.

the topographic and temperature field must be represented in complete detail for the model to provide realistic and verifiable results.

Topography, Climatology, and Winds

Two parameters are required if the model is to define the topographic influence on throughflow. The first of these, the depth of the rigid lid at the top of the slab, should normally be expected to be 1,500 to 2,000 m above the spatially smoothed terrain. The second parameter, the thickness of the shallow layer, refines the first estimate of terrain influences. It is 1.25 times the difference between the smoothed terrain and the actual terrain. These guidelines for the relationship between throughflow and terrain were determined from a large number of test cases where the coefficients were varied systematically. The final choice was a judgment of which relationships produced the most acceptable resultant wind field.

Grid point spacing is also related to topographic variations. In rugged terrain, a closely spaced grid is required to resolve the local winds, while in gently rolling terrain, a low-resolution grid will give acceptable wind fields. Guidelines for selecting appropriate grid spacing were developed from procedures similar to those used in evaluating layer thicknesses.

Numerous analyses were carried out with the same data sets so that performance could be evaluated by overall resultant wind field errors. Grid spacings between 1 and 6 km were evaluated for maximum terrain differences of 300 to 1,500 m. These analyses indicated that grid spacing should be reduced by 1 km for every increase in terrain range of 300 m. If the terrain within an area 10,000 km square varies by 300 m or less between the highest and lowest spatially averaged elevations, then a 6-km grid would be appropriate. If, on the other hand, the terrain variation were 1,500 m a 1-km grid would be appropriate. These spacings must be modified to the smallest grid spacing if the wind field is intended to be used for fine-scale analysis of pollution patterns or fire spread, or to larger spacing if broad geographic coverage is required. Grid spacing of 500 m is probably the minimum the model will treat properly. Close grid spacing does not permit a 50- by 50-point grid to include major terrain features. These two nonmodel dependent factors (terrain complexity and computer resources) must be considered in selecting the grid interval. The spacings specified here represent maximum spacing—not optimum for any particular application.

The seven cases in this analysis all came from detailed mesometeorological research studies. Such intensive data would not normally be available. Detailed temperature patterns can be estimated from climatological relationships developed for slope temperatures. Super and Grainger (1969) and Hayes (1941) made detailed studies of slope temperatures by aspect and time of day. Baker (1944), using maximum and minimum temperatures, characterized the slope temperatures for 20 mountainous areas of the Pacific and Rocky Mountain States. These climatological relationships will approximate the temperature distribution when the available observations and topography are used to fine tune the slope functions.

Using the Model for Planning—A Case Study

Consider a case where engineers and architects are designing a new plant at a mine mouth. The mineral extraction process will create a large volume of tailings over a period of years. These tailings could be hot. In the design study the questions are asked: (1) What will be the effect of changing the terrain in the immediate area by filling the gulches and small valleys with tailings on the downwind dispersal of stack contaminants?, and (2) What will be the effect on downwind dispersal if the tailings are approximately 70°C warmer than the surrounding areas?

The wind model may be used to estimate probable consequences of the mining activity on pollution dispersal patterns. To illustrate this use, we assumed a light wind of 0.45 m per second (1 mile per hour) from the southwest; temperature distribution was given by climatology for nighttime conditions. Wind patterns before construction showed well-organized drainage flow into and down the valleys and gulches (fig. 9).

Two cases of land change were simulated to anticipate influence on the local wind patterns. In the first case, the valleys and gulches were filled with heated tailings. Changes in the flow were calculated near the modified landform. Heated areas increased the windspeeds and changed the directions to a uniform south-southwest flow down the major gulch (fig. 10). Airflow in the large river drainage to the north was turned and flowed up canyon. The second case considered was that the same gullies and canyons were filled with tailings, but the tailings were not heated. This modification also increased and organized the drainage flow (fig. 11). Winds were from the southwest over the tailings for this case. How-

● indicates plant and mine site.

Figure 9. —Local wind pattern before construction of a hypothetical plant and mine tailings.

● indicates plant and mine site.

Figure 10. —Simulated wind field for a case with heated tailings.

● indicates plant and mine site.

Figure 11. — Simulated wind field for a case with cold tailings.

ever, air did not flow up the canyon from the major river drainage. The two cases predicted increases in windspeed of as much as 1 m per second and direction changes of 180 degrees near the planned mine activities.

Summary and Conclusions

Local thermally driven flows such as mountain and valley winds are simulated reasonably well. Interactions of these local flows, and influence of the larger scale potential flow on these local winds, are also included in the resultant flow. These thermally driven flows are determined properly primarily because the thermal forcing processes are stationary and locked to the terrain features. Also, these thermal features are in a quasi-steady state for several hours. Thus, neglect of the advective process is permissible, and the impulse integration to steady state approximates the flow field.

Thermal modification of potential flow across the terrain features dominates the driving forces. Potential flow was three times as important as rotational flow.

Error analysis of seven case studies and the application example indicated that the model could be used as an aid in fire and air-quality programs because of the low data requirements and the reduced computer effort required.

The wind model developed here was based on simplifications of the complete set of equations governing atmospheric flow over complex terrain. These simplifications imposed several limitations on the use of the model, both in types of flow that can be depicted and in spatial coverage of the solutions. Moving flow systems and flows which are characterized by intermittency or by separation are explicitly excluded, because (1) advection was eliminated, and (2) the model is intended to depict quasi-steady state processes. Coefficients describing static stability and overall wind through-flow place spatial limits on the model because (1) constant static stability prohibits larger scale baroclinicity, and (2) the single-valued wind vector prohibits large-scale flow discontinuity. Also, the neglect of advective processes excludes strong interaction of the mesoscale with larger scales, and does not allow for modification of the downwind environment.

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APPENDIX

List of Symbols

Symbol	Definition	Units
c_p	Specific heat at constant pressure	1.003 joules $\text{gm}^{-1} \text{ } ^\circ\text{K}^{-1}$
f	Coriolis parameter	sec^{-1}
g	Acceleration of gravity	9.8 m sec^{-2}
H	Thickness of rigid lid layer	m
h	Thickness of second approximation to flow	m
k	von Karman constant	0.4
$\hat{k}$	Unit vector in vertical direction	dimensionless
K	Turbulent viscosity	$\text{m}^2 \cdot \text{sec}^{-1}$
p	Pressure	dynes cm^{-2}
p_0	Reference pressure	$10^6 \text{ dynes cm}^{-2}$
p_*	Non-dimensional pressure $\left(\frac{p}{p_0} \right)^{\frac{R}{c_p}}$	-----
R	Ideal gas content	$0.287 \text{ joules gm}^{-1} \text{ } ^\circ\text{K}^{-1}$
T	Temperature	Deg K
t	Time	Sec
$u, \bar{u}, u_0$	Windspeed in west to east direction	m sec^{-1}
u_*	Friction velocity in west-east direction	m sec^{-1}
$\vec{v}$	Horizontal velocity vector	m sec^{-1}
$\bar{v}, \bar{v}_0$	Windspeed in south-north direction	m sec^{-1}
v_*	Friction velocity in south-north direction	m sec^{-1}
w_w	Vertical windspeed	m sec^{-1}
x	Horizontal coordinate in west-east direction	m
y	Horizontal coordinate in south-north direction	m
z	Vertical coordinate	m
z_0	Surface roughness length	m
$\bar{\delta}, \bar{\delta}$	Horizontal divergence	sec^{-1}
$\bar{\zeta}, \bar{\zeta}$	Vertical component of vorticity	sec^{-1}
θ	Potential temperature $\theta = \frac{T}{P_*}$	Deg K
ρ	Density of air	kg m^{-3}
σ	Static stability $\sigma = \frac{1}{\theta} \frac{\partial \theta}{\partial z}$	m^{-1}
ϕ	Velocity potential	$\text{m}^2 \text{ sec}^{-1}$
ψ	Stream function	$\text{m}^2 \text{ sec}^{-1}$
∇	Horizontal vector gradient operator	m^{-1}
∇^2	Horizontal laplacian operator	m^{-2}
Δ	Horizontal grid spacing	m
Δt_τ	Impulse time for vorticity	sec
Δt_δ	Impulse time for divergence	sec

APPENDIX B

Topographic Analysis System (TOPAS)

TOPOGRAPHIC ANALYSIS SYSTEM
USER'S GUIDE
SECOND EDITION

TOPAS

Forest Service
U.S. Department of Agriculture
Washington, D.C. 20250

JANUARY 1976

PREFACE

The TOPAS system of programs and associated User's Guide has been in use for over a year. However, just as any computer program needs "debugging" to function properly, so does a user's instruction of this scope. This second edition, the TOPAS User's Guide, has been published to clarify, correct, update, and add features which will make the system easier to use and understand.

This new edition has been professionally edited to standardize chapter format and insure consistency of terminology throughout the text. All programs, segments and functions which were included in the original manual have been edited and are included in this edition with the exception of the program VIEWIT. This program has been renamed SEEN to distinguish it from PSW's VIEWIT program. The program is otherwise unchanged.

Several additions to the original TOPAS system have been incorporated into this edition. They are programs ITOPAS, ARRAY, COPYNCIC, and FLIGHT. A section is devoted to each of these programs. In addition, function CAT has been included in the MANUv segment of DTIS.

A glossary of commonly used acronyms, abbreviations and technical terms has also been added for easy user reference.

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CHAPTER I

INTRODUCTION

SECTION 1. BASIC CONCEPTS

TOPAS Program Package

TOPAS is the acronym for TOPographic Analysis System. It is the code name given to a package of computer programs that have been developed for the collection, manipulation, and analysis of digital terrain data.

Exhibit 1.1 illustrates the basic concept of TOPAS and all the computer programs within the system. Exhibit 1.2 lists these programs in an alphabetical order, and gives brief descriptions of the major functions of each program.

The sub-set of programs, which are used in the generation of digital terrain data directly from existing topographic maps or from airphotos, have been code-named DTIS (DIGITAL Terrain Information System). This system of programs may be used to produce scan profiles for ortho photo production or to generate cross-section elevations for road design analysis.

Output Products from TOPAS

The following types of output products can now be generated with TOPAS:

1. Contour map
2. Isoslope plots
3. Drawing of slope zones
4. Drawing of aspect zones
5. Perspective view
6. Delineation of visible area from view points
7. Scan profiles for ortho-photo production
8. Cross-section elevations for road design applications
9. Flight planning plot using DMA tapes
10. Perspective contour view
11. Skyline logging ground profile data
12. Slope or aspect zone data for input to program GELO

Generation of Digital Terrain Data

There are three basic methods by which digital terrain data of a given area can be obtained. These are:

1. Existing terrain data, such as the digital terrain data tapes that the Defense Mapping Agency (DMA) has generated from the USGS 1:250,000 scale maps.
2. Existing topographic maps, such as the 1:24,000 and 1:62,500 USGS maps. These maps can be easily digitized to provide numerical data of the terrain.
3. Air photos. Conventional photogrammetric mapping procedures can be used to create a three-dimensional optical model of the terrain, which can, in turn, be digitized to provide numerical data.

Gridded and Non-Gridded Digital Data

Depending on the method used in the digitization process, the digital terrain data can be stored in either a gridded or non-gridded (also referred to as random or irregular) pattern. If the data is digitized in a rectangular pattern, as shown in Exhibit 1.3, the grid spacing remains constant, and only the elevation of data points need to be recorded. Thus, the digital terrain data tape from a gridded digitization procedure will consist of a string of elevation data. Knowing the grid spacing and the number of rows and columns in the grid, the exact x and y coordinates of each elevation point can be easily derived.

An irregular digitization procedure, such as that shown in Exhibit 1.4, will result in an irregular (random or non-gridded) distribution of data points. In order to define the spatial positions of each data point, the x, y, and z coordinates of each point must be recorded in the data file.

The non-gridded approach is most commonly used in the manual digitization process because it reduces the number of data points that need to be recorded. For example, digitization of a 10" x 10" area of a 1:24,000 map sheet in a gridded pattern with a grid size of .01 inch x .01 inch, will result in about 1,000,000 data points. However, by following a non-gridded approach and digitizing only terrain points which show sharp change in topography, the number of data points may be reduced by a factor of 100 or higher.

On the other hand, gridded data are more convenient in computation. Hence, most application programs either require gridded data as input or have the capability of converting non-gridded data into gridded format before entering the computation phase. Programs MANUv, FSGPCP, or ARRAY in the TOPAS package may be used to perform the conversion.

Project Data File

A digital terrain data tape or file usually contains digital data for a large area. For example, a DMA digital terrain data tape stores approximately 2,000,000 data points for one-half of a 1:250,000 sheet. However, none of the application programs within TOPAS can accept a data file containing more than 14,641 data points. Therefore, it is necessary to extract a subset of data from an existing data file. This subset of data will be referred to as project data file in this manual.

TOPOGRAPHIC ANALYSIS SYSTEM (TOPAS)

B-3

Exhibit 1.1 - Topographic Analysis System (TOPAS)

Programs	Functions
1. ARRAY	Converts MANUV generated grid data to Calcomp GPCP ARRAY formats.
2. BLOCK	Collect up to 500 points of UNITrecord data or RESOource data into a single record with Min-Max, North-East for the included data.
3. BLOCK- BACK	Reformat Blocked Terrain Data File to card image.
4. CON3D	Produce a perspective contour or contour plot from Digital Terrain Data.
5. COPY	Copy a DMA tape to a USFS tape to establish a permanent data file.
6. FLIGHT	Produce a Profile and Flight Planned Data from Digital Terrain Data Tape.
7. FORCOR	Convert State Plane coordinates to or from Geodetic Positions or from one State-zone to another.
8. FSGPCP	1. Convert random data into gridded data. 2. Plot contour map. 3. Plot isoslope lines.
9. LISTING	Produces a listing of all DTD tapes available to FCCC.
10. MANUV	Operate on the Digital Terrain Data base. (see MANUV functions)
11. ONESHOT	Transform spatial coordinates of a controlled model to ground. May also be called with a 'SPAT' Segment call card.
12. PREP3D	Draw perspective view using every second data point in a gridded data file.
13. PRINT	List the x and y coordinates of the corners of all the 7 1/2-minute quads contained in a DMA tape.
14. SCANDMA	Scan a DMA tape and extract the elevation data within some local area to build a project data file.
15. SCANDTIS	Produce a random file formatted for use in DTIS from a DMA type terrain tape.
16. SEEN	Identifies all data points that are directly visible from a given viewpoint. The visible area is denoted by a Calcomp and/or line-printer plot.

Exhibit 1.2 – List of Programs in TOPAS

Programs	Functions
17. SLOPE	Computes the slope and aspect at each elevation point, and stores the results in a new data file.
18. THREED	Draw a perspective view of the elevation grid which represents the terrain surface.
19. XYTRAN	Transform map coordinates to ground.
20. ZONEIT	Provides a graphic plot of slope or aspect zones.

Data File:

z_1	z_2	z_3	z_4	z_n	z_{n+1}	z_{n+2}	z_{2n}	z_{2n+1}
-------	-------	-------	-------	-------	-----------	-----------	----------	------------

DATA FILE				X	Y	Z	X	Y	Z	X	Y	Z	.	.	.	.	.
				1	1	1	2	2	2	3	3	3	.	.	.	.	.

SECTION 2. TOPAS GLOSSARY

ARRAY	DTIS segment. Converts MANUv gridded data to Calcomp ARRAY block format.
ARRAY block	Calcomp GPCP formatted gridded data file.
ARRAY	TOPAS program to generate a gridded data file in an ARRAY block from random or pattern data.
BLOCK	DTIS segment. Converts punched TDF to blocked TDF.
BLOCK	DTIS input/output option to generate or enter data from a blocked TDF.
BLOCKBACK	TOPAS program to retrieve terrain from a blocked TDF and generate a punched TDF.
Blocked TDF	Terrain data file where each record in the file contains up to 500 positions with the area covered by these positions described (Min-Max, North-East).
Boxed data	MANUv function STOF1 collects terrain data into regular areas. This method (boxing) generates a "boxed data" file.
CI	Abbreviation, Contour Interval
CON3D	TOPAS program to generate a perspective contour plot.
COPY	TOPAS program to create a copy of a DMA Tape.
COPYDMA	Same as copy.
COPYNCIC	TOPAS program to create a copy of a NCIC terrain data tape. The result of this copy procedure is in the DMA tape format.
CT50	Forest Service Road Design System Card type used to input road cross-section information.
DE	MANUv segment variable. Describes the east-west size of the work area.
Defined File	Mass storage file which can be accessed either randomly or sequentially.
DELDE	MANUv segment variable. Describes the east distance to the work area from the Project southwest corner.
DELDN	MANUv segment variable. Describes the north distance to the work area from the Project southwest corner.

DIF	MANUv segment variable. Describes the size of "boxes" when collecting and operating on boxed data.
DMA	Abbreviation, Defense Mapping Agency.
DMA Tapes	Elevation data collected by the DMA from USGS 1:250,000 Maps at .01 inch interval. These tapes, or versions of them, are available to the government and to the public. They are adequate for area planning, but generally not accurate enough for use in planning on small areas (sites).
DTD	Abbreviation, Digital Terrain Data. A collection of positional information (x, y, z) dense enough to describe the terrain covered by them.
DTIS	A TOPAS Program, Digital Terrain Information System. This program is a group of functions for transforming spatial terrain data from stereo model or map coordinates to ground positions, and, to grid, profile, and/or reformat the data for use by other programs in the TOPAS system.
EOF	Abbreviation, End of File.
FCCC	Abbreviation, Fort Collins Computer Center.
FILL	A MANUv function which creates the Work Area Data File from the Project Data File.
FLIGHT	A TOPAS program which generates ground profiles and determines flying elevation and degradation of side lap at maximum terrain elevation. It generates a graphic of the ground profile. The source terrain data for program FLIGHT is a DMA Tape.
FORCor	A MANUv function which converts either geographic positions to State Plane positions, or vice versa. It can also convert from one State Plane zone to another.
FORCor	A MANUv input/output option which enables the user to enter control points for function XYTRan in geographic positions. These are converted to State Plane coordinates.
FSGPCP	Abbreviation, Forest Service General Purpose Contouring Program. It generates contour plots from Digital Terrain Data (DTD), or from gridded data (ARRAY blocks). This program was purchased from Calcomp and was slightly modified for TOPAS. It cannot be copied, given away, or sold by the Forest Service.
GPCP	Abbreviation, General Purpose Contouring Program. This was purchased by the Forest Service from Calcomp for use only at FCCC. This program cannot be copied, moved, sold, or given away by the Forest Service.

GRID	A MANUv function which interpolates elevations at a regular interval along the profiles generated by ORTHO. (Grids the ORTHO profiles.)
GRID	A MANUv Input/Output option which generates grid lines at a specified interval on the Ortho photo overlay generated by MANUv function SETUp.
IBOT	A variable describing the southern boundary of an area to be retrieved from a DMA tape. (Distance in .01 inch units from bottom of Quad.)
ILEFT	A variable describing the western boundary of an area to be retrieved from a DMA tape. (Distance in .01" units from left edge of Quad.)
INC	A variable, Increment of collection of data from a DMA tape. For example, when $INC = 2$, alternate elevations are collected from alternate columns.
IN80	MANUv Input/Output option which enables user to input control points (80 series points) in Standard SPATL format, while DTD is entered from blocked TDF.
IRIGHT	A variable, eastern boundary of area to be retrieved from a DMA tape (see ILEFT).
IRITE	A variable, same as IRIGHT.
Isoline	A line joining points of equal value. For example, a contour is an isoline joining points of equal elevation.
Isoslope	A line joining points of equal slope.
ITOP	A variable, northern boundary of area to be retrieved from a DMA tape (see IBOT).
ITOPAS	A TOPAS program to generate and submit for execution, runstreams to produce graphic products where the source data is from DMA tapes.
IXSW	A variable, map location of the southwest corner (X) of the grid data on a DMA tape.
IYSW	A variable, map location of the southwest corner (Y) of the grid data on a DMA tape.
JCL	Abbreviation, Job Control Language. Used here to refer to the Univac 1100 Series Executive Command Language.
KODE	A variable, the first two characters of a DTD position, consisting of KODE, ID, and position. When KODE is from 80 to 89, the point is a control point. When it is less than 80, the point is a terrain point, and when it is 90 to 99, the point is an "EOF" indicator.

MANUv	DTIS segment. MANUv is the calling routine for the DTD handling functions.
NECE	A variable, east value for northeast corner of the Project Data File.
NECN	A variable, north value for northeast corner of the Project Data File.
NEEL	DTIS Input/Output Option. The order of ordinates on the input DTD is North, East, Elevation.
NOBLock	DTIS Input/Output option. DTD generated by ONEShot or XYTRan is to be output as a Punched TDF. Input DTD to MANUv is Punched TDF.
NOPLot	MANUv Input/Output option specified when MANUv function SETUp is not to generate an Ortho photo overlay.
ONEShot	DTIS segment. Transforms controlled stereo model spatial coordinates to ground positions. Outputs DTD in blocked or, optionally, in punched TDF.
ORTHo	A MANUv function which generates north running profiles across the Work Area for use by functions PRORt and/or GRID.
Ortho Photo	Scale corrected aerial photo image.
Pattern Data	A method of collecting non-gridded digital terrain data. Ridges, drains, and major breaks are digitized (collected), then additional data is collected by digitizing along "Form lines" or contour lines.
PLINe	A MANUv function which generates cross-section data in RDS CT-50 format for input to the RDS program.
PLOT	MANUv Input/Output option. Causes MANUv option SETUp to generate an Ortho photo overlay.
PREP3D	A TOPAS program which generates and submits for execution, a run-stream, to prepare a perspective plot using Calcomp program THREED.
PRINT	A TOPAS program. From the 4 sets of corner coordinates of a 1 degree quad, the corner coordinates for the 64 7-1/2 minute quads are generated and graphically printed. This graphic is very useful when running programs SCANDTIS or SCANDMA.
Project Data File	An area of digital terrain selected by MANUv function STOF1 for division into one or more work areas by MANUv function FILL.
PRORt	A MANUv function which generates a plotted Ortho photo storage plate (profile plate), to drive the Zeiss Ortho photo projector.

PSW	Abbreviation, U. S. Forest Service Pacific Southwest Forest and Range Experiment Station.
Punched TDF	Card image terrain data in SPATL packed format (2 positions per card image).
Random Data	See Pattern Data.
RDS	Abbreviation, a program called Forest Service Road Design System.
RESORce	DTIS Input/Output option. Terrain Data Input into DTIS segments ONEShot or MANUv is in SPATL Resource format.
SCALE	A variable, generally scale denominator ($SCALE = 24000$ for a scale of 1:24000). Except in MANUv function FILL, SCALE is the feet per inch value. ($SCALE = 2000$ for a scale of 1:24000).
SCANDMA	A TOPAS program which retrieves from a DMA tape, a selected area, and outputs it in an ARAY Block.
SCANDTIS	A TOPAS program which retrieves from a DMA tape, a selected area or areas, and outputs it as a blocked TDF.
SCN	A variable. In MANUv function FILL, it describes the Ortho photo scan width and/or grid size.
SEEN	A TOPAS program (formerly TOPAS version of VIEWIT) which determines what terrain can be seen from 1 or a number of viewpoints. It produces a plot of the seen areas at any scale, and optionally produces a printer map of each seen area (this printer map is not to scale).
SETUp	A MANUv function which produces a table of Zeiss Ortho photo projector setup coordinates, and optionally plots an Ortho photo overlay.
SIZE	Card type in program FSGPCP which describes the area to be contoured.
SLOPE	A TOPAS program which generates slope and aspect files in the ARAY block format from an elevation ARAY block.
SPATL	An aerotriangulation program developed by R. O. Mahan, USFS, Division of Engineering, to bridge strips and blocks, and perform ground adjustment of terrain data. This program was extensively modified and made into MANUv segment ONEShot. Note: ONEShot is <i>not</i> an aerotriangulation program.
SPATL Digitizer format	A card image format containing 3 spatial positions per card.

SPATL Packed format	A card image format containing 2 ground terrain positions per card.
SPATL Resource format	A tape image format containing 1 ground or spatial position, and 72 characters of resource descriptors per 112 character tape record.
SPATL Standard format	A card image format containing 1 ground position per card.
STOF1	A MANUv function which generates a Project data file (boxed data) from either punched or blocked TDF.
SWCE	A variable. Describes the east value for the southwest corner of the Project data file.
SWCN	A variable. Describes the north value for the southwest corner of the Project data file.
TDF	Abbreviation, Terrain Data File. This usually refers to blocked Terrain Data File.
TOPAS	Acronym for TOPographic Analysis System. A collection of programs to produce a variety of graphics from gridded or non-gridded (pattern) terrain data.
THREED	TOPAS program. Generates perspective (warped grid) plot from gridded data. This program was purchased from Calcomp, and cannot be copied, moved, sold, or given away by the Forest Service.
TYPE50	MANUv Input/Output option. It causes road design cross-sections to be output in the RDS CT50 format.
UNITrecord	DTIS Input/Output option. It indicates that DTD input to one of the DTIS segments will be in 1 of the 3 SPATL card image formats; standard, packed, or digitizer.
UPERIN	A variable. In program ZONEIT, the number of grid Units PER INch at plot scale.
USGS	Abbreviation, United States Geological Survey.
VGRID	MANUv function. Generates gridded data in the printer output format required by PSW's program, VIEWIT.
VIEWIT	A PSW program for generating seen areas, slope and aspect. A user's guide is available from PSW.

Viewpoint	A viewing station or location, and an input to program SEEN.
Work Area Data File	The area, and boxed data associated with it, as described for, and collected by, MANUv function FILL.
XYTRan	A DTIS segment which transforms digitized map coordinates, digitized in any unit of measure, to ground positions.
XYZ	A DTIS Input/Output option which indicates that the punched DTD input to any of the DTIS segments will be in the order X (East), Y (North), Z (Elevation). Note that the east and north values are in reverse order from those of I/O option NEEL.

CHAPTER II

PROCUREMENT OF DMA DATA TAPES

Description of DMA Tapes

The Defense Mapping Agency (DMA), formerly the U. S. Topographic Command (TOPOCOM), has produced digital tapes of the entire 1:250,000 USGS map series covering the United States. These tapes contain only elevation data. Each 1:250,000 map sheet is subdivided into an East half and a West half, with the data from each half being contained on a separate tape.

The DMA tapes store the elevation data in a rectangular grid pattern. Exhibit 2.1 shows the subdivision of a 1:250,000 sheet into East half and West half, and Exhibit 2.2 shows the grid pattern and the rectangular coordinate system for the two halves. The distance between two adjacent data points, in both the x and the y directions, was 0.01 inch on the 1:250,000 map sheet, which is equivalent to 208-1/3 ft on the ground. Thus, each DMA tape contains approximately 2,000,000 data (elevation) points.

Exhibits 2.3 and 2.4 are index maps of the 1:250,000 USGS maps for the western and eastern parts of the United States, respectively.

USFS Library of DMA Tapes

A library of DMA tapes available in the USFS, is stored in the Fort Collins Computer Center (FCCC). These tapes are kept in permanent storage, and can be directly accessed by any region.

