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CONTENTS

LIST OF FIGURES

LIST OF TABLES

SUMMARY

Overview

This report documents a test of a region of influence (ROI) methodology and a biophysical base-line data base (BDB) which supports the data requirements of the methodology. Environmental issues at Vandenberg Air Force Base (VAFB) provided practical scenarios for demonstrating the ROI methodology. Using this methodology, the investigator determined the geographic extent of air-quality changes due to space shuttle launches, water-quality changes at discharge points on VAFB, and potential water-supply sources to meet future water needs at VAFB.

The geographic distribution of both physical (e.g., topography) and biological (e.g., vegetation) attributes on VAFB and the surrounding region is maintained in the BDB. The BDB utilizes a computerized Geographic Information System (GIS) to provide the necessary automated bookkeeping of the spatial data about the attributes and a computerized data-base management system to provide statistical analyses of thematic data.

The ROI methodology uses conventional modeling techniques to determine the geographic extent of a disturbance. Regulatory standards and criteria and/or the potential for biophysical effects define the boundary condition of an ROI. Defining an ROI for a proposed action includes three major steps. (1) careful definition of the types of disturbances that may be caused by the action; (2) determination of an appropriate boundary condition (e.g., regulatory criteria); and (3) mapping the ROI boundary, using transport and fate models or physical attributes (e.g., aquifer boundaries) that constrain the transport of the disturbance.

Scenarios

Air-quality changes associated with space shuttle launches at VAFB represent an environmental issue having spatial characteristics suitable for demonstrating an ROI. The shuttle produces a plume (cloud) that spreads biologically active material over the landscape. This part of the ROI test used the Rocket Exhaust Effluent Diffusion (REED) model to evaluate plume transport, the BDB to characterize the vegetation pattern in the ROI, and the graphic output devices to produce mapped hard copy.

The ROI methodology for water-quality issues was demonstrated using water-quality data obtained from space launch complex (SLC) and stream monitoring activities. Statistical and dispersion modeling techniques showed pollutant concentrations in discharges to have insufficient strength to generate an ROI (using drinking water standards as boundary conditions). Further analysis using the methodology characterized the conditions under which boundary thresholds would be established (and therefore the conditions which would generate an ROI). In addition, the analysis uncovers insufficiencies in the current monitoring regime, to provide data appropriate for proper ROI determination. Inadequate time series and data limited the numerical and statistical models that could be used and increased the uncertainty levels in the projections.

Water-quantity issues incorporate important spatial components. The scenario used in this report demonstrated the potentially large geographic areas that might have to be incorporated into an ROI determination. The water-quantity analysis used a number of studies and data that quantified the boundaries of the supply water ROI to VAFB. This ROI included much of the

San Antonio Creek Valley, the Lompoc Upland Basin, the Lompoc Plain Basin, and the Lompoc Terrace Basin. As with the other ROI designations, this ROI has been digitized for use in the GIS. The analysis highlighted overdraft problems and the importance of providing adequate water flow rates to the Barka slough to protect the unique biota in that part of San Antonio Creek.

Biophysical Base-Line Data Base

Data in the BDB includes Landsat thematic mapper scenes, aquifer boundaries, topography, water monitoring stations, and the Vandenberg Environmental Planning System (EPS). The BDB is structured to handle any spatial data that may be necessary for the ROI methodology. In addition, it is designed to make extensive use of GIS systems, provide data-base management and statistical support for relational data bases, and generate different types of graphic output (e.g., maps and figures). Further, the system provides on-line entry, editing, and analysis of monitoring station data.

1. INTRODUCTION

This document discusses a regional approach to environmental planning and decision making at U.S. Air Force (USAF) installations. The methodology involves determining a biophysical region of influence (ROI) and a subsequent comparison of the ROI with a regional biophysical base-line data base (BDB). An ROI is determined from the spatial extent of a disturbance (using generic analytical tools), while the BDB consists of the existing pattern of physical attributes and ecological receptors (e.g., vegetation) used in the ROI methodology. The goal of this study is to show how the ROI methodology can be applied to environmental issues arising from USAF activities and to demonstrate the use of computers in data-base management, issue analysis, and graphic display of the results.

The ROI reflects the geographic extent of a disturbance that results from some action at an installation. In this methodology the spatial extent of the disturbance is determined for air- or water-mediated transport processes. Thus, an ROI shows the geographic area at risk to potential impact, and only considers biological or physical changes that could result from the disturbance as they relate to the setting of boundary conditions. For example, the boundary conditions for an ROI will be based on criteria and standards that may include potential effects on the biota; water quality criteria can define a dose-response level that can potentially damage aquatic organisms. This dose-response function could be used to define the boundary of an ROI. The BDB consists of statistical and spatial (thematic) data on physical and biological attributes (e.g., terrain, vegetation, soils) used by the methodology. By overlaying the ROI onto the current ambient conditions (i.e., the BDB), the area of the disturbance (i.e., the ROI) can be mapped onto the geographic pattern of the attributes in the region. This one-to-one overlay mapping is a necessary first step in evaluating possible changes to the attributes. The analyst would use this evaluation to determine and report potential impacts to the environment.

The USAF, as required by Federal law, is responsible for assessing the potential environmental impacts of its proposed actions and programs. The environmental impact analysis process used by the USAF involves (1) identifying potentially affected attributes and quantifying their current state; (2) using conventional analytical models or other means to simulate the disturbance of the action in terms of the changes generated in potentially affected attributes, and (3) evaluating the disturbance identified in step two of the process on the attributes (base-line data) identified in step one, to determine probable impacts to the environment. Historically, during scoping meetings and public hearings concerning effects to the environment, a major point of controversy between the Air Force and potentially affected communities has been public disagreement over the appropriate ROI designation. Entire studies have been redone simply because an inappropriate ROI was selected. To date, many ROI designations have been determined ad hoc, and there exists no uniform methodology in the Air Force for developing a coherent approach to defining the boundaries of a disturbance. To evaluate biophysical impacts properly, it is necessary to determine accurately (and extremely helpful to map) the effective geographic range of the disturbance. Graphics techniques can then be used to depict the functional biophysical ROI's that result from USAF actions.

To test the ROI methodology, USAF and Oak Ridge National Laboratory (ORNL) staff jointly selected environmental scenarios from Vandenberg Air Force Base (VAFB), California. This report documents the results of the methodology application to the following scenarios. (1) air-quality changes associated with space shuttle launches, (2) water-quality changes at discharge points on the base, and (3) potential water-supply sources needed to ensure long-term water availability for the base. A BDB which explicitly included the spatial pattern of receptors and attributes and statistical information on monitored activities at VAFB was used in the test and is also documented in this report.

The methodology test used data and models available from Air Force installations and open literature, as well as information from public agencies. No original data or models were constructed specifically for the study. Throughout this report, data sets and models are described that are integral to the development of ROI boundaries or that characterize the pattern of attributes and receptors. Although the methods and results of this prototype test are presented, most of the data sets and analytical models are maintained on computers and graphic display systems at ORNL. The data and models are reported on but are not explicitly included in this report. Dobson (1985) describes computer hardware and software which would be available to the USAF for implementing the ROI methodology.

2. DESCRIPTION OF THE REGION OF INFLUENCE METHODOLOGY

The ROI reflects the geographic extent of a disturbance generated by an action. Information on the spatial pattern of attributes that occur within the ROI and statistical analysis of ambient conditions is contained in the BDB. Determining the appropriate ROI boundaries for each attribute and comparing the selected ROI with ambient conditions, using overlay mapping techniques, enables the analyst to assess the impacts of an action or a program. Three steps must be followed to implement the methodology: (1) careful definition of the types of disturbance that may be caused by the action; (2) determination of an appropriate boundary condition (e.g., regulatory criteria); and (3) mapping of the ROI boundary, using transport and fate models or physical attributes (e.g., aquifer boundaries) that constrain the transport of the disturbance. consequences from an action seems obvious, many environmental analyses fail to project impacts adequately because they do not include the appropriate questions(Basta and Bower 1982; Krummel, Gilmore, and O'Neill 1984). Appropriate questions are especially important when choosing statistical or simulation models to use in defining a biophysical ROI. At this initial stage in the development of an analysis strategy, consultation with individuals familiar with a particular suite of problems (e.g., modeling water-quality impacts) is extremely useful. Characterization of pollutant types and emission levels, which are functions of the type of action is also completed at this time. This characterization will help set priorities on the types of models needed to define the ROI and will assist in the establishment of monitoring criteria. Indeed, careful accounting of emission types and levels will provide needed insight in defining the types of questions asked in an analysis.

With the suite of questions asked in the problem definition stage, appropriate statistical or simulation models are chosen by the analyst to define ROI boundary conditions. An ROI may be determined by analyzing air- and water-mediated transport processes that propagate a disturbance through the environment. Boundary conditions are based on regulatory standards and criteria and/or on some threshold determined by the conditions which could alter physical or biological attributes. For example, an air-quality study might be used to locate high SO_2 levels for determining potential areas of risk to vegetation (Krummel, Gilmore, and O'Neill 1984).

Observable physical units also may be used to define boundary conditions for the ROI. These physical units can place a priori constraints on the extent to which a disturbance can propagate through a transport medium, irrespective of the specific location of the action that initiates the disturbance. Examples include watersheds, topographically determined airsheds, and aquifers. It is useful to think of transport processes as being constrained by these physical units of the landscape. Depending on the location or origin of a disturbance, analysis of transport and fate processes may reveal that a functional ROI will overlap in two or more physical units. For example, a large release of air pollutants may alter air quality in several air-quality control regions (AQCR) (Basta and Bower 1982).

In addition to defining the ROI, the methodology requires information from the BDB. The BDB consists of spatial and statistical data that characterize the current base-line condition. To be useful as a generic data base for each USAF installation, a BDB will contain both relatively static and dynamic data sets. A static data base is generally composed of spatial and statistical data (e.g., soil types, topography, aquifers, and major vegetation associations) that change slowly over time; thus, this data base type requires little updating. Static data bases provide (1) information on how the pattern of a landscape (i.e., the mix of soil or aquifer types) can influence the transport of a disturbance or (2) data for evaluating the interaction (e.g., dose response) between a disturbance and the potential receptors in the ROI. Dynamic data bases consist of information that has a high degree of temporal or spatial variation. Examples of these background data include up-to-date air- and water-quality conditions, animal population distribution, and surface-water flow rates. In general, dynamic data bases provide important background-level information on the normal fluctuations and the ambient levels of stress in a natural system.

With the ROI methodology, the geographic area of a disturbance (the ROI) is quantified by conventional models and/or the analysis of geophysical constraints provided by the BDB. This computer-based bookkeeping and analysis capability allows the methodology to contribute to the next step in an environmental analysis (i.e., the analysis of fate and effects based on the one-to-one, or overlay, mapping of the ROI and the sensitive attributes). Linking these components of the methodology requires computerized data-base management, numerical and statistical analysis, and graphic display (e.g., maps).

The analyses in this report, using scenarios described in Section 3, make extensive use of a geographic information system (GIS) to provide spatial bookkeeping of the attribute data and graphics. The data base is also structured to link the dynamic and static data sets that allows statistical analysis of changes in the ambient environment. This data base structure combines data-base management and statistical analysis and can be used interactively by an investigator at a specific Air Force installation. With the automated BDB and the definition of an ROI based on a specific issue, the methodology provides the Air Force with a coherent set of principles with which to investigate actions at installations; to maintain up-to-date inventories of the environmental characterization of the installation; and to provide computerized graphic displays in the form of maps, tables, and figures.

3. METHODOLOGY TEST

The issues addressed in this methodology test were jointly selected by the USAF and ORNL. The issues represent environmental disturbances originating from specific actions that are or will be occurring at VAFB. The criteria used to select these issues were (1) spatial magnitude of the disturbance, (2) water- and/or air-mediated transport of the disturbance, and (3) importance of the issue to staff at VAFB. Based on these criteria, the selected ROI test scenarios were air-quality changes from shuttle launches, surface-water-quality changes based on monitored activities (e.g., launches and waste disposal), and future water-supply needs for VAFB. All the ROI analyses used available models and data, and the scenarios should be viewed as examples that develop the ROI boundaries and utilize the BDB.

3.1 SPATIAL EXTENT OF AIR-QUALITY CHANGES FROM SHUTTLE PLUME

3.1.1 Introduction

The space shuttle program at VAFB represents a new action that will probably affect air quality (USAF 1978). Vandenberg is especially important because it is located on a promontory along the California coast, where missiles can be launched both West and South over the Pacific Ocean. It is the only location in the continental United States suitable for conducting launches into polar orbit. In general, the Vandenberg launch azimuths complement the over-water launch azimuths available at the Eastern Test Range in Florida.

During the entire ignition and lift-off sequence, emitted rocket engine exhausts will be ducted under the launch pad and discharged to the side, whereupon the plumes (clouds) will rise and merge into what is called a ground cloud. The thermal buoyancy of the hot [initially about 2888 K (4729°F)] exhaust induces the strong convective currents that will lift and transport dust and debris within the cloud. Note that this is a highly localized and short-term event. Substantial quantities of ambient air will be entrained during the turbulent rise of the cloud to its stabilization altitude (~1 km). As cloud drift continues, the cloud will expand and disperse further in accordance with the meteorological conditions prevailing at the time of launch.

To determine the air-quality ROI for the shuttle launch requires information on the types of pollutants emitted, their estimated concentrations, the criteria or standards applied to the pollutants, and their ambient concentrations. Calculating the air-quality impacts of the shuttle launches at VAFB is difficult due to the nature of the pollutants emitted and the manner in which they are released. However, the approximate dose level resulting from the launches can be estimated using special dispersion models and, thus, the ROI can be defined.

The pollutants emitted by the shuttle launches are represented by the estimates from the shuttle environmental impact statement (USAF 1978). The actual emissions may vary slightly as a result of modifications in the propellant chemistry or in the quantity burned but are probably well represented by these values. The manner in which the pollutants are released into the atmosphere is also likely to vary, depending on mission parameters, but the differences are unlikely to affect the results of the analysis. Therefore, the release parameters presented in Table 1 are assumed to represent the actual emissions during a launch and are used in the ROI determination.