An up-to-date listing of all the DMA tapes at FCCC may be obtained by the execution of the following simple program:

@ RUN

@ ASG,A GEOM*DMATAPES

@ PRT,S GEOM*DMATAPES.LISTING

@ FIN

Exhibit 2.5 is an example output listing. It includes the following data for each 1:250,000 map sheet:

Data Type	Example
Sheet Name	ALTURAS
DMA Sheet Number	NK-10-9
East or West Half	WEST
FCCC Tape No.	FO2710

Data Type (cont)	Examples (cont)
State	CALF
Latitude of SW Corner of sheet	41
Longitude of SW Corner	122
FCCC Tape Label	GEOM*K1009W
X-coordinate of SW Corner	276
Y-coordinate of SW Corner	225
X-coordinate of SE Corner	1601
Y-coordinate of SE Corner	218
X-coordinate of NW Corner	296
Y-coordinate of NW Corner	1975
X-coordinate of NE Corner	1601
Y-coordinate of NE Corner	1968
Latitude of SW Corner	41
Longitude of SW Corner	122

This listing provides all the information and data that is needed to access any tape stored in the FCCC file.

NCIC Digitized Terrain Data Computer Tapes

The National Cartographic Information Center (NCIC) is now acquiring the Department of Defense, Defense Mapping Agency's library of digital terrain tapes for sale to civilian users.

These tapes were prepared from the USGS 1:250,000-scale topographic quadrangle map series for the contiguous 48 states. All contour lines falling within a one-degree block of latitude and longitude were first digitized. Next, a matrix of elevations was generated, with one elevation for every .01 inch on the map, or about 200 feet on the ground. As 1:250,000 quads generally cover one degree by two degrees, two one-degree matrices were prepared for each quad; generally, an East and a West portion, each on one 7-track computer tape produced on a UNIVAC 1108 computer system.

NCIC will store eight one-degree quadrangles of latitude-longitude on each 9-track 1600 byte-per-inch tape (4 at 800 bytes/inch). For this reason, NCIC uses a flexible pricing approach which results in the cost of each one-degree block decreasing as more blocks are ordered.

How to Order DMA Tapes

Requisitions for DMA tapes contain the following:

Latitude and longitude of one-degree block or 1:250,000 quad name and number.
East or West half.

Example:

Digital Topographic tape as follows:

DMATC Tape, Ashton sheet, NL-12-11-E 1 ea. \$15.00

DMATC Tape, Ashton sheet, NL-12-11-W 1 ea. \$15.00

The Digital Terrain Data tapes are available from the following two sources:

1. Director - DMA-TC
6500 Brooks Lane
Washington, D.C. 20315
Attn: Code 40320

Cost - \$15.00 for loan of each 1° by 1° quad.

2. National Cartographic Information Center
U. S. Geological Survey
National Center, Mailstop 507
Reston, Virginia 22092
Attn: Information Unit/Digital Terrain Data Tapes

NCIC Sales Price

	Regular Processing	Priority Processing*
Per tape	\$15	\$15
Per one-degree block	\$ 6	\$10

Example:

An order for 8 one-degree blocks, regular processing, will cost:

On 1600 bytes-per-inch tape: \$15 for one tape plus 8 times \$6 = \$63

On 800 bytes-per-inch tape: \$30 for two tapes plus 8 times \$6 = \$78

* Priority processing guarantees 2 day turnaround on the computer, but NCIC can make no guarantee on shipping time. Capacity may not be available for priority processing of large orders (over 10 tapes).

If you wish to order tapes from NCIC, identify the one-degree blocks you need by latitude-longitude, or by quad name or number, and East and West half, or simply by marking "X's" in the areas needed on the enclosed index map. Unless you state a preference between 800 or 1600 bytes-per-inch, we will send you a 1600 byte-per-inch tape. Prepayment is required. Make check or purchase order payable to U. S. Geological Survey. Delivery time should not exceed 15 days.

How to Create a Permanent Data File Tape for a New DMA Tape

After a new DMA digital data tape has been purchased from the appropriate source, the following steps should be taken to store the new tape in a permanent data file at FCCC:

1. Send the tape to FCCC.
2. Create a data file tape at FCCC by executing program COPY, which copies the original DMA tape into a data file tape. Where tapes were purchased from NCIC, execute program COPYNCIC.
3. Make the data file tape permanent by executing a save tape program.

4. Determine the x and y coordinates of the SW corner of that half 1:250,000 sheet from the output listing of program COPY.
5. Send the necessary information to WO for updating the library listing of DMA tapes.

Transmitting DMA Digital Terrain Data Tapes to Fort Collins Computer Center. The new DMA digital terrain data tapes must be sent to the Fort Collins Computer Center for processing. Send to:

Mr. Ken Lini
Department of Agriculture
Fort Collins Computer Center
Fort Collins, Colorado 80521

A speed-memo should accompany the tape, with the wording similar to the following:

"Enclosed is a 7 track-556 BPI (9 track 1600 BPI if from NCIC) unlabeled tape. Please call me concerning reel number at (703) 235-8006."

Thanks,

Harold Greenlee

When the tape librarian has received the tape, you will be notified and given the user reel number (i.e. UR0123), which you can then use to create a permanent data file tape by using program COPY.

Exhibit 2.1 – Subdivision of a 1:250,000 Sheet

Exhibit 2.2 – Rectangular Coordinate System of Grid Pattern

Exhibit 2.3 – Index Map for Western United States

Exhibit 2.4 – Index Map for Eastern United States

TAPES LISTING

7-10 10/08-09109:51

```

*****
*
* USFS FCCC TAPE LIBRARY *
* DMA DIGITAL TERRAIN TAPES *
*
*****

=====
DMA SHEET NAME DMA SHEET HALF USER TAPE STATE SW CORNER TAPE LABEL
=====
NAME NUMBER NUMBER
ALUMAS NK-10-9 WEST F02710 CALF 41 122 GEOM* K1009W
276 225 1801 218 296 1975 1801 1968 41 122
=====

=====
DMA SHEET NAME DMA SHEET HALF USER TAPE STATE SW CORNER TAPE LABEL
=====
NAME NUMBER NUMBER
ASHTON NL-12-11 EAST MONT 44 111 STORED WO
33 50 1295 57 33 1800 1274 1807 44 111
SEX SMT SEX SET NXX NMT NEX NEY LAT LONG
=====

=====
DMA SHEET NAME DMA SHEET HALF USER TAPE STATE SW CORNER TAPE LABEL
=====
NAME NUMBER NUMBER
ASHTON NL-12-11 WEST MONT 44 112 DMA MEMORY
41 127 1304 119 63 1877 1304 1869 44 112
SEX SMT SEX SET NXX NMT NEX NEY LAT LONG
=====

=====
DMA SHEET NAME DMA SHEET HALF USER TAPE STATE SW CORNER TAPE LABEL
=====
NAME NUMBER NUMBER
BUZEMAN NL-12-6 EAST MONT 45 111 STORED WO
300 250 1542 256 300 1999 1520 2007 45 111
SEX SMT SEX SET NXX NMT NEX NEY LAT LONG
=====

=====
DMA SHEET NAME DMA SHEET HALF USER TAPE STATE SW CORNER TAPE LABEL
=====
NAME NUMBER NUMBER
BUZEMAN NL-12-6 WEST F00511 MONT 45 112 GEOM* BUZEMAN
322 264 1564 255 345 2012 1564 2004 45 112
SEX SMT SEX SET NXX NMT NEX NEY LAT LONG
=====

=====
DMA SHEET NAME DMA SHEET HALF USER TAPE STATE SW CORNER TAPE LABEL
=====
NAME NUMBER NUMBER

```

Exhibit 2.5 – Example Listing of DMA Tapes Available in USFS FCCC Tape Library

CHAPTER III

NON-GRAPHIC PROGRAMS

SECTION 1. PROGRAM COPY

Create A Data File Tape with Program COPY

Program: COPY

Data Source: DMA digital Terrain Data (DTD) Tape

Function: Copy DMA Tape to a USFS tape to establish a permanent data file.

Data Card: Only one data card is needed for this program. This card contains, in columns 1 to 2, the latitude (in degrees) of the south boundary of the 1:250,000 sheet half. Format (I2).

Naming New Tape: In order to identify the tape in the FCCC library, a label name must be assigned to it at this time. A standardized method of naming tapes will insure that all tapes have a unique label.

Each 1:250,000 sheet has a name and an alphanumeric code number.

Example:

Name	Code Number
WEED	NK 10-8
REDDING	NK 10-10

Each 250 sheet has two tapes per sheet (one for the east half and one for the west half).

By using the alphanumeric code number, we can label each tape half with a unique name. All alphanumeric codes start with an N. Therefore, we can drop the N in our label and add an E or W at the end to distinguish between the east and west halves of the sheet.

Examples: K1008E or K1008W
K1011E or K1011W

This will be the name used in the COPY program in the two following JCL statements:

@ ASG,T GEOM*K1008W,U9V

@ USE 9.,GEOM*K1008W See Input Deck Assembly

This name will also appear in the system log at the end of the run with the qualifier making up the complete tape label name. Example:

GEOM*K1008E

see system log

GEOM*K1008W

Input Deck See Exhibit 3.1 for a schematic diagram of the input deck.
Assembly:

Sample See Exhibit 3.2 for a sample input deck listed in Fortran Coding Form.
Input:

Sample See Exhibit 3.3.
Output:

Program There are two messages printed on the Printout:
Diagnostics:

1. AN ERROR HAS OCCURRED ON RECORD NUMBER (OCTAL NUMBER). Run COPY again. If this error persists, contact FCCC.
2. TAPE HAS BEEN COPIED. This indicates a normal end of job.

Program The output is used to find the x and y coordinates of the four corners of the
Output: half 1:250,000 map sheet. The output is graphic as well as digital, and shows
the convergence of the meridians.

Program COPYNCIC

Program COPYNCIC converts Digital Terrain Data (DTD) files available from the U. S. Geological Survey (NCIC) to the DMA DTD tape format.

The program operates without any control cards. The map location of the 4 corners of the Quad is available in the NCIC DTD.

The NCIC DTD tape can contain up to 8 DTD files. Before execution of COPYNCIC, it is necessary to put the tape at the beginning of the file that contains the terrain to be converted. This is done by use of the MOVE command. If the selected file is the first on the NCIC DTD tape, go directly to execution. If the file selected is not the first on the NCIC DTD tape, use @MOVE, and pass all files preceeding the selected file.

Example:

The selected file is file 4 on the NCIC DTD tape. It is necessary to move past 3 files to get to the beginning of the selected file. The @MOVE command is:

@ MOVE 7.,3

Where 7 is the use attached to the NCIC DTD tape.

Sample Input for COPYNCIC

@ RUN

@ ASG,A DTIS*ABS

@ ASG,T 7.,U9V,UR_____user reel number of NCIC DTD tape

@ ASG,T GEOM*K1008E,U9V

@ USE 8.,GEOM*K1008E.

@ MOVE 7.,(N-1) where N is the file number of the selected file

NOTE: If the file selected is first on the tape do not use the @ MOVE command.

@ XQT DTIS*ABS.COPYNCIC

@ FIN

To Make the New File Permanent. This procedure is outlined in the FCCC user's manual on System Bulletin 75-010, dated 6/04/75. This run should be made for each tape copied to make sure the tape is retained in the library for an extended period. The standard purge date will be 12/30/80.

To Save a Tape File.

@ RUN,M RUNID,ACCOUNT#,PROJECT QUALIFIER

@ SAVE,T QUAL*FILE(1).,751231,F01000,01,01

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX (Tape Data Description)

@ FIN

@ @

@ @

Where: QUAL*FILE(1). is the file's complete name. The qualifier must be explicitly stated. If an absolute cycle number is not explicitly identified, it is assumed that the user intends to save the most recently created cycle of the file.

751231 is the purge date for the file in YYMMDD format.

F01000 is the reel number of the tape file being saved. Note that this parameter is only valid in saving a tape file.

01,01 is the sequence of the reel if the tape file is multi-reel. These can be omitted, and 01,01 will be used as default values. Note that these parameters are only valid in saving a tape file.

XXXXXXXXXX is a separate card image or line providing a 50 character description of the file which is being saved. This card (or line) must be submitted or the entire save transaction will be rejected.

Note: Tape activity data is posted on the save files on a nightly basis. Do not attempt to save a tape file immediately after creation. Instead, allow overnight posting of tape transactions before a save is run. This limitation does not apply to mass storage files, which can be saved immediately upon creation.

To Find Corner Coordinates. As shown in Exhibit 2.2, the corners on the east and west of the 250 sheet are not due north and south of each other. Due to meridional convergence, the corner coordinates have to be obtained from the output of program COPY.

The convergence will appear in the first fifty scan lines on the west half, and in approximately the last fifty scan lines on the east half.

To find the corner coordinates for the west half, scan the x-bottom, y-bottom and y-top printout from COPY. Usually, the first x-bottom and y-bottom will be the S.W. corner coordinates. If these values are more than three (3) units higher or lower than the next scan line limits, use the second set of values. Search down the first fifty scan line values until you reach a point where y-top stops increasing, and the remainder of the values are within $\pm$ two (2) units. At this point, using the x-bottom and y-top values, you have the northwest corner coordinates. The southeast and northeast corners are found in the last fifty scan lines. These two corners are the last scan line values. The southeast corner coordinates are the x-bottom and y-bottom values. The northeast corner coordinates are the y-bottom and y-top values.

The east half corner coordinates may be obtained by using the same approach as above, except the convergence will occur in the last fifty scan lines for the half.

The method of finding corner coordinates is illustrated in Exhibit 3.3.

Updating Library Listing

Washington Office will be responsible for keeping an up-to-date listing of all the DMA digital terrain data tapes available in FCCC. Therefore, whenever a permanent file is created for a new DMA tape at a given Region, that Region should send the following information to WO for updating purposes.

1:250,000 sheet name:	_____	(e.g. ALTURAS)
DMA sheet number:	_____	(e.g. NK-10-9)
East or West half:	_____	
FCCC Tape no.:	_____	(from output of COPY, see Exhibit 3.3)
State:	_____	
FCCC Tape Label Name:	_____	(e.g. GEOM*K1009W)
X-coordinate of SW Corner:	_____	

Y-coordinate of SW Corner: _____ NOTE: x and y coordinates from
 X-coordinate of SE Corner: _____ output of Program COPY.
 Y-coordinate of SE Corner: _____
 X-coordinate of NW Corner: _____
 Y-coordinate of NW Corner: _____
 X-coordinate of NE Corner: _____
 Y-coordinate of NE Corner: _____
 Latitude of SW Corner: _____
 Longitude of SW Corner: _____

Creating a Temporary Data File for a 7-1/2 or 15-Minute Quad

A 1:250,000 map sheet measures approximately 17.5 inches x 23.5 inches. As the DMA tapes stored the elevation data in a .01" x .01" grid pattern, each DMA tape of one-half of a 1:250,000 sheet will contain approximately 2,000,000 data points.

At present all the application programs, such as FSGPCP for contouring, and SLOPE for computing slopes and aspects, can handle only a maximum of about 14,000 data points in each computer run. If every data point in the original DMA tape is to be used in the computation, the existing application programs can only operate on a map area containing 3-3/4 minutes of longitude and 3-3/4 minutes of latitude. If every second data point is used, these programs can operate on a 7-1/2 minute quad, and if every fourth data point is used, they can operate on a 15-minute quad. However, as the spacing between adjacent data points increases, the digital data presents a decreasingly accurate representation of the terrain surface.

The following two computer programs have been developed to generate a small file of digital terrain data for direct input to the application programs:

1. Program PRINT - to list the x and y coordinates of the corners of all the 7-1/2-minute quads contained on a DMA tape.
2. Program SCANDMA - to scan a DMA tape and extract the elevation data within a certain area of interest.

These two programs are documented in the next two sections.

Exhibit 3.1 – Input Deck Assembly for Program Copy

Exhibit 3.3 -- Sample Output from Copy

X-BOTTOM	Y-BOTTOM	Y-TOP
1547	81	1828
1548	81	1828
1549	81	1828
1550	81	1828
1551	81	1829
1552	81	1830
1553	81	1828
1554	81	1828
1555	81	1828
1556	81	1828
1557	79	1828
1558	81	1828
1559	81	1828
1560	81	1828
1561	82	1828
1562	82	1828
1563	82	1828
1564	82	1828
1565	82	1828
1566	82	1828
1567	78	1828
1568	82	1828
1569	82	1828
1570	82	1828
1571	82	1828
1572	82	1828
1573	82	1828
1574	82	1828
1575	80	1828
1576	79	1828
1577	82	1828
1578	82	1828
1579	82	1830
1580	82	1831
1581	82	1828
1582	82	1828
1583	82	1828
1584	82	1828
1585	82	1828
1586	81	1828
1587	82	1828
1588	82	1828
1589	82	1828
1590	80	1828
1591	82	1828
1592	82	1830
1593	82	1828
1594	82	1828
1595	82	1828
1596	81	1828
1597	81	1831
1598	81	1828
1599	82	1828
1600	82	1828
1491	82	1828
0	1472	3216

NE Corner

Exhibit 3.3 – Sample Output from Copy (Continued)

CL 73-1

RUNID: 51913 ACCT: 1152007705 PROJECT: GEOM

LOAD F02710 16/7 K1009r -1 K51913

LOAD BLANK 16/8 JSMITH -1 W51913

SERVICE 17/7 F02710 W51913

TAPE LABEL NAME		
GEOM*JSMITH	F00716	101274

TIME: TOTAL: 00:01:31,405

CPU: 00:00:13,733 I/O: 00:01:02,004

CC/ER: 00:00:15,002 WAIT: 00:00:00,000

IMAGES READ: 9 PAGES: 5

START: 07:16:40 OCT 09, 1974 FIN: 07:20:40 OCT 09, 1974

EST COST: TOTAL: 00006,46 BASE: 1,00 CPU: 00001,6M I/O: 00003,78

ESTIMATED COST IS COMPUTED AT SUBMITTED PRIORITIES.

DISCOUNTS FOR RUNS NOT PROCESSED IN SPECIFIED

TORN-AROUND TIMES ARE AUTOMATICALLY COMPUTED IN THE

MONTHLY BILLING.

SECTION 2. PROGRAM PRINT

Function

To list the x, y coordinates of the corners of all the 7-1/2 - minute quads contained in a DMA digital terrain data tape. These coordinates can be used by the user to define the area of interest within the DMA tape.

Data Cards

There are two types of data cards to be included in the data deck. The formats of these two types of data cards are explained in Exhibits 3.4, 3.5, and 3.6. Note that all the information needed for these data cards can be obtained directly from the listing of FCCC library, see Chapter 2.

Input Deck

Assembly

See schematic diagram of an input deck in Exhibit 3.6.

Sample Input

See Exhibit 3.7.

Sample Output

See Exhibit 3.8.

DATA 1 CARD

PURPOSE: Identifies DMA Sheet information and Forest Service tape number that will be incorporated in page header.

FORMAT:	cc	use	format
	1-30	Name of DMA 1:250,000 Sheet	(5A6)
	31-42	DMA Sheet number	(2A6)
	43-50	(Blank)	
	51-62	DMA Sheet Half (East or West)	(2A6)
	63-68	(Blank)	
	69-80	USFS Tape number	(2A6)

ALL VALUES ARE LEFT JUSTIFIED

Exhibit 3.4 – Data 1 Card

DATA 2 CARD

PURPOSE: This card is used to input the machine x and y limits for the DMA Sheet Half involved. The SW latitude and longitude are also put on this card to be placed in the page header with the DMA Sheet information.

FORMAT:	cc	use	format
	1-5	DMA SW X	(I5)
	6-10	DMA SW Y	(I5)
	11-15	DMA SE X	(I5)
	16-20	DMA SE Y	(I5)
	21-25	DMA NW X	(I5)
	26-30	DMA NW Y	(I5)
	31-35	DMA NE X	(I5)
	36-40	DMA NE Y	(I5)
	41-45	SW Latitude of Sheet Half	(I5)
	46-50	SW Longitude of Sheet Half	(I5)

ALL VALUES ARE RIGHT JUSTIFIED

Exhibit 3.5 – Data 2 Card

Exhibit 3.6 – Input Deck Assembly for Program PRINT

CHALLIS									
EAST									
THE AMS 1/250,000 SHEET NL-11-12 IS ON TAPE F011.0									
THE S.W. COORDINATES FOR THIS HALF ARE LATITUDE = 44-00 AND LONGITUDE = 115-00.									
IXSH = 300 IYSH = 217									
+X#	0	+X#	155	+X#	310	+X#	465	+X#	621
Y#	1751	Y#	1751	Y#	1752	Y#	1752	Y#	1753
+X#	0	+X#	155	+X#	310	+X#	466	+X#	622
Y#	1532	Y#	1532	Y#	1533	Y#	1533	Y#	1534
+X#	0	+X#	155	+X#	311	+X#	467	+X#	623
Y#	1313	Y#	1313	Y#	1314	Y#	1314	Y#	1315
+X#	0	+X#	155	+X#	311	+X#	468	+X#	624
Y#	1094	Y#	1094	Y#	1095	Y#	1095	Y#	1096
+X#	0	+X#	156	+X#	312	+X#	469	+X#	626
Y#	875	Y#	875	Y#	876	Y#	876	Y#	877
+X#	0	+X#	156	+X#	313	+X#	470	+X#	627
Y#	656	Y#	656	Y#	657	Y#	657	Y#	658
+X#	0	+X#	156	+X#	313	+X#	471	+X#	628
Y#	437	Y#	437	Y#	438	Y#	438	Y#	439
+X#	0	+X#	156	+X#	314	+X#	472	+X#	629
Y#	218	Y#	218	Y#	219	Y#	219	Y#	220
+X#	0	+X#	157	+X#	315	+X#	473	+X#	631
Y#	0	Y#	0	Y#	1	Y#	1	Y#	2

X# 1006 Y# 1756
 7-1/2'
 QUAD
 X# 1006 Y# 1537

X# 935 Y# 1317
 15' QUAD
 X# 937 Y# 1098
 X# 1099 Y# 880

Exhibit 3.8 – Sample Output from Program PRINT

SECTION 3. PROGRAM SCANDMA

Function

To scan a DMA tape and extract the elevation data within a certain area defined in the input data cards. The extracted elevation data are stored in a Fastran file under the name assigned on the @ASG,UP card; example, GEOM*JSMITH. This Fastran file can then be used as direct input to the application programs.

Data Card

There is only one type of data card in the input deck. Each data card defines the x and y limits, grid increment, and southwest corner of the quad for the map area desired.

Exhibits 3.9 and 3.10 explain the format in the data card.

Input Deck Assembly

See Exhibit 3.11.

Sample Input Deck

Exhibit 3.12 shows a sample input deck for extracting data of a 15-minute quad.

DATA CARD

PURPOSE: This card defines the limits of x and y for the AREA to be searched.

FORMAT: ALL VALUES RIGHT JUSTIFIED

cc	use	format
1-5	ILEFT – The lowest x value to be scanned decreased by INC.*	(15)
6-10	IRIGHT – The highest x value to be scanned increased by INC.*	(15)
11-15	IBOT – The lowest y value to be scanned decreased by INC.*	(15)
16-20	ITOP – The highest y value to be scanned increased by INC.*	(15)
21-25	INC – Scan interval. For example, if INC = 3, every third elevation point will be copied from a DMA tape.	(15)
26-30	IXSW-X value of SW corner obtained from PRINT.	(15)
31-35	IYSW-Y value of SW corner obtained from PRINT.	(15)

*This value is increased and decreased to insure overlap of your 7-1/2 minute quads. THIS PROCEDURE SHOULD NOT BE USED FOR QUADS AROUND THE BORDER OF THE 1/250,000 HALF. In this case, take the highest value of ILEFT or IBOT, and the lowest value of ITOP or IRITE that is divisible by INC.

Exhibit 3.11 – Input Deck Assembly for Program SCANDMA

SECTION 4. PROGRAM SCANDTIS

Function

The function of SCANDTIS is to extract the elevation data from a DMA tape (or tapes) to build a Blocked TDF (see Chapter IV). The program is selective and will only extract those points which were originally digitized and ignores those points which were mathematically interpolated. The Blocked TDF can then be used for any of the DTIS functions.

Data Cards

A minimum of four data cards are required as follows (Exhibit 3.13):

1. Title card
2. Ground Coordinates of the four corners of the one degree by one degree quadrangle
3. Map Coordinates from "PRINT" (see Section 2) for the same four corners
4. Limits of area to be scanned — this card may be repeated

Input

See Exhibits 3.14 and 3.15 for a sample runstream. An explanation of the cards in these runstreams follow:

@RUN

Time — allow at least 5 minutes if the entire tape is to be converted.

Pages — allow 20

@ASG,A DTIS*ABS.

Assign the program file.

@ASG,T GEOM*K1008W,U9V,F00346

Assign the DMA tape to a nine track drive.

@USE 7,GEOM*K1008W

Assign Fortran logical unit 7 for the input of the DMA tape.

@ASG,T GEOM*KLAMATH,U9V

New
Blocked
TDF

Assign a tape to collect the Blocked terrain.

or

Old @MSG,W PLACE WRITE RING IN F12345
Blocked
TDF @ASG,T GEOM*KLAMATH,U9V,F12345

Assign an existing Blocked TDF tape labeled GEOM*K1008W and
a tape number of F12345

@USE 9,GEOM*KLAMATH
@XQT DTIS*ABS.SCANDTIS

Execute the program.

Title Card:

cc	use	format
1-60	Alphanumeric Title	10A6
60-69	Blank	9X
70	Block Status Old=0 New=1	11

Ground Coordinate Card. The following values are generally State Plane coordinates for the four corners of the 1 degree quadrangle:

cc	use	format
1-10	SW Corner of 1° quad - x value	F10.0
11-20	SW Corner of 1° quad - y value	F10.0
21-30	SE Corner of 1° quad - x value	F10.0
31-40	SE Corner of 1° quad - y value	F10.0
41-50	NW Corner of 1° quad - x value	F10.0
51-60	NW Corner of 1° quad - y value	F10.0
61-70	NE Corner of 1° quad - x value	F10.0
71-80	NE Corner of 1° quad - y value	F10.0

Map Coordinates Card. The following values are obtained from the output of program "PRINT". They are the map coordinate values for the four corners of the 1 degree quadrangle.

cc	use	format
1-5	SW Corner of 1° quad - X map value	F5.0
6-10	SW Corner of 1° quad - Y map value	F5.0
11-15	SE Corner of 1° quad - X map value	F5.0
16-20	SE Corner of 1° quad - Y map value	F5.0
21-25	NW Corner of 1° quad - X map value	F5.0
26-30	NW Corner of 1° quad - Y map value	F5.0
31-35	NE Corner of 1° quad - X map value	F5.0
36-40	NE Corner of 1° quad - Y map value	F5.0
41-45	IXSW - from print	
46-50	IYSW - from print	

Limit Cards. The limit cards define the area to be extracted from the DMA tapes. Those limits are expressed in map coordinates as follows:

cc	use	format
1-5	ILEFT - left limit	I5
6-10	IRIGHT - right limit	I5
11-15	IBOT - bottom limit	I5
16-20	ITOP - top limit	I5
21-25	INC - use every INCth scan	I5

Limit card may be repeated as needed.

@FIN

On a new tape, the tape number must be saved if you need to keep it.