Table 1. Expected shuttle exhaust constituents (percentage by weight of nozzle exit plane flow)[a]

Constituent	Location	
	Plane (at nozzle exit)	Plane (1 km downstream)[b]
Hydrogen chloride (HCl)	21.41	14.18
Chlorine (Cl_2)	0.008	1.60
Atomic chlorine (Cl)	0.245	0.013
Nitric oxide (NO)	0.001	0.989
Nitrogen peroxide (NO_2)	0	0.02
Carbon monoxide (CO)	24.36	0.052
Carbon dioxide (CO_2)	3.33	30.85
Hydrogen (H_2)	2.09	0
Hydroxyl (OH) and atomic hydrogen (H)	0.02	0
Nitrogen (N_2)	8.78	8.26
Water (H_2O)	9.39	28.59
Aluminum oxide (Al_2O_3)	30.32	22.56
Aluminum chloride ($AlCl_3$)	0.02	0.02
Iron chloride (FeCl)	0.97	0.97
Total	100.0	108.1[c]

[a]Total mass flow 9400 kg/s.

[b]Afterburning complete.

[c]Total is greater than 100% because of chemical addition of air to form water, nitric oxide, and carbon dioxide.

Reference: Stephens and Stewart 1977.

3.1.2 Determining a Region of Influence

Concentrations of the pollutants emitted from the launches are calculated using the Rocket Exhaust Effluent Diffusion (REED) model. The REED model is a Gaussian plume code modified to calculate peak concentrations, deposition, and precipitation scavenging. The code requires emission source inputs from the shuttle vehicle, fuel properties, and heat emission data. Since the REED model is continually being improved, the version used in this analysis to produce the estimates of concentrations is not the final version that will be operational during actual shuttle launches at VAFB. However, it should provide sufficient accuracy for demonstrating the technique discussed in this analysis. Representative values for the REED model are input from launch data at Cape Canaveral. Because the meteorological data during any specific launch are unknown, actual meteorological data from the launch tower and the forecast values at the Cape are input into the code. Although this approach may not yield results completely representative of air-quality changes which will occur at VAFB, the meteorological conditions that prevail during any launch are unlikely to vary significantly from those of this example because of the stringent meteorological "windows" defined for the shuttle program. An example of the meteorological data input for this analysis is presented in Fig. 1. Although wind direction will be a major determinant of the amount in material carried over sensitive receptor areas, the direction will probably not determine the viability of a launch opportunity. Therefore, these values can be used to determine the ROI for all possible wind directions by rotating the data point at which the boundary condition is met around the release point.

The code for the REED model calculates concentrations of the various pollutants emitted by the launch vehicle and plots isopleths of material concentrations. Plots of representative plume centerline maximum concentrations for HCl and isopleths of ground-level aluminum oxide concentrations are presented in Figs. 2 and 3 respectively. These figures are taken from the examples presented in the MSFC/REED documentation and the space shuttle EIS. Fig. 3 shows the isopleth extrapolated to the appropriate scale and plotted on a base map that incorporates land-cover information from VAFB. Although the code precisely calculates the projected concentrations, the results have some uncertainty (in a probabilistic sense) and any interpretation of the effects of a shuttle launch that includes the air-quality impacts must account for these potential errors and incorporate the possible variance in the analysis.

For this scenario, projected HCl pollutant levels from the shuttle launch emissions (Fig. 2) are compared with known public health effects data (Table 2, USAF 1978). To account for the likely inaccuracies in the predicted concentrations and to include ambient concentrations of the shuttle emissions that could be higher than those assumed, a level 50% below the 10-min short-term public limit (STPL) for HCl (Table 2) is chosen to define the ROI boundary condition for public health. The ROI for the shuttle launch, as defined by this procedure, is presented as Fig. 4. Projected peak concentrations in the Lompac valley, 9 to 10 km (5.5 to 6 miles) from the launch site, could reach 2 ppmv (Fig. 4). However, due to the transient nature of the plume, the 10-min average is expected to be less than the 2-ppmv maximum instantaneous level.

Although the areas affected by the shuttle launch can be determined using the procedures above, the uniqueness of the action does not fully use the power of the technique. A more typical example demonstrating the ROI methodology applied to an air-quality issue would utilize existing sources of data on emissions and would compare predicted values with federal, state, and local regulations.

In a more typical analysis (e.g., dispersion modeling for a coal-fired boiler), the pollutant resultant concentration would be compared with air-quality standards, and the areas projected to exceed standards could be expected to be affected by the action and would mark the boundary of the ROI. However, the materials released by the shuttle are not typical air pollutants and shuttle launches are not regulated as sources of emissions. To demonstrate this more typical scenario, an analysis of air-quality changes at Chanute AFB is included in this report as Appendix A. This typical scenario describes a modification at an existing power plant located at the base.

3.2 REGION OF INFLUENCE BASED ON WATER-QUALITY MONITORING INFORMATION

3.2.1 Introduction

Because monitoring data for surface-water quality are available (see Fig. 5), surface water was selected as a medium for demonstrating the ROI methodology. The specific issue used for this demonstration involves effluent discharges from space launch complex (SLC) pads into receiving

ORNL-DWG 86-9585

DATE: 12 NOV 1981 TIME: 1015 EST PLOTTED AT: HEC FROM FILE: RRSOND

SURFACE PRESSURE: 1016.9MB DENSITY: 1190.4G/M3 o - STAB HT: 1525.5M ** - CALC HT: 0.0M

	LAYER1 SURFACE	LAYER1 TOP	LAYER2 BOT	LAYER2 TOP
ALTITUDE (M)	0.0	1047.0	1047.0	3048.0
DRY TEMP (DEG C)	22.4	11.7	11.7	6.8
POT TEMP (DEG C)	23.0	22.2	22.2	35.1
WIND SPEED (M/S)	7.7	8.8	8.8	8.8
WIND DIR (DEG)	337.0	28.0	28.0	354.0

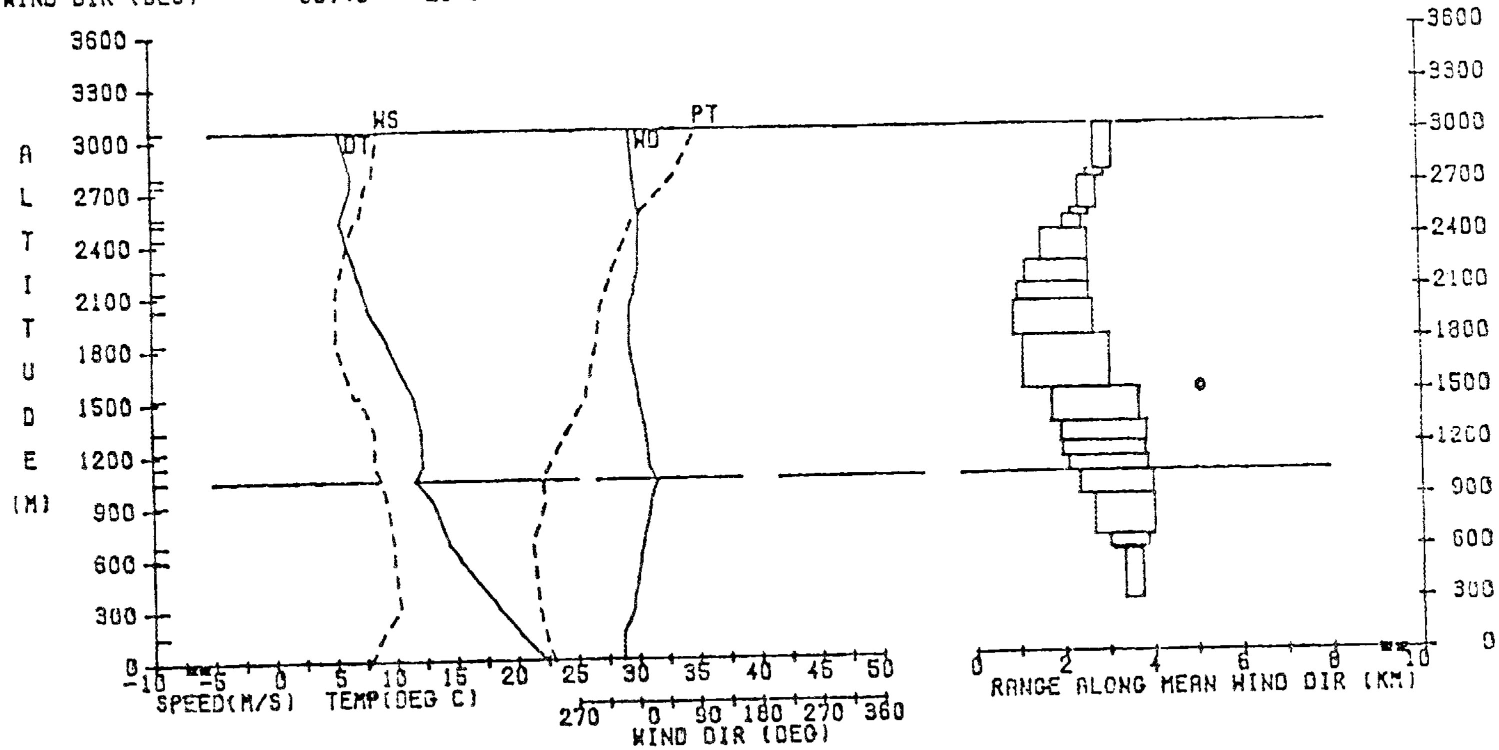

Fig. 1. Meteorological profile plot of wind speed, wind direction, temperature, and potential temperature, taken from rawinsonde observations at Cape Kennedy, Florida, 12 November 1981.

ORNL-DWG 86-9586

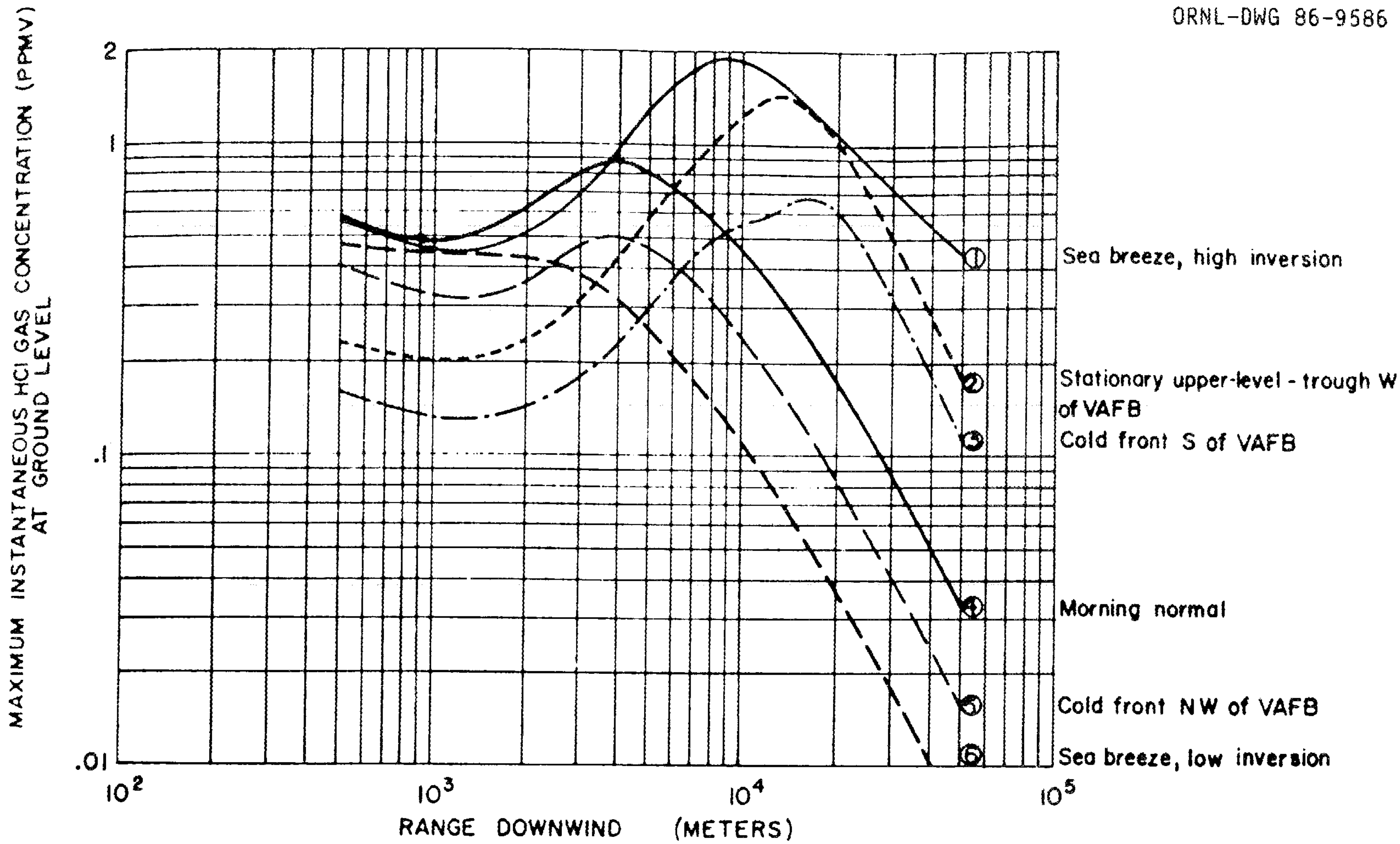

Fig. 2. Predicted maximum instantaneous HCl concentrations at ground level for six generic meteorological conditions at VAFB.

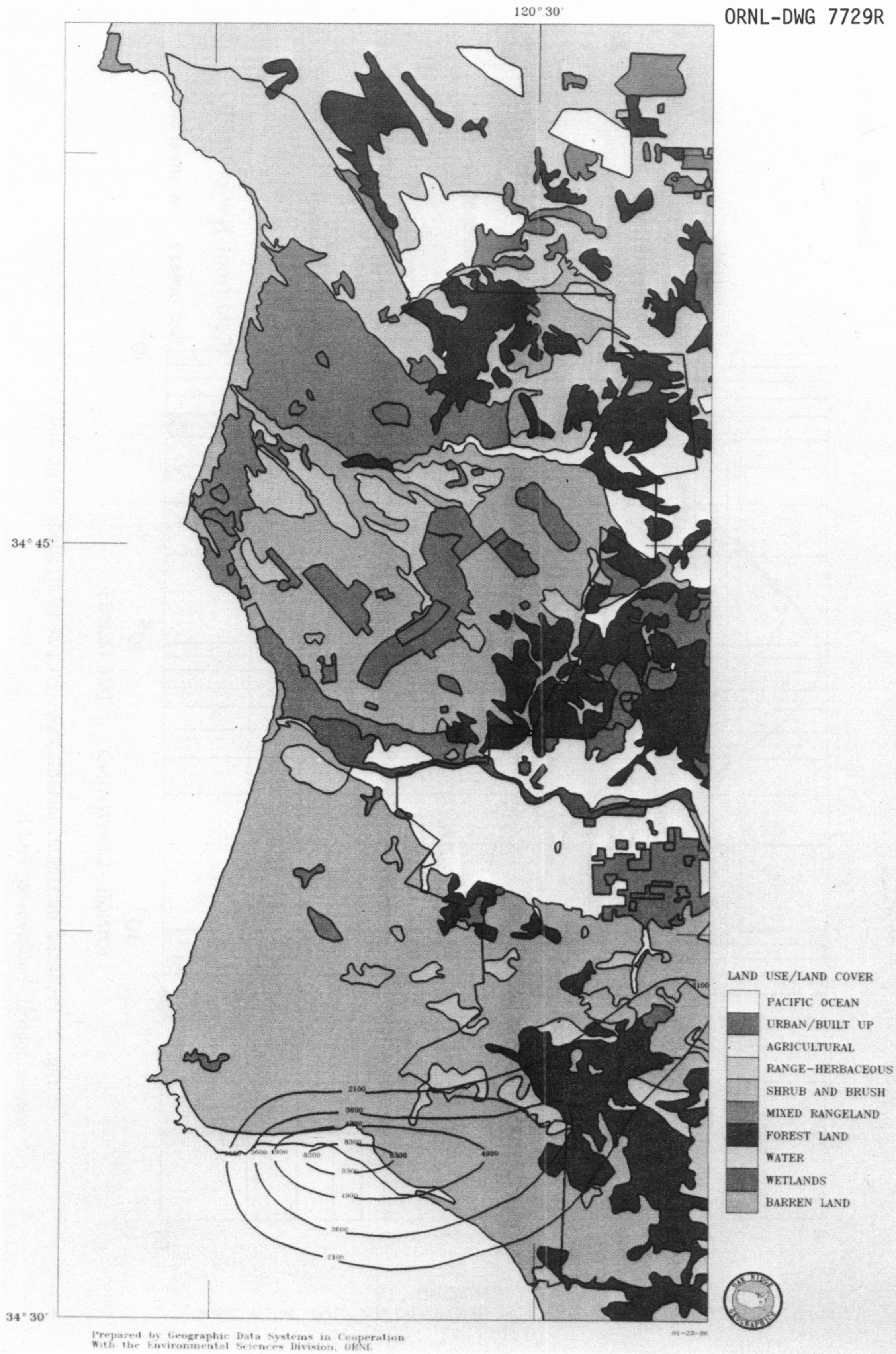

Fig. 3. Plot of isopleths of aluminum oxide (mg/m3) concentration overlain on land cover on VAFB and the surrounding area.

Table 2. Recommended limits on public exposure to hydrogen chloride (HCl) and chlorine (Cl_2)

Species	Type of limit	Duration of limit	Time-weighted average concentration	Comments
Hydrogen chloride (HCl)	Short-term public limit (STPL)	10 min	4.0 ppmv	Excursions above these levels are likely to produce objectionable odors and/or irritation
		30 min	2.0 ppmv	
		60 min	2.0 ppmv	
		1 h daily	2.0 ppmv	
		5 h/d, 3-4 d/month	0.7 ppmv	
	Public emergency limit (PEL)	10 min	7.0 ppmv	Possible temporary discomfort to people at these levels, but effect is reversible
		30 min	3.0 ppmv	
		60 min	3.0 ppmv	
Chlorine (Cl_2)	Short-term public limit (STPL)	10 min	1.0 ppmv	3.0 ppmv[a]
		30 min	0.5 ppmv	1.0 ppmv[a]
		60 min	0.5 ppmv	1.0 ppmv[a]
	Public emergency limit (PEL)	10 min	3.0 ppmv	Levels are ceiling limits and should not be exceeded
		30 min	2.0 ppmv	
		60 min	2.0 ppmv	

[a]Recommended maximum allowable instantaneous excursions. Any excursion above the STPL should be compensated for by an equivalent reduced exposure during the applicable time period.

Source: USAF 1978, Table 5.1.2-3.

streams. Pollutant concentrations in these effluents are highly variable (Fig. 6). Results from simple transport models using stream monitoring data provided information needed to locate the ROI boundaries from these discharges. This analysis, as a side benefit, also allowed an evaluation of the current monitoring data to determine its usefulness in establishing ROI boundaries.

Published reports containing information on water quality at VAFB include "Appraisal of Ground-Water Resources in the San Antonio Creek Valley, Santa Barbara County, California" (Hutchinson 1980) and "Ground-Water Resources in the Lompoc Area, Santa Barbara County, California" (Miller 1976). The U.S. Geological Survey (USGS) monitored both groundwater and

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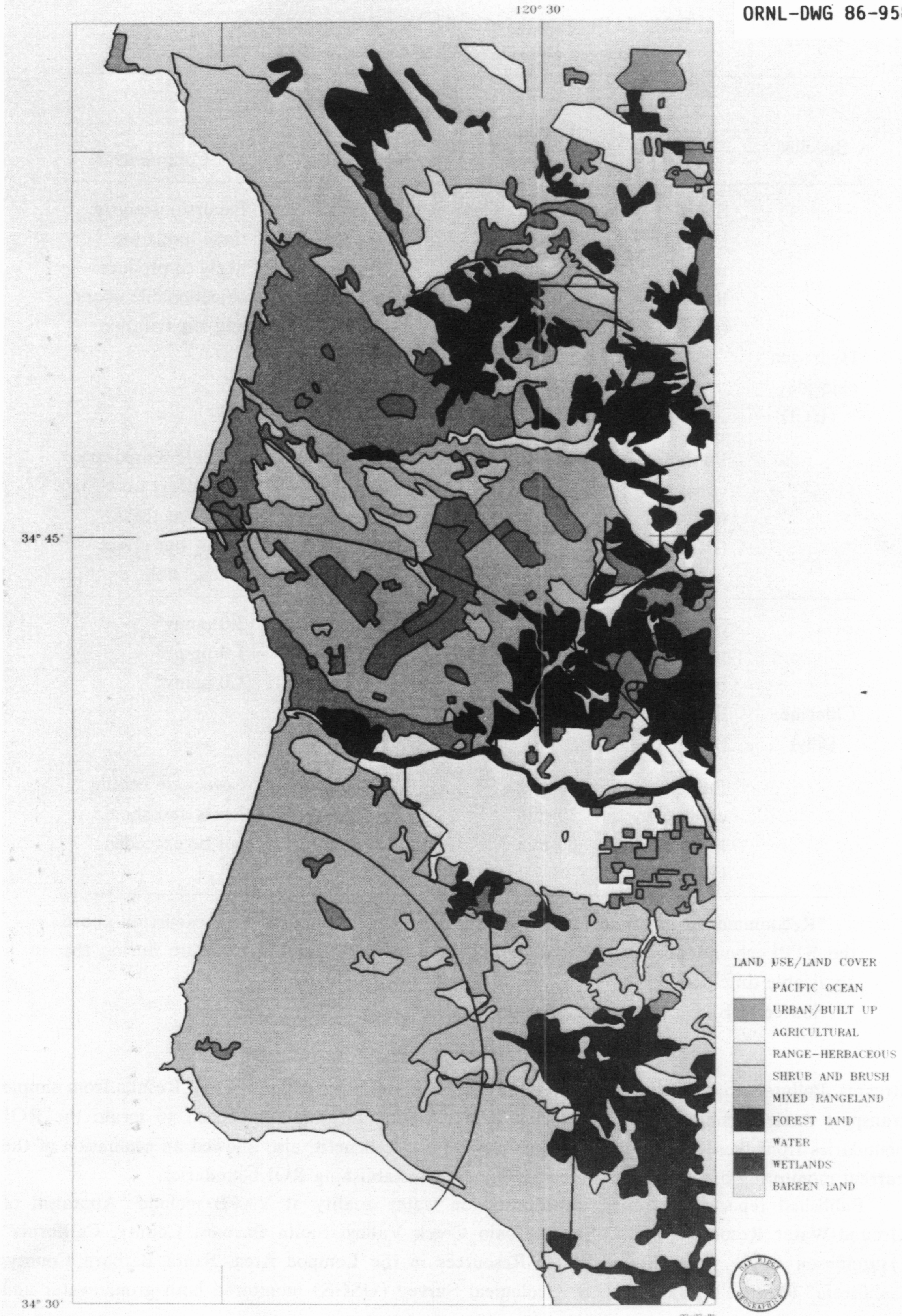

Fig. 4. ROI for maximum at threshold (inner circle) and 50% of threshold (outer circle) from maximum HCl concentrations that affect human health caused by the shuttle emissions, plotted on land-cover data from Section 4.0.

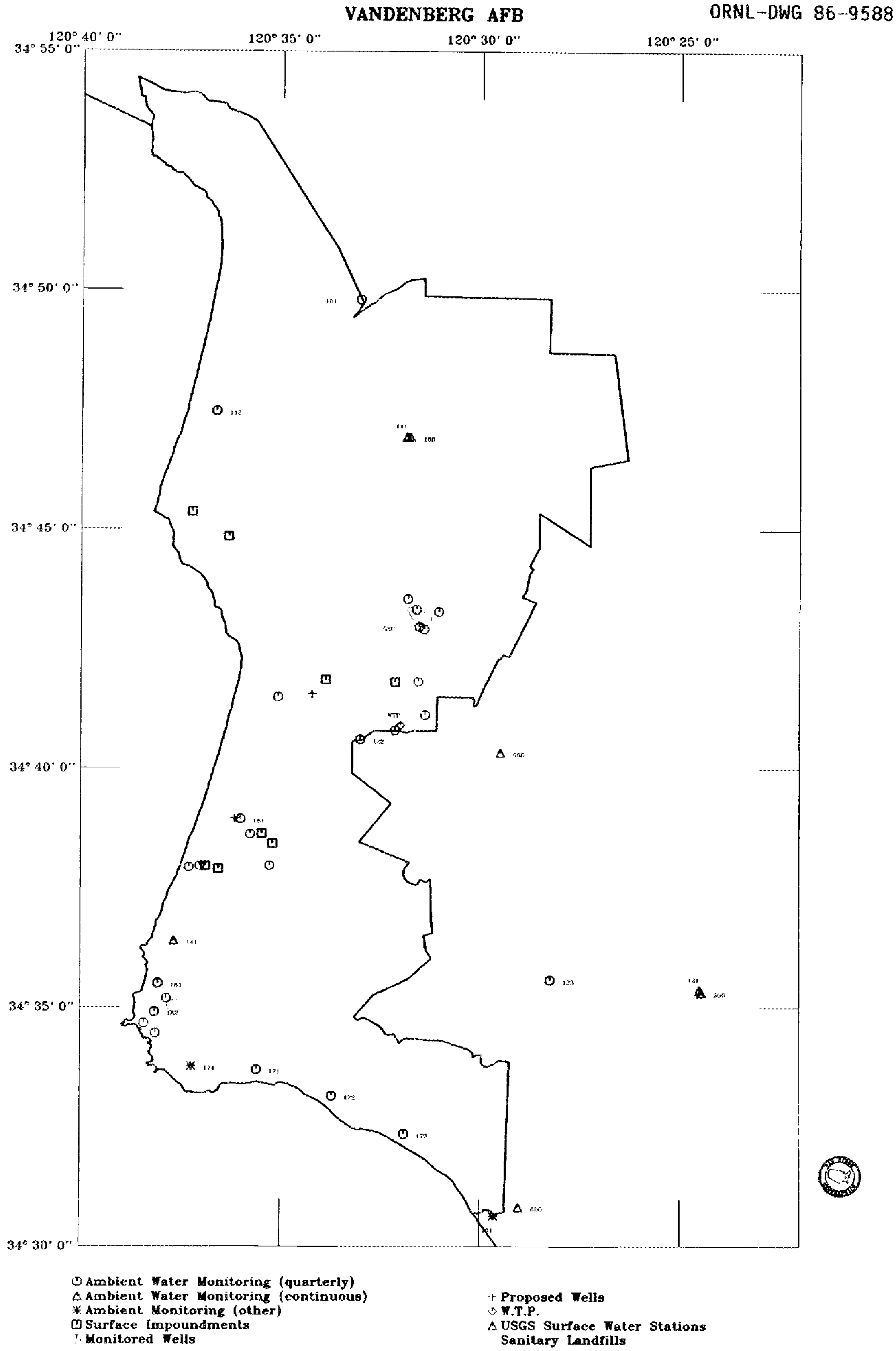

Fig. 5. Locations and types of water-quality monitoring stations at VAFB.

ORNL-DWG 86-9589

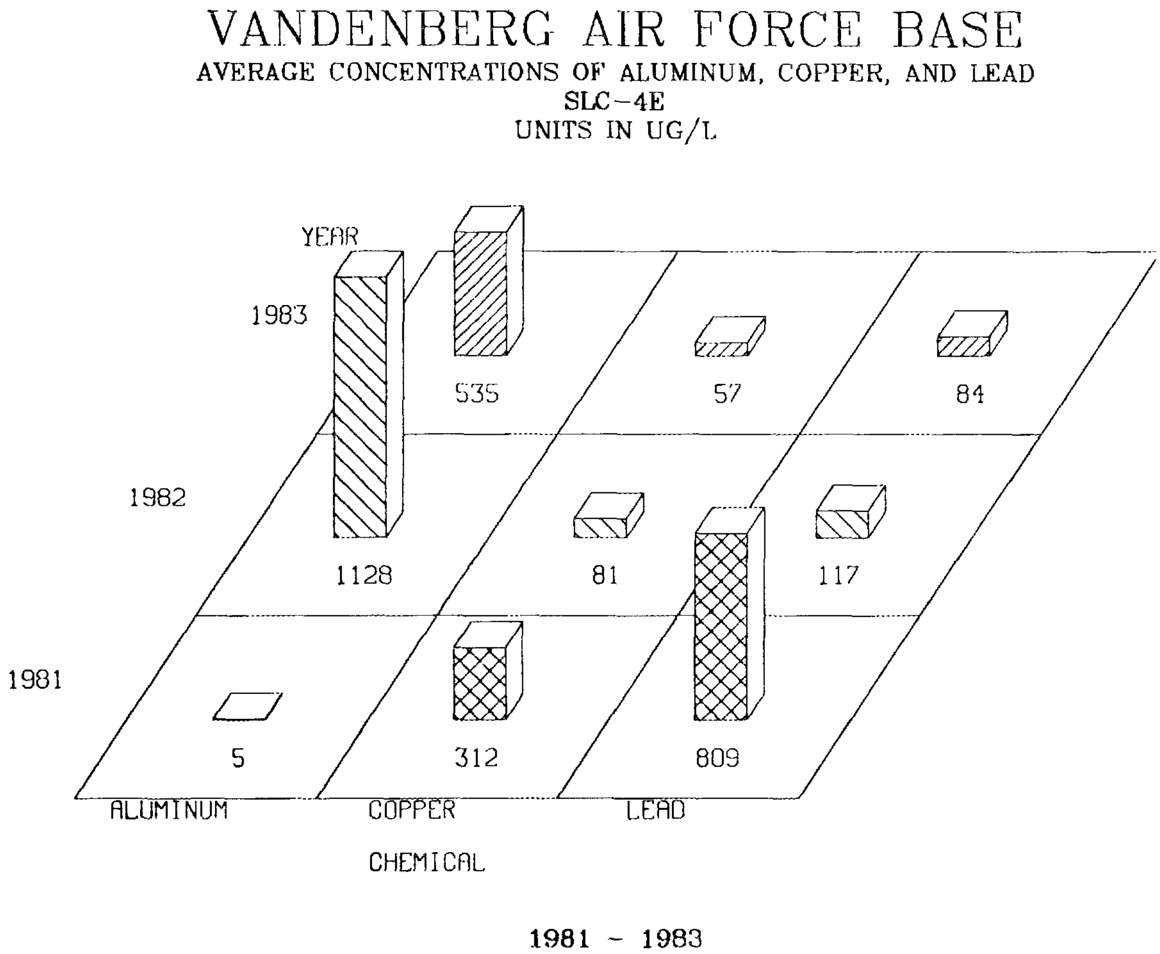

Fig. 6. Average concentrations of aluminum, copper, and lead for 1981–1983 discharge from SLC-4E.

surface-water quality on the base. These data are available from the USGS or the U.S. Environmental Protection Agency's (EPA) STORET system. Surface-water and impoundment monitoring data collected by VAFB through October 1983 reside in Statistical Analysis System® (SAS) data files and can be accessed via the ORNL computer system. This data base is discussed in further detail in Section 4 of this report.