[illegible]

CHAPTER IV

DIGITAL TERRAIN MODEL PROGRAMS

SECTION 1. DIGITAL TERRAIN INFORMATION SYSTEM

The U. S. Forest Service Digital Terrain Information System (DTIS) is a computer program package that has been developed for the manipulation and analysis of digital terrain data. The data has been collected directly from topographic maps or from a photogrammetric stereoplotter. The program package can perform two basic functions:

1. Transformation of the new digital data into an appropriate ground coordinate system, and then store the transformed data in a format which is compatible with the requirements of the application programs. Characteristically, an efficient digitizing operation requires that the data points be selected at the break points in the topography, resulting in a set of nongridded (or basically, randomly spaced) data points. DTIS was designed to provide efficient handling and storage of large files of random digital topographic data. For example, with the DTIS package, it is possible to store 1-1/2 million data points (which may constitute a complete data file for an entire National Forest) on a single computer tape.
2. Generation of four types of application products from an existing data file:
 - a. scan profiles and set-up information for the production of ortho photos;
 - b. cross-section elevations along a center-line in the standard U. S. Forest Service card type 50 (CT50) format;
 - c. a new data file with the data points being arranged in a gridded pattern; and
 - d. a ground profile for input to skyline logging analysis programs.

Program Segments in DTIS

The DTIS program package consists of six major program segments: ONEShot, XYTRan, BLOCK, MANUv, ARAY, and FORCor. Exhibit 4.1 illustrates the functions of these program segments and their inter-relationship.

When digitizing is performed directly in a stereoplotter, the spatial position of the model points may be defined in an arbitrary, rectangular coordinate system. Program segment ONEShot accepts these model coordinates as input, and transforms them into a ground reference coordinate system through the use of ground control points. ONEShot is basically a coordinate transformation program, and is not intended for analytical aerotriangulation. At the option of the user, ONEShot may output the transformed data as either "punched" terrain data file (TDF), or blocked TDF.

In a "punched" TDF, the data points are arranged in the same order as the original input data to ONEShot. The spatial position of each data point is defined by its horizontal coordinates X and Y, and vertical coordinate Z. Since the data points do not follow a gridded pattern, the entire data file must be searched whenever it is necessary to identify all the data points that are located within a certain boundary.

In a blocked TDF, the data points are collected into groups containing up to 500 points. The lower and upper limits in X- (or easting) and Y- (or northing) coordinates of each data group are determined and stored in the file. The blocked format reduces the computing time required to search a file. By checking the boundary limits, it is possible to eliminate, at one time, an entire group of data points from the search process.

When rectangular digitizers are used to digitize terrain data from existing topographic maps, the spatial position of each data point is usually defined by a pair of rectangular coordinates (x,y), and its elevation above mean sea level. The rectangular coordinates are usually in the same scale as the map, and are arbitrarily oriented. Program segment XYTRan accepts this type of coordinates as input, and transforms the horizontal coordinates from the digitizer system into a ground reference coordinate system, such as the State Plane coordinates. The output from XYTRan may also be in either the "punched" TDF or blocked TDF format.

The Calma Digitizing System may be used to digitize topographic maps, and produce digital terrain data directly in a ground reference coordinate system. Further coordinate transformation is not needed. However, program segment BLOCK may be used to collect the data points and output a block TDF.

Program segment MANUv is the application program within DTIS. It is used to produce ortho photo scan profile plates, cross-section elevation data, or a gridded terrain data file (TDF).

Program segment FORCor is a utility program that is not directly related to other program segments within DTIS. It may be used to convert State Plane coordinates to geographic coordinates (longitude, latitude, and elevation) or vice versa. It may also be used to convert State Plane coordinates from one State-zone to another.

Program segment ARAY provides a link between the DTIS program package and the contouring program FSGPCP within TOPAS. ARAY is used to rearrange a gridded TDF, which has been generated from MANUv into the proper format for input to FSGPCP.

Two other programs provide additional links between DTIS and other portions of TOPAS. Program SCANDTIS, as documented in Chapter III, is used to scan a DMA tape and to generate a block TDF for input to program segment MANUv. Program BLOCKBACK, as documented in Section 3, is used to rearrange the data in a block TDF for input to the application programs in TOPAS. Through the use of these data manipulation programs, DTIS becomes an integral part of TOPAS. The inter-relationship between DTIS and the remaining part of TOPAS has already been illustrated in Exhibit 1.1.

Segment Call Card

Any of the program segments in DTIS can be brought into execution by the use of a segment call card. The call card may consist of eight fields of the following format: 8(A4.A6). The first four characters of each field constitute the key word of the command, and must not contain an erroneous entry. The remaining 6 characters are not tested by the program and are used primarily to provide convenient command words in the segment call cards. The field specifications for the segment call card are as follows:

cc	use
1-10	Name of program segment to be called: ONEShot, XYTRan, BLOCK, MANUv, ARAY, or FORCor. A blank field would signal the normal end of job.
11-20	I/O option
21-30	I/O option
31-40	I/O option
41-50	I/O option
51-60	I/O option
61-70	I/O option
71-80	I/O option

The I/O options available for each of the program segments will be discussed in conjunction with the data input requirements of that segment. Following is a listing of the I/O options with brief explanation of their uses:

d=default parameter. This option is assumed unless the default disabling option is input.

option	action	segments affected
NEEL or XYZ	d Input is in N, E, EL coordinate order on the INPUT records. Input is in X, Y, Z order (disables NEEL).	BLOCK, MANUv, ONEShot, SPATL, XYTRan
BLOCK or NOBLock	d Output from the transformation segments is to be blocked into 500 positions per record (blocked TDF). Input to MANUv is in the blocked TDF format (unit 9 contains the blocked data). Output from the transformation segments is to be left in the same type (UNITrecord or RESource) and the format is either Packed Spatl Format or Resource Spatl Format. Input to MANUv is of the type UNITrecord or RESource. format is either Packed Spatl or Resource Spatl Format.	ONEShot, XYTRan MANUv ONEShot, XYTRan

option	action	segments affected
UNITrecord	d Input (and output) is one of the Standard Spatl Formats.	MANUv, BLOCK, ONEShot, XYTRan
or		
RESOource	Input (and output) is in the Resource Spatl Format (RESOource data input is unit 21. output is unit 22).	MANUv, BLOCK, ONEShot, XYTRan
NOPLot	d Disable optional plotting	- SETUp
or		
PLOT	Enable optional plotting	- SETUp
GRID	Causes plotting of grid lines at a given interval on the ortho photo setup overlay. The GRID interval is input in the Segment Call Card in the field immediately following the 'GRID' (F10.0). If 'GRID' is not input or the grid value is 0, no grid lines are drawn.	- SETUp
SCALE	SCALE option inputs the scale denominator from the Segment Call Card from the field following the SCALE call (F10.0) (Not currently used).	
CI or CONT	CI or CONT input the contour interval from the field immediately following the CI or CONT call on the Segment Call Card (F10.0) (not currently used).	
TYPE50	d Cross-section output from MANUv functions PLINe or LLINe is in the RDS card type 50 Format.	MANUv functions PLINe
or		
XYZ	CROSS SECTIONS output is in elevation/offset format.	

option	action	segments affected
IN80	Input 80 series points through the card reader while terrain data is blocked TDF input. This option, when used in conjunction with the default option BLOCK on the Segment Call Card MANUv, allows input of the 80 series points in Standard Spatl Format through the card reader, and the terrain data through Unit 9 (Blocked TDF) during Function STOF1. A 98 card signals the end of the 80 series points. If the Option IN80 appeared on the MANUv Segment Call Card, STOF1 expects a deck of 80 series points to follow the Project Definition Card.	MANUv

Identification Code (KODE) and Formats for Data Points

KODE. KODE is used throughout DTIS. It is the first two characters of the terrain point identification number. The values of KODE are assigned as follows:

KODE	point identification
80	Tie points between strips of photography
81	Pass points between models
82	Vertical control points
83	Horizontal control points
84	Horizontal and vertical control points
87	Points used to determine airplane point
86	Computed airplane points
Less than 80	Terrain data

Range Checking. Range checking is used throughout DTIS to throw out erroneous records. Any points that do not fall within specified limits are "thrown out." The range limits are determined by the following methods:

range check value	function
0	Range limit developed from 12 airplane points (87)
1	Use the first six cards in the input deck
-1	Range values on following card (Format 6F10.2 HX, LX, HY, LY, HZ, LZ)
-2	Use Preset Values 6000.00 and -4000.00 as range limits.
-3	Disable range checking

Card Formats. There are 4 card formats referred to throughout DTIS (Exhibit 4.2). They are as follows:

Standard Spatl:

cc	use	format
1-2	KODE	I2
3-10	POINT ID	I8
11-20	X or Northing	F10.2
21-30	Y or Easting	F10.2
31-40	Z or Elevation	F10.2

Packed Spatl:

cc	use	format
1-2	KODE	I2
3-10	POINT ID	I8
11-20	X or Northing	F10.2
21-30	Y or Easting	F10.2
31-40	Z or Elevation	F10.2
41-42	KODE	I2
43-50	POINT ID	I8
51-60	X or Northing	F10.2
61-70	Y or Easting	F10.2
71-80	Z or Elevation	F10.2

Digitizer Spatl:

cc	use	format
1-2	KODE	I2
3-8	POINT ID	I6
9-14	X	F6.2
15-20	Y	F6.2
21-26	Z	F6.2
27	Blank	1X
28-29	KODE	I2
30-35	POINT ID	I6
36-41	X	F6.2
42-47	Y	F6.2
48-53	Z	F6.2
54	Blank	1X
55-56	KODE	I2
57-62	POINT ID	I6
63-68	X	F6.2
69-74	Y	F6.2
75-80	Z	F6.2

Resource Spatl: (R-5)

cc	use	format
1-2	KODE	I2
3-10	POINT ID	I8
11-20	X or Northing	F10.2
21-30	Y or Easting	F10.2
31-40	Z or Elevation	F10.2
41-112	Resource Data	12A6

ONEShot

ONEShot is a simplified version of R. O. Mahan's program SPATL. It is used to transform model coordinates measured in a stereoplotter to a ground coordinate system. It is not an aerotriangulation program.

INPUT

Refer to Exhibits 4.3 and 4.4.

· RUN

Time — 15 seconds per model — 1 minute minimum

Pages — 10 per model — 100 minimum

@ASG,A DTIS*ABS

Assign program file.

@ASG,T LOLO*LOLO.U9V (For new block)

OR

@MSG,W Put Write Ring in F00345

@ASG,T LOLO*LOLO.U9V,F00345 (For old block)

Assign a labeled tape. File name will be LOLO*LOLO. At the end of the run, the tape number assigned will be listed. This tape must be "saved" using the same procedure as described in Chapter III. Subsequent assigns must use the tape label (LOLO*LOLO), tape number (F00345), and @MSG.W PUT WRITE RING IN.

@USE 9.LOLO*LOLO

Use Fortran logical unit 9 to write or read from the tape labeled LOLO*LOLO.

Needed if BLOCK option is used

@XQT DTIS*ABS.DTIS

Execute the mainline program:

ONEShot	(XYZ) NEEL	(NOBLock) BLOCK	(RESOurce) UNITrecord
---------	---------------	--------------------	--------------------------

Directs program to the ONEShot segment. NEEL, BLOCK, and UNITrecord are default options: XYZ, NOBLock (card image), and RESOurce are default disabling options and must be specified if desired.

Title Card: (see Exhibit 4.5)

cc	use	format
1-60	Title	10A6
61-69	Blank	9X
70	Block file status 1 = new 0 = old (Exercise caution as your data file created in a previous run can be wiped out with a 1 in cc70)	11
71-80	Rejection limit (standard error of the transformed model coordinates above this value will cause segment termination. There will be no output for this model, but all previous model output will be preserved). This value should be approximately 1 part in 2500 of the flight height.	F10.0

Ground Control Cards: (up to 500)

Input is in Standard Spatl Format.

cc	use	format
1-2	KODE	I2
3-10	ID	I8
11-40	Coordinates of Control point (X, Y, & Z if XYZ option. North. East and Elevation if NEEL option)	3F10.2

98 Card:

A "98" card tells the program that it has completed reading ground control points.

Model Title Card: (see Exhibit 4.5)

cc	use	format
1	Record type of model coordinates 1=Standard Spatl Format 2=Packed Spatl Format 3=Digitizer Spatl Format 4=Resource Spatl Format	I1
2-4	Left Plate Number	I3
5-8	Right Plate Number	I4
9-12	Strip Number	I4
13-30	Model Title (Alphanumeric)	3A6
31-39	Blank	9X
40-55	Switches (In general, leave blank. For further information, see R.O. Mahan documentation on SPATL.)	16I1
56-78	Blank	23X
79-80	Range Checking	I2

Model Coordinates (Unlimited Number)

Model coordinates are in one of the four Spatl Formats which has been selected in column 1 of the "Model Title Card." This deck contains model coordinates for all points — pass, tie, airplane, control, and terrain points. The model coordinates with KODE values of 80-87 must be at the front of the deck. The coordinates are in X, Y, and Z (north, east, and elevation is not a valid input for model coordinates).

98:

This "98" card indicates the last model coordinates have been read in.

Blank Card

A blank card signifies the end of the segment ONEShot and returns control to the mainline program.

END:

Segment call to END makes a normal exit from DTIS.

@FIN:

System end of run.

If Resource Spat1 Format data is to be entered, it must already be in a catalogued file at FCCC; i.e., data could be entered using a @DATA,I SIXRIVERS*SIX. The file is read from logical unit 21 and written on logical unit 22.

Sample:

```

@ASG,A SIX*SIX
@USE 21,SIX*SIX
@ASG,UP SIX*SIXGRND,U9V
@USE 22,SIX*SIXGRND
  
```

OUTPUT

There are three possible outputs from ONEShot.

1. Packed Spat1 Format output to logical unit 8.
2. Blocked TDF output to logical unit 9. This can be a new blocked file or an addition to an existing blocked TDF.
3. Resource Spat1 Formatted data to logical unit 22.

BLOCK

BLOCK is a program used to build a random terrain data file from ground coordinates entered through the card reader, or RESource data entered through logical unit 21. BLOCK collects input records into groups of up to 500 points, determines the Northing and Easting limits of the group, and outputs the block (group) on logical unit 9. The program can be used very effectively with the Calma Digitizing System. The program can be used to build a new file or add to an existing file.

INPUT

See Exhibit 4.6 for Sample Card Setup, 4.7 for Input Deck

@RUN

Time — one minute per 20,000 points entered
Pages — 50 pages

@ASG,A DTIS*ABS.

Assign program file

@ASG,T LOLO*LOLO,U9V (For new block)

OR

@MSG,W Put Write Ring in F00345

@ASG,T LOLO*LOLO,U9V,F00345 (For old block)

Assign a labeled tape. File name will be LOLO*LOLO. At the end of the run, the tape number will be listed. This tape must be "saved" using the procedure as outlined in Section 1 of Chapter III. Subsequent assigns must use the tape label (LOLO*LOLO) and tape number (F00345).

@USE 9,LOLO*LOLO

Use Fortran logical unit 9 to read or write from the tape labeled LOLO*LOLO.

@XQT DTIS*ABS.DTIS

Execute the program

(XYZ) (RESOurce)

BLOCK NEEL UNITrecord

Directs the program to the BLOCK segment of the program. The input is defaulted to North, East, and Elevation. X, Y, Z ground coordinate input must have an XYZ option in the BLOCK card.

Title Card:

cc	use	format
1-60	Alphanumeric Title	10A6
60-69	Blank	9X
70	Block file status 1 = new 0 = old	11
71-80	Blank	10X

Data Cards:

Data cards in Packed Spatl Format.

98:

"98" terminates BLOCK segment of program.

END:

Normal exit from DTIS.

@FIN:

Normal end of job.

OUTPUT

Output is Fortran Unformatted records 2005 words long. The output Unit is unit 9. The record structure is:

word	use
1	Number of positions this record
2-5	Max-Min North-East for the positions in this record
6-505	500 combined KODE-ID's
506-2005	500 positions (N,E,EL)

XYTRan

XYTRan is used to transform X and Y coordinates in digitizer units to a ground coordinate system. An option within the program allows entry of control positions in geographic coordinates (latitude-longitude) which are converted to state plane coordinates. (See Exhibits 4.9 and 4.10 for sample setup.)

INPUT

@RUN

Time - 15 seconds per 5000 points - 1 minute minimum
 Pages - 20 per model - 100 minimum

@ASG,A DTIS*ABS.

Assign program file.

@ASG,T LOLO*LOLO (new BLOCked data tape)

OR

@MSG,W PUT WRITE RING IN F00345

@ASG,T LOLO*LOLO,U9V,F00345 (old BLOCked data tape)

Assign a labeled tape. The file name will be LOLO*LOLO. At the end of the run, the tape number assigned will be listed. This tape must be "saved" using the same procedure as described in Chapter III. Subsequent assigns must use tape label (LOLO*LOLO) and tape number (F00345).

@USE 9,LOLO*LOLO

Use FORTRAN logical unit 9 to write or read from the tape labeled LOLO*LOLO.

@XQT DTIS*ABS.DTIS

Execute the mainline program

XYTRan	XYZ	NOBLocK	RESOurce	FORCor	0502
	NEEL	BLOCk	UNITrecord	(BLANK)	(BLANK)

This directs program to XYTRan segment. Options NEEL, BLOCk, and UNITrecord are default options - XYZ and RESOurce must be specified if desired. If control file (described later) is to be input in geographic position, FORCor must be specified, and if specified, the state plane zone number (see Exhibit 4.8) must be left registered in the next field.

Title Card:

cc	use	format
1-68	Alphanumeric Title	11A6.A2
69-77	Blank	9X
78-79	Range Checking Switch	I2
80	Block file status	I1
	1 = New	
	0 = Old	

Ground Control Cards: (map identifiable ground coordinates or grid ticks)

cc	use	format
1-2	KODE	I2
3-10	ID	I8
11-40	Position	
	a. If FORCor option is not specified — position is in X, Y, Z, or North, East, Elevation (Standard SPATL format)	3F10.2
	b. If FORCor option is specified, position is in:	
	Degrees latitude	F3.0
	Minutes latitude	F2.0
	Seconds latitude	F5.3
	Degrees longitude	F3.0
	Minutes longitude	F2.0
	Seconds longitude	F5.3

98

End of Ground Control Cards

Model Coordinates of Ground Control

Input can be in "Standard SPATL" or "RESOource SPATL" formats. Coordinates must be in digitizer units. These coordinates are not output.

98

End of Model Coordinates of Ground Control

Model Coordinates to be Transformed.

Input can be in "Standard SPATL" or "RESOource SPATL" format. The X and Y coordinates are in digitizer units, and the Z is not transformed, and therefore, must be in ground units.

98:

End of the model coordinates to be transformed.

98:

Two "98" cards make a normal exit from XYTRan segment.

END:

Normal exit from DTIS

@FIN:

Normal end of job

OUTPUT

The output from XYTRan is identical with ONEShot.

MANUv

Function Programs in MANUv.

1. STOF1 — the function program STOF1 is used to collect digital terrain data into "boxes" of a given size and store them for use by other MANUv function programs. A maximum of 50 terrain data points may be stored in one box. STOF1 is used to extract a small set of terrain data from a large data file, and to box the data according to geographical regions for efficient processing. These files are to be further subdivided into Work Areas by function program FILL.

2. FILL — the function program FILL enters the direct access files created by STOF1 and collects a still smaller area (called the Work Area) of "boxed" data for use by other function programs in MANUv. Exhibit 4.11 illustrates the application of STOF1 and FILL. A large existing file could contain all the random digital terrain data for an entire national forest. STOF1

is used to extract from this file, a small set of the data and create a "Project data file", and FILL is used to extract a smaller subset of the "project data file" and store it as a "work area data file".

3. **SETUp** — this function program accesses the "80" series file created by function program **STOFI** and outputs a table of point coordinates that are needed to set up the GZ-1 for ortho photo production. Optionally, it can also be used to produce a plot tape to make the ortho photo overlay.

4. **ORTHo** — generates north-running profiles from the "Work Area data file" at a specified interval.

5. **PRORt** — inputs from the direct access file generated by **ORTHo**, and generates a plot tape for the preparation of an ortho photo storage plate for the GZ-1.

6. **GRID** — inputs from the direct access file generated by **ORTHo** and converts the profiled data to gridded data. The output product is a gridded data file for the work area described by the input to function **FILL**.

7. **VGRId** — inputs from the direct access file generated by **ORTHo**, and converts the profiles data to the properly spaced formatted grid for input into PSW's version of **VIEWIT**.

8. **PLINe** — produces P-Line cross-section elevations for road design applications. The output will be cross-section elevations in the standard RDS CT50 format.

9. **CAT** or **PROFile** — produces ground profiles for the skyline logging program analysis **Sky18**.

MANUv Segment Call Card. Program segment **MANUv** is called into execution by the use of the following segment call card:

```
(NOBLoCk) (XYZ) (RESOUrce)
MANUv  BLoCk  NEEL  UNITrEcOrd
```

The default options are **BLoCk**, **NEEL**, and **UNITrEcOrd**; which means that the input data are **BLoCk**ed and are defined in Northing, Easting, and Elevation coordinates. The default option **UNITrEcOrd** means that the data input is to be in the **UNITrEcOrd** format when the **NOBLoCk** option is used.

The **MANUv** call card is followed by cards calling for the function programs. The call cards for each function program have different requirements and are described separately in the following sections.

SPECIAL DEVICES NEEDED

MANUv always references unit 20 which contains a backup file either before or after the first function (**STOFI**) is called. If plotting is to be done (Functions **PRORt** or **SETUp**), unit 7 must be assigned. **RESOUrce** input is on unit 21, or **BLoCk**ed input is on unit 9, or **UNITrEcOrd**

(Packed Spatl Formatted) data is on the card reader. Card image output (CAT, GRID, VGRID, PLINE) is to unit 8.

STOF1. This function collects digital terrain data into 'boxes' of a given size and stores them for use by the other MANUv functions. It creates a backup file of the boxed data. Optionally, it can restore from an old backup.

STOF1 uses temporarily (dynamically) assigned DEFINED FILES as direct access files. It creates these files and stores the data in them for the other functions to use. STOF1 inputs the terrain data, sorts and 'boxes' it, and stores the 'boxed' data to a maximum of 50 points per box on a direct access file. It also inputs '80' series points and stores them on another dynamically-assigned, sequentially-accessed file. When all the data has been stored, STOF1 backs these files up by writing them to unit 20. During a restore function, it reads unit 20 and restores the files.

INPUT

STOF1 requires a call card, a control card, and a file of terrain data.

Call Card:

cc	entry
1-5	STOF1

The call card contains no input/output options. All options pertaining to input data must have been input on the MANUv Segment call card.

Control Card: (see Exhibits 4.12 and 4.13 for graphic representation of variables)

cc	use	format
1-10	'Box' block size DIF	F10.0
11-20	Project SW Cor. (N) SWCN	F10.0
21-30	Project SW Cor. (E) SWCE	F10.0
31-40	Angle of rotation (dec. degrees) (See Exhibit 4.12)	F10.0
41-50	Project size or NE Cor. (N) NECN	F10.0
51-60	Project size or NE Cor. (E) NECE	F10.0

If the block size (DIF) is 0, the restore function is enabled. If DIF is non-zero, the collect and store function is enabled.

If the Project size is 0, the Project size defaults to 1,000,000. A file must be assigned to the backup data unit (20) whenever MANUv is called, because this unit is referenced either to create the backup, or to restore from the backup. Function STOF1 must always be the first function called.

If the input terrain is Resource Spatl Format, it is assigned to unit 21. If the input terrain is UNITRecord (Packet Spatl Format) it is input through the card reader.

In the case of UNITRecord (Packed SPATL) input, an EOF card (98) must follow the terrain data.

If the input is blocked TDF, it is input through unit 9.

OUTPUT

During a store function, a file is written to unit 20.

FILL. This function accesses the files created by STOF1 and collects a 'Work Area' of 'boxed' data for use by other functions. Function STOF1 must have been previously called.

INPUT

Call Card:

cc	entry
1-4	FILL

Boundary Card: (see Exhibit 4.12 for graphic representation of variables)

cc	use	format
1-10	Distance N from the Project SW Corner DELDN	F10.0
11-20	Distance E from the Project SW Corner DELDE	F10.0
21-30	SCALE expressed in FT=1 INCH	F10.0
31-40	Size N of the 'Work Area' DN	F10.0
41-50	Size E of the 'Work Area' DE	F10.0
51-60	Distance between profiles SCN. If SCN is less than 10 it is mm measured at SCALE. If it is 10 or greater, it is in ground units.	F10.0

OUTPUT

FILL produces a 'printer map' showing the number of positions in each 'box' in the local area. If the number of positions is 50 in a large number of boxes, the value of DIF was too large, and data is being lost. If the number of positions is 0 in a large number of boxes, the area was not fully digitized, or the value of DIF is too small. Try to average 25 in all boxes.

SETUp. This function accesses the '80' series file created by function STOF1, and produces a table of coordinates needed to set up the GZ-1 to produce an ortho photo. Optionally, it can also produce a plot tape to make the ortho photo overlay.

INPUT

Call Card:

cc	use	format
1-5	SETUp - Call function program.	
11-20	PLOT (optional) - Produce a plot tape to make the ortho photo overlay. The graphical plot would include the data points to be used for setting up the GZ-1. If this field is left blank, no plot tape would be produced.	
21-30	GRID (optional) - The plot tape will also include grid lines, and the grid size is specified in the next field.	
31-40	GRID size	F10.0

Function programs STOF1 and FILL must have been previously called.

Identify Airplane Point Number:

cc	use	format
1-2	KODE	I2
3-10	ID (the airplane point number)	I8

OUTPUT

The table of setup coordinates for the ortho photo projector. The plot tape is optional.

ORTHo. ORTHo produces North-running profiles from the bottom to the top of the Work Area and progresses East, at 1 SCN at a time, across the area. This data is stored for gridding and/or storage plate output by other MANUv functions.

Functions STOF1 and FILL must have been previously called (Exhibit 4.14).

INPUT

Call Card:

cc	entry
1-5	ORTHo

The call card contains no Input/Output options.

OUTPUT

The sets of coordinates describing the profiles are stored on a direct access file for use by functions PRORt and/or GRID.

PRORt. This function inputs from the direct access file generated by function ORTHo and generates a plot tape for the preparation of an ortho photo storage plate for the GZ-1.

Functions STOF1, FILL, SETUp, and ORTHo must have been previously called.

INPUT

Call Card:

cc	entry
1-5	PRORt

This call card contains no input/output options.

OUTPUT

PRORt generates a plot tape.

GRID. GRID is called with the Segment Call Card 'GRID'. This function inputs from the direct access file generated by function ORTHo and converts the profiled data to gridded data. It then accesses the '80' series file and extracts all the points which fall inside the Work Area, and produces a card image file containing all the pertinent information about the Work Area, the '80' series points, and the gridded data deck.

Functions STOF1, FILL, and ORTHo must have been previously called (Exhibits 4.15 and 4.16).

INPUT

None

OUTPUT

GRID produces a gridded data deck for the Work Area described by the input to function FILL.

VALID INPUT-OUTPUT OPTION

None

PLINe. PLINe is called with the Segment Call Card 'PLIN'. This call will read from the card reader the coordinates of points of intersection (PI's), the length, and the distance between the desired cross-sections. Using this information, the terrain data selected by functions STOF1 and FILL are interrogated to generate the elevations on breaks along the cross-sections.

INPUT

Call Card:

cc	entry
1-5	PLINe

This call card contains no input/output options.

Road Number Card:

cc	use	format
1-10	Road number for RDS	I10

Beginning Station Card:

1-10	Beginning Stationing i.e., 0+00.00 = 0.0 1+23.22 = 123.22	F10.0
------	---	-------

PI Cards: (as many as needed up to 50)

1-2	Line Number	I2
3-4	PI Number	I2
5-10	Blank	6X
11-20	Northing	F10.1
21-30	Easting	F10.1

98:

End of entry of PI's

Cross-section Spacing Card:

cc	use	format
1-10	Cross-section Spacing	F10.0

Cross-section Length Card:

cc	use	format
1-10	Cross-section Length Each Side (Maximum of 999 Feet)	F10.0

OUTPUT

Output from PLINe is cross-sections formatted for use in RDS. Output is on logical unit 8.

VGRId. VGRId inputs from the direct access file, generated by function ORTHo, and converts the profiled data to the properly spaced and formatted grid to go into PSW's version of VIEWIT. This gridded data is output to a file on logical unit 8, which should be catalogued.

Functions STOF1, FILL, and ORTHo must have been previously called.

INPUT

Call Card:

cc	entry
1-5	VGRId

The call card contains no Input/Output options.

OUTPUT

VGRId produces a file which can be read into PSW's VIEWIT with the following options: BY COLS, FORMAT = '(16F5.0)'.

PROF1 or CAT. This function accesses the "Work Area data file" of "boxed" data collected by functions STOF1 and FILL to produce a ground profile between two points. This profile information is output in the format acceptable to the skyline logging analysis program, SKY18.

Functions STOF1 and FILL must have been previously called.

INPUT

Call Card:

cc	entry
1-5	CAT or PROF1

This call card contains no Input/Output option.

Data Cards:

cc	use	format
1-2	KODE must be greater than zero and less than 90 for a data card	I2
3-10	ID Point ID	I8
11-20	North ordinate of the position	F10.2
21-30	East ordinate of the position	F10.2

Two data cards are required to describe a profile, one for each end. As many profiles as desired may be generated with a single call to this function. Each profile requires 2 position cards. This function is terminated by a blank or 98 card. Control is returned to MANUv.

OUTPUT

CAT writes card image data to file 8 in the format acceptable to the skyline logging analysis program, SKY18. Each profile is output in 2 type records. Record type 1 is a partial header record which contains the position along the profile of the 2 ends and their elevations.

cc	use	format
1-10	Not used	10X
11-15	Distance from beginning of profile (0)	I5
16-20	Elevation of beginning point	I5
21-25	Not used	5X
26-30	Distance to end of profile	I5
31-35	Elevation of end point	I5

Record type 2 contains distance and elevation information of all detected terrain breaks on the profile.

Each card contains 8 distance and elevation sets.

cc	use	format
1-5 (11-15, 21-25) etc.	Distance from beginning of profile to a terrain break	I5
6-10 (16-20, 26-30) etc.	Elevation of the terrain break	I5

ARRAY. The program segment ARRAY provides a link between the DTIS and the contouring program FSGPCP inside TOPAS. It reformats gridded data deck or decks generated by the function program GRID in MANUv for direct input to the contouring program FSGPCP as a single grid (ARRAY block).

INPUT

Segment Call Card: (see Exhibit 4.18)

cc	entry
1-4	ARRAY

The call card contains no Input/Output options.

Boundary Card:

cc	entry	format
1-10	S.W. Corner (N) of the ARRAY block	F10.0
11-20	S.W. Corner (E) of the ARRAY block	F10.0
21-30	N.E. Corner (N) of the ARRAY block	F10.0
	or size (N) of the ARRAY block	F10.0
31-40	N.E. Corner (N) of the ARRAY block	F10.0
	or size (N) of the ARRAY block	F10.0

If the Size (N.E. Cor.) fields are left blank, these values default to 1,000,000. If the S.W. Cor. fields are left blank, the values default to the Work Area S.W. Cor. of the first MANUv gridded data deck input.

Gridded Data Decks from MANUv:

The MANUv gridded data decks are unchanged from the o/p of MANUv function GRID.

End of File Card:

The End of File Card is a blank or a 98 card.

Operation. ARAY inputs the boundary card and the 4 control cards from the first MANUv gridded deck, and from this information, sets the constants for this call of the segment. These constants are: ARAY S.W. Cor., ARAY size, grid size, number of rows and columns in the ARAY block, MANUv Project S.W. Cor., and the row and column offsets from ARAY S.W. Cor. to Project S.W. Cor.

Failure of any MANUv Project S.W. Cor. or Grid Size to compare with these constants causes a segment termination without any ARAY block output.

The grid points which fall within the ARAY block are put in a holding array, and the next MANUv gridded data deck is input and processed.

When an EOF card is encountered, the segment preps and outputs the ARAY block.

OUTPUT

ARAY outputs ARAY blocks in the Calcomp GPCP ARAY type 2 and type 3 formats, and a BEND card.

FORCor. FORCor converts State Plane Coordinates (x,y, elevation) to geographic coordinates (longitude, latitude, and elevation) or vice versa. It can also convert State Plane coordinates from one zone to another.

FORCor is called into execution by the following segment call card.

cc	entry
1-6	FORCor

The call card contains no I/O option. If card image output of the transformed coordinates is desired, it can be specified in the header card as explained in the documentation which follows.

FORCor

Description. Given Geographic Coordinates or State Plane Coordinates, this program will compute State Plane Coordinates or Geographic Coordinates in the State Lambert or State Transverse Mercator grid coordinate systems. The program will also compute a Zone-to-Zone transformation within a projection system, or from one projection system to another.

Header Card. The header card must signify the type of transformation desired. The Format for the header card is as follows (see Exhibit 4.21):

cc	use
1-4	State Code of Input (0 if geographic coordinates)
5	Blank
6-9	State Code of Output (0 if geographic coordinates)
	CAUTION - BOTH STATE CODE FIELDS CANNOT BE 0
10	Blank
11	Number of records per card to be punched (0 = print only, 1, or 2)
12-14	Blank
15-80	Alphanumeric identification

Data Card. The data card at this time is formatted for SPATL (Independent Model Bridging) and is as follows (see Exhibit 4.22):

cc	use
1-4	Point Code
5-10	Point Number
	} May be blank
11-20	X = Easting (feet to 2 decimals); Decimal understood between cc 18 & cc 19
	OR
11-20	Latitude (Deg, Min, Sec to 3 decimals); Decimal understood between cc 17 & cc 18
21-30	Y = Northing (feet to 2 decimals); Decimal understood between cc 28 & cc 29
	OR
21-30	Longitude (Deg, Min, Sec to 3 decimals); Decimal understood between cc 27 & cc 28
31-40	Elevation (feet to 2 decimals); Decimal understood between cc 38 & cc 39
41-76	Ignored (May be used for alphanumeric identification)
70-80	Sequence number if desired

Each data deck must be followed by a 98 (cc 1-2) card, and after the last 98 card, a @FIN card. (See sample deck set-up, Exhibit 4.23.)

Exhibit 4.1 – Functional Relationship of DTIS Program Segments

USDA-FOREST SERVICE				PROGRAM NAME:		PROGRAM NUMBER:									
MULTIPLE-CARD LAYOUT FORM				FORMAT DESIGNED BY:		DATE:									
						PAGE: _____ OF _____									
CARD IDENT.	Standard SPATL	(12) K O D E	(18) Point I.D.	(F10.2) X or Northing	(F10.2) Y or Easting	(F10.2) Z or Elevation									
		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80													
Packed SPATL	(12) K O D E	(18) Point I.D. Number	(F10.2) X or Northing	(F10.2) Y or Easting	(F10.2) Z or Elevation	(12) K O D E	(18) Point I.D. Number	F10.2 X or Northing	(F10.2) Y or Easting	(F10.2) Z or Elevation					
		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80													
Digitizer SPATL	(12) K O D E	(16) Point I.D. Number	(F6.2) X	(F6.2) Y	(F6.2) Z	X (12) K O D E	(16) Point I.D. Number	(F6.2) X	(F6.2) Y	(F6.2) Z	X (12) K O D E	(16) Point I.D. Number	F6.2 Y	F6.2 X	F6.2 Z
		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80													
Resource SPATL	(12) K O D E	(18) Point I.D. Number	(F10.2) X or Northing	(F10.) Y or Easting	(F10.) Z or Elevation	(12A6) to cc. 112 or on second card. Alpha/Numeric Resource Data									
		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80													

ONESHOT CARD DECK SETUP *Exhibit 4.3 – ONESHOT Card Deck Setup*

USDA-FOREST SERVICE		PROGRAM NAME: ONESHOT		PROGRAM NUMBER:	
MULTIPLE-CARD LAYOUT FORM		FORMAT DESIGNED BY:		DATE:	
				PAGE: OF	

CARD IDENT.	Title Card	(10A6)																																																												(9X) blank		F10.0	
		ALPHA/NUMERIC JOB TITLE CARD																																																												(11) Block Status New = 1 Old = 0		Rejection Limit	
		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80																																																															

Model Title Card	Format Number	Left Plate Number	Right Plate Number	Strip Number	3A6		9X	1611	23X		Exchange Checking
					ALPHA/NUMERIC TITLE CARD		blank	"Switches"	blank		
		11		14	14						
		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80									

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80																																																																															
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80																																																																															

Exhibit 4.5 – ONEShot Input Cards

Exhibit 4.6 – BLOCk Card Deck Setup

[illegible]

Ala.	W.	0102	Ky.	N.	1601	N.Y.	E.	3101	W. Va.	N.	4701
	E.	0101		S.	1602		C.	3102		S.	4702
							W.	3103			
Ariz.	E.	0201	La.	N.	1701		L.I.	3104	Wisc.	N.	4801
	C.	0202		S.	1702					C.	4802
	W.	0203				N.C.		3200		S.	4803
			Maine	E.	1801						
Ark.	N.	0301		W.	1802	N.D.	N.	3301	Wyo. (1)	E.	4901
	S.	0302					S.	3302	(2)	E.C.	4902
									(3)	W.C.	4903
			Md.		1900				(4)	W.	4904
Calif.	I	0401				Ohio	N.	3401			
	II	0402	Mass.				S.	3402			
	III	0403	(Mainland)		2001				Puerto Rico		5001
	IV	0404	Island		2002	Okla.	N.	3501			5002
	V	0405					S.	3502			
	VI	0406	Mich.	E.	2101				Hawaii		5101
	VII	0407		C.	2102	Ore.	N.	3601			5102
				W.	2103		S.	3602			5103
Colo.	N.	0501									5104
	C.	0502	Minn.	N.	2201	Pa.	N.	3701			5105
	S.	0503		C.	2202		S.	3702			
				S.	2203						
Conn.		0600				R.I.		3800			
			Miss.	E.	2301						
Del.		0700		W.	2302	S.C.	N.	3901			
							S.	3902			
Fla.	E.	0901	Mo.	E.	2401						
	W.	0902		C.	2402	S.D.	N.	4001			
	N.	0903		W.	2403		S.	4002			
Ga.	E.	1001	Mont.	N.	2501	Tenn.		4100			
	W.	1002		C.	2502						
				S.	2503	Texas	N.	4201			
Idaho	E.	1101					N.C.	4202			
	C.	1102	Nebr.	N.	2601		C.	4203			
	W.	1103		S.	2602		S.C.	4204			
							S.	4205			
Ill.	E.	1201	Nev.	E.	2701						
	W.	1202		C.	2702	Utah	N.	4301			
				W.	2703		C.	4302			
Ind.	E.	1301					S.	4303			
	W.	1302	N.H.		2800						
						Vt.		4400			
Iowa	N.	1401	N.J.		2900						
	S.	1402				Va.	N.	4501			
							S.	4502			
			N.Mex.	E.	3001						
Kans.	N.	1501		C.	3002						
	S.	1502		W.	3003	Wash.	N.	4601			
							S.	4602			

Exhibit 4.8 - Codes for Plane Coordinate Computation

XYTRAN CARD DECK SETUP

Exhibit 4.9 – XYTRan Card Deck Setup

Exhibit 4.11 – Application of STOFI and FILL

Exhibit 4.12 – STOFI Variables

SELECTING S.W. CORNER and ROTATION ANGLE

N, E – COORDINATES OF INPUT DIGITAL TERRAIN

n, e – COORDINATES AFTER ROTATION

SWCN, SWCE – PROJECT SW CORNER. THIS IS THE ONLY PLACE WHERE INPUT & ROTATED COORDINATES ARE EQUAL (ROTATIONAL PIVOT POINT)

DELDN, DELDE, DN, DE – AS DESCRIBED IN EXHIBIT 4.12

NOTE

THE STRIP STAYS N and E OF SWCN, SWCE IN BOTH COORDINATE SYSTEMS. Dots in the diagrams represent pass points for a strip.

Exhibit 4.13 – STOFI Variables

[illegible]

Exhibit 4.17 – PLINe from Blocked Data (Continued)

[illegible]

USDA-FOREST SERVICE				PROGRAM NAME:		PROGRAM NUMBER:	
MULTIPLE-CARD LAYOUT FORM				FORMAT DESIGNED BY:		DATE:	
						PAGE: _____ OF _____	
CARD IDENT.	HEADER CARD	STATE CODE OF INPUT	STATE CODE OF OUTPUT	blank	ANY ALPHA-NUMERIC IDENTIFICATION		
		3901	1002	0	SOUTH CAROLINA NORTH ZONE to GEORGIA WEST ZONE		
		0	1001	1	GEOGRAPHIC COORDINATES to GEORGIA EAST, ZONE.		
		1002	0	0	GEORGIA WEST ZONE to GEOGRAPHIC COORDINATES		

Exhibit 4.21 – FORCor

Exhibit 4.25 – CAT Card Deck Setup

SECTION 2. PROGRAM ARRAY

Gridding from Random Data

This program inputs random data for a selected area from the blocked TDF. It then grids this area by the least square fitting of a saddle function ($z = Ax^2 + Bxy + Cy^2 + Dx + Ey + F$) onto the nearest 12 to 50 points to the grid point, and outputs the gridded information in Calcomp GPCP ARRAY block format. The program also selects and outputs a set of Control. 80 series, points for use in Calcomp GPCP program.

One control card is required.

cc	use	format
1-10	XMIN Low X value	F10.0
11-20	XMAX High X value	F10.0
21-30	XINC X size of the grid (cell)	F10.0
31-40	YMIN Low Y value	F10.0
41-50	YMAX High Y value	F10.0
51-60	YINC Y size of the grid (cell)	F10.0
61-65	ISPLIT Number of times the random file is to be split into bands. If left zero or blank, the default value of 4 will be used. This value is input data dependent, and should be set to obtain 1500 to 2500 random data points per band for optimum program efficiency and grid point elevation accuracy.	I5

Typical Runstream for Program ARRAY:

```

@RUN
@ASG.A DTIS*ABS
@ASG.A BLANCHARD*TDF
@USE 9,BLANCHARD*TDF
@ASG.UP ARAYFILE,F24
@ASG.UP 80SFILE,F24
@USE 7.ARRAYFILE
@USE 8.80SFILE
@XQT DTIS*ABS.ARRAY
701000. 703000. 33.33 1817000. 1818500. 33.334 0
@FIN

```


The GPCP ARRAY block will be put in file ARRAYFILE, and the Control. 80 series, points into 80SFILE.

SECTION 3. PROGRAM BLOCKBACK

Description

The program BLOCKBACK recovers data from the blocked TDF in a selected area. It outputs the recovered data in Standard Spatl Format.

The program was written to bypass use of DTIS Segment MANU/ as gridder for small areas where contours are desired. Program FSGPCP grids small amounts of random (terrain) data efficiently and can go directly to contouring.

One data card is required to run BLOCKBACK. That card describes the area to be recovered.

Data Card Format:

cc	use	format
1-10	SWCN Southwest Corner (N) of Area	F10.0
11-20	SWCE Southwest Corner (E) of Area	F10.0
21-30	NECN Northeast Corner (N) of Area	F10.0
31-40	NECE Northeast Corner (E) of Area	F10.0
41-50	Upper Elevation limit Elevations above this value are ignored	F10.0

Input Deck Assembly. Exhibit 4.26 is a schematic diagram of an input deck for program BLOCKBACK.

Exhibit 4.26 – BLOCKBACK Card Deck Setup

SECTION 4. GRIDDING OF IRREGULAR TERRAIN DATA WITH PROGRAM FSGPCP

Gridded and Irregular Data

Digital terrain data can be generated in either one of two different formats: gridded and non-gridded. In the gridded format, spot elevations are recorded at a regular gridded interval. Since the grid intervals are constant, the data file basically consists of strings of spot elevations. In the non-gridded format, the terrain elevations are digitized in an irregular manner, and each data point must be defined by its three rectangular coordinates, x, y, and z.

Most of the application programs included in the TOPAS program package require that the terrain data be stored in a gridded pattern. If a terrain data file contains irregularly sampled data, a corresponding data file, consisting of gridded elevation data, can be generated using program FSGPCP.

FSGPCP is the acronym for Forest Service General Purpose Contouring Program. It can be used to generate elevation contour plots from either gridded or non-gridded data files. If the input data is non-gridded, FSGPCP first computes the spot elevations along a rectangular grid, and then generates a contour plot. At the discretion of the user, the computed grid elevations may be written onto a data file or punched out on cards.

The application of FSGPCP for plotting contours will be explained in Chapter VI. This section will emphasize the use of this program to build a gridded data file from a set of irregular digital terrain data.

Data Card Formats

SIZE Card.

Purpose: This card introduces the parameters XSCALE, YSCALE, X00, Y00, XMIN, XINC, XMAX, YMIN, YINC, and YMAX, which determine the size, scale, position of the map; and grid size.

Notes: The map will correspond to the Region that has X between XMIN and XMAX, and Y between YMIN and YMAX. The scale will be XSCALE units/inch in the X direction, and YSCALE units/inch in the Y direction. The point $X = XMIN$, $Y = YMIN$ will be plotted at the point (X00, Y00) (inches) on the plotter, and other values of X and Y will be plotted relative to this point. Any linear units may be used. But the units used in this card must be the same as those used in the elevation data card.

Format:	cc	use	format
	1-4	SIZE	A4
	5	Blank	
	6-10	XSCALE (units/inch) of plot	F5.0
	11-15	YSCALE (units/inch) of plot	F5.0
	16-20	XOO (inches)	F5.0
	21-25	YOO (inches)	F5.0
	26-35	XMIN (units)	F10.0
	36-40	XINC (units), grid interval along x-direction	F5.0
	41-50	XMAX (units)	F10.0
	51-60	YMIN (units)	F10.0
	61-65	YINC (units), grid interval along y-direction	F5.0
	66-75	YMAX (units)	F10.0
	76-80	Blank	

Data Card for Terrain Points: (one card to define each terrain point)

cc	use	format
1-10	Blank	10X
11-20	X-coordinate	F10.0
21-30	Y-coordinate	F10.0
31-40	Elevation	F10.0

BLEV Card: (to specify contour interval)

cc	use	format
1-4	BLEV	A4
5	Blank	1X
6-10	Contour interval	F5.0

Input Deck Assembly. Exhibit 4.27 illustrates the input deck assembly for generating gridded data from a set of irregular data, and plotting a contour map of the terrain. The gridded terrain data is stored in a file called GEOM*FILE.

For further explanation on the various command cards shown in Exhibit 4.27, the users can refer to Chapter VI.

[illegible]

CHAPTER V

SLOPE AND ASPECT PROGRAM (SLOPE)

Program Function

Program SLOPE takes as input a rectangular array of elevation data points which have been stored in a data file. For example, a data file can be created from an existing DMA tape using program SCANDMA.

Program SLOPE computes the slope and aspect as the center of the cell described by 4 elevation points, and stores the output in a new data file. It employs a least square algorithm to determine the best-fitting plane with respect to the four adjacent elevation points. The steepest slope along that plane and its aspect angle are then used as the slope and aspect at that elevation point.

If graphic outputs are desired, isoslope lines may be generated using program FSGPCP (see Chapter VI), and program ZONEIT may be used to plot zones of various slopes and aspects (see Chapter VI).

Data Card Formats

Only one data card is needed for input to program SLOPE. The card format is as follows:

cc	use	format
1-10	XINC Ground distance between adjacent elevation points in the X-direction.	F10.2
11-20	YINC Ground distance between adjacent elevation points in the Y-direction.	F10.2

In the case of DMA tapes, the ground distance between adjacent data points in the original data tape is 208.3 ft., in both the x and y directions. If only every second point is used, then the ground distance between adjacent points becomes 416.7 ft.

Input Deck for Generating a Slope and an Aspect Data File. Exhibit 5.1 is a sample input deck for generating a slope and an aspect data file. The elevation data is input from a file called GEOM*JSMITH, and the slopes are stored in a new file called GEOM*JSMITHS. The aspects are stored in a file called GEOM*JSMITHA. Chapter VI will show how the slope file can be used as input to program FSGPCP to produce an isoslope plot.

CHAPTER VI

GRAPHIC PRODUCT PROGRAMS

SECTION 1. CONTOURING PROGRAM (FSGPCP)

Program Function

FSGPCP is the acronym for Forest Service General Purpose Contouring Program. This program was developed by California Computer Products, Inc. (Calcomp). It is for general use in displaying, by means of a contour diagram, functions dependent on two independent variables, x and y , such as elevation contours and isoslope lines. This computer program determines the contours and presents them in a form suitable for display on any Calcomp graphic system.

The program can accept either gridded or non-gridded elevation data. The user can specify arbitrary regions in which the contours are not to be plotted, and/or regions in which the contours are to be plotted as special lines (dashed, ticked, etc.). Contours can be plotted as heavy lines, lines with cross ticks, lines with ticks on one side, or dashed lines. At the user's option, labels can be printed on contours.

One unique feature of the program is its ability to produce stereoscopic contour maps; that is, maps containing pairs of images of the contour lines which appear to be three dimensional when viewed in a stereoscope.

When the surface is represented by random (non-gridded) data, the data is first converted to gridded format. The values of the function at the mesh points are computed, and the contours are produced from this gridded data. Spacing between grid points is specified by the user.

This chapter will present only a simplified documentation of the program for common application problems in geometronics. For more details in documentation, the users are referred to Calcomp User's Manual for GPCP (Reference 1).

The use of this program for converting random data into gridded format is explained in Chapter IV.

Data Card Formats. The data deck for FSGPCP consists of a series of command cards which guide the program to perform the proper tasks. The most commonly used commands for plotting contours and isoslope maps are explained on the following pages.

JOB Card

Association: Phase 0.

Purpose: This card initiates a new job.

Category: This is a Parameter Card.

Action Taken: The job identification is plotted on the map, and operation is transferred to Phase 1.

Notes: Every job must begin with a JOB card.

Format:	cc	use	format
	1-4	JOB	A4
	5	Blank	
	6-80	Any alphanumeric information (printed as identification)	18A4,A3

PAGE Size Card

Association: Phase 1.

Purpose: This card introduces the width PAGESIZ of the plotter paper.

Category: This is a Parameter Card.

Action Taken: None.

Notes: If the map is so large that it will not fit on the plotter paper, it is automatically split into two or more pages. If a PAGE card is not present, PAGESIZ is taken to be 28.0.

Format:	cc	use	format
	1-4	PAGE	A4
	5	Blank	
	6-10	PAGESIZ (inches)	F5.0
	11-80	Blank	

SIZE Card

Association: Phase 1.

Purpose: This card introduces the parameters XSCALE, YSCALE, XOO, YOO, XMIN, XINC, XMAX, YMIN, YINC, and YMAX, which determine the size, scale, and position of the map.

Category: This is a Parameter Card.

Action Taken: This card causes the scale factors to be plotted on the edge of the map, and causes operation to be transferred to Phase 2.

Notes: The map will correspond to the region that has X between XMIN and XMAX, and Y between YMIN and YMAX. The scale will be XSCALE units/inch in the X direction, and YSCALE units/inch in the Y direction. The point X = XMIN, Y = YMIN will be plotted at the point (XOO, YOO) (inches) on the plotter, and other values of X and Y will be plotted relative to this point. The values of XINC and YINC printed (on the printer) will be the ones actually used, and will not necessarily match those on the data cards.

Format:	cc	use	format
	1-4	SIZE	A4
	5	Blank	
	6-10	XSCALE (units/inch)	F5.0
	11-15	YSCALE (units/inch)	F5.0
	16-20	XOO (inches)	F5.0
	21-25	YOO (inches)	F5.0
	26-35	XMIN (units)	F10.0
	36-40	XINC (units)	F5.0
	41-50	XMAX (units)	F10.0
	51-60	YMIN (units)	F10.0
	61-65	YINC (units)	F5.0
	66-75	YMAX (units)	F10.0
	76-80	Blank	

ARrAY Card

Association: Phase 2.

Purpose: This card indicates whether the array points are to be posted on the map, and if so, what format is to be used. It also indicates whether the array is to be cleared before the new values are loaded into it.

Category: This is a Parameter Card.

Action Taken: This card begins an array block.

Format:	cc	use	format
	1-4	ARRAY	A4
	5	Blank	
	6-10	Half width of center marks (+)	F5.0
	11-15	Height of symbols for posting array points	F5.0
	16-20	Number of digits following decimal point in numbers to be posted (if =-1, no decimal point)	I5
	21-25	ICTL (posting-control number). If = 1 or 5, mark centers but do not post levels of of array points; = 2 or 6, do not mark centers or post array- point levels; = 3 or 7, mark centers and post array-point levels; = 4 or 8, draw the grid, but do not post array- point levels. If $ICTL \leq 4$, the array is cleared before the new values are substituted into it; otherwise, the array is not cleared.	I5
	26-80	Blank	

Basic (contour) LEVels Card

Association: Phase 4.

Purpose: This card indicates the contour-level spacing, and causes contour curves to be generated and plotted.

Category: This is a Parameter Card.

Action Taken: Contours are determined and plotted. Every IBOLDth contour curve is plotted as a heavy line with a label. (See BOLD card.) Contour curves around depressions are plotted with tick marks on the downhill side.

Notes: The maximum and minimum values of the function given on CNTL or ARAY cards are used as limits for the contour levels plotted.

Format:	cc	use	format
	1-4	BLEV	A4
	5	Blank	
	6-10	Contour-level spacing	F5.0
	11-80	Blank	

BOLD Contours Card

Association: Phase 4.

Purpose: This card changes the number of light contours between bold contours.

Category: This is a Parameter Card.

Action Taken: See Purpose.

Notes: IBOLD is the number of levels between bold contours. The number of light contours between bold ones is IBOLD-1. (If no BOLD card is present, IBOLD is 5.)

Format:	cc	use	format
	1-4	BOLD	A4
	5	Blank	
	6-10	IBOLD	F5.0
	11-80	Blank	

PLOT Map Card

Association: Phase 5.

Purpose: This card causes the Program to transfer operation to Phase 5.

Category: This is a Sequence Card.

Action Taken: See Purpose.

Format:	cc	use	format
	1-4	PLOT	A4
	5-80	Blank	

LINE Card

Association: Phase 5.

Purpose: This card causes a line to be drawn from (X1, Y1) to (X2, Y2). The line format is determined by the parameters TDIST, THEIT, SHIFT, GAP, and LINE, in the same manner as for a LEVb card. The parameter ICODE determines whether (X1, Y1) and (X2, Y2) are in inches relative to the plotter origin O_p (ICODE = 0), or in units relative to the map origin (ICODE = 1).

Category: This is a Parameter Card.

Action Taken: See Purpose.