To utilize the ROI methodology, the investigator needs to be aware of federal and state water-quality criteria and standards (Table 3) and water-quality planning criteria based on designated uses for a stream or basin (Table 4). These will be used as initial boundary delineators for the ROI. Special discharge prohibitions may also exist. For example, near VAFB the following discharges are prohibited: (1) waste discharge to all surface waters within the San Antonio Creek Subbasin; (2) discharges to all coastal surface streams and natural drainage ways that flow directly to the ocean, except where discharge is associated with an approved wastewater reclamation program; and

Table 3. Water-quality planning activities and objectives by use and stream (mg/L)
(California State Water Resources Control Board 1975)

Planning criteria	Total dissolved solids	Chloride	Sulfate	Barium	Sodium	Nitrate-N and nitrite-N
Municipal supply[a]	500/1500	250/600	250/500			10
Agricultural supply	700/2000	175/350		0.5/2.0	69	
Noncontact water recreation						2.0
Cold freshwater habitat						1.0
Santa Ynez subbasin Lompoc[b]	1000	100	350	0.4	100	

[a]Values are limiting concentrations; where two values appear (e.g., a/b), the first is the threshold value, the second is the short-term limit value.

[b]Median surface-water-quality objectives.

(3) the discharge of oil or any residual petroleum products, except those in accordance with discharge requirements (California State Water Resources Control Board 1975).

3.2.2 Determining a Region of Influence

Plotting the raw data values against time is a simple method for determining the existence of the temporal and seasonal patterns often needed to evaluate dynamic changes in the ROI. For example, dissolved oxygen concentrations in San Antonio Creek are compared with the EPA criterion of 6 mg/L for support of a mixed fish population in Fig. 7. The figure shows that low levels of dissolved oxygen routinely occur at the San Antonio Creek exit station during summer months. At VAFB, the dominant seasonal influence is rainfall, 95% of which occurs between November and May (Hutchinson 1980). Therefore, data are divided into a wet season (November—May) and a dry season (June—October), for statistical analysis.

In addition to seasonal variation in water-quality levels, spatial variation must be obtained to determine the ROI. This information can be obtained by placing monitoring stations at different locations around discharge areas. For example, the San Antonio Creek monitoring stations allow one to be aware of any changes in water quality between the midpoint station (195NA111) and the exit station (195NA112). Monthly average sulfate concentrations are higher at the midpoint station, except during the winter months of November through January (Fig. 8). Sulfate concentrations in Bear Creek are substantially lower than those in San Antonio Creek.

The major question asked in this demonstration is, What is the spatial extent of the ROI at Bear Creek for discharges from SLC-3 launch facilities? Water quality is monitored in the impoundment at SLC-3W, the impoundment at SLC-3E, and in Bear Creek. The univariate

Table 4. State-designated existing uses of inland surface waters near VAFB, California (California State Water Resources Control Board 1975)[a]

Subbasin and watercourse	Municipal supply	Agricultural supply	Industrial service supply	Groundwater recharge	Water contact recreation	Noncontact water recreation	Wildlife habitat	Cold freshwater habitat	Warm freshwater habitat	Fish migration	Fish spawning
San Antonio Creek Subbasin											
San Antonio Creek	I	I		I	I	E	E	I	I		
Santa Ynez River Subbasin											
Santa Ynez River (downstream from reservoir)	I	I		I		E	E		I	I	I
Lompoc Canyon	I	I	I	I	I	E	E		I		
Oak Canyon	I	I	I	I	I	E	E		I		
Salsipuedes Creek	E	E	E	E	E	E	E	I	I	I	I
El Jaro Creek	I	I	I	I	I	E	E	E	E	E	E

[a]E = existing beneficial water use; I = beneficial water use in a watercourse with intermittent flow characteristics.

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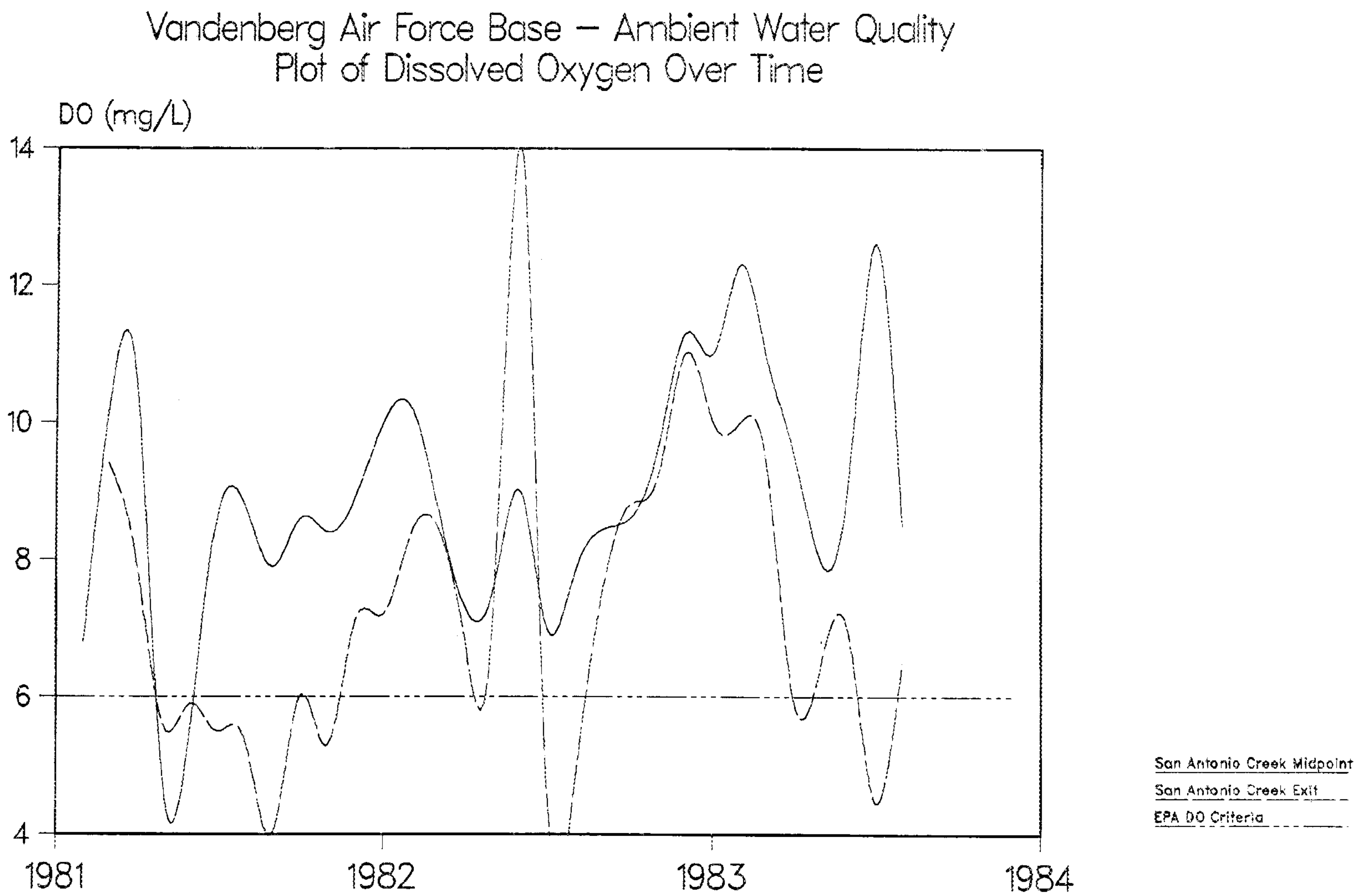

Fig. 7. Plot of dissolved oxygen over time at San Antonio Creek with a comparison to EPA criteria for dissolved oxygen.

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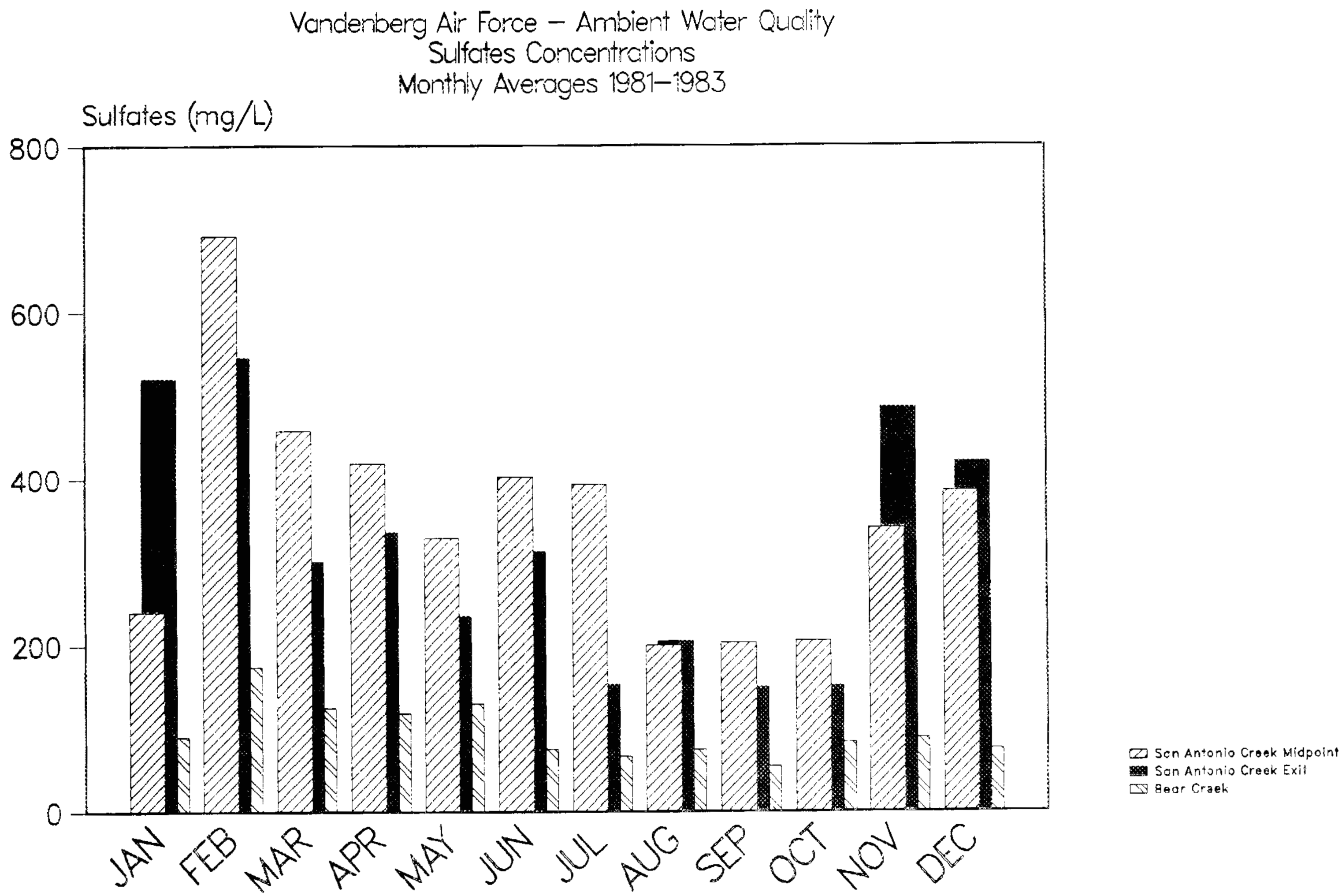

Fig. 8. Plot of sulfates concentration over time from San Antonio Creek and Bear Creek.

procedure in SAS was used to get descriptive statistics on selected water-quality data for the SLC-3E and SLC-3W impoundment monitoring sites and for Bear Creek. Figure 9 shows a sample model output of this procedure with the set of descriptive statistics from SLC-3W.

Using a plot and the descriptive statistics for the monitoring data at the SLC-3 impoundments and Bear Creek, one can determine the concentration of pollutants in Bear Creek after a discharge and thus map the ROI of such a release. The procedure outlined in Fig. 10 is followed in determining the level of refinement necessary for assessing the aquatic fate of a pollutant. By following this sequence of refinements, one should be able to eliminate, with a minimum of time and effort, cases in which water-quality problems are unlikely. One can assume the pollutants act conservatively (e.g., are not reactive, remain in either solution or in suspension, and are advected through the water column at the velocity of the river with no loss of mass). This is a first-level analysis to see if criteria or standards are violated. If violations are not projected, no further analysis is necessary. If violations are projected, or if concentrations are high enough to be of concern, a more detailed analysis should be performed by considering the various processes affecting the pollutant in the stream. For example, one should consider the processes of transport and speciation over a given reach of stream. A more detailed analysis would also consider transformation processes. If, through this iterative process, standards or criteria are exceeded, the methodology can be used to overlay the ROI against the base-line data and, through conventional analytical procedures, to assess the impact of the disturbance on the environment.

An inorganic substance (sodium), a heavy metal (lead), and two organics (trichloroethylene and chloroform) were evaluated for the test scenario. These pollutants were chosen for evaluation because they occur often in impoundment discharges and are monitored at both SLC-3 impoundments and Bear Creek and because all but sodium have water-quality criteria or standards (see Table 5).

Both SLC-3 impoundments are intermittent, point-source discharge, as are all the missile impoundments at VAFB. For the scenario analyses, the best data for each case study were selected to illustrate the question under investigation. Thus, SLC-3W was used to investigate the discharge of sodium, whereas SLC-3E was used to investigate the discharge of lead and organic pollutants. A worst-case analysis (low-flow) is done by assuming the pollutants to be conservative and the discharge, continuous. The instream concentration of a pollutant is calculated for the mixing zone, the short reach of river where a point source and river water mix. For simplification, mixing is often assumed to be instantaneous and complete across the entire width of the channel. Assuming complete mixing, the concentration of a pollutant in a river after mixing is

$$C = \frac{C_u Q_u + C_w Q_w}{Q_w + Q_u} \quad (1)$$

$$= \frac{C_u Q_u + W/5.38}{Q_w + Q_u}, \quad (2)$$

where C is the concentration of pollutant in the river following mixing (mg/L), C_w is the concentration in the point source (mg/L), C_u is the concentration in the river above the point source (mg/L), Q_w is the discharge rate of the point source [m^3/s (ft^3/s)], Q_u is the flow rate of the river above the point of discharge [m^3/s (ft^3/s)], and W is the pollutant mass emission rate [kg/d (lb/d)].

ORNL-DWG 86-9592

```
                                            SAS                          12:31 MONDAY, FEBRUARY 27, 1984   16

                                  LOCNAME=SLC-3W    SEASON=WET

                                         UNIVARIATE

VARIABLE=SODIUM

              MOMENTS                                       QUANTILES(DEF=4)                           EXTREMES

N                  6   SUM WGTS          6      100% MAX    70.9     99%    70.9          LOWEST     HIGHEST
MEAN         30.1333   SUM           180.8       75% Q3    50.35     95%    70.9             7.8         8.6
STD DEV      25.5979   VARIANCE    655.251       50% MED      25     90%    70.9             8.6        10.5
SKEWNESS    0.756016   KURTOSIS  -0.684097       25% Q1      9.4     10%     7.8            10.5        39.5
USS          8724.35   CSS         3276.25        0% MIN     7.8      5%     7.8            39.5        43.5
CV           84.9487   STD MEAN    10.4503                            1%     7.8            43.5        70.9
T:MEAN=0     2.88349   PROB>|T|  0.0344473      RANGE       63.1
SGN RANK        10.5   PROB>|S|  0.0360317      Q3-Q1      41.95
NUM ^= 0           6                            MODE         7.8
W:NORMAL    0.854474   PROB<W        0.212

          STEM LEAF                      #    BOXPLOT                    NORMAL PROBABILITY PLOT
             7 1                         1       |          75+                                                  *
             6                                   |            |                                                  +
             5                                +-----+         |
             4 3                         1    |     |         |                                       *
             3 9                         1    |  +  |         |                                   *
             2                                *-----*         |                                +
             1 0                         1    |     |         |                             +  *
             0 39                        2    +-----+         |
            ----+----+----+----+                             5+                   *        *
          MULTIPLY STEM.LEAF BY 10**+01                        +----+----+----+----+----+----+----+----+----+----+
                                                                  -2        -1        +0        +1        +2

                                          FREQUENCY TABLE

               PERCENTS                        PERCENTS                        PERCENTS
VALUE COUNT   CELL   CUM     VALUE COUNT   CELL   CUM     VALUE COUNT   CELL   CUM
  7.8     1   16.7  16.7      10.5     1   16.7  50.0      43.5     1   16.7  83.3
  8.6     1   16.7  33.3      39.5     1   16.7  66.7      70.9     1   16.7 100.0
```

Fig. 9. Example of univariate output from SAS® for sodium at SLC-3W during the wet season.

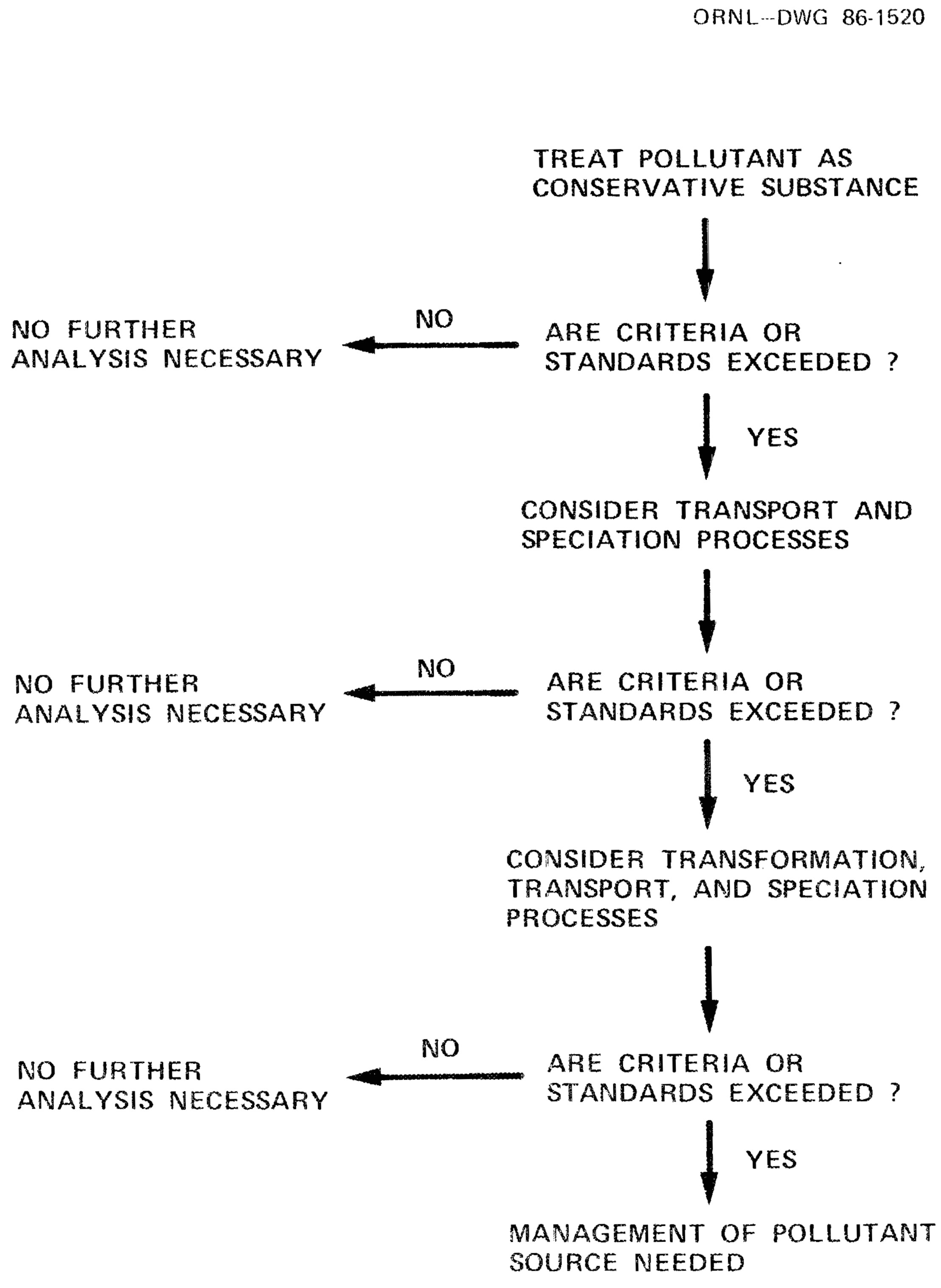

Fig. 10. Sequence of events for determining level of complexity for toxic-water-quality screening model.

Table 5. Water-quality criteria for human health and freshwater and saltwater organisms (concentrations in mg/L unless otherwise specified) (45 FR 79318)

Toxic pollutant	Human health	Freshwater aquatic life		Saltwater aquatic life	
		Animals	Algae	Animals	Algae
Acenaphthene	20[a]	1,700	520	970/710[b]	500
Acrolein	320	68/21		55	
Acrylonitrile	0.58/0.058/0.006[c]	7,550			
Aldrin-dieldrin					
Aldrin	0.74/0.074/0.0074 (ng/L)	3.0		1.3	
Dieldrin	0.71/0.071/0.0071 (ng/L)	2.5/0.0019		0.71/0.0019	
Antimony	146	9,000/1,600	610		
Arsenic	22/2.2/0.22 (ng/L)[c]	440/40[b]		508	
Asbestos	300,000/30,000/3,000 (fibers/L)				
Benzene	6.6/0.66/0.066	5,300		5,100	
Benzidine	1.2/0.12/0.01 (ng/L)	2,500			
Beryllium	37/3.7/0.37 (ng/L)	130/5.3			
Cadmium	10	exp[1.05ln(h)-3.73/ exp[1.05ln(h)-8.53][d]		59/4.5	
Carbon tetrachloride	4.0/0.40/0.04	35,200		50,000	
Chlordane	4.6/0.46/0.046 (ng/L)	2.4/0.0043		0.09/0.0040	
Chlorinated benzenes		250		160/129	
Hexachlorobenzene	7.2/0.72/0.072 (ng/L)				
1,2,4,5-Tetrachlorobenzene	38				
Pentachlorobenzene	74				
Monochlorobenzene	488				
	20[a]				
Chlorinated ethanes					
1,2-Dichloroethane	9.4/0.94/0.094	118,000/20,000		113,000	
Trichloroethanes	6.0/0.6/0.06 or 18.4 mg/L[e]	18,000/9,400		31,200	
Tetrachloroethanes	1.7/0.17/0.017	9,320/2,400		9,020	
Pentachloroethane		7,240/1,100		390/281	
Hexachloroethane	19/1.9/0.19	980/540		940	
Chlorinated naphthalenes		1,600		7.5	
Chlorinated phenols		30 to 500,000			
Monochlorophenol	0.1[a]				
4-Monochlorophenol	0.1[a]			29,700	
2,3-Dichlorophenol	0.04[a]				
2,5-Dichlorophenol	0.5[a]				
2,6-Dichlorophenol	0.2[a]				
3,4-Dichlorophenol	0.3[a]				
2,3,4,6-Tetrachlorophenol	1.0[a]				
2,4,5-Trichlorophenol	2.6 mg/L or 1.0[a]				
2,4,6-Trichlorophenol	12/1.2/0.12[c] or 2.0[a]	-/970			
2-Methyl-4-chlorophenol	1,800[a]				
3-Methyl-4-chlorophenol	3,000[a]				
3-Methyl-6-chlorophenol	20[a]				
2,3,5,6-Tetrachlorophenol				440	
Chloroalkyl ethers		238,000			
Bis-(chloromethyl)-ether	0.038/0.0038/0.00038 (ng/L)				
Bis-(2-chloroethyl)-ether	0.3/0.03/0.003				
Bis-(2-chloroisopropyl)-ether	34.7				

Table 5. (continued)

Toxic pollutant	Human health	Freshwater aquatic life		Saltwater aquatic life	
		Animals	Algae	Animals	Algae
Chloroform	1.90/0.19/ 0.019	28,900/1,240			
2-Chlorophenol	0.1[a]	4,380			
Chromium					
Hexavalent	50	21/0.29		1,260/18	
Trivalent	170 mg/L	exp[1.08ln(h)+3.48]/44		10,300	
Copper	1 mg/La	exp[10.94ln(h)-1.23]/5.6		23/4.0	
Cyanide (free)	200	52/3.5		30/2.0	
DDT and metabolites					
DDT	0.24/0.024/0.0024 (ng/L)	1.1/0.0010		0.13/0.0010	
TDE		0.06		3.6	
DDE		1,050		14	
Dichlorobenzenes	400	1,120/763		1,970	
Dichlorobenzidines	0.103/0.0103/0.00103				
Dichloroethylenes	0.33/0.033/0.0033	11,600		224,000	
2-4 Dichlorophenol	3.09 (mg/L) 0.3[a]	2,020/365			
Dichloropropanes		23,000/5,700		10,300/3,040	
Dichloropropenes	87	6,060/244		790	
2,4-Dimethylphenol	400[a]	2,120			
2,4-Dinitrotoluene	1.1/0.11/0.011	330/230		590	370
1,2-Diphenylhydrazine	422/42/4 (ng/L)	270			
Endosulfan	74	0.22/0.058		0.034/0.0087	
Endrin	1.0	0.18/0.0023		0.037/0.0023	
Ethylbenzene	1.4 mg/L	32,000		430	
Fluoranthene	42	3980		40/16	
Haloethers		360/122			
Halomethanes	1.9/0.19/0.019	11,000		12,000/6,400	11,500
Heptachlor	2.78/0.28/0.028 (ng/L)	0.52/0.0038		0.053/0.0036	
Hexachlorobutadiene	4.47/0.45/0.045	90/9.3		32	
Hexachlorocyclohexane					
Lindane		0.08/2.0		0.16	
BHC		100		0.34	
Alpha-HCH	92/9.2/0.92 (ng/L)				
Beta-HCH	163/16.3/1.63 (ng/L)				
Tech-HCH	123/12.3/1.23 (ng/L)				
Gamma-HCH	186/18.6/1.86 (ng/L)				
Hexachlorocyclopentadiene	206 1.0[a]	7.0/5.2		7.0	
Isophorone	5.2 (mg/L)	117,000		12,900	
Lead	50	exp[2.35ln(h)-9.48]/ exp[1.22ln(h)-0.47]			
Mercury	144 (ng/L)	0.20/4.1		0.10/3.7	
Naphthalene		2,300/620		2,350	
Nickel	13.4	exp[0.76ln(h)+1.06]/ exp[0.76ln(h)+4.02]		140/7.1	

Table 5. (continued)

Toxic pollutant	Human health	Freshwater aquatic life		Saltwater aquatic life	
		Animals	Algae	Animals	Algae
Nitrobenzene	19.8 (mg/L) 30.0[a]	27,000		6,680	
Nitrophenols		230	150		4,850
2,4-Dinitro-o-cresol	13.4				
Dinitrophenol	70				
Nitrosamines		5,850		3,300,000	
n-Nitrodimethylamine	14/1.4/0.14 (ng/L)				
n-Nitrodiethylamine	8/0.8/0.08 (ng/L)				
n-Nitrosodi-n-butylamine	64/6.4/0.064 (ng/L)				
n-Nitrosodiphenylamine	49,000/4,900/490 (ng/L)				
n-Nitrosopyrrolidine	160/16.0/1.60 (ng/L)				
Pentachlorophenol	1.01 (mg/L) 30[a]	55/3.2		53/34	
Phenol	3.5 (mg/L) 0.3 (mg/L)[a]	10,200/2,560		5,800	
Phthalate esters		940/3		2,944	3.4
Dimethylphthalate	313 (mg/L)				
Diethylphthalate	350 (mg/L)				
Dibutylphthalate	34 (mg/L)				
Di-2-ethylhexyl-phthalate	15 (mg/L)				
Polychlorinated biphenyls	0.79/0.079/0.0079 (ng/L)	0.014		0.030	
Polynuclear aromatic hydrocarbons	28/2.8/0.28 (ng/L)			300	
Selenium	10				
Inorganic selenite		260/35		410/54	
Inorganic selenate		760			
Silver	50	exp[1.72ln(h)-6.52]/0.12		2.3	
Tetrachloroethylene	8/0.8/0.08	5,280/840		10,200/450	
Thallium	13	1,400/40		2,130	
Toluene	14.3 (mg/L)	17,500		6,300/5,000	
Toxaphene	7.1/0.71/0.07 (ng/L)	1.6/0.013		0.070	
Trichloroethylene	27/2.7/0.27	45,000		2,000	
Vinyl chloride	20/2.0/0.2				
Zinc	5 (mg/L)[a]	exp[0.83ln(h)+1.95]/47		170/58	

[a]Organoleptic data for controlling undesirable taste and odor.