Notes: If ICODE = 1, if Z1 and Z2 have been given on an ELEV card *immediately preceding this card*, and if non-zero parallax is being used, the line is drawn from the apparent position (X1, Y1, Z1) to the apparent position (X2, Y2, Z2). The parameter GAP is equal to THEIT if LINE = ± 4 .

Format:	cc	use	format
	1-4	LINE	A4
	5	Blank	
	6-10	ICODE	I5
	11-15	X1	F5.0
	16-20	Y1	F5.0
	21-25	X2	F5.0
	26-30	Y2	F5.0
	31-35	TDIST = Distance in inches between tick marks or gap centers	F5.0
	36-40	THEIT = Height of tick marks in inches (may be negative) or GAP = Width of gaps in inches	F5.0
	41-45	SHIFT = Lateral displacement, in inches, in line	F5.0
	46-50	LINE (integer value determines the line type). If: =0, plot a solid bold line of width 2 * SHIFT. =±1, plot solid line; =±2, plot tick marks on one side of the line (uphill side if THEIT is positive, downhill if it is negative); =±3, plot tick marks that cross the line; =±4, plot a gapped line. If LINE is positive, the line is not displaced. If LINE is negative, the line is displaced by SHIFT inches.	I5
	51-80	Blank	

Input Deck Plotting Contours from Gridded Data

Exhibit 6.1 is a schematic diagram of an input deck for plotting elevation contours from gridded data. The elevation data has already been stored in a Fastran computer file called GEOM*JSMITH, which is now used directly as input to the program FSGPCP. When DMA digital terrain tapes are used as the data source, the Fastran file can be built using programs PRINT and SCANDMA, as described in Chapter III.

Exhibit 6.2 is a sample input deck. The area to be contoured is a 15-minute USGS quad sheet from a DMA tape. Exhibit 6.3 is a sample graphic output from running FSGPCP.

Exhibit 6.1 – Input Deck for Plotting Elevation Contours from Gridded Data with Program FSGPCP

CONTOUR MAP
50 ft contour interval
Computer cost \$ 10.00 per plot

Exhibit 6.3 – Sample Output from Program FSGPCP

SECTION 2. ISOSLOPE PROGRAM (FSGPCP)

Program Function

The general purpose contouring program FSGPCP may also be used to plot isoslope lines (e.g. lines of equal slopes). The program takes as input slope, data that has been computed through program SLOPE (Chapter V). The user can specify the isoslope lines (such as the 10%, 20%, or 35% slope lines) to be plotted.

Data Card Format

In addition to the card types described in Section 1 for plotting elevation contours with FSGPCP, two other command cards are particularly useful for plotting isoslope lines. These command cards are NWPEN and LEV.

Command Card NWPEN. This card is used to activate a new pen for the next isoline. For example, suppose that the CALCOMP plotter has three pens with pen 1 containing black ink, pen 2, red ink, and pen 3, green ink. By using this command card to activate a particular pen, the user can specify the color for each isoslope line.

cc	use	format
1-4	NWPEN	A4
5	Blank	
6-10	Pen number to be used for the next isoslope line.	I5

Command Card LEV. This card is used to specify the parameters for an isoslope line.

cc	use	format
1-4	LEV6	A4
5	Blank	
6-10	ALEVEL = Slope in Percent	F5.0
11-15	ALABEL = Numerical label for isoslope line	F5.0
16-20	ARCDST = Distance in inches along isoslope line. from line start to label	F5.0
21-25	HEIGHT = Height of numerals in label	F5.0
26-30	TDIST = Distance in inches between tick marks or centers of gaps	F5.0
31-35	GAP = Width of gaps in inches	F5.0
36-40	THEIT = Height of tick marks in inches (may be negative)	F5.0
41-45	SHIFT = Lateral displacement in inches	F5.0
46-50	LINE (integer value determines the line type). If: =+1. plot solid line: =+2. plot tick marks on one side of the line (uphill side if THEIT is positive, downhill if it is negative): =+3. plot tick marks that cross the line: =+4. plot a gapped line. If LINE is positive, the contour line is not displaced. If LINE is negative, the contour line is displaced by SHIFT inches.	I5
51-55	NOCHRS = Number of characters in label	I5
56-60	IFMT = Number of digits after decimal point in the label	I5
61-80	Blank	

Input Deck for Plotting Isoslope Lines

Exhibit 6.4 is a schematic diagram of the input deck for plotting isoslope lines. The slope data has already been generated using program SLOPE (see Chapter V) and is stored in a Fastran file called GEOM*JSMITHS, which is now used as input to program FSGPCP.

Exhibit 6.5 is the layout for a sample input deck. Exhibit 6.6 is a sample graphic output.

Exhibit 6.4 – Input Deck for Plotting Isoslope Lines

ISOSLOPE MAP
30 and 55% slope intervals
Computer cost \$ 5.00 per plot

Exhibit 6.6 – Sample Output of Isoslope Plot

SECTION 3. ZONE PLOT PROGRAM (ZONEIT)

Program Function

The program ZONEIT takes as input rectangular arrays of slope (or aspect) data, and produces a graphic plot delineating zones of various ranges of slope (or aspect). The slope or aspect zones to be plotted are to be specified by the user in the input deck. A maximum of 20 zones can be included in one plot.

By producing a separate plot of slope zones and aspect zones, and then superimposing the two plots, it will be possible to identify the areas that fall within a certain slope and aspect zone. The program ZONEIT does not have the capability of directly delineating areas of certain slope and aspect combinations.

Data Card Format

Card 1:

cc	use	format
1-2	Logical unit for card reader; if left blank, unit 5 is used as default	I2
3-4	Logical unit for card punch; default = 9 If set = 99, no card image output (input to GELO) is generated.	I2
5-6	Logical unit for line printer, Default = 6	I2
7-8	Logical unit from which the gridded slope or aspect data is to be read, Default = 8	I2
9-10	Logical unit for plot tape, Default = 7	I2
11-12	A 1 in column 12 gives a cross-hatched plot. 0 in card column 12 gives a numbered plot	I2
21-56	MAP LABEL. This label will be printed along the left hand edge of the plot.	6A6

Card 2: (when ZONEIT is used to plot slope zones)

cc	use	format
1-4	Upper limit of zone 1 (Example: = 15 if zone 1 is to be 0-15% slope)	F4.0
5-8	Upper limit of zone 2	F4.0
9-12	Upper limit of zone 3	F4.0
.	.	.
76-80	Upper limit of zone 20	F4.0

The last zone specified in this card must be either blank or the maximum possible slope in the area.

Card 3: (to Define Boundary limits of Data Array)

cc	use	format
1-10	ILEFT -10 = lowest value of X in grid units	F10.0
11-20	IRIGHT -10 = highest value of X in grid units	F10.0
21-30	IBOT -10 = lowest value of Y in grid units	F10.0
31-40	ITOP -10 = highest value of Y in grid units	F10.0
41-50	UPERIN - plot scale to be expressed in grid units per inch; if left blank, the plot will be scaled to fit a format of 30" x 30"	F10.0

In the case of DMA digital terrain data tapes, the grid unit is one hundredth of an inch (.01 inch) on a 1:250,000 map sheet. The value for UPERIN may be computed with the following expression:

$$\text{UPERIN} = 0.0004 \times \text{scale factor of the output drawing}$$

Example: Plot scale wanted = 1:24,000
 Scale of Digital Data = 1:250,000

$$\text{UPERIN} = 24,000 \times 0.0004 = (\text{data grid units/inch})$$

Card 4:

cc	use	format
1-10	XONE - X-coordinate in grid units of SW corner of array	F10.0
11-20	YONE - Y-coordinates in grid units of SW corner of array	
21-30	XTWO - X-coordinate in grid units of SE corner of array	F10.0
31-40	YTWO - Y-coordinate in grid units of SE corner of array	F10.0
41-50	XTHREE - X-coordinates in grid units of NW corner of array	F10.0
51-60	YTHREE - Y-coordinate in grid units of NW corner of array	F10.0

Card 5: (coordinates of A Registration Point)

cc	use	format
1-2	Latitude in degrees	I2
3-4	Latitude in minutes	I2
5-8	Latitude in hundredths of seconds	I4
9-11	Longitude in degrees	I3
12-13	Longitude in minutes	I2
14-17	Longitude in hundredths of seconds	I4
18-20	Blank	3X
21-30	X-coordinate of registration point in grid units	F10.0
31-40	Y-coordinate of registration point in grid units	F10.0
41	= 1 if this is the last registration point in the data deck = 0 otherwise	I1

There should be one Card-5 for each registration point. The last registration card has a 1 in column 41. There must be at least one Card-5 (with a 1 in cc 41) in each ZONEIT run.

Input Deck Assembly

Exhibit 6.7 is a schematic diagram of an input data deck for program ZONEIT. The slope (or aspect) data has been stored in a file called GEOM*JSMITHS (or GEOM*JSMITHA) which is to be used as input to ZONEIT.

Application Example. Exhibits 6.8 and 6.10 are sample input decks for plotting slope zones and aspect zones respectively.

Exhibits 6.9 and 6.11 are sample outputs of using ZONEIT to plot slope and aspect zones respectively.

Exhibit 6.7 – Input Deck Assembly for Program ZONEIT

SLOPE ZONE MAP
 Zone 1 - 0 30%
 Zone 2 - 30 56%
 Zone 3 - 56% and above
 Computer cost \$ 5 00 per plot

Exhibit 6.9 – Sample Plot of Slope Zones

[illegible]

Exhibit 6.10 – Sample Input for Plotting Aspect Zones Using Program ZONEIT

ASPECT ZONE MAP

Zone 1 - N
 Zone 2 - NW
 Zone 3 - W
 Zone 4 - SW
 Zone 5 - S
 Zone 6 - SE
 Zone 7 - E
 Zone 8 - NE
 Computer cost \$ 5.00 per plot

Exhibit 6.11 – Sample Plot of Aspect Zones

SECTION 4. VIEW AREA PROGRAM (SEEN)

Program Function

View area program (SEEN) was formerly the TOPAS version of VIEWIT. Given an array of elevation points and a viewpoint, Program SEEN identifies all the array points that are directly visible from that viewpoint. The program will output a plot tape for the Calcomp 900-1136 drum plotter to show the visible points and the viewpoint in their true location at a specified scale. At the option of the user, the output can also include a map plotted on the line printer. However, this printer map will not be plotted to scale.

The viewpoint need not be located within the area of the elevation array, but the elevation of the viewpoint may be either on or above the actual terrain elevation. If the viewpoint is not within the area, its elevation must be supplied.

More than one viewpoint may be specified for each view plot. The graphic output will show all the array points that can be seen from one or more of the viewing stations. The maximum number of viewing points to be included in a single plot is 50.

The number of points in the elevation array must not be greater than 14,641 (121 x 121). The maximum viewing distance is currently set at 50 times the grid size.

Data Card Format

There are four types of data cards included in an input deck for program SEEN:

1. Parameter card
2. Elevation grid data (ARRAY block)
3. Viewpoint card
4. Switch card

Parameter Card Format:

cc	use	format
1-10	Scale factor of plot (e.g., 24000 if desired scale is 1:24,000)	F10.2
11-20	Ground distance in feet between adjacent grid points	F10.2
21-25	Number of rows in the elevation array (default is 121)	I5
26-30	Number of columns in the elevation array (default is 121) — note that the product of the number of rows and the number of columns must not be greater than 14641 (121 x 121).	I5
31-78	Blank	48X
79	=0 Do not produce a line printer plot =1 Produce a line printer plot	I1
80	=1 Elevation array to be input from an existing data file (this option is not recommended)	I1

Viewpoint Card Format:

cc	use	format
1-34	Blank	34X
35-40	Name of Viewpoint	A6
41-43	Column on which the viewpoint is located (x-coordinate in columns)	I3
44-46	Row in which the viewpoint is located (y-coordinate)	I3
47-50	Blank	4X
51-60	1. If the elevation field has a "+" elevation (+100), that elevation is added to the array elevation. 2. If the elevation field is blank, the array elevation is used. 3. If the elevation field has an elevation (5650), it replaces the array elevation.	F10.0

There should be one card for each viewpoint, and the maximum number of viewpoints in a given plot is 50.

Switch Card

A switch card has 999999 punched in columns 41-46.

A switch card must be used to close a viewpoint set; that is, a 999999 switch card must follow that last viewpoint card in a set (combined viewpoint plot).

A second 999999 switch card directly following the first 999999 card will signal the beginning of a new data set which is to be processed in the same execution. SEEN areas can be generated on several sets of terrain (ARRAY blocks) in one execution. Another elevation grid and the viewpoints to be processed against it, follow the second 999999 card.

Input Deck Assembly

Exhibit 6.12 is a schematic diagram of an input deck consisting of only one viewpoint set. Exhibit 6.13 shows a deck consisting of two viewpoint sets.

Application Example. Exhibit 6.14 is a sample input deck. The elevation array has been stored in a file called GEOM*JSMITH, which is now used as input to SEEN.

Exhibit 6.15 is a sample plot from program SEEN.

Exhibit 6.12 – Input Deck Setup for Program SEEN Containing One Viewpoint Set

Exhibit 6.13 — Input Deck Setup for Program SEEN Containing Two Viewpoint Sets

[illegible]

Exhibit 6.14 – Input Deck for Program SEEN

SEEN AREA MAP

15 points along a proposed road location
Computer cost \$ 1.00 per plot

SECTION 5. PERSPECTIVE PROGRAM (THREED OR PREP3D)

Program Function

Program THREED accepts as input gridded elevation data from a project data file, and produces a perspective view of the grid which represents the terrain surface. The program uses every data point in preparing the perspective drawings. For a perspective plot of a large area, such as that contained in a 7-1/2- or 15-minute USGS quad, the computer cost for drawing a perspective view using program THREED can be quite high.

In order to reduce computer cost and to simplify the input data deck, a modified version of Program THREED was specifically developed for drawing terrain perspective. This version is code-named Program PREP3D. Instead of using every data point in the input elevation grid, Program PREP3D uses only every second data point to prepare the perspective. The cost of preparing a perspective drawing using PREP3D is approximately 1/6 of that required by THREED.

This documentation will only explain the use of Programs THREED and PREP3D in drawing terrain perspective. Program THREED may also be used to prepare perspective drawings from non-gridded data, and to prepare perspective drawings for stereoscopic viewing. For a complete documentation of Program THREED, the user may refer to the Calcomp manual (Reference 2).

Data Card Format

All the card types described below are needed for running program THREED. However, only card types F, G, H and I need to be included in the input deck for program PREP3D.

Card Type A: (parameter card for the entire run)

cc		use	format
1	ITYPE	'A' identifies card type.	A1
2-5	NSETS	The number of data sets to be plotted by this run	I4
6-10	IPRNT	Message-output logical-device number — if IPRNT is zero or blank, the program uses the normal system printer; e.g., 6.	I5
11-15	IPLTP	The logical unit for the plot tape — if execution is halted for lack of core after gridding is completed the gridded data is written onto this tape (provided that no plotting has already been done)	I5
16-80	(Not used)		

Card Type B: (parameter card for a data set)

cc		use	format
1	ITYPE	'B' identifies card type.	A1
2-5	ICNTL	Switch indicating type of task—if: = 1—Read Z values directly into the rectangular array, column by column, with no smoothing = 2—Same as = 1, except with smoothing = 3—Read Z values directly into the rectangular array, row by row, with no smoothing = 4—Same as = 3, except with smoothing	I4
6-10	NSTUP	Number of different perspectives to be drawn for the data set being processed	I5
11-15	MN	Zero if gridding is not required	I5
16-20	IENT	Zero if gridding is not required	I5
21-25	M	Number of rows in the gridded data	I5
26-30	N	Number of columns in the gridded data	I5
31-35	IX	If smoothing is required, IX is the number of rows to be inserted between each pair of already existing rows; zero otherwise.	I5
36-40	IY	Analogous to IX, for columns	I5
41-45	INLU	The input-data logical-unit number — if INLU is zero or blank, the program assumes the unit to be the card reader	I5
61-70	ZFACT	In some situations it may be necessary or desirable to adjust the input Z values. The program adjusts array values as follows:	F10.0
71-80	ZADD		F10.0

$$Z_{\text{new}} = Z_{\text{input}} * ZFACT + ZADD$$

where the default value of ZFACT is 1. and the default value for ZADD is zero.

Card Type C: (variable format for input elevation data)

cc	use	format
1	ITYPE 'C' identifies card type	A1
2-80	FMT Variable format for input elevation data	13A6

Example: When the project data file is created from DMA digital terrain data files by using program SCANDMA, the following format should be entered in column 2-80:

Either: (1X./Q(5X,5E14-61), 5X,RE14-6/) if $R \neq 0$

Or: (1X./Q(5X,5E14-6/)) if $R = 0$

such that $M=5Q+R$ and R is less than 5.

The value of M is stated in Card type B.

Card Type F: (parameter card; see Exhibit 6.16 for illustration of the parameters)

cc	use	format
1	ITYPE 'F' identifies card type.	A1
2-10	XMIN	F9.0
11-20	YMIN Define minimum and maximum X, Y, Z boundaries for view area	F10.0
21-30	ZMIN	F10.0
31-40	XMAX	F10.0
41-50	YMAX	F10.0
51-60	ZMAX	F10.0
61-70	QS A scale factor which controls the size of the perspective drawing — see suggested formula below	F10.0
71-75	H Height and width of the perspective window	F5.0
76-80	FINE =0.5, 0.25, or 0.125 — the fineness with which visibility checking is to be performed; 0.5, 0.25, or 0.125 of distance between two grid points Normally, 0.5 will be sufficient to provide a satisfactory plot.	F5.0

Formula for computing QS from a given focal length (f):

$$QS = \frac{1}{H} \sqrt{H^2 + 4f^2}$$

Card Type G: (parameter card)

cc		use	format
1	ITYPE	'G' identifies card type.	A1
2-5	NVUES	The number of perspective plots to be drawn from the given data set – each perspective plot is to be defined by one H-Card as described below	I4

Card Type H: (define parameters for a perspective plot, see Exhibit 6.16 for illustration of the parameters)

cc		use	format
1	ITYPE	'H' identifies card type.	A1
2-10	IVIS	=1 position of view point to be defined by angles THETA and GAMMA and distance factor Q =4 position of view point to be defined by its X, Y, and Z coordinates	I9
11-20	THETA or X	Theta angle (see Exhibit 6.16) of viewing axis, if IVIS=1 X-coordinate of view point is IVIS=4	F10.0
21-30	GAMMA or Y	Gamma Angle (see Exhibit 6.16) of view axis, if IVIS=1 Y-coordinate of view point, if IVIS=4	F10.0
31-40	Q or Z	If IVIS=1 Q=Ratio of the viewing distance to the radius of the sphere enclosing the three-dimensional Region – Q must be greater than zero (see Exhibit 6.16). If IVIS=4, Z=coordinate of view point.	F10.0

Card Type I: (title card)

cc		use	format
1	ITYPE	'I' identifies card type.	A1
2-51	PT	Title to be labeled on the perspective plot for the purpose of identification	9A6
52-80		Not used	

Input Deck for Drawing Perspective with Program THREED. Exhibit 6.17 illustrates the data deck set-up for running program THREED. Exhibit 6.18 is a sample input data deck for running THREED. The gridded elevation data is stored in a project data file called GEOM*JSMITH, which is used as input to the program. Exhibit 6.19 is a sample graphic output from program THREED.

Input Deck for Drawing Perspective with Program PREP3D. Exhibit 6.20 illustrates the input deck assembly for running program PREP3D. Exhibit 6.21 is a sample input deck. Note that only card types F, G, H, and I are needed in the data deck. The gridded elevation data has been stored in a project data file called GEOM*JSMITH, which is used as input to the program. Exhibit 6.22 is a sample graphic output from program PREP3D.

Exhibit 6.16 - Three Dimensional Region and Image Scale Determination

Exhibit 6.17 – Input Deck Assembly for Program THREED

[illegible]

Exhibit 6.18 -- Sample Input for Program THREEED

PERSPECTIVE VIEW MAP
FROM N. W.
Computer cost \$ 10.00 per plot

Exhibit 6.19 – Sample Graphic Output for Program THREED

Exhibit 6.20 – Input Deck Assembly for Running Program PREP3D

[illegible]

Exhibit 6.21 – Sample Input for Program PREP3D

PERSPECTIVE VIEW MAP
FROM S W
Computer cost \$ 10.00 per plot

Exhibit 6.22 – Sample Graphic Output for Program PREP3D

SECTION 6. PERSPECTIVE CONTOUR PROGRAM (CON3D)

Program Functions

This program is used to generate perspective contours from gridded data.

The program presently can accept a maximum of 12,000 data points. Output from the SCANDMA program can be used directly as input to this program.

The perspective is generated by the principle of central perspectives. The following parameters can be specified by the user in the input data:

1. x and y dimensions of the view window (i.e. frame size of the photo);
2. focal length of the viewing camera;
3. location from which the view is to be made;
4. the location of the point which is to be at the center of the view window, i.e., photo (this point can be on, below, or above the ground surface);
5. the orientation of the line-of-sight, i.e., optical axis of the view camera.

Data Card Formats

Assuming that the digital terrain data has already been generated and stored in a file called GEOM*JSMITH, there are only 4 data cards in the input deck to program CON3D.

Card 1

cc	use	format
1-5	NROW - No. of rows of gridded data	I5
6-10	NCOL - No. of columns of gridded data	I5
11-20	Contour Interval in feet	F10.0
21-30	SCALE denominator of the map from which the digital terrain coordinates (x and y) are based (for example, 250,000 for all DMA tape data)	F10.0
31-40	Spacing (in inches) between adjacent columns	F10.0
41-50	Spacing (in inches) between adjacent rows	F10.0
51-60	Scale of the contour map to be plotted (omit this field if perspective contours are to be generated)	F10.0
61-65	I3D - option indicator = 0 generate contour map = 1 generate perspective contours	I5

Card 2: @ADD GEOM*JSMITH.

Card 3: (omit this card if the program is used to generate contour map)

cc	use	format
1-5	XCAM – Column number of station from which the view is to be made	F5.0
6-10	YCAM – Row number of station from which the view is to be made	F5.0
11-15	HCAM – Elevation of the view station	F5.0
16-20	XP – Column number of the object point which will be at the center of the perspective drawing; that is, the point to be looked at (optional)	F5.0
21-25	YP – Row number of the object point which will be at the center of the perspective drawing (optional)	F5.0
26-30	HP – Elevation of the object point which will be at the center of the perspective plot (optional)	F5.0
31-40	FRSZX – X-dimension (width) of the perspective plot in inches	F10.3
41-50	FRSZY – Y-dimension (height) of the perspective plot in inches	F10.3
51-60	FL – Focal length of the viewing camera in inches	F10.3
61-65	IORINT – Input option indicator = 0 the line-of-sight is defined by the coordinates of the center picture point (XP, YP, HP) = 1 line-of-sight is defined by the orientation angles of the optical axis – these angles are input in the next card	I5

Card 4: (omit this card if either the program is used to generate contour map, or the line-of-sight is defined by coordinates of center picture point)

cc	use	format
1-5	IOPT – Input option indicator = 1 line-of-sight to be defined by forward tilt, azimuth measured clockwise from North, and sideward tilt = 2 line-of-sight to be defined by the conventional omega (ω), phi (ϕ) and kappa (κ) angles	I5
6-10	ID1 – Degrees forward tilt (or omega)	I5
11-15	M1 – Minutes forward tilt (or omega)	I5
16-25	SEC1 – Seconds forward tilt (or omega)	F10.3
26-30	ID2 – Degrees azimuth (or phi)	I5
31-35	M2 – Minutes azimuth (or phi)	F10.3
36-45	SEC2 – Seconds azimuth (or phi)	F10.3
46-50	ID3 – Degrees sideward tilt (or kappa)	I5
51-55	M3 – Minutes sideward tilt (or kappa)	I5
56-65	SEC3 – Seconds sideward tilt (or kappa)	F10.3

The sign for the angles of rotation, if negative, must be included in each of the Degrees, Minutes, and Seconds fields.

SECTION 7. PROGRAM FLIGHT

Function

Program FLIGHT scans a DMA tape and produces profiles from the elevation data at intervals determined by the scale and sidelap of aerial photography for flight line planning.

Data Card 1. This is the control card on which is specified the scale, sidelap, beginning flight line (strip) number, and a title.

Data Card 2. This is the data card which defines the x and y limits, in grid increments, of the area to be scanned (same format as the data card required by SCANDMA).

Output

The output of program FLIGHT is a plot of the profiles. The profiles are labeled with the data input on card #1. The plots are stacked and each plot shows the strip number, horizontal and vertical scale, and a horizontal and vertical graph (see Exhibit 6.26).

Data Card 1

Purpose. This card specifies the title, scale, sidelap, and beginning strip number for flight line profiles. (Note: strip number is incremented automatically from West to East.)

Format: (all values right justified)

cc	use	format
1-10	SCALE — Denominator of desired aerial photography scale	I10
11-15	SIDELAP — In percent (15% = 15)	I5
16-20	Beginning STRIP number	I5
21-80	Title or description	

Data Card 2

Purpose. This card defines the limits of x and y for the area to be searched.

Format: (all values right justified)

cc	use	format
1-5	ILEFT - The lowest x value to be scanned	I5
6-10	IRIGHT - The highest x value to be scanned	I5
11-15	IBOT - The lowest y value to be scanned	I5
16-20	ITOP - The highest y value to be scanned	I5
21-25	INC - Scan interval. For example, if INC = 3, every third elevation point will be copied from a DMA tape.	I5
26-30	IXSW-X value of SW corner obtained from PRINT	I5
31-35	IYSW-Y value of SW corner obtained from PRINT	I5

[illegible]

PROGRAM FLIGHT

The output from COPY defines *IXSW* and *IYSW*. The output from PRINT will assist in determining *ILEFT*, *IRITE*, *IBOT*, *ITOP*.

NOTE

ILEFT is the location of the centerline of the first flight.

TEST RUN FLIGHT2 PROFILE GENERATOR
 PHOTO SCALE = 1/42000 SIDE LAP = 20%
 HORIZONTAL SCALE = 1/250.000 VERTICAL SCALE = 1000 FT = 1 IN

ELEVATION					
MEAN 10333 MIN 9133 MAX 12800					
FL	FLIGHT	SCALE			7 0/LAP
	ELEV	MEAN	MIN	MAX	MAX
3.50	22612	12000	45331	33578	-0
5.00	31333	12000	41280	37078	9
8.25	39214	12000	43659	39420	13

B-168

Exhibit 6.26 - Sample Graphic Output for Program FLIGHT

SECTION 8. PROGRAM ITOPAS

This program is a self-tutorial program to create and execute runstreams for graphic products where the terrain source is DMA tapes.

The program is executed from DEMAND as follows:

```
@RUN  
@ASG.A DTIS*ABS  
@XQT DTIS*ABS.ITOPAS
```

The program then responds by asking questions pertaining to required system information, such as account number and RUN number. This is followed by queries about the desired area, tape name and number, location of southwest corner of the tape, and location of the 4 corners of the data to be retrieved. It then requests the type of plot or plots desired. Finally, it schedules the generated runstream for execution.

Optionally, the runstream can be modified and manually scheduled. The annotated runstream on the following pages shows how the program operates, and describes what is being generated for the runstream.

@RUN R06SHW,1106527117XU,GEOM
DATE: 100675 TIME: 135905
>@ASG,A DTIS*ABS
FACILITY WARNING 000200000000
>@XQT DTIS*ABS.ITOPAS

ITOPAS VERS 1
NEED HELP?