[b]When two values are given (as in a/b), the first is for acute toxicity and the second is for chronic toxicity.

[c]For maximum protection of human health, the ambient water concentration should be zero.The numbers correspond to the incremental increase of cancer risk over a lifetime of 10-5, 10-6, and 10-7 for ingestion of contaminated water and aquatic organisms.

[d](h) = water hardness measured in mg/L as CaCO3 unless otherwise specified.

[e]18.4 mg/L is for 1,1,1-trichloroethane, while other values are for 1,1,2-trichloroethane.

3.2.3 Example Analyses

This section gives some examples using data from VAFB to implement the ROI methodology for water quality.

3.2.3.1 Launch Discharges and Increases in the Concentrations of Sodium or Lead in Bear Creek

A worst-case scenario for discharges from the surface impoundments at SLC-3 treats the discharge as a point source that flows directly into Bear Creek during the dry or low-flow season. The pollutant of interest is sodium, which is treated as a conservative pollutant. Sodium concentrations in Bear Creek and the SLC-3W impoundment and streamflow in Bear Creek are plotted for the period of record in Figs. 11, 12, and 13 respectively. On July 14, 1983, 75.6 m^3 (20,000 gal) of waste were discharged at a rate of 8.5 x 10^{-4} m^3/s (0.03 cfs). This waste contained 356.6 mg/L of sodium. At station 195NA151 on July 12, 1983, the flow rate was 22.6 x 10^{-3} m^3/s (0.8 cfs), with a sodium concentration of 97.8 mg/L. Using Eq. 1:

$$C = \frac{(97.8)(0.8) + (356.6)(0.03)}{0.03 + 0.8}$$

$$= 107.16\, mg/L\,.$$

This discharge increased the concentration of sodium in Bear Creek in the mixing zone (highest instream concentration for a discharge) by 9.36 mg/L or 10%. If this concentration exceeded the agricultural supply planning criteria in Table 3, one could use this calculation to determine the agricultural supply ROI for sodium.

A similar calculation can be made for the trace metal lead. Lead concentrations in Bear Creek and SLC-3E are plotted for the period of record in Figs. 14 and 15 (samples with lead concentrations below the detection limit are plotted as negative). On April 26, 1983, the streamflow at station 195NA151 was 51 x 10^{-3} m^3/s (1.8 cfs), with a lead concentration of <50 $\mu g/L$. On May 31, 1983, 118 $\mu g/L$ of lead were discharged in 242 m^3 (64,000 gal) of waste at a rate of 2.8 x 10^{-3} m^3/s (0.1 cfs). In October 1982, a lead concentration of 30 $\mu g/L$ was detected in Bear Creek. If $C_u = 0\ \mu g/L$, then

$$C_w = \frac{(0.0)(1.8) + (118)(0.1)}{0.1 + 1.8} = 6.2 \mu g/L\,.$$

The drinking water standard is 50 $\mu g/L$ for lead. If instream concentrations are zero above the discharge, the lead concentrations in the mixing zone are well below this standard. If C_u ranges between 30 and 50 $\mu g/L$, then C ranges between 35 and 54 $\mu g/L$. If lead levels in the stream ever exceed 46.2 $\mu g/L$, then discharges could cause concentrations in the mixing zone to reach or exceed the drinking water standard of 50 $\mu g/L$.

To protect freshwater aquatic organisms, instream lead concentrations should not exceed the value calculated from the following equation (see also Table 5):

$$C_w = exp[1.22 log(h) - 0.47 \quad , \tag{3}$$

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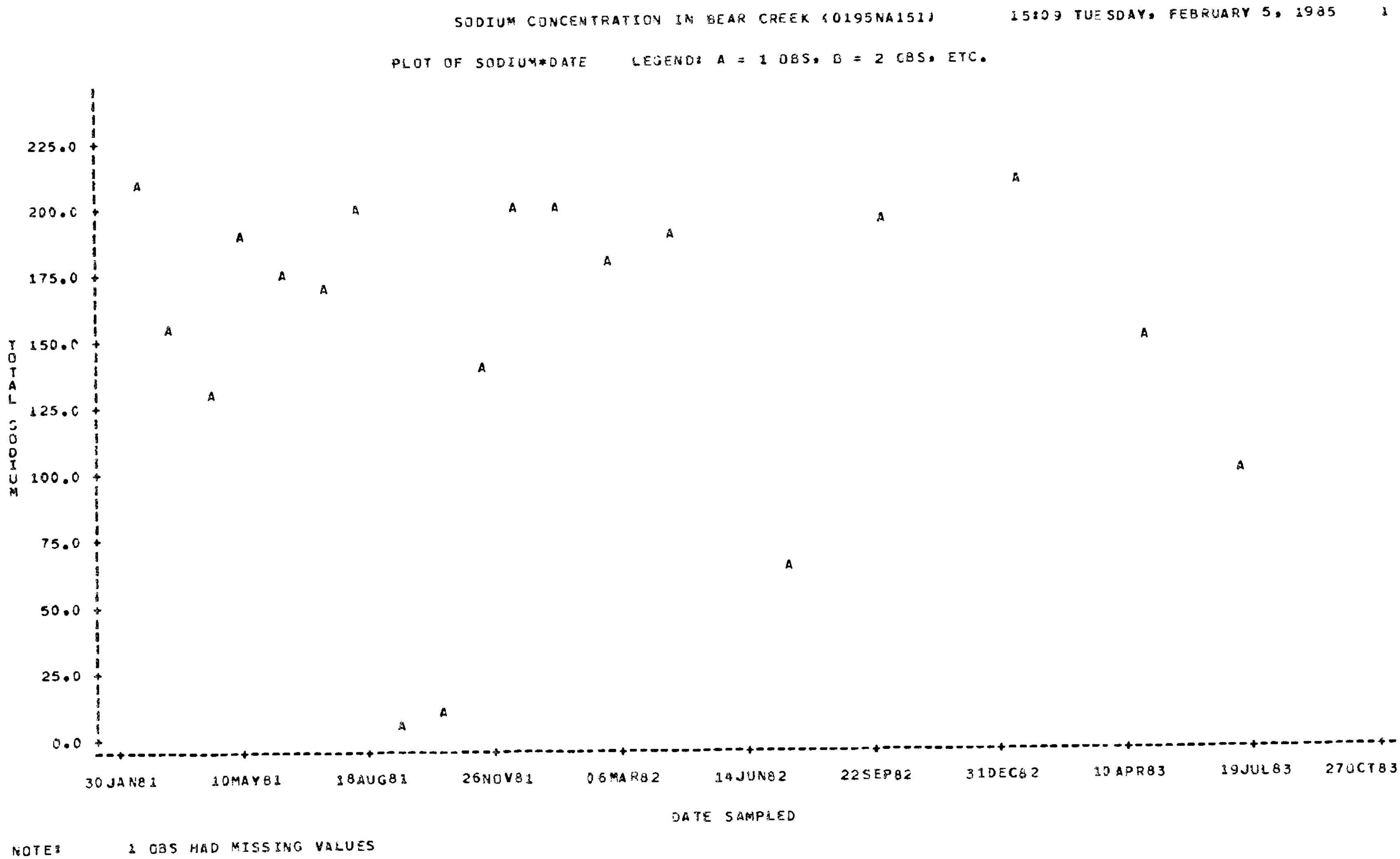

Fig. 11. Sodium concentrations found in Bear Creek monitoring station (30 January 1981 through 27 October 1983).

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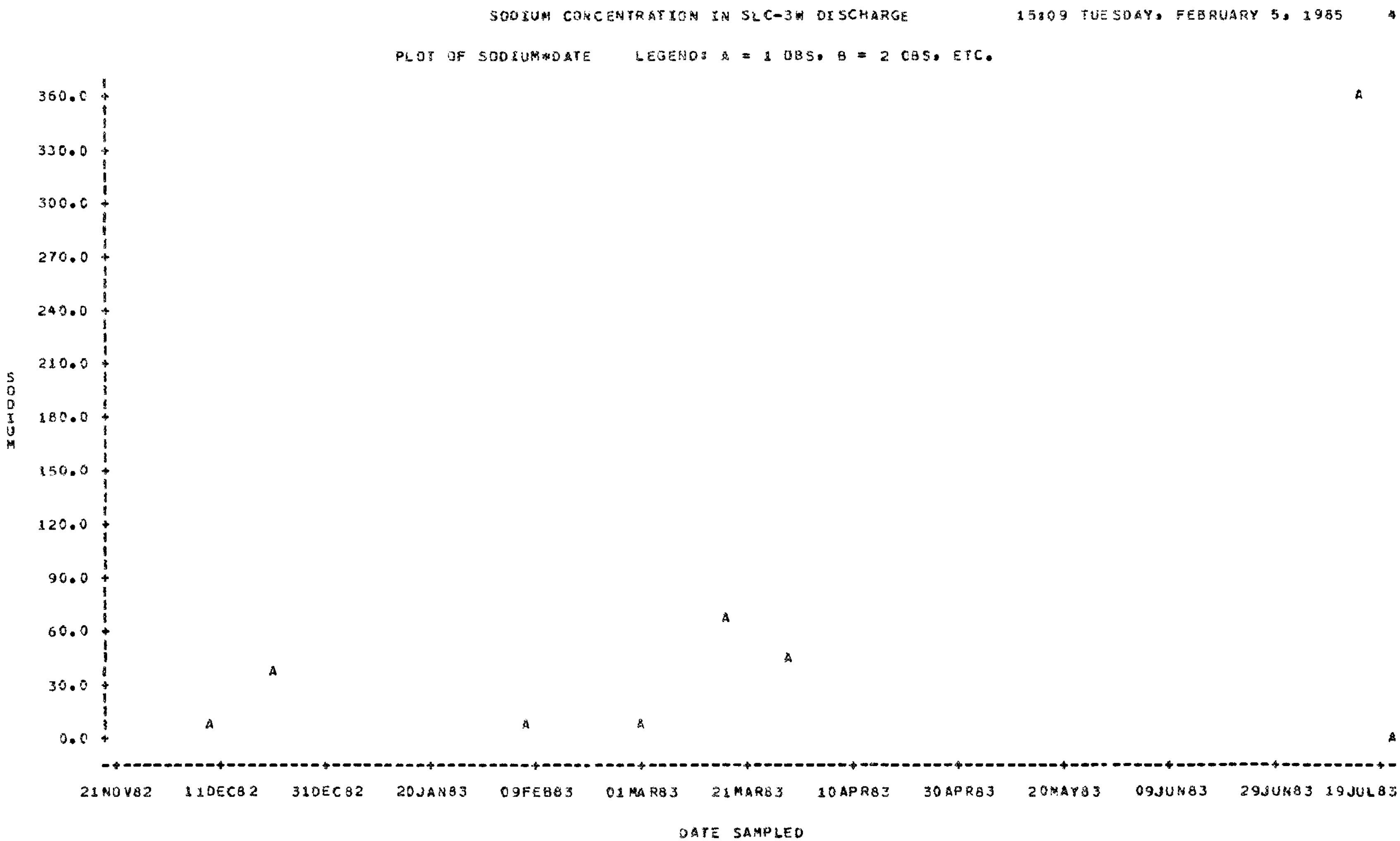

Fig. 12. Sodium concentration found at the SLC-3W monitoring station (21 November 1982 to 19 July 1983).