>Y
TO RUN ITOPAS YOU WILL BE ASKED A SERIES OF QUESTIONS
WHICH ARE TO BE ANSWERED Y(YES),N(NO),H(HELP),OR WITH THE VALUE
REQUESTED

12 DIGIT ACCT. NO.?
>1106527117XU
ACCOUNT IS 1106527117XU RIGHT?
>Y

YOUR NAME AND SPECIAL INSTRUCTIONS?
>SHERRY FRIESEN PLOT ON PAPER

@ASG,UP 140143. .
@USE 7,140143. .
@FREE 140143. .
@START 140143.,,,1106527117XU .
140143

6 DIGIT RUN NUMBER?
>R06SAW

PLOT MAILING AND HANDLING INSTRUCTIONS TO WHICH FOREST?
>SIUSLAW S.O. MAIL FIRST CLASS

1. Enter an @ RUN Card.
2. Enter @ ASG,A ALB*ALB.
3. After the facility warning, enter @ XQT
ALB*ALB.ITOPAS

If you need help enter a Yes (Y) if you don't,
enter a (N) no and you will be asked the next
question.

The 12 digit account number used in the @RUN
statement needs to be entered here.

The name of the person who is requesting the
plot and any special instructions like paper
type, pens, ball point or ink, liquid is
standard when not requested up to 60 char-
acters are allowed.

Files are automatically set up by the ITOPAS
program.

The 6 digit run number used in the @Run
statement needs to be entered here.

Enter the name of Forest office or district
where you would like your plot or plots
mailed to. 60 characters are allowed.

WHAT FCR NUMBER DO YOU WANT THIS PLOT ROUTED TO?
ENTER 3 DIGITS ONLY

>019
PLOT TO BE ROUTED TO FCR019---RIGHT?
>Y

TAPE LABEL?--EXAMPLE GEOM*M1110W
>GEOM*K0910E
TAPE LABEL IS GEOM*K0910E RIGHT?
>Y

6 DIGIT TAPE NUMBER?
>F02398
TAPE NUMBER IS F02398 RIGHT?
>Y

THE FOLLOWING QUESTIONS MUST BE ANSWERED WITHOUT A DECIMAL POINT
USE COMMAS TO SEPARATE 2 VALUES WHEN REQUESTED
ENTER VALUES OF IXSW,IYSW AS SHOWN ON TOP OF PRINT SHEET
>201,57
IXSW = 201 IYSW = 57 RIGHT?
>Y

NOW ENTER CORNER COORDINATES OF THE QUAD SELECTED
SW CORNER X,Y?
>480,219
SW CORNER X,Y = 480 219 RIGHT?
>Y

SE CORNER X,Y?
>640,220
SE CORNER X,Y = 640 220 RIGHT?
>Y

NW CORNER X,Y?
>479,438
NW CORNER X,Y = 479 438 RIGHT?
>Y

019 is the FCR number used by Region 6 for all plots.

Enter the tape label from the DMA print sheet.

Enter the 6 digit tape number from the DMA print sheet.

Enter the IXSW and IYSW values from the print sheet. Separate the 2 values with a comma. If these values are correct answer either yes (Y) or no (N).

Enter first the (X) coordinate, then the (Y) coordinate, separating them only by a comma. If the values that you have given are correct, answered either Yes (Y) or No (N). (Follow this same procedure for each corner of the quad).

Same as above.

Same as above.

NE CORNER X,Y?
>639,439
NE CORNER X,Y = 639 439 RIGHT?
>Y

INCREMENT ? --NORMALLY 2 FOR 7.5 MIN. QUAD.
AND 4 FOR A 15 MIN. QUAD
>2
INCREMENT = 2 RIGHT?
>Y

IS THE AREA YOU HAVE SELECTED ON THE LEFT EDGE, RIGHT EDGE,
OR MIDDLE OF THE ONE DEGREE QUADRANGLE ON THIS TAPE? USE (L),(R) OR
(M).
>L

Z DO YOU WANT CONTOUR MAP(C), ISOSLOPE(I), SLOPE ZONE(S)
, ASPECT ZONE(A), VIEWIT(V), PERSPECTIVE PLOT(P),
PERSPECTIVE CONTOURS(T) OR DONE(D)
>C
TITLE TO BE PRINTED ON CONTOUR MAP?
> MT.CLAIRE MAIL TO SIUSLAW S.O.
DESIRED PLOT SCALE IN FT. PER INCH-USE DECIMAL POINT
>2640.
SCALE REQUESTED IS 2640.00 FEET PER INCH--RIGHT?
>Y
ENTER CONTOUR INTERVAL INCLUDING THE DECIMAL POINT
>40.
CONTOUR INTERVAL IS 40.00 RIGHT?
>Y

Same as above.

Use a (2) for a 7 1/2 minute quad, as a (4) for a 15 minute quad.

Enter an (L) for the left edge of the quad.
(R) for the right edge of the quad.
(M) if in the middle of the quad.

Contour example.

1. You are asked what title you would like. It is wise to include the forest name along with the title. Sixty characters field.
2. The next question now deals with the scale for the plot. Any basic map scale is acceptable.
3. Now you are asked if this is the scale you asked for. Answer (Y) yes or (N) no.
4. You are now asked what contour interval you desire.
5. Now you are asked if this is the contour interval you asked for. Answer (Y) yes (N) no.

DO YOU WANT CONTOUR MAP(C),ISOSLOPE (I),SLOPE ZONE(S)
,ASPECT ZONE(A),VIEWIT(V), PERSPECTIVE PLOT(P),
PERSPECTIVE CONTOURS(T) OR DONE(D)

>I

TITLE TO BE PRINTED ON ISOSLOPE MAP?

> MT.CLAIRE MAIL TO SIUSLAW S.O.

DESIRED PLOT SCALE IN FT. PER INCH-USE DECIMAL POINT

>2640.

SCALE REQUESTED IS 2640.00 FEET PER INCH--RIGHT?

>Y

TYPE IN THE SLOPE ZONES DESIRED(UP TO 6) SEPARATED
BY COMMAS,WITH NO DECIMAL PTS, AND IN ASCENDING ORDER
FOR EXAMPLE - 5,15,30,45,65,,,,

>5,20,45,60,90,,,,

ZONES ARE 5 20 45 60 90 0 RIGHT?

>Y

Isoslope

1. You are asked what title you would like. It is wise to include the forest name along with the title. Sixty characters field.
2. The next question now deals with the scale for the plot. Any basic map scale is acceptable.
3. Now enter the slope zones you desire (up to 6) in ascending order. After the last value, enter 4 commas.
4. Now you are asked if this is the Isoslope zones you have asked for. Answer (Y) yes (N) no.

DO YOU WANT CONTOUR MAP(C), ISOSLOPE(I), SLOPE ZONE(S)
 , ASPECT ZONE(A), VIEWIT(V), PERSPECTIVE PLOT(P),
 PERSPECTIVE CONTOURS(T) OR DONE (D)

>V

NEED HELP?

>Y

IT IS BEST TO HAVE A COMPUTER GENERATED CONTOUR MAP TO BE USED FOR
 SELECTING VIEWPOINTS. THE WIDTH AND HEIGHT OF THE MAP IN INCHES
 WILL BE NEEDED FOR THIS RUN. THE X DISTANCE FROM THE LEFT EDGE
 AND THE Y DISTANCE FROM THE BOTTOM EDGE WILL BE NEEDED FOR EACH VIEWPOI
 NT.

VIEW PLOTS FROM A SINGLE POINT OR A SERIES OF POINTS CAN BE GENERATED.

SCALE OF VIEWIT PLOT DESIRED IN FT/INCH INCLUDING DECIMAL POINT?

>2640.

SCALE IS 2640.00 FEET PER INCH - RIGHT?

>Y

WIDTH OF MAP IN INCHES INCLUDING DECIMAL POINT?

>25.6

HEIGHT OF MAP IN INCHES INCLUDING DECIMAL POINT?

>32.7

WIDTH IS 25.600 INCHES AND HEIGHT IS 32.700 RIGHT?

>Y

ENTER NAME(6 LETTERS OR NUMBERS) OF VIEWPOINT

>V.P.AA

ENTER DX,DY VALUES OR HELP

>HELP

ENTER X DISTANCE AND Y DISTANCE OF VIEWPOINT FROM LEFT

AND BOTTOM EDGE OF MAP, INCLUDING DECIMAL POINT AND SEPARATED BY COMM

AS

FOR EXAMPLE 20.2,3.18

>16.3,9.7

ENTER G(GROUND), P(PLUS), E(ELEVATION, OR H(HELP)

>H

G(GROUND)-VIEWPOINT WILL BE FROM GROUND LEVEL

P(PLUS)-VIEWPOINT WILL BE FROM GROUND LEVEL PLUS ELEVATION TO BE READ

E(ELEVATION)-VIEWPOINT WILL BE FROM ELEVATION TO BE ENTERED

ENTER G(GROUND), P(PLUS), E(ELEVATION, OR H(HELP)

>G

POINT V.P.AA IS 16.300 INCHES FROM LEFT AND 9.700 INCHES UP FROM BOT
 TOM

AND WILL BE VIEWED FROM GROUND -RIGHT?

>Y

ENTER V(ANOTHER VIEW TO FOLLOW), P(PLOT CUMULATIVE VIEW NOW
 OR D(DONE WITH VIEWIT)

>D

DO YOU WANT CONTOUR MAP(C), ISOSLOPE(I), SLOPE ZONE(S)
, ASPECT ZONE(A), VIEWIT(V), PERSPECTIVE PLOT(P),
PERSPECTIVE CONTOURS(T) OR DONE (D)

>A

DO YOU WANT CROSS HATCH(C) OR NUMBERED(N) PLOT?

>N

WHAT TITLE DO YOU WANT ON PLOT?

> MILES LAKE STUDY AREA

DO YOU WANT FOUR(4) OR EIGHT(8) CARDINAL DIRECTIONS FOR ASPECT?

>8

ENTER DESIRED PLOT SCALE(IN FT. PER INCH WITH THE DECIMAL POINT)
 SUCH AS 2000.

>5280.

YOU HAVE ASKED FOR A 5280.000 FT. PER INCH PLOT-RIGHT?

>Y

DO YOU WANT CONTOUR MAP(C), ISOSLOPE(I), SLOPE ZONE(S)
, ASPECT ZONE(A), VIEWIT(V), PERSPECTIVE PLOT(P),
PERSPECTIVE CONTOURS(V) OR DONE (D)

>P

PERSPECTIVE PLOT NOT READY YET

DO YOU WANT CONTOUR MAP(C), ISOSLOPE (I), SLOPE ZONE(S)
, ASPECT ZONE(A), VIEWIT(V), PERSPECTIVE PLOT(P),
PERSPECTIVE CONTOURS(T) OR DONE (D)

>T

PERSPECTIVE CONTOURS NOT READY YET

DO YOU WANT CONTOUR MAP(C), ISOSLOPE(I), SLOPE ZONE(S)
, ASPECT ZONE(A), VIEWIT(V), PERSPECTIVE PLOT(P)
PERSPECTIVE CONTOURS(T) OR DONE(D)

>D

ENTER S TO START A BATCH RUN OR E TO EDIT THE RUN

>S

NOTE: AFTER EDITING YOU MUST ENTER

@START 140143.,.,,1106527117XU . .

>@FIN

Aspect

1. Enter a (C) for a cross hatched plot or an (N) for a numbered plot.
2. You are asked what title you would like. It is a good idea to include the forest name along with the title. Sixty character field.
3. Enter either 4 or 8 for cardinal directions of Aspect.
4. The next question now deals with the scale for the plot. Any basic map scale is acceptable.
5. Now you are asked if this is the scale you asked for. Answer (Y) yes or (N) no.

When you are finished enter a (D) for Done.

Enter an (S) to start a batch run of all the plots you have just finished. You have an option to (E) edit the run.

RUNID: R06SAW ACCT: 1106527117 PROJECT: GEOM
TIME: TOTAL: 00:00:04.629
CPU: 00:00:00.714 I/O: 00:00:00.428
CC/ER: 00:00:03.486 WAIT: 00:18:44.568
START: 13:59:04 OCT 06,1975 FIN: 14:24:38 OCT 06,1975

SIZE: 010K

EST COST: TOTAL: 00002.91

CPU: 00000.36 I/O: 00000.00 CONNECT: 0002.55
TERMINAL INACTIVE

APPENDIX A

ACCESS TO TOPAS THROUGH USFS UNIVAC 1108 COMPUTER

Location of TOPAS Computer Program Package

The entire package of TOPAS computer programs is stored in the UNIVAC 1108 Computer at Fort Collins Computer Center (FCCC). In addition, all the DMA digital terrain data tapes that are presently available within the USFS are also stored and cataloged at FCCC. Access to any of the programs or DMA tapes can be made by following instructions provided in this guide.

In order to make full use of the complete capability of the TOPAS computer program package, a user's terminal should have the following computer equipments:

- 1 System input device (card reader and/or typagraph)
- 1 System output (printer and/or typagraph)
- 1 System output device 9-track tape
- 1 9-track to 7-track tape routine to convert print image data to a plot tape
- 1 Calcomp graphic plotter

A Data 100 Level 2 or 3 will meet these requirements.

WO will be responsible for the maintenance and revision of the TOPAS programs. Suggestions for program modifications and improvements should accordingly be forwarded to WO. Users should not make any attempt to modify any of the TOPAS program files.

Job Control Cards

An input deck to any of the TOPAS programs will consist of two types of cards: job control cards, and data cards. Generally, the job control cards activate the proper program in the TOPAS package, and assign the logical units required for proper execution of the job. The data cards contain the input to the computer program. This guide will outline, for each computer program, the job control cards that are needed to run that particular program. A thorough understanding of the job control language (JCL) for the UNIVAC Computer is desirable, but not essential. However, for the benefits of the users who have no prior knowledge of JCL for the UNIVAC 1108 computer, several commonly-used JCL statements are briefly explained in the following pages.

Job Routing

A job can be submitted either through a regular batch-run terminal, or through a teletype terminal on demand basis. The following programs involve very little printout, and require short execution time, and therefore, may be run through a teletype terminal:

1. Request listing of DMA library tapes
2. Program COPY
3. Program PRINT
4. Program SCANDMA
5. Program SLOPE

The following programs usually have graphic output and require longer execution time, and are, therefore, appropriate for batch-run:

1. Program FSGPCP
2. Program ZONEIT
3. Program THREED
4. Program PREP3D
5. Program SEEN
6. Program DTIS

Procedure for Using a Teletype Demand Terminal

The following procedures may be followed to establish a run with the UNIVAC 1108 through a teletype terminal:

1. Link up telephone and wait for dial tone.
2. Dial the assigned 1108 installation communication system telephone number.
3. The telephone will ring at least once followed by a high pitched tone to indicate a completed connection.
 - a. If a busy signal is received, all lines are active.
 - b. Wait a few minutes and re-dial.
4. When the tone is heard, type the assigned SITEID for the Terminal. Six (6) characters are established at system generation time.
 - a. The SITEID should not be followed by a CR.
5. The 1108 will respond with the message: UNIVAC 1108 TIME/SHARING EXEC
 - a. The exact response may vary between installations.
 - b. If no response is received after submission of a SITEID, there may have been noise on the line, parity error or other loss of transmission, or it may be in use by another terminal.
 - (1). Resubmit SITEID
 - (2). If there is still no response, type SITEID.
 - (3). If there is still no response, submit another acceptable SITEID.
 - (4). If this fails, call the central site operator to verify SITEID.
6. Define page width and characters for delete.

Example: @@TTY W,132,L,],C,\ CR

W, 132 means page width will be 132 characters.

,L,] means the character ']' will be used to denote line delete.

,C,\ means the character '\' will be used to denote character delete.
7. Enter a RUN Statement in the form:

@ RUN RUNID,Account #,Project Qualifier

 - a. @RUN must be in positions 1-4.
 - b. RUNID: 1-6 Alpha/Numeric Characters followed by a comma.
 - c. Account: 12 characters
 - (1) Followed by comma if project field is used.
 - d. Project: optional 1-12 characters. This is the implied FILE QUALIFIER.
8. 1108 will respond with a message of the form:

DATE----- TIME-----

The program can now be entered statement by statement, and data card by data card. The run will be executed and the printed output listed.

9. At the completion of the run, terminate the job with the statements below:

@FIN

@@TERM

For further details on the use of the demand terminal, the user may consult the UNIVAC User's manual (Reference 4).

Brief Description of UNIVAC @ED Processor

Under EXEC 8, card images may be maintained on mass storage in symbolic elements. These elements are organized into files. The complete internal name for a symbolic element is of the form:

FILENAME.ELEMENTNAME

The @ED processor is a text editor which allows the user to create, update, and replace symbolic elements in a cataloged file. Basic editor options are:

C Create new element if old element does not exist

(used with option U)

I Initial creation of new symbolic element

(file must already be cataloged)

R Read existing symbolic element

(no updates allowed)

U Update existing symbolic element

To call the @ED processor from a demand or batch-run enter:

@ED,OPTIONS FILENAME.ELEMENTNAME

The @ED processor operates in two modes: input and edit. In input mode, all lines entered are directly inserted into the text. In edit mode, various commands may be used to modify existing text. To change modes, enter a blank line.

Basic commands to the @ED processor while in edit mode are listed below. Some commands may be abbreviated to 1 or 2 characters as specified. All may be abbreviated to 3 characters. These commands may not be used in input mode.

COMMAND	DESCRIPTION
CHANGE /S1/S2/ C/S1/S2	This command searches the current line for the character string S1. The first occurrence of S1 in the line is changed to S2. Either S1 or S2 may be empty.
DELETE N1 N2	This command deletes lines. The first form deletes lines N1 through N2.
DELETE N1	The second form deletes N1 lines starting with the current line. The third
DELETE	form deletes the current line. DELETE may be abbreviated as D.
EXIT	This command applies all corrections, and then exits.

COMMAND	DESCRIPTION
INSERT S1 I S1	This command inserts S1 into a new line following the current line. The new line becomes the current line.
LNP	(See PRINT — identical except line numbers are printed.)
LOCATE S1 L S1	This command searches the text, starting with the next line, and stopping when S1 is located.
OMIT	This command exits without applying the corrections made.
PRINT N1 N2 PRINT N1 PRINT!	This command prints lines of text. The first form prints lines N1 through N2. The second form prints the next N1 lines. The third form prints the entire element from the top. Print may be abbreviated as P.
N1 +N1 -N1	These commands position the editor at a desired line. First form directs the editor to line N1. The second and third forms direct the editor to move N1 lines forward or back from the current line.

For complete information on all editor options and commands, see:

UNIVAC UP 4144, Rev. 2 (Level 27 EXEC)

UNIVAC UP 4144, REV. 3 (Level 30 EXEC)

@RUN STATEMENT

EXAMPLE

@RUN,A/TPC RUN115,321667,PROJ27,4,100/30

"RUN" COMMAND _____

"A" PRIORITY _____

TERMINATE IF CPU TIME, _____
PAGES, CARDS EXCEED

RUN-ID _____

ACCOUNT NUMBER-MUST BE VALID _____

PROJECT-USED AS IMPLIED FILE QUALIFIER _____

RUN TIME ESTIMATE(MAX CPU TIME IN MINUTES) _____
TERMINATE IF OPTION CONTAINS "T"

100 PAGES MAXIMUM. TERMINATE IF OPTION CONTAINS "P" _____

30 CARDS OUTPUT MAXIMUM-TERMINATE IF OPTION CONTAINS "C" _____

@ASG Statement - General Format

@ASG,options Filename, Facilities, ID's

Removable unit identifiers
(i.e., tape reel ID or Disc pack ID)

Unit related information
(i.e., type, size, hardware characteristics, etc.)

Name by which the file is known to the system and should be of the form Qualifier*Name. Both Qualifier and Name can include 1-12 characters A-Z, 0-9, hyphen and S.

Characteristics to be exhibited by the file

Requests system facilities for the current job

Example:

1. @ASG,A DTIS*ABS. 2. @ASG.T GEOM*K1009W,
U9V,F00528 3. @ASG,UP GEOM*K1009W,
F24

-means activate an existing file called DTIS*ABS. For use in this run.

-means mount a tape for this run.

-means assign space for a new file.

-T means that it will be used for this run only.

-the file is to be named GEOM*K1009W.

-GEOM*K1009W is the tape label.

-F24 means it is to be a Fastran file.

-U9V means it is a 9 track tape

-U means new file.

-F00528 is the reel number of the tape.

-P means for public use.

GENERAL @ASG STATEMENT OPTIONS

@ASG, OPTIONS

FILENAME, FACILITIES.ID's

FILES TO BE CATALOGUED

C CATALOGUE WHEN FREE'D IF RUN NORMAL TO THAT POINT

U CATALOGUE UNCONDITIONALLY WHEN FREE'D

R CATALOGUE IN READ ONLY MODE

P CATALOGUE AS PUBLIC FILE (NO P = PRIVATE FILE)
(R,W,P USED IN COMBINATION WITH C OR U)

W CATALOGUE IN WRITE ONLY MODE

CURRENTLY CATALOGUED FILES

A TERMINATE RUN IF FILE NOT FOUND IN DIRECTORY OF CATALOGUED FILES. SHOULD ALWAYS BE USED WHEN ASSIGNING A CATALOGUED FILE FOR USE IN CURRENT RUN

X ASSIGN CATALOGUED FILE FOR EXCLUSIVE USE BY CURRENT RUN. (TEMPORARY FILE IMPLIES EXCLUSIVE USE. IN EXISTENCE CURRENT RUN ONLY.)

D DECATALOGUE WHEN FREE'D IF RUN IS NORMAL TO THAT POINT

K DECATALOGUE UNCONDITIONALLY WHEN FREE'D

D OR K ONLY DECATALOGUED AFTER ALL RUNS CURRENTLY HAVING THE FILE ASSIGNED HAVE FREE'D THE FILE

NOTE: FREE'D IS THE TIME THAT A @FREE FILENAME OR @FIN IS ENCOUNTERED.

@USE STATEMENT

EXAMPLES: 1. @USE 7.,9 - Use logical unit 7 for unit 9

2. @USE 7.,GEOM*K1009W - Use logical unit 7 for the file which is
labeled GEOM*K1009W

@ADD STATEMENT

@ADD FILENAME. - means insert an existing file called GEOM*K1009W
@ADD GEOM*K1009W. into the run stream

-
OR

@ADD FILENAME.ELTNAME - means insert an existing element called AMY2 of file
@ADD DTIS*DTIS.AMY2 DTIS*DTIS into run stream

@XQT STATEMENT

@XQT PROGRAM ELEMENT NAME

Example: @XQT DTIS*ABS.FSGPCP

-means load and execute a program called FSGPCP which is
stored in a program package called DTIS*ABS

@FIN STATEMENT

@FIN

COMMENT

MAY NOT BE CONTINUED ON ANOTHER
CARD.

COMMAND

1. ALL OPEN FILES ARE CLOSED (TAPES CLOSED AND REWOUND WITH INTERLOCK).
2. ALL USER TEMPORARY FILES ARE RELEASED.
3. ANY FILES REMAINING TO BE CATALOGUED AT RELEASE ARE ENTERED INTO THE MASTER FILE DIRECTORY.
4. ACCOUNTING ROUTINES ARE ENTERED AND SYSTEM LOG UPDATED.
5. PRINTS AND PUNCHS FILES IF ANY ARE QUEUED TO PROPER SYMBIONT.

APPENDIX B

LIST OF REFERENCES

1. GPCP — A General Purpose Contouring Program
California Computer Products, Inc.
2411 W. LaPalma Avenue
Anaheim, California 92801 August 1973
2. THREE-D — A Perspective Drawing Software System
California Computer Products, Inc.
2411 W. LaPalma Avenue
Anaheim, California 92801 July 1969

APPENDIX C

Wind Flow Patterns in Northeastern Washington

The original intention of this study was to choose a single background speed and direction for the study area for each day and time simulated and then compare the predicted winds at specific grid points with the meteorological data collected. For most situations, however, it is impossible to realistically assume a single prevailing flow over the entire grid area. The area to be modeled was enlarged from the original "core" area in an attempt to include important topographic features that would have a strong influence on the resultant wind field in the proposed refinery development area. The problem still remains, however, that in a real situation the flow over the grid area will have been channelized and perturbed by surrounding terrain features before it reaches the study area.

The northern Puget Sound region seen in Figure A1 shows three interconnected low level channels. These are Puget Sound to the southeast, the east-west oriented Strait of Juan de Fuca in the southwestern portion of the study area and the Strait of Georgia, filling the north-central portion of the area and oriented somewhat northwest-southeast. The interior of Vancouver Island, the Olympic Peninsula and the foothills of the Cascades on the eastern edge of the area surround the sea level passages with much higher terrain. A paper dealing with air pollution and meteorology in the southern portions of Puget Sound (Welch, 1975) shows the channelization effect of these low level passages on winds approaching in the northern Puget Sound region from various directions. A low level pass through the coastal mountains occurs to the south of the study area near Hoquiam. Winds approaching the coast from a southwesterly direction may be channeled through this low point and enter the study area as a south to southeasterly flow from Puget Sound. At the same time,

Figure C1. Northern Puget Sound Region Showing Three Low Level Interconnecting Channels: Hoquiam-Puget Sound, Strait of Juan de Fuca, Strait of Georgia.

wind in the Strait of Juan de Fuca is likely to be from the west and flow in the Strait of Georgia southeasterly. A more westerly component may channel the winds from the northwest in Puget Sound while flow is still westerly in Juan de Fuca and southeasterly in the Strait of Georgia. A shift to the northwest may bring about a 180° reversal in the Strait of Georgia with flow still from the west in Juan de Fuca and northwesterly in Puget Sound. Likewise, winds from other quadrants may result in strikingly different patterns in the three "valley" regions represented by the sea level passages. The patterns described are illustrated as Figures A2 through A7.

Danard (1977) has simulated winds in the same general area but on a somewhat larger scale. His simulations showed several critical angles for the background geostrophic flow around which small changes in the prevailing direction would result in abrupt, 180° reversals in wind direction in the Straits of Juan de Fuca and Georgia. For geostrophic directions from about 60° to 220° , the simulated winds are from the southeast in the Strait of Georgia and east to southeasterly in Juan de Fuca Strait. However, when geostrophic directions are in the critical range of approximately 200° to 250° , winds become west to northwesterly in Juan de Fuca, yet remain southeasterly in the Strait of Georgia. From 240° to 30° , winds in the Strait of Georgia become northwesterly and continue from the west in Juan de Fuca Strait. Geostrophic directions between 30° and 60° resulted in generally northwesterly flow in Georgia Strait and easterly winds in the Strait of Juan de Fuca.

The previous examples serve to illustrate the complex nature of wind flow in the region. Wind speed and direction at the study area boundary will depend on the influence of channelization through the

Figure C2 . Flow Pattern for Background Direction;

Figure C3 . Flow Pattern for Background Direction;

Figure C4. Flow Pattern for Background Direction;

Figure C5 . Flow Pattern for Background Direction;

Figure C6. Flow Pattern for Background Direction:

Figure C7. Flow Pattern for Background Direction:

three low level passages on the Pacific coast, with the result that several combinations of flow direction in the three sea level channels can occur. Thus, southeasterly flow from Puget Sound may be accompanied by easterly winds in Juan de Fuca Strait and northwesterly flow in the Strait of Georgia or by easterly winds in the Strait of Juan de Fuca and southeasterly flow in the Strait of Georgia, or a southeast flow in Puget Sound may be coupled with westerly flow in Juan de Fuca and southeasterly flow in Georgia Strait, etc. This can result in quite different prevailing background flow characteristics for various sections of the grid area.

APPENDIX D

A Topographic Air Pollution Analysis System (TAPAS)

D-1

A TOPOGRAPHIC AIR POLLUTION ANALYSIS SYSTEM

by

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ABSTRACT

The Topographic Air Pollution Analysis System (TAPAS) was developed from meteorological and air pollution dispersion models in order to incorporate air quality into land use plans. TAPAS allows planners to introduce the air quality constraints early in the planning activity. A wind field model was combined with dispersion models to determine a mixing volume. This mixing volume, along with the Pollutant Standard Index, provides a means of determining total emission at prespecified air quality levels. The result and index, the π matrix, contains no source information, so planners would use a spatial matrix of the index as an input constraint in land use plans. Allowable emissions are calculated from the π index matrix and the ambient air quality standards. These allowable emissions for each pollutant form an atmospheric constraint matrix for air pollution which is compatible with economic, social and other models in land use planning.

INTRODUCTION

There has been a longstanding need to incorporate air quality constraints at an early stage in land use planning. Traditionally, there has been no direct feedback of air quality information in planning until after plans were somewhat formalized. Then, air quality would be evaluated as a residual calculation. Non-degradation requirements set by the Environmental Protection Agency (Code of Federal Regulations 1975) require that all areas of the United States be classified into areas in which no degradation of air quality is permitted (Class I), areas in which some degradation is permitted (Class II), and areas which allow air quality up to the National Ambient Air Quality Standards (Class III). Because of such regulations, an air quality index which defines the carrying capacity defined by an appropriate mixing volume within a geographic region is required. Such an index could be combined with emissions from planned activities in order to project air quality. Generally a planner can use this index to determine the intensity and kind of development, compatible with a predefined level of air quality. An index we define as the pollution index is described in this paper. It is shown to accommodate the land use requirements we have described.

THE PLANNING INDEX

The Topographic Air Pollution Analysis System outlined in Figure 1 is based on a set of meteorological simulation models

to calculate the surface temperature and the two-dimensional wind vector over a rectangular grid. Other meteorological factors affecting dispersion, namely stability and the large scale meteorological environment, are required inputs developed from climatology by considering worst-case conditions on a seasonal basis. Dispersion is calculated using a Gaussian plume model with a slight alteration to make it more appropriate for complex topography. The dispersion calculation is output in an index form which represents available mixing volume. This in turn is coupled with the appropriate form of the applicable ambient air quality standard to provide the Pollution Index (PI or π) matrix.

The wind and temperature models have been described previously (Fosberg, Marlatt and Krupnak 1976, and Fox et al. 1975) and so will not be detailed here. However, it is significant to note that the calculation of winds is a multistep process. First, a potential flow field is generated from a large-scale driving wind applied over the model domain. The potential flow is then altered by impulse acceleration of the lagrangian forces generated by surface roughness and surface temperature variations. This alteration is done by calculating the vorticity and divergence of the flow field. The divergence calculated is used in the dispersion component. The divergence forms a correction to the classical Gaussian plume model (Fosberg et al. 1976) incorporated in our analysis.

The essence of TAPAS is a mixing volume index. This index represents the volume that would be incorporated by a plume located within each cell. Basically, this is the air available for mixing the effluent. The theoretical development of this index is based on the Gaussian plume model.

The ambient concentration, χ , can be estimated from dispersion models. For simplicity, consider the mixing volume index as defined by the Gaussian dispersion model for complex terrain (Fosberg, Fox, Howard, Cohen 1976). The concentration is given by

$$\chi = \frac{Q}{u} G$$

where

$$G = \frac{1}{\sqrt{2\pi} \sigma_y \sigma_z} \exp \left[-\frac{1}{2} \left(\frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2} \right) - \delta \Delta t \right]$$

is the Gaussian distribution,

χ is the ambient concentration

Q is the emission rate of the pollutant

u is the wind speed

σ_y and σ_z are coefficients of plume spread (Turner 1969)

δ is the mass divergence in the airshed and

Δt is the time increment over which the divergence act.

The expression for the mixing volume index, I , is simply

$$I = \frac{\chi}{Q} \times 10^6 = \frac{G(x)}{u} 10^6$$

where

10^6 = scaling factor

The scaling factor, 10^6 , was chosen by considering Turner's (1969) maximum value of $\chi \frac{u}{Q}$ from a ground level source with Class F stability. The maximum index value is 1000 although it will generally be well below 100.

The mixing volume index is coupled with the Pollutant Standards Index (PSI or Ψ) (Thom and Ott 1976) given by

$$\Psi = a + b \chi / \chi_s$$

where χ_s is the ambient air quality standard for a particular pollutant, and a and b are constants.

The two indices can be combined to yield the Pollution Index by eliminating the ambient concentration and solving for Q

$$Q = \frac{(\Psi - a) \chi_s 10^6}{b I}$$

Emission rates from a mix of sources of a given pollutant are used in the land use model so that $Q = \sum n_i Q_i$ where

n_i is the number of sources in a particular activity, and

Q_i is the emission rate for that activity

Total permissible emission within an airshed are

$$\pi = \sum n_i Q_i = \frac{(\Psi - a)}{b I} \chi_s 10^6$$

where π is the allowable Pollution Index, in units of mass per unit time, and represents the total emission which will result in air quality of a given Ψ value within each cell. This short-term

π value represents the instantaneous emission rate. Since emissions as well as meteorological conditions do not remain fixed in time, we apply this value only to short-term standards no longer than 3 hours.

For emissions that are highly non-uniform or intermittent and for standards longer than 3 hours, a different π is calculated. The long-term index, π_L , is based upon using Gaussian dispersion to define a mixing cross-sectional area, and then using concepts similar to the box model (Fox 1975) to complete the volume. The Gaussian form of the mixing volume index is transformed to a ventilated box model. The Gaussian term, G , has the dimensions m^{-2} and when considering centerline values, $y = 0$, $z = 0$, it describes a half ellipse shaped cross-sectional area. The area swept by the plume, which accounts for 99.87% of the mass, is simply defined by including 3 times the standard deviation (σ) in each direction. This area is $(\pi \ 3\sigma_y \ 3\sigma_z)$. Defining an index based upon the flux through the area gives

$$I \equiv \frac{G}{9 \pi u} 10^6$$

The π index for the longer standards or for intermittent sources is then obtained in the same fashion as above and is

$$\pi_L = \frac{(\Psi - a) \chi_s 10^6}{b I} \frac{9X_L}{2U}$$

where X_L is the length of the grid cell. Notice that the dimension of π_L is mass. An emission rate must be multiplied by the length of time it is operating in order to calculate the allowable pollution loading for a given cell.

The π and π_L matrices can be calculated without reference to any source information.

APPLICATIONS OF TAPAS TO LAND USE PLANNING

Output from TAPAS is made directly useful to a planner by providing a technical limitation on development maximums that are commensurate with predefined levels of air quality. Since the information is site specific with good spacial resolution, TAPAS allows identification and evaluation of alternate sites to mitigate air pollution impact. Finally, since TAPAS represents the state of the art in meteorological and air quality model development, it has scientific defensibility far beyond that associated with economically competitive available methods.

The π matrix output by TAPAS is conservative. How conservative depends upon how extreme the climatological inputs are. In general, we chose meteorological conditions that are likely to occur as average worst conditions in a season. Air quality violations are often associated with rare event extreme stabilities for which we do not suggest planning. These episodal situations must be handled by restrictions on sources for the episode period. For the vast majority of time, however, our π numbers represent conservatively

the amount of pollution that can be accommodated within the cell. This, we feel represents the proper position for planning. Should anyone propose sources in excess of those allowable under TAPAS outputs, it is incumbent upon the proposer to provide data and analysis to support that position.

From the wildland development planning perspective that we address two major source types emerge, namely transportation and general community development. The pollutants include particulates, carbon monoxide (CO), nitrogen oxides, hydrocarbons and oxidants. Major sources appear to be vehicular traffic and space heating, particularly with wood-burning fireplaces.

The first step in development of a Land Use-Air Quality Analysis is to identify Ψ values, the allowable pollution levels for the area in question. For large areas certain portions will no doubt be associated with different values of Ψ . A critical issue is how to allocate Ψ values. For example, controversy is currently raging in the United States over the issue of non-deterioration. Since ambient air quality standards are set on the basis of protection of human health and welfare, there are many areas, particularly in national trust lands, where air quality is substantially above these standards. Use of the matrix provides an ability to illustrate to the concerned public the restrictions necessary to insure non-degradation of pristine air.

The PI matrix represents maximum allowable emission under episode conditions. They therefore, require an assessment of

current emissions to be made before planned changes can be evaluated. Emission factors (EPA 1976) multiplied by the number of sources for each activity and summed for a given pollutant cannot exceed the PI matrix value. As an example, consider the PI matrix for CO based on the 1-hour standard. Assuming a typical mix of vehicles (90% automobiles and light duty vehicles, 10% heavy duty trucks) operating at slow speeds (30 mph) at 7000 ft. above sea level, we find an emission figure of 60 gm per vehicle mile for 1975, which is doubled for traffic above 5000 ft. to give 120 gm per vehicle mile. The number of vehicles permitted through a 3 km by 3 km cell with 3 miles of road in a one-hour period without exceeding air quality standards is then

$$\text{No. of Vehicles} \times \text{Emission Factor} = \text{PI matrix}$$

or

$$\text{No. of Vehicles} = \frac{\text{PI matrix}}{\text{Emission Factor}}$$

$$\frac{\text{No. of Vehicles}}{\text{hour}} = \frac{(\pi_n) \mu\text{gm/sec} \quad 3600 \text{ sec/hr}}{120 \text{ gm/veh.mi.} \cdot 10^6 \mu\text{gm/gm} \cdot 3 \text{ miles of road}}$$

where π_n = PI matrix value for each cell.

$$\frac{\text{No. of Vehicles}}{\text{hour}} = \pi_n \times 10^{-5}$$

Similarly, the number of vehicles per eight hours would be calculated as

$$\frac{\text{No. of Vehicles}}{8 \text{ hours}} = \frac{\pi_n \text{ } \mu\text{gm veh. miles gm}}{120 \text{ gm } 10^6 \mu\text{gm } 3 \text{ miles of road}}$$

$$\frac{\text{No. of Vehicles}}{8 \text{ hours}} = 278 \times 10^{-9} \pi_n$$

To illustrate this, consider a cell with a daytime 1-hour π_n value of 46×10^8 , a nighttime 1-hour π_n value of 5×10^8 , and an 8-hour π_n value of 586×10^{13} . Day and night π matrix values are based on diurnal variations in wind speed and stability. The 8-hour π matrix value is based on average of day and night mixing volume. This allows 26,000 vehicles per hour peak traffic load during the daytime, 5000 vehicles per hour at night, and 163,000 vehicles in a given 8-hour period. Peak traffic volumes during short time periods must be compensated for by light traffic such that the total number of vehicles does not exceed the 8-hour volume.

Calculations involving a mix of sources (i.e. emission factors) are somewhat more complicated. As an example, consider a cell containing 2 miles of secondary road (30 mph traffic) and one mile of primary road (55 mph traffic). This calculation would be set up as follows for the 8-hour standard

$$\frac{\text{No. Vehicles (55)} \text{ } 70 \text{ gm } 10^6 \mu\text{gm } 1 \text{ mile of road}}{\text{vehicle mile gm}} + \frac{\text{No. Vehicles (30)} \text{ } 120 \text{ gm } 10^6 \mu\text{gm } 2 \text{ miles of road}}{\text{vehicle mile gm}} =$$

$$\pi_n \text{ gm}$$

or

$$NV(55) 7 \times 10^7 + NV(30) 2.4 \times 10^8 = \pi_n$$

At this point, some consideration must be given to the intended use of land within the cell. As a hypothetical example of the type of additional information required, assume that the secondary road is a loop road leading to and from a scenic viewpoint which would attract 75 percent of the vehicles (assumed situations and traffic ratios are purely hypothetical in order to illustrate the calculation). This traffic mix gives 3 vehicles on the secondary road to each vehicle on the primary road. Thus, for each 4 vehicles, 3/4 of the emissions will come from this secondary road and 1/4 from the primary road. These weighting factors allow the total number of vehicles to be calculated as

$$NV \text{ (all speeds)} \frac{3}{4} \times \text{emission factor (30)} +$$

$$NV \text{ (all speeds)} \frac{1}{4} \times \text{emission factor (55)} = \pi_n$$

$$\text{No. of Vehicles (all speeds)} =$$

$$\frac{\pi_n 10^{11}}{1/4 \cdot 7 \times 10^7 + 3/4 \cdot 2.4 \times 10^8}$$

$$= \frac{\pi_n 10^4}{7/4 + 72/4} = \frac{\pi_n 4 \times 10^4}{79}$$

$$= 506 \times 10^{-9} \pi_n$$

For the cell used in the first example, this would give 296,516 vehicles each eight hours.

SUMMARY

A complex system such as TAPAS must undergo extensive validation in order to assure its usefulness. For a mountain air quality analysis system, such a validation is difficult and expensive.

To date, components of TAPAS have been validated. The Winds Model component, for example, has been compared with data from wind studies performed in mountainous terrain. Certainly the Gaussian Diffusion Model needs no validation on our part. The combination of these two models, and the unique manner of their use, however, should be studied.

Toward this end we have undertaken a study in a Colorado mountain valley (Fox et al. 1976) measuring meteorological and air quality parameters. We have used preliminary data to determine, given existing traffic patterns, how many fireplaces could be accommodated within the valley before the applicable air quality standards would be violated. Results indicate that the valley is operating near these standards currently. Measurements support this conclusion.

One of the missing pieces of information in an analysis of mountain air quality is the existing conditions. TAPAS can make an estimate of what local sources might contribute to the ambient air pollution, but the problem of determining background pollution levels, namely pollution received from distant sources, remains.

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Topographic Air Pollution Analysis System (TAPAS)

Figure 1 - The conceptual outline of TAPAS, a combination of complex data files and sophisticated computer simulation models which provide a useful, simply applied index of the air pollution carrying capacity of mountain lands.

APPENDIX E

Data and Results for Daily and Annual Cases

This appendix contains data, descriptions and results of the four daily cases and the annual situation simulated in the analysis. Summary tables of the simulation inputs and results, with accompanying discussion, are presented within the body of the report.

Wind flow modeling results are presented in map form. Coasts and islands are outlined and the resultant wind speed and direction at each grid point is shown as a wind flag. The directions predicted define a 16-point compass and wind speeds are presented in meters per second.

In the meteorological data tables, the reported direction, speed in meters per second and the actual time of the observations are given. In some cases the observation times differ from the time simulated by as much as 30 minutes (i.e. Smith Island station). The WINDS results tables are in a similar format but no time is recorded.

PI-Matrix calculations from the TAPAS system are presented in map form. The magnitude of emissions in each grid cell that would result in ambient concentrations corresponding to the pollutant standards described is shown in a series of shaded maps, each representing a separate case. Character codes used for the hourly and 24-hour cases are shown in Table E1. Mixing volume index maps are included for the annual case. Character code series for the annual conditions are shown on each of the annual maps.

January 3, 1975

Air quality data collected for the northern Puget Sound study area showed violations of SO₂ standards at Bellingham on January 3, 1975. The three hour average reached a high value of 69 pphm at this location and the 24-hour average a maximum of 21 pphm.

Table E1. Character Codes and Range Data for PI-Matrix Maps

Character	Emission Rate for Each Simulation (g/s)	Total Emission for 24 Hour Period (kg)
Blank	<30	<19.90
.	30-59	19.90-19.99
-	60-89	20.00-20.09
+	90-119	20.10-20.19
=	120-149	20.20-20.29
*	150-179	20.30-20.39
#	180-209	20.40-20.49
\$	210-239	20.50-20.59
N	240-269	<u>≥</u> 20.60
X	<u>≥</u> 270	<u>≥</u> 20.60

The meteorological information shows a low pressure center at the surface in northern Alberta at the beginning of the simulation period (0300 PST, January 3) and a diffuse high pressure system to the south-east, centered over northern Nevada and Utah. A cold front had passed through the study region sometime in the 24 hours prior to the period of simulation. Twenty-four hours after the first period simulated, the meteorological maps show a low pressure center just east of the Puget Sound area. The high pressure system was over the Four Corners area with an occluded front over Idaho at this time.

At 850 mb., a low pressure center developed off the coast to the west of the study area during the first half of the simulation period and then moved through the area during the final eight hours. The 700 mb. maps show westerly flow over the area for the first 12 hours of the simulation, switching to a southerly to southwesterly direction as a

depression developed to the northwest. The direction of flow switched to northeast by 0300 PST, January 4 as the trough moved through the region. The 500 mb. maps show zonal flow at the beginning of the analysis with little warm air advection -- the warm air advection increased through the simulation period.

Temperature and pressure profiles can be seen from the sounding data taken at Quillayute (Table E2).

Table E2. Quillayute Sounding Data, January 3 and 4, 1975.

	Height (m)/ Pressure (mb)	Temperature (°C)	Direction (Degrees)	Speed (knots)
<u>0300 PST January 3, 1975</u>				
Surface (56 m)	1019.6 mb	3.9	30	3
850 mb.	1511 m	-5.3	255	14
700 mb.	3003 m	-14.3	280	40
500 mb.	5489 m	-27.5	280	54
<u>1500 PST January 3, 1975</u>				
Surface (56 m)	1003.1 mb	5.0	60	7
850 mb.	1390 m	-2.9	140	41
700 mb.	2909 m	-10.1	180	53
500 mb.	5429 m	-26.5	220	53
<u>0300 PST January 4, 1975</u>				
Surface (56 m)	1015.1 mb	3.9	135	-
850 mb.	1365 m	-5.0	315	30
700 mb	2868 m	-13.0	315	35
500 mb	5334 m	-33.0	315	35

Meteorological data collected for January 3, 1975 is shown as Table E3 and wind flow modeling results for the meteorological station grid points are presented as Table E4. Figures E1 through E6 are maps of predicted wind speeds and directions for each hour of the simulation. The PI-Matrix results are shown in Figures E7 through E13.

January 24, 1975

The northern Puget Sound air quality data indicate that particulate concentrations in Mt. Vernon averaged $128 \mu\text{g}/\text{m}^3$ for a 24 hour period on January 24, 1975. While within standard limitations, this is the highest ambient concentration recorded at this receptor site on any sampling day in 1975 or 1976.

The meteorological situation shows a fairly weak low pressure center to the southwest of the study area over the Pacific at the beginning of the simulation period. A high pressure system was located over southwestern Idaho. By 0300 PST on January 25, the depression had moved to the east and was centered along the Washington-Oregon State line, southeast of the northern Puget Sound region. Surface flow over the State of Washington was light and from the southeastern quadrant at the beginning of the simulation period; light and variable to calm conditions prevailed over the state in the early morning hours of January 25, 1975.

Upper level maps for the simulation period all show a strong low pressure center in the Gulf of Alaska. During the simulation period, a low pressure system developed and intensified over the north-central United States and south-central Canadian provinces -- flow at the upper levels appears to have been primarily governed by these two depressions.

Table E3

DATA FOR WINDS VALIDATION -- JANUARY 1, 1975

Station Code	TIME					
	0300	0700	1100	1500	1900	2300
FABC	220 8	160 4	140 2	70 6	100 7	360 3
	0300	0700	1100	1500	1900	2300
FMEL	220 6	180 5	110 2	90 3	110 3	40 6
	0300	0700	1100	1500	1900	2300
JELA	210 7	180 7	140 2	30 3	40 6	360 4
	0259	0657	1055	1455	1855	2256
SELC	200 6	130 4	80 2	30 2	90 2	360 4
	0300	0700	1100	1500	1900	2300
SELT	204 6	158 4	107 1	29 2	26 4	12 4
	0300	0700	1100	1500	1900	2300
ASBL	220 4	140 4	130 4	100 6	120 4	120 5
	0300	0700	1100	1500	1900	2300
ALLC	200 4	315 2	310 3	290 4	315 4	300 2
	0300	0700	1100	1500	1900	2300
ANVP	170 -	140 -	130 -	80 -	130 -	100 -
	0300	0700	1100	1500	1900	2300
ATEX	210 4	130 3	130 5	90 6	120 9	110 5
	0300	0700	1100	1500	1900	2300
EWIL	270 3	315 2	68 3	68 6	68 6	68 6
	0300	0700	1100	1500	1900	2300
WRLD	180 0255	100 0655	130 1055	100 1455	120 1855	120 2255
SMTH	135 5	135 4	- -	112 3	113 7	- -
	0330	0630	-	1530	1830	-
VICA	148 3	203 2	135 2	90 6	90 9	10 7
	0300	0700	1100	1500	1900	2300
VICH	225 3	225 2	90 4	90 5	90 10	45 3
	0300	0700	1100	1500	1900	2300
PAGG	- -	00 00	- -	- -	- -	- -
	-	0700	-	-	-	-
PAPA	- -	100 2	90 00	00 00	- -	- -
	-	0700	1100	1500	-	-
EVRT	131 2	139 3	147 4	118 4	118 5	134 3
	0300	0700	1500	1500	1900	2300
QUIL Surface	60 2	90 2	90 2	50 2	40 5	40 4
	0255	0657	1156	1455	1857	2255
QUIL 550 ab.	253 ?	- -	- -	140 20	- -	- -
	0315	-	-	1515	-	-

Key: 120 Wind Direction (0-360)

12 Wind Speed (knots)
0300 Time of Observation

Table E4 RESULTS FROM WINDS MODELING -- JANUARY 3, 1975

Station Code	TIME					
	0300	0700	1100	1500	1900	2300
FARC	225	158	113	68	90	23
	5	3	2	4	4	5
FMBL	225	158	135	68	90	23
	6	4	2	3	4	4
BELA	225	180	135	45	90	23
	6	4	2	3	3	4
BELC	203	180	135	68	90	23
	6	4	2	3	3	4
BELT	203	180	135	68	90	23
	6	4	2	3	3	4
ASHL	225	158	113	68	90	23
	4	3	2	4	4	5
ANWP	225	158	113	68	90	23
	4	3	2	4	4	5
ATEX	225	158	113	68	90	23
	4	3	2	4	4	5
BHIL	248	158	113	90	90	68
	7	2	3	5	7	3
WHID	180	135	113	113	113	113
	2	2	2	3	4	5
SMTH	158	135	135	135	135	135
	3	3	3	4	5	7
VICA	225	135	113	68	90	23
	4	3	2	3	3	4
VICH	225	135	113	68	90	23
	6	2	2	3	4	4

Key: 120 Wind Direction (0-360)

A
12 Wind Speed (knots)

Flow direction at 850 mb. was between 245° and 325° during the simulation and westerly at 700 mb. and 500 mb. for the entire period.

The temperature and pressure profiles from the Quillayute sounding data are shown in Table E5.

Table E5. Quillayute Sounding Data, January 24 and 25, 1975.

	Height(m)/ Pressure (mb.)	Temperature ($^{\circ}$ C)	Direction (degrees)	Speed (knots)
<u>0300 PST January 24, 1975</u>				
Surface (56 m)	1016.5 mb.	6.3	100	4
850 mb.	1496 m	-3.0	245	9
700 mb.	3017 m	-5.5	270	58
500 mb.	5586 m	-20.1	270	75
<u>1500 PST January 24, 1975</u>				
Surface (56 m)	1012.1 mb.	7.6	340	4
850 mb.	1466 m	-1.9	325	9
700 mb.	2996 m	-7.3	265	38
500 mb.	5570 m	-19.5	270	77
<u>0300 PST January 25, 1975</u>				
Surface (56 m)	1019.3 mb.	2.8	-	Calm
850 mb.	1461 m	-4.0	293	10
700 mb.	2969 m	-12.0	270	30
500 mb.	5486 m	-27.0	270	80

Meteorological data collected for January 24, 1975 is shown as Table E6 and wind flow modeling results for the meteorological station grid points are presented as Table E7. Figures E14 through E19 are maps of predicted winds speeds and directions for each hour of the simulation. The PI-Matrix results are shown in Figures E20 through E26.

Table E6.

DATA FOR WINDS VALIDATION -- JANUARY 24, 1973

Station Code	TIME					
	0300	0700	1100	1500	1900	2300
FARC	210	170	190	170	00	300
	4	4	3	2	00	4
	0300	0700	1100	1500	1900	2300
FREL	190	190	190	190	00	310
	3	3	2	1	00	3
	0300	0700	1100	1500	1900	2300
BELA	200	150	190	200	180	00
	6	2	4	4	2	00
	0258	0655	1054	1457	1859	2258
BELC	150	40	170	220	00	20
	3	1	2	1	00	1
	0300	0700	1100	1500	1900	2300
BELT	156	77	190	00	233	00
	2	1	1	00	1	00
	0300	0700	1100	1500	1900	2300
ASHL	140	130	130	140	120	30
	3	4	4	2	1	2
	0300	0700	1100	1500	1900	2300
JALC	180	135	135	120	180	15
	3	3	2	1	1	2
	0300	0700	1100	1500	1900	2300
AMUT	120	130	110	100	200	350
	-	-	-	-	-	-
	0300	0700	1100	1500	1900	2300
ATEX	180	120	150	00	00	00
	3	2	3	00	00	00
	0300	0700	1100	1500	1900	2300
BHEL	293	90	113	113	315	225
	1	2	3	2	1	1
	0300	0700	1100	1500	1900	2300
WHID	150	100	110	110	250	00
	1	2	2	1	1	00
	0255	0655	1055	1455	1855	2255
SMTX	180	113	-	00	225	-
	5	3	-	00	3	-
	0330	0630	-	1530	1830	-
VICA	203	00	270	293	293	270
	6	00	2	2	2	2
	0300	0700	1100	1500	1900	2300
VICH	225	225	225	225	270	315
	6	4	1	4	3	2
	0300	0700	1100	1500	1900	2300
PACG	-	00	-	270	248	-
	-	00	-	2	2	-
	-	0700	-	1500	1900	-
PAPA	-	00	00	320	-	-
	-	00	00	2	-	-
	-	0700	1100	1500	-	-
EVRI	199	130	141	195	-	-
	2	3	2	1	-	-
	0300	0700	1100	1500	-	-
QUIL Surface	90	00	10	340	00	00
	2	00	2	2	00	00
	0257	0658	1058	1455	1858	2257
QUIL 350 mb.	245	-	-	325	-	-
	4	-	-	4	-	-
	0315	-	-	1513	-	-

Key: 220 Wind Direction (0-360)

12 Wind Speed (knots)
0300 Time of Observation

Table E7. RESULTS FROM WINDS MODELING -- JANUARY 24, 1975

Station Code	TIME					
	0300	0700	1100	1500	1900	2300
FARC	180	135	158	180	225	360
	3	2	2	2	2	1
FMBL	180	158	180	203	225	315
	4	3	3	2	2	1
BELA	180	158	180	180	203	360
	4	2	3	2	2	1
BELC	180	158	180	180	203	360
	4	3	3	2	2	1
BELT	180	158	180	180	203	360
	4	2	3	2	2	1
ASHL	180	135	158	158	248	360
	3	2	2	1	1	2
ANWP	180	135	158	158	248	360
	3	2	2	1	1	2
ATEX	180	135	158	158	248	360
	3	2	2	1	1	2
BHIL	203	135	158	203	248	225
	2	3	2	2	2	1
WHID	180	135	158	135	270	360
	3	2	2	1	1	2
SMTH	180	135	135	135	225	360
	3	2	2	1	1	2
VICA	180	135	158	180	225	338
	3	2	2	1	1	2
VICH	180	225	225	248	248	293
	4	2	2	3	3	2

Key: 220 Wind Direction (0-360)

12 Wind Speed (knots)

A similar situation existed at 700 mb., with a low pressure center over southern California and a strong depression along the western Canadian coast at 0300 PST January 30. Flow was westerly over Puget Sound. The low pressure center "stacked" to the northwest of the study area intensified and moved south to a point slightly northwest of Puget Sound by 0300 PST January 30, while the southern California low disappeared. Flow over western Washington shifted toward the southwest and was stronger and southerly 24 hours after the beginning of the simulation period.