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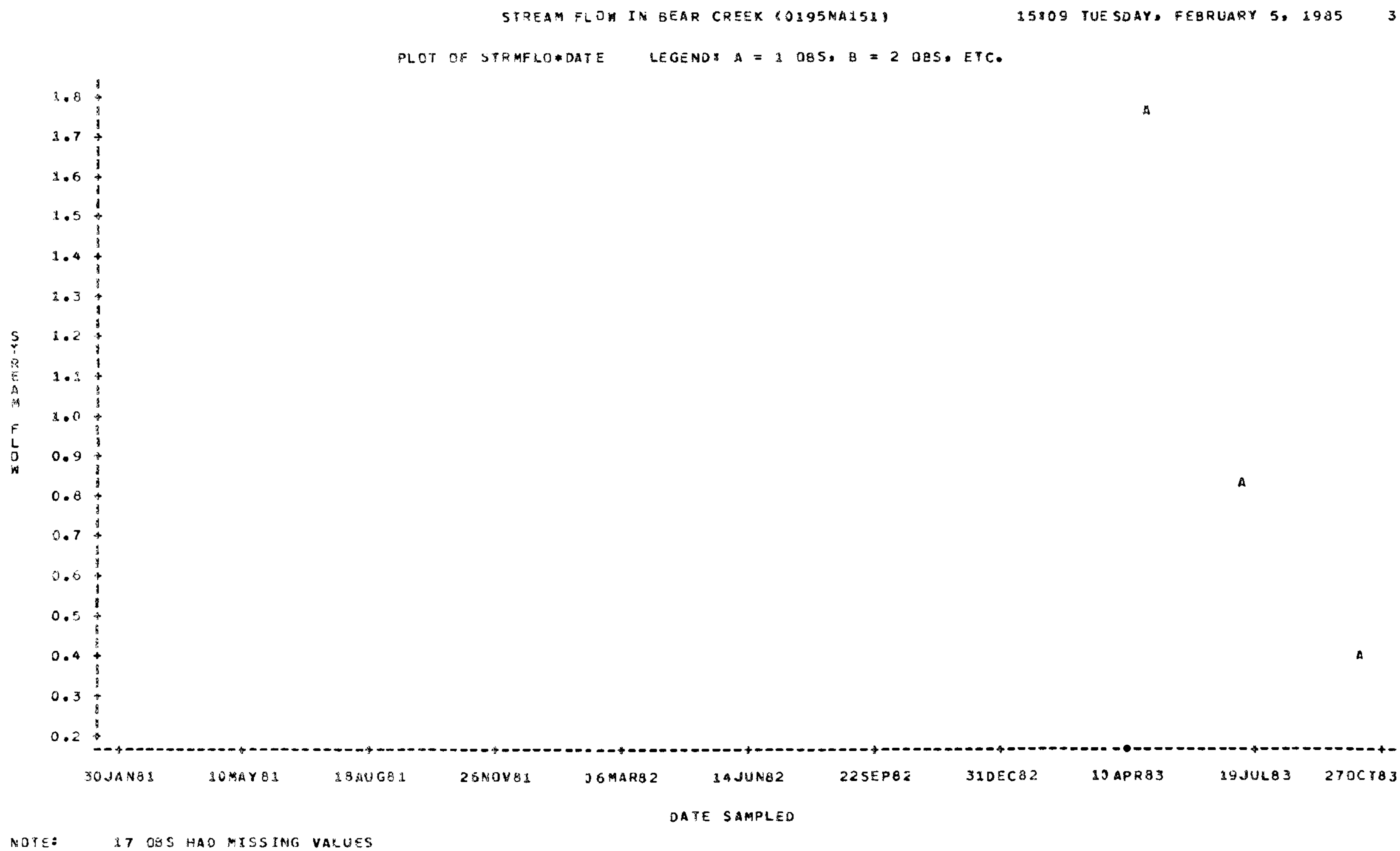

Fig. 13. Streamflow at Beak Creek showing the decline in discharge rates from the wet to the dry season.

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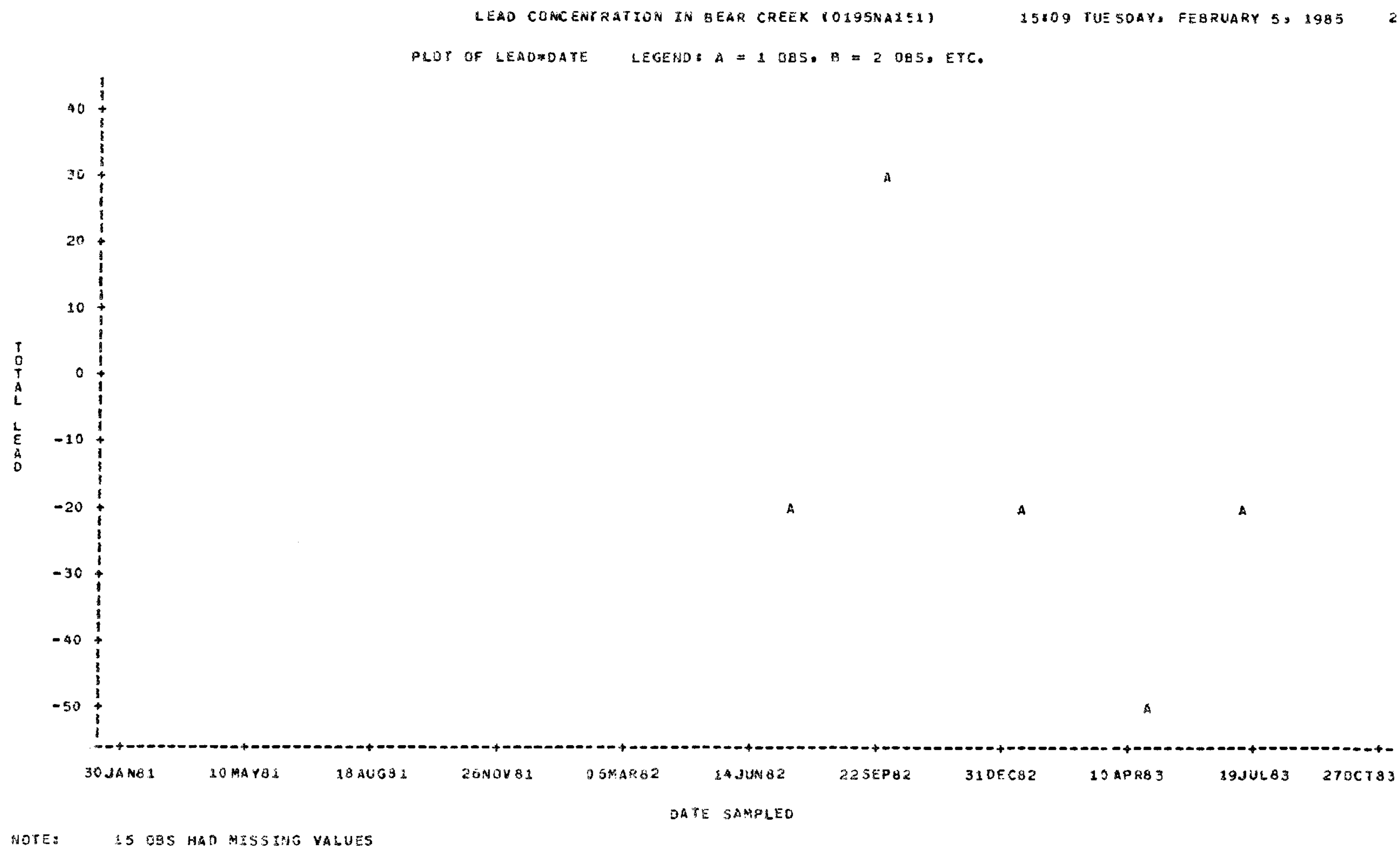

Fig. 14. Lead concentrations found in Bear Creek (14 June 1982 through 19 July 1983).

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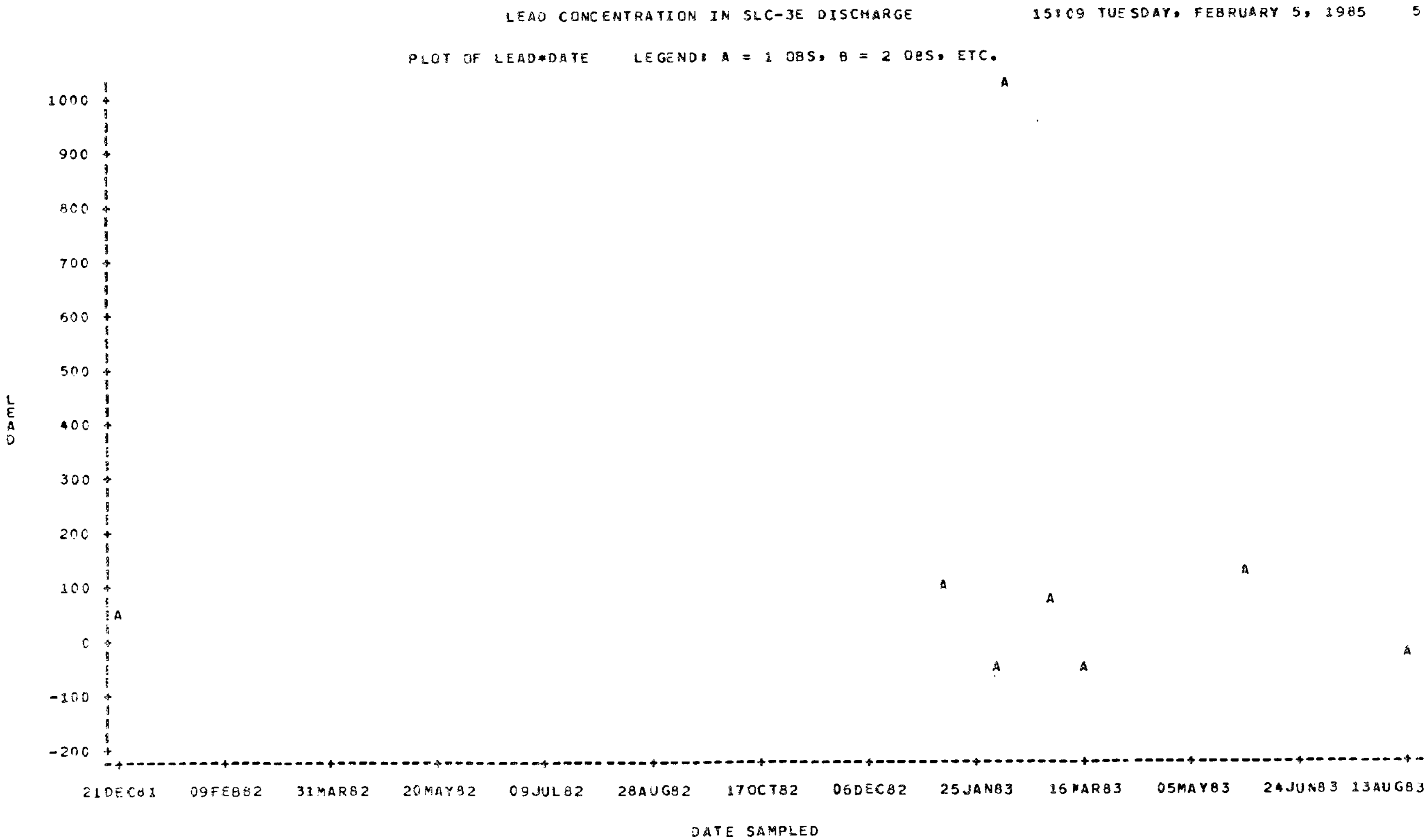

Fig. 15. Lead concentrations in discharge from SLC-3E (late December 1982 through summer of 1983).

where h is water hardness (in mg/L). Because hardness is not measured in Bear Creek, the value of 248 mg/L (obtained from the monitoring data of Bear Creek) for total alkalinity is used for (h). Substituting 248 mg/L in h of equation (3) and solving for C shows that lead concentrations should not exceed 521 $\mu g/L$ (from Eq. 1). Because this value is an order of magnitude greater than any derived concentration calculated above, lead from SLC-3E does not appear to be a problem for aquatic organisms in Bear Creek.

3.2.3.2 Lead Discharges from the SLC-3E Launch Site and the Criterion for Aquatic Organisms in the Mixing Zone

If $C_u = 0$ and the discharge has a maximum flow of 6.5 x 10^{-3} m^3/s (0.23 cfs), then

$$C_w = \frac{(521\,\mu g/L)(1.9\,cfs)}{0.23\,cfs} = 4304\,\mu g/L\,.$$

3.2.3.3 Possible Impact on Bear Creek of Organic Pollutants in the Discharges from SLC-3W

Both trichloroethylene and trichloromethane (chloroform) were discharged from impounded wastewaters at SLC-3W on 14 July 1983. The discharge volume was 75.6 m^3 (20,000 gal) at a rate of 0.03 cfs. The concentrations of these chemicals in Bear Creek are currently assumed for purposes of this study to be zero because no analyses have been done for organics in this stream. The stream flow at station 195NA151 was 22.6 x 10^{-3} m^3/s (0.8 cfs) on 12 July of that year.

The first step in determining if 4.7 $\mu g/L$ of trichloroethylene in this discharge causes a water-quality problem is to treat it as a conservative pollutant (Fig. 9) and use Eq. 1.

$$C_w = \frac{(4.7\,\mu g/L)(0.03\,cfs)}{0.8 + 0.03\,cfs} = 0.17\,\mu g/L\ .$$

A comparison of this concentration with criteria in Table 5 indicates that this level of trichloroethylene is below the aquatic standard and below the level (10^{-7}) for cancer risk in humans. No further steps in the analysis of this toxic substance are necessary.

The discharged wastewater contained 1.1 $\mu g/L$ of chloroform. How much chloroform would have to be discharged under the conditions stated earlier to reach the following criteria for chloroform?

- The acute toxicity for freshwater aquatic life is 28,900 $\mu g/L$.
- A concentration of 0.19 $\mu g/L$ may result in an incremental increase of cancer risk of one in a million over a person's lifetime as a result of ingesting contaminated water and aquatic organisms.

Assume chloroform to be a conservative pollutant and $C_u = 0$.

For aquatic life

$$C_w = 28{,}900\,\mu g/L\,\frac{(0.8 + 0.03\,cfs)}{0.03\,cfs} = 800\,mg/L\ .$$

For human health

$$C_w = 0.19\,\mu g/L\,\frac{(0.8 + 0.03\,cfs)}{0.03\,cfs} = 5.26\,\mu g/L\ .$$

Volatilization is an important process for chloroform. The volatilization half-life under laboratory conditions is 21 min, so an acute toxicity concentration within the mixing zone would be rapidly diminished by volatilization.

3.2.3.4 Conclusions

The ROI boundaries, as defined by regulatory standards and/or criteria, for sodium, lead, trichloroethylene, and chloroform concentrations in the discharges analyzed in this scenario do not extend beyond the mixing zone in Bear Creek. No impact on aquatic or human uses of this water is occurring, even in worst-case situations. However, the above examples do show how an ROI is determined using monitoring data. Similar calculations could be done for chemicals of interest at other launch sites, to determine if any ROIs exist for surface-water quality.

Good monitoring data are essential in determining surface-water ROIs. Flow data in some instances are especially sparse, yet such data are essential to these calculations. One to two years of flow-monitoring data collected at least monthly would provide a good background data set for flow. Of course, many of the VAFB streams are dry during several months. To determine with confidence whether discharges from missile launches are affecting receiving streams, at a minimum, the receiving stream immediately above and below the discharge should be monitored before and after a discharge. If the ROI boundary conditions are exceeded in the mixing zone, the extent of the ROI should be established and a series of instream samples taken before and after releases. These data would be the basis for determining pollutant concentrations downstream of a release, both temporally and spatially, and thereby would verify the ROI methodology determinations. If it is determined that releases are not affecting receiving waters, monitoring frequencies can be returned to base-line frequencies (e.g., quarterly). Otherwise, management of the pollutant source would be required.

3.3 WATER QUANTITY

3.3.1 Introduction

The ROI methodology is a useful technique for conceptualizing the complex physical, institutional, and environmental constraints that limit the procurement of reliable, low-cost water supplies. While it is common for water specialists to map water sources in the form of reservoirs, streams, and aquifers or to sketch physical structures such as wells, pumping stations, and aqueducts on maps. they are not likely to integrate supply, legal, and impact concerns into map units. Yet, such units are of concern to the planner and the interested public in their attempts to visualize various development options.