The low pressure center to the northwest of the study area is also evident on 500 mb. maps and moved southward through the analysis period. A depression off the southern California coast weakened and disappeared during the same period as flow over northern Puget Sound moved from west to south-southwest during the simulation.

The pressure and temperature profiles recorded at Quillayute are shown in Table E8.

Meteorological data collected for January 30, 1975 is shown as Table E9 and wind flow modeling results for the meteorological station grid points are presented as Table E10. Figures E27 through E32 are maps of predicted winds speeds and directions for each hour of the simulation. The PI-Matrix results are shown in Figures E33 through E39.

February 12, 1975

Air quality data for 1975 show that violations of the short-term standards for SO_2 occurred at the Bellingham site on February 12, 1975. Concentrations of 40 pphm were recorded for a 24 hour average, the highest 24 hour concentration recorded at this location over the two year period examined (1975 and 1976).

January 30, 1975

The air quality data collected indicate that particulate levels reached a concentration of $119 \mu\text{g}/\text{m}^3$ for a 24 hour period on January 30, 1975 at Mt. Vernon. This was the second highest concentration recorded at this location over a two year period.

Surface meteorological data for the beginning of the simulation period show a low pressure system centered to the northwest of the study area, with a warm front just off the western Washington coast and a cold front somewhat further off shore over the Pacific. A high pressure center was evident at the surface over southeastern Idaho and southwestern Montana. By 0300 PST January 31, the low pressure center had moved south and was located directly west of the study area. The warm front had apparently passed through the northern Puget Sound region and lay to the north of the study area, while a cold front extended along the Pacific coast. The high pressure system was still centered over southeastern Idaho. The general direction of flow over western Washington was southeasterly to east-southeasterly at both sounding periods.

The 850 mb. maps show a strong depression moving south along the Pacific coast from the Gulf of Alaska early on January 30, 1975. A weak low pressure system was centered over southern California, with a weak high pressure center over southeastern Idaho. During the simulation period, the high pressure center moved east and the southern California trough weakened and disappeared. At the same time, the low to the northwest intensified and continued to move south to a point directly west of the Puget Sound region by the end of the simulation. Flow at this level was light and from the southwest at the beginning of the analysis, shifting to the south and south-southeast and becoming stronger through the following 24 hours.

Table E8. Quillayute Sounding Data, January 30 and 31, 1975.

	Height(m)/ Pressure (mb.)	Temperature (°C)	Direction (degrees)	Speed (knots)
<u>0300 PST January 30, 1975</u>				
Surface (56 m)	1008.8 mb.	1.3	160	5
850 mb.	1427 m	-6.3	205	17
700 mb.	2918 m	-14.6	265	18
500 mb.	5403 m	-28.6	290	28
<u>1500 PST January 30, 1975</u>				
Surface (56 m)	999.0 mb.	2.7	140	4
850 mb.	1340 m	-6.1	170	38
700 mb.	2840 m	-14.5	205	23
500 mb.	5302 m	-32.2	210	34
<u>0300 PST January 31, 1975</u>				
Surface (56 m)	998.9 mb.	1.1	90	15
850 mb.	1328 m	-5.0	158	45
700 mb.	2785 m	-13.0	180	40
500 mb.	5243 m	-34.0	180	50

Surface weather maps for the February 12, 1975 simulation period show a strong low pressure system centered immediately west of the study area at 0300 PST February 12, 1975. An occluded front extended through the northern Puget Sound region. A high pressure center was evident near the Four Corners area over southern Colorado and a second ridge extended across northern Alberta and Saskatchewan. During the 24 hour simulation period, the low pressure center weakened and moved over northern Vancouver Island, with an occluded front across the northern portions of the study region.

Table E9.

DATA FOR WINDS VALIDATION -- JANUARY 30, 1975

Station Code	TIME					
	0300	0700	1100	1500	1900	2300
PARC	90	100	90	100	90	90
	5	4	6	4	6	8
FMEL	0300	0700	1100	1500	1900	2300
	110	110	110	110	110	100
FMEL	3	4	4	4	6	7
	0300	0700	1100	1500	1900	2300
BELA	30	40	20	160	100	30
	4	2	5	2	5	4
BELC	0255	0656	1055	1459	1855	2258
	-	-	-	-	-	-
BELC	-	-	-	-	-	-
	-	-	-	-	-	-
BELT	25	35	149	120	86	87
	2	2	3	2	5	4
ASBL	0300	0700	1100	1500	1900	2300
	140	140	150	140	150	130
ASBL	4	8	6	8	4	4
	0300	0700	1100	1500	1900	2300
AALC	135	135	150	135	130	130
	3	4	4	4	3	2
AMWP	0300	0700	1100	1500	1900	2300
	140	140	150	140	120	140
ATEX	2	3	4	3	2	2
	0300	0700	1100	1500	1900	2300
ATEX	130	130	140	130	120	120
	6	7	8	8	3	4
BREL	0300	0700	1100	1500	1900	2300
	68	68	68	68	68	68
BREL	6	6	6	4	6	6
	0300	0700	1100	1500	1900	2300
WHED	110	110	120	130	120	110
	5	5	6	8	4	3
SMTH	0255	0655	1055	1455	1855	2255
	135	135	-	135	113	-
VICA	9	11	-	12	12	-
	0330	0630	-	1530	1830	-
VICA	113	158	135	135	135	113
	4	3	11	11	3	2
VICH	0300	0700	1100	1500	1900	2300
	135	135	135	135	90	135
PACG	7	8	12	16	18	16
	0300	0700	1100	1500	1900	2300
PACG	-	-	-	-	-	-
	-	-	-	-	-	-
PAPA	-	00	00	00	-	-
	-	00	00	00	-	-
EVRT	-	0700	1100	1500	-	-
	136	127	136	129	111	113
QUIL	4	6	4	6	9	9
	0300	0700	1100	1500	1900	2300
QUIL Surface	140	150	150	150	140	160
	2	2	4	2	2	2
QUIL 350 mb.	0258	0658	1056	1455	1856	2258
	205	-	-	170	-	-
	8	-	-	18	-	-
	0315	-	-	1515	-	-

Key: 220 Wind Direction (0-360)

12 Wind Speed (knots)

0300 Time of Observation

Table E10. RESULTS FROM WINDS MODELING -- JANUARY 30, 1975

Station Code	TIME					
	0300	0700	1100	1500	1900	2300
FARC	113	113	113	113	113	113
	4	4	6	4	7	6
FMBL	113	113	113	113	113	113
	4	4	5	4	6	6
BELA	113	113	113	113	113	113
	3	3	4	3	5	6
BELC	113	113	113	113	113	113
	3	3	4	3	5	6
BELT	113	113	113	113	113	113
	3	3	4	3	5	6
ASHL	113	113	113	113	113	113
	4	4	5	4	6	6
ANWP	113	113	113	113	113	113
	4	4	5	4	6	6
ATEX	113	113	113	113	113	113
	4	4	5	4	6	6
BHIL	113	113	90	113	90	90
	6	6	8	6	10	9
WHID	135	135	135	135	135	135
	5	5	5	8	6	8
SMTH	135	135	135	135	135	135
	6	6	6	10	6	9
VICA	113	113	113	113	113	113
	4	4	5	4	6	6
VICH	90	90	90	90	90	90
	5	6	10	9	12	11

Key: 220 Wind Direction (0-360)

12 Wind Speed (knots)

The 850 mb. situation shows a strong low pressure center just west of the northern Puget Sound region at the beginning of the simulation period. Flow over the study area was generally from the southwest. An intense depression was centered northeast of the Newfoundland coast over the Atlantic Ocean, and a ridge of high pressure extended across west-central Canada and the west-central United States between the two low pressure systems. Flow over the Canadian region and northern United States was governed by these two strong depressions off either coast. Strong warm air advection is evident through the following 24 hours at the 850 mb. level. During this period, both low pressure systems weakened. By 0300 PST February 13, the depression off the western Washington coast had weakened appreciably, while a low pressure center in the Gulf of Alaska had intensified. The ridge across the central United States and Canada had moved eastward and also weakened. Overall flow through western Washington remained from the southwestern quadrant through the 24 hour period.

Again, the pattern at 700 mb. is similar to that seen at 850 mb. with a depression northwest of the study area and a strong low pressure center over northeastern Canada at 0300 PST February 12. The Pacific low pressure center was weaker at 700 mb. than the Atlantic depression, with a stronger low pressure system over the Gulf of Alaska. A high pressure ridge extended across the west-central part of the country. During the simulation, the low pressure center to the west of the study area weakened and disappeared while both the Gulf of Alaska depression and low pressure system over north-eastern Canada strengthened and moved south. The associated ridge between the two depressions has shifted somewhat east by 0300 PST February 13. Flow over the northern Puget

Meteorological data collected for February 12, 1975 is shown as Table E12 and wind flow modeling results for the meteorological station grid points are presented as Table E13. Figures E40 through E45 are maps of predicted wind speeds and directions for each hour of the simulation. The PI-Matrix results are shown in Figures E46 through E52.

Annual Cases

Figures E53 through E60 are maps of predicted wind speeds and directions for the annual analysis. Figures E61 through E68 show the mixing volume index maps for the eight directions. The mixing volume index is a measure of the potential for pollutant dispersal in each grid cell -- low index values indicate greater dispersion potential than high values.

Sound region was strong and southwesterly at 0300 PST February 12, shifting to somewhat more westerly and then to south-southwesterly over the following 24 hours and becoming lighter.

At 500 mb., low pressure centers can be seen over the Gulf of Alaska and the northwestern Atlantic with southwesterly flow over Washington at the beginning of the simulation period. Both depressions intensified during the simulation but little change was apparent in flow direction or speed over the northern Puget Sound region.

The temperature and pressure profiles can be seen from the sounding data taken at Quillayute (Table E11).

Table E11. Quillayute Sounding Data, February 12 and 13, 1975.

	Height(m)/ Pressure (mb.)	Temperature (°C)	Direction (degrees)	Speed (knots)
<u>0300 PST February 12, 1975</u>				
Surface (56 m)	980.8 mb.	8.3	160	15
850 mb.	1229 m	3.0	220	52
700 mb.	2777 m	-4.4	220	44
500 mb.	5338 m	-22.6	220	51
<u>1500 PST February 12, 1975</u>				
Surface (56 m)	990.4 mb.	6.8	240	7
850 mb.	1290 m	-2.2	245	19
700 mb.	2806 m	-11.8	255	36
500 mb.	5306 m	-27.4	235	45
<u>0300 PST February 13, 1975</u>				
Surface (56 m)	1004.7 mb.	3.9	290	5
850 mb.	1334 m	-3.0	248	15
700 mb.	2851 m	-11.0	203	30
500 mb.	5334 m	-29.0	225	35

Table E12.

DATA FOR WINDS VALIDATION -- FEBRUARY 12, 1975

Station Code	TIME					
	0300	0700	1100	1500	1900	2300
FARG	-	-	160	30	30	350
	-	-	6	6	6	2
	-	-	1100	1500	1900	2300
FMBL	00	100	180	220	180	170
	00	5	6	3	3	1
	0300	0700	1100	1500	1900	2300
SELA	10	180	170	200	170	200
	4	7	8	8	4	2
	0239	0654	1055	1455	1855	2255
SELC	120	130	160	200	150	160
	4	8	9	6	2	2
	0300	0700	1100	1500	1900	2300
SELT	358	156	158	201	165	30
	3	8	9	4	2	90
	0300	0700	1100	1500	1900	2300
ASHL	150	170	170	270	150	140
	10	8	10	8	4	5
	0300	0700	1100	1500	1900	2300
AALC	320	350	350	90	135	145
	4	3	4	7	3	3
	0300	0700	1100	1500	1900	2300
ALMP	160	160	170	280	160	160
	4	5	4	3	2	3
	0300	0700	1100	1500	1900	2300
ATEX	140	160	170	260	140	140
	12	9	14	10	3	6
	0300	0700	1100	1500	1900	2300
SEIL	68	68	130	225	58	58
	15	9	10	11	3	7
	0300	0700	1100	1500	1900	2300
WHID	130	130	150	270	00	130
	8	9	8	6	00	1
	0255	0655	1055	1455	1855	2255
SMTH	135	135	-	270	270	-
	12	9	-	8	4	-
	0330	0630	-	1530	1830	-
VICA	270	00	158	225	203	293
	4	00	4	12	2	4
	0300	0700	1100	1500	1900	2300
VICH	135	45	135	225	270	270
	10	2	4	11	6	4
	0300	0700	1100	1500	1900	2300
PACG	-	00	-	-	-	-
	-	30	-	-	-	-
	-	0700	-	-	-	-
PAPA	-	50	50	230	-	-
	-	2	2	5	-	-
	-	0700	1100	1500	-	-
EVRI	141	168	165	191	70	158
	5	3	3	3	3	4
	0300	0700	1100	1500	1900	2300
QUIL Surface	160	190	220	210	250	220
	4	4	6	4	6	2
	0257	0658	1057	1455	1857	2255
QUIL 350 m.	220	-	-	245	-	-
	26	-	-	9	-	-
	0315	-	-	1515	-	-

Key: 120 Wind Direction (0-360)

12 Wind Speed (knots)
0300 Time of Observation

Table E13. RESULTS FROM WINDS MODELING -- FEBRUARY 12, 1975

Station Code	TIME					
	0300	0700	1100	1500	1900	2300
FARC	113	158	180	248	158	158
	5	6	6	5	3	2
FMBL	113	158	180	248	180	180
	5	6	7	6	3	2
BELA	113	180	180	225	158	180
	4	6	8	6	3	2
BELC	113	180	180	225	158	180
	4	7	8	6	3	2
BELT	113	180	180	225	158	180
	4	6	8	6	3	2
ASHL	113	158	180	248	158	158
	5	6	7	5	3	2
ANWP	113	158	180	248	158	158
	5	6	7	5	3	2
ATEX	113	158	180	248	158	158
	5	6	7	5	3	2
BHIL	90	135	203	248	158	158
	7	4	4	9	2	2
WHID	135	135	158	248	158	135
	8	9	7	6	2	2
SMTH	135	135	135	248	158	135
	10	10	9	6	3	2
VICA	113	158	180	248	158	158
	5	6	6	5	3	2
VICH	113	158	158	248	248	248
	4	4	4	9	4	3

Key: 220 Wind Direction (0-360)

12 Wind Speed (knots)

Figure E1. Windfield Analysis of Northern Puget Sound Study Area
for January 3, 1975 at 0300 PST. Background flow input:
225.0 degrees at 5.0 meters per second (↙).

Wind Flag Codes:		m/s
	↙	5.0
	└	2.0
	┐	1.0
	•	<1.0

Figure E2. Windfield Analysis of Northern Puget Sound Study Area for January 3, 1975 at 0700 PST. Background flow input: 157.5 degrees at 3.0 meters per second (↖).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E3. Windfield Analysis of Northern Puget Sound Study Area for January 3, 1975 at 1100 PST. Background flow input: 112.5 degrees at 2.0 meters per second ($\searrow$).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E4. Windfield Analysis of Northern Puget Sound Study Area for January 3, 1975 at 1500 PST. Background flow input: 67.5 degrees at 3.5 meters per second ($\searrow$).

Wind Flag Codes:	<u>m/s</u>
		5.0
		2.0
		1.0
		<1.0

Figure E5. Windfield Analysis of Northern Puget Sound Study Area for January 3, 1975 at 1900 PST. Background flow input: 90.0 degrees at 4.0 meters per second ($\text{—}\text{||}$).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E6. Windfield Analysis of Northern Puget Sound Study Area for January 3, 1975 at 2300 PST. Background flow input: 22.5 degrees at 4.0 meters per second ($\nearrow$).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

FIGURE E7. PI (π) MATRIX FOR JANUARY 3, 1975 AT 03:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	%	x
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E8. PI (π) MATRIX FOR JANUARY 3, 1975 AT 07:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	S	H	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E9. PI (π) MATRIX FOR JANUARY 3, 1975 AT 11:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	S	N	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E10. PI (π) MATRIX FOR JANUARY 3, 1975 AT 15:00

SO₂ Standards are .4 ppm

FIGURE E11. PI (π) MATRIX FOR JANUARY 3, 1975 AT 19:00

SO₂ Standards are .4 ppm

FIGURE E12. PI (π) MATRIX FOR JANUARY 3, 1975 AT 23:00

SO₂ Standards are .4 ppm

FIGURE E13. PI (π) MATRIX FOR JANUARY 3, 1975 COMBINED

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	%
TOTAL EMISSION (kg)	<19.90	19.90-19.99	20.00-20.09	20.10-20.19	20.20-20.29	20.30-20.39	20.40-20.49	20.50-20.59	≥20.60

SO₂ Standards are .1 ppm

Figure E14. Windfield Analysis of Northern Puget Sound Study Area
for January 24, 1975 at 0300 PST. Background flow input:
180.0 degrees at 3.0 meters per second (1).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E15. Windfield Analysis of Northern Puget Sound Study Area for January 24, 1975 at 0700 PST. Background flow input: 135.0 degrees at 2.0 meters per second ($\searrow$).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E16. Windfield Analysis of Northern Puget Sound Study Area for January 24, 1975 at 1100 PST. Background flow input: 157.5 degrees at 2.0 meters per second (\).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E17. Windfield Analysis of Northern Puget Sound Study Area
for January 24, 1975 at 1500 PST. Background flow input:
180.0 degrees at 1.0 meters per second (L).

Wind Flag Codes:		m/s
	↖	5.0
	└	2.0
	┐	1.0
	•	<1.0

Figure E18. Windfield Analysis of Northern Puget Sound Study Area for January 24, 1975 at 1900 PST. Background flow input: 225.0 degrees at 1.0 meters per second ($\swarrow$).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E19. Windfield Analysis of Northern Puget Sound Study Area
for January 24, 1975 at 2300 PST. Background flow input:
360.0 degrees at 1.0 meters per second (f).

Wind Flag Codes:		m/s
		<hr/>
		5.0
		2.0
		1.0
		<1.0

FIGURE E20. PI (π) MATRIX FOR JANUARY 24, 1975 AT 03:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	N	M
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E21. PI (π) MATRIX FOR JANUARY 24, 1975 AT 07:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	N	M
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E22. PI (π) MATRIX FOR JANUARY 24, 1975 AT 11:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	N	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E23. PI (π) MATRIX FOR JANUARY 24, 1975 AT 15:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	N	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E24. PI (π) MATRIX FOR JANUARY 24, 1975 AT 19:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	S	N	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E25. PI (π) MATRIX FOR JANUARY 24, 1975 AT 23:00

SO₂ Standards are .4 ppm

FIGURE E26. PI (π) MATRIX FOR JANUARY 24, 1975 COMBINED

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	*	#	\$	X	
TOTAL EMISSION (kg)	<19.90	19.90-19.99	20.00-20.09	20.10-20.19	20.20-20.29	20.30-20.39	20.40-20.49	20.50-20.59	≥20.60

SO₂ Standards are .1 ppm

Figure E27. Windfield Analysis of Northern Puget Sound Study Area for January 30, 1975 at 0300 PST. Background flow input: 112.5 degrees at 4.0 meters per second ( ).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E28. Windfield Analysis of Northern Puget Sound Study Area
for January 30, 1975 at 0700 PST. Background flow input:
112.5 degrees at 4.0 meters per second ($\sim$).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E29. Windfield Analysis of Northern Puget Sound Study Area
for January 30, 1975 at 1100 PST. Background flow input:
112.5 degrees at 5.5 meters per second (~ 4).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E30. Windfield Analysis of Northern Puget Sound Study Area
for January 30, 1975 at 1500 PST. Background flow input:
112.5 degrees at 4.0 meters per second ($\swarrow$).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E31. Windfield Analysis of Northern Puget Sound Study Area
for January 30, 1975 at 1900 PST. Background flow input:
112.5 degrees at 6.5 meters per second (~~4~~).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E32. Windfield Analysis of Northern Puget Sound Study Area for January 30, 1975 at 2300 PST. Background flow input: 112.5 degrees at 6.0 meters per second ( )

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

FIGURE E33. PI (π) MATRIX FOR JANUARY 30, 1975 AT 03:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	N	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E34 PI (π) MATRIX FOR JANUARY 30, 1975 AT 07:00

SO₂ Standards are .4 ppm

FIGURE E35. PI (π) MATRIX FOR JANUARY 30, 1975 AT 11:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	S	N	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E36. PI (π) MATRIX FOR JANUARY 30, 1975 AT 15:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	%	N
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E37. PI (π) MATRIX FOR JANUARY 30, 1975 AT 19:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	S	N	N
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E38. PI (π) MATRIX FOR JANUARY 30, 1975 AT 23:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	N	N
EMISSION RATE (g/s)	<30	30-39	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E39. PI (π) MATRIX FOR JANUARY 30, 1975 COMBINED

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	%
TOTAL EMISSION (kg)	<19.90	19.90-19.99	20.00-20.09	20.10-20.19	20.20-20.29	20.30-20.39	20.40-20.49	20.50-20.59	≥20.60

SO₂ Standards are .1 ppm

Figure E40. Windfield Analysis of Northern Puget Sound Study Area for February 12, 1975 at 0300 PST. Background flow input: 112.5 degrees at 5.0 meters per second ( )

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E41. Windfield Analysis of Northern Puget Sound Study Area for February 12, 1975 at 0700 PST. Background flow input: 157.5 degrees at 6.0 meters per second (↖).

Wind Flag Codes:		m/s
	↖	5.0
	└	2.0
	└	1.0
	!	<1.0

Figure E42. Windfield Analysis of Northern Puget Sound Study Area
for February 12, 1975 at 1100 PST. Background flow input:
180.0 degrees at 6.5 meters per second ($\underline{\text{E}}$).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E43. Windfield Analysis of Northern Puget Sound Study Area
for February 12, 1975 at 1500 PST. Background flow input:
247.5 degrees at 5.5 meters per second ( )

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
	<1.0

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Figure E44. Windfield Analysis of Northern Puget Sound Study Area
for February 12, 1975 at 1900 PST. Background flow input:
157.5 degrees at 2.5 meters per second (E).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E45. Windfield Analysis of Northern Puget Sound Study Area
for February 12, 1975 at 2300 PST. Background flow input:
157.5 degrees at 1.5 meters per second (\).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

FIGURE E46. PI (π) MATRIX FOR FEBRUARY 12, 1975 AT 03:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	%	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E47. PI (π) MATRIX FOR FEBRUARY 12, 1975 AT 07:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	S	N	M
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E48. PI (π) MATRIX FOR FEBRUARY 12, 1975 AT 11:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	N	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E49. PI (π) MATRIX FOR FEBRUARY 12, 1975 AT 15:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	%	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E50. PI (π) MATRIX FOR FEBRUARY 12, 1975 AT 19:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	N	M
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E51. PI (π) MATRIX FOR FEBRUARY 12, 1975 AT 23:00

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	=	*	#	\$	N	X
EMISSION RATE (g/s)	<30	30-59	60-89	90-119	120-149	150-179	180-209	210-239	240-269	≥ 270

SO₂ Standards are .4 ppm

FIGURE E62. PI (π) MATRIX FOR FEBRUARY 12, 1975 COMBINED

EMISSION RESTRICTION CODES:

CODE	Blank	.	-	+	*	#	S	X	
TOTAL EMISSION (kg)	<19.90	19.90-19.99	20.00-20.09	20.10-20.19	20.20-20.29	20.30-20.39	20.40-20.49	20.50-20.59	≥20.60

SO₂ Standards are .1 ppm

Figure E53. Windfield Analysis of Northern Puget Sound Study Area
Annual Case North. Background flow input: 0.0 degrees
at 5.5 meters per second (¶).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E54. Windfield Analysis of Northern Puget Sound Study Area
Annual Case Northeast. Background flow input:
45.0 degrees at 5.5 meters per second (∇).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E55. Windfield Analysis of Northern Puget Sound Study Area
Annual Case East. Background flow input: 90.0 degrees
at 5.5 meters per second ($\rightarrow$).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E56. Windfield Analysis of Northern Puget Sound Study Area
Annual Case Southeast. Background flow input:
135.0 degrees at 5.5 meters per second (.

Wind Flag Codes:		<u>m/s</u>
		5.0
		2.0
		1.0
		<1.0

Figure E57. Windfield Analysis of Northern Puget Sound Study Area
Annual Case South. Background flow input:
180.0 degrees at 5.5 meters per second ( ).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E58. Windfield Analysis of Northern Puget Sound Study Area
Annual Case Southwest. Background flow input:
225.0 degrees at 5.5 meters per second (↙).

Wind Flag Codes:		<u>m/s</u>
	↙	5.0
	└	2.0
	└	1.0
	•	<1.0

Figure E59. Windfield Analysis of Northern Puget Sound Study Area
Annual Case West. Background flow input: 270.0 degrees
at 5.5 meters per second (∇).

Wind Flag Codes:		m/s
		5.0
		2.0
		1.0
		<1.0

Figure E60. Windfield Analysis of Northern Puget Sound Study Area
Annual Case Northwest. Background flow input:
315.0 degrees at 5.5 meters per second (↖).

Wind Flag Codes:		m/s
	↖	5.0
	└	2.0
	└	1.0
	•	<1.0

FIGURE E61. MIXING VOLUME INDEX FOR ANNUAL CASE-WIND FROM NORTH.

FIGURE E62. MIXING VOLUME INDEX FOR ANNUAL CASE-WIND FROM NORTHEAST.

FIGURE E63. MIXING VOLUME INDEX FOR ANNUAL CASE-WIND FROM EAST.

FIGURE E64. MIXING VOLUME INDEX FOR ANNUAL CASE-WIND FROM SOUTHEAST.

MIXING VOLUME INDEX:

CODE	Blank	.	-	+	=	*	#	S	N	X
INDEX (sec./m ²)	<20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	>180

FIGURE E65. MIXING VOLUME INDEX FOR ANNUAL CASE-WIND FROM SOUTH.

FIGURE E66. MIXING VOLUME INDEX FOR ANNUAL CASE-WIND FROM SOUTHWEST.

MIXING VOLUME INDEX:

CODE	Blank	.	-	+	=	*	#	S	H	X
INDEX (sec./m ³)	<20	20-40	40-60	60-80	80-100	100-120	120-140	140-160	160-180	>180

FIGURE E.67. MIXING VOLUME INDEX FOR ANNUAL CASE-WIND FROM WEST.

FIGURE E68. MIXING VOLUME INDEX FOR ANNUAL CASE-WIND FROM NORTHWEST.

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