Because water-supply ROIs are based on biophysical, economic, and legal constraints (unlike perturbations to air or water, which can be mapped based only on physical and/or biological rules), we have developed the following list to summarize the primary considerations involved in determination of water-planning ROIs.

1. Water-planning ROIs should include all users of a water source shared by the Air Force who have legal claim to some portion of the supply or who perceive the withdrawal of water by the Air Force as a threat to the continuity of their supply. An example might include the area underlain by an aquifer and its recharge area plus any lands of users (appropriators) of the aquifer water outside of these boundaries.

2. Any area where management practices or development activities might change the quality or quantity of an Air Force water source should be included. Examples include clear-cuts in the headwaters of a watershed and areas contributing significant underflow to aquifers of interest.

3. Areas likely to be affected by Air Force water withdrawals should be included in the ROI. This might include downstream reaches affected during periods of low flow or areas affected by interbasin transfers.

4. ROIs should reflect legal or institutional concerns. Thus, if a question of water rights threatens the reliability of a supply, the land holdings of the various parties served by the supply in question should be outlined. If appropriate, water districts or governmental units might be included in the ROI.

5. It is necessary to consider the combination of hydrologic, geologic, environmental, social, and legal factors. That this must be done represents one of the strengths of the ROI concept because it forces the planner to systematically integrate diverse aspects of the supply problem into a comprehensive understanding of the total situation.

6. To meet future demand, a number of ROIs will have to be prepared to express the situation at any given time. The ROIs should be viewed as dynamic representations of areas both influencing the future supply of water and receiving impacts from water withdrawals. The ROIs may cover all or part of the installation and may fall outside of the installation boundaries. ROIs should be updated periodically as water studies are completed or relationships among the interested parties change. An example of such a change would be the formation of a coalition of users willing to fund the construction of a reservoir. The dynamic nature of the ROI qualifies it for computer automation. With current computer graphics capability, ROIs can easily be created and modified. ROIs can be overlayed with various spatial parameters and useful analyses performed that will support of planning decisions.

7. Estimating future water availability requires expert skills and judgment unlikely to exist at the typical installation. Water parameters vary significantly in time and across space, and reliable supply estimates can only be achieved with sophisticated analytical procedures and computer models. However, such experts are normally reluctant to become embroiled in the political, legal, and environmental issues so often surrounding water supply questions. The integration of the various concerns is normally the responsibility of installation planners and the major command. Even where recommendations for water development options are made by a contractor, the Air Force must still understand the ramifications of the options and decide among them intelligently. By developing ROIs from inputs supplied by various sources, the planners are forced to systematically evaluate expert input and to obtain clarification and understanding of missing or unclear input. In the process of interpreting data and conclusions from different sources, Air Force planners will gain confidence in their ability to present and defend options. Finally, the mapped ROIs become one component in the presentation materials needed for decision making and implementation.

The remainder of this section illustrates the application of the ROI methodology to VAFB. The ROI methodology is applied to the most viable alternative for enhancing current water sources, based on data from the 1982 Supplemental Water Study for VAFB, California (ESA 1982a).

3.3.2 Vandenberg Air Force Base Water Supplies

The climate of the region surrounding VAFB is mediterranean, characterized by moderate temperatures, low rainfall, and summer periods without rainfall. Rainfall varies from 37 cm (14 in.) at the coast to more than 101 cm (40 in.) in the coast range to the east. There are few storms during the rainy season, but they are quite intense. Most of the runoff occurs in a few short periods each winter. For example, more than 50% of the runoff of the Santa Ynez occurs in 1 to 4% of the time (within 4-15 d). Most surface runoff passes to the ocean. Streams traversing VAFB are intermittent and without flow for most of the drier months.

For large cities, the prevailing solution to regional water supply problems is to depend on interbasin transfers; for medium-sized cities, to rely on local reservoirs; and for small cities, to secure water from well fields in unconsolidated rock, often in alluvial valleys. VAFB is traversed by two major alluvial valleys containing extensive aquifers from which it draws water for many diverse needs. The watersheds of these valleys and their mainstem streams, San Antonio Creek and the Santa Ynez River, are shown in Fig. 16.

The Santa Ynez River basin trends westward 113 km (70 miles) from its headwaters in Juncal Canyon, just inside Ventura County, to the ocean at Surf, California. The basin is a structural depression, physically altered by erosion and deposition, into which the Santa Ynez River has incised itself along the southern border, close to the north flank of the Santa Ynez Mountains, which separate the basin from the coast line. In the upper reaches of the valley, the river-channel deposits and younger alluvium are relatively thin, ranging from 56 m (185 ft) at the narrows just east of Lompoc, to less than 12 m (40 ft) in the headwaters area. These deposits are also quite narrow and are generally bounded by consolidated rocks that contribute little recharge. Together these factors limit the usefulness of these deposits as a source of significant quantities of groundwater. However, tributaries carrying low-flow discharge from unconsolidated formations on the northern edge of the watershed help maintain streamflow and support the four reservoirs established in this section. The primary recipient is Santa Barbara, whic receives this storage through an interbasin transfer of 850 m^3 (30,000 acre-ft) annually by means of the Tecolote Tunnel. VAFB has no access to reservoir storage at present.

The primary source of water for users occupying the Santa Ynez River basin are three distinct but interconnected groundwater aquifers occupying 19,650 ha (48,500 acres). The most important of these is the aquifer occupying the younger alluvium and river-channel deposits underlying the Lompoc plain on which the city of Lompoc is situated. The plain is about 19 km (12 miles) long and nearly 5 km (3 miles) wide at its maximum. Its alluvial fill ranges in thickness from 56 to 58 m (185-200 ft). Water-bearing formations lie below the alluvium and, together with the lower member of the younger alluvium, contain the deep water body from which most water is taken. The upper member contains water of poorer quality because it is most directly affected by irrigation return flows. The amount of groundwater in storage above mean sea level in the Lompoc plain is on the order of 3.5×10^8 m^3 (285,000 acre-ft) and the consumptive use of water from the plain is estimated to have been 1.7×10^7 m^3 (14,367 acre-ft) in 1980, nearly equal to the average annual recharge of 1.85×10^7 m^3 (15,000 acre-ft). Prior to 1980, annual deficit withdrawals were true of

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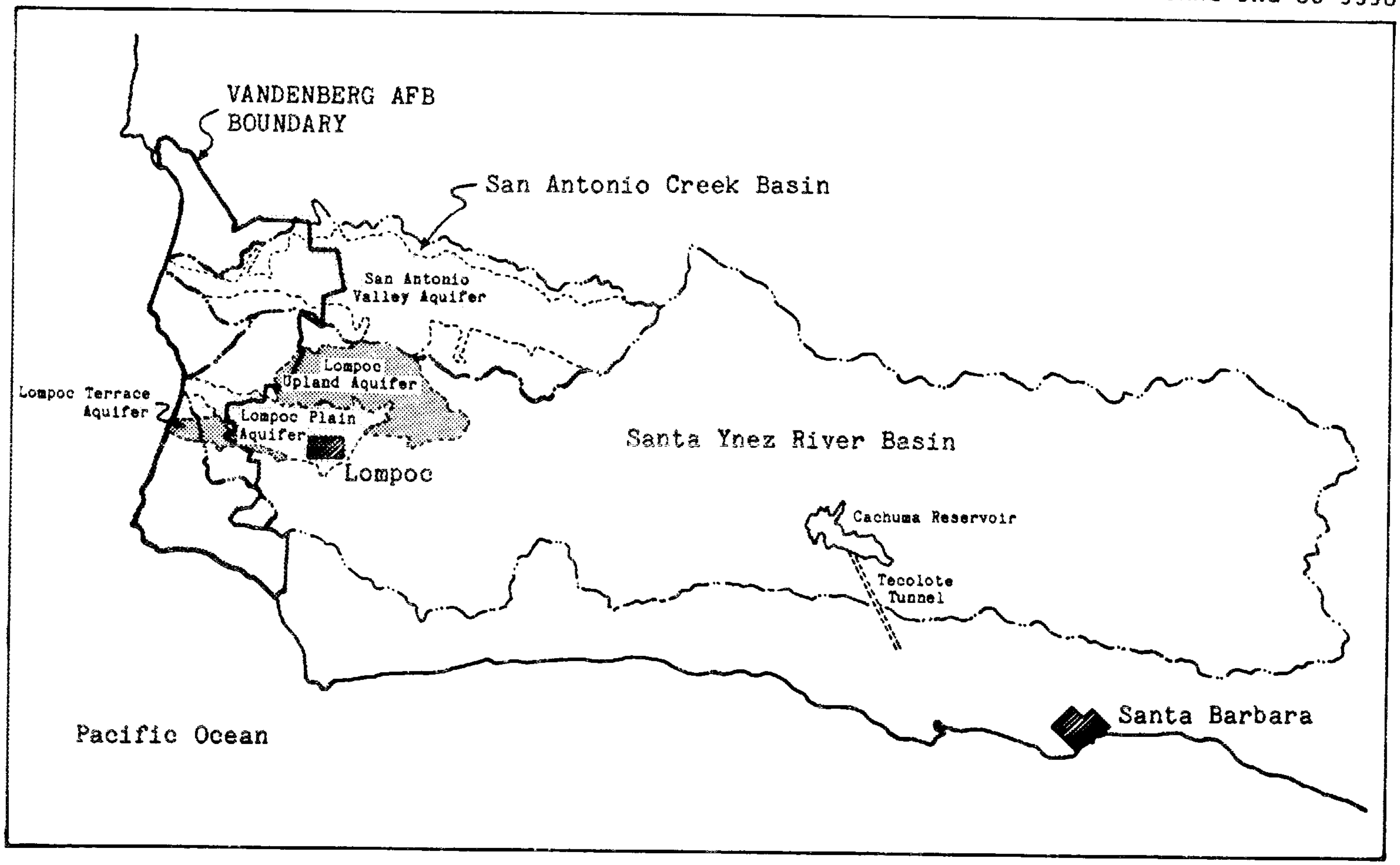

Fig. 16. Watersheds and associated groundwater aquifers that supply water to VAFB.

the aquifer. The situation changed just prior to 1980 as a result of two independent actions by VAFB. VAFB shifted the bulk of its withdrawals to the San Antonio Valley Aquifer and transferred its wastewater to the city of Lompoc for treatment. The city discharges its treated water to the Lompoc plain aquifer with the result that VAFB effectively recharges the Lompoc plain aquifer with water from the San Antonio Creek basin.

Until very recently, VAFB relied on the Lompoc plain aquifer as its primary source of water. In 1978, most of the withdrawals were shifted from the Lompoc plain aquifer to the San Antonio Valley Aquifer because of the continuing deterioration of water quality. Remaining withdrawals are taken from the Santa Ynez River in the Lompoc Plain near the Federal Correctional Institution (FCI) and satisfy a commitment to supply FCI with water. At present, the primary users of groundwater from the Lompoc Plain are irrigated agriculture, the city of Lompoc, and the FCI.

The second most important source of water occurs in the unconsolidated formations underlying the Lompoc Uplands north and east of the Lompoc Plain. This area is not tapped extensively by wells but contains over 4.9 x 10^8 m^3 (400,000 acre-ft) of water in storage, of which 1.6 x 10^6 m^3 (1300 acre-ft) is transmitted to the Lompoc plain aquifer annually through underflow. The area is approximately 19 km (12 miles) long and 6 km (4 miles) wide. Its surface area comprises 9170 ha (22,660 acres) or some 90 km^2 (35 $miles^2$). The primary users of the Lompoc uplands aquifer are Vandenberg Village, Mission Hills, and irrigated agriculture. The annual consumptive use of water from the uplands is estimated to have been 3.8 x 10^6 m^3 (3100 acre-ft) in 1980, producing a water deficit of 5.5 x 10^5 m^3 (450 acre-ft) against the average annual recharge of 3.3 x 10^6 m^3 (2650 acre-ft).

The third source of groundwater for VAFB in the Santa Ynez River basin is the Lompoc Terrace Aquifer, extending west from the Lompoc Plain to the ocean. The Lompoc terrace aquifer is approximately 6.4 km (4 miles) long and 3.2 km (2 miles) wide and is contained almost completely within the boundaries of VAFB. Thus only VAFB pumps water from this area. The terrace is underlain by a generally south-dipping wedge of unconsolidated deposits that are in fault contact with consolidated rocks along the south boundary and perhaps along part of the north boundary of the basin. While potential and actual yields from the terrace are small compared with those from the plain, the quality of terrace water is much better. The amount of water in storage above mean sea level is probably on the order of 3.7 x 10^7 m^3 (30,000 acre-ft). The annual consumptive use of water is estimated to have been 7.4 x 10^5 m^3 (600 acre-ft) in 1980, producing a deficit of 1.8 x 10^5 m^3 (150 acre-ft) against the average annual recharge of 5.5 x 10^5 m^3 (450 acre-ft).

The watershed of principal interest to VAFB is the San Antonio Creek basin lying to the north of the Santa Ynez River basin (Fig. 16). The watershed is about 4.8 km (30 miles) long and 11 km (7 miles) wide and covers some 4 x 10^4 ha (98,560 acres) or 400 km^2 (154 $miles^2$). VAFB overlies the western one-fourth of the watershed. While the valley mainstem stream, the San Antonio Creek, flows continuously across VAFB, it flows intermittently throughout most of its upper reaches. The valley occupying the watershed trends westward and lies between bordering uplifted hills composed of older resistant rocks. The valley floor is underlain by unconsolidated valley-fill deposits and a series of marine and continental sediments that compose the basin aquifer. The aquifer extends beyond the valley floor, underlying an area of 2.8 x 10^4 ha (70,400 acres) or 285 km^2 (110 $miles^2$). The unconsolidated deposits making up the aquifer are some 1100 m (3600 ft) thick at their maximum, producing significant aquifer storage on the order of 2.8 x 10^9 m^3

(2,250,000 acre-ft) above mean sea level. In 1980, VAFB took 4.8 x 10^6 m^3 (3,861 acre-ft) of water from the San Antonio Valley aquifer, more than 80% of the total consumption of the base.

The San Antonio Creek Basin is sparsely populated. The town of Los Alamos, with a population of 900, is the principal urban center. Except for the western quarter, the valley is privately owned, with the uplands being used primarily for dry farming or grazing and the flatlands along streams for irrigated farming. Users of aquifer water include irrigated agriculture, VAFB, and, to a much lesser extent, municipalities and industries. A dramatic change has occurred in the pattern of consumption among these users in the last few years. Through irrigation, 1012 ha (2500 acres) of vineyards and 485 ha (1200 acres) of truck-farmed vegetables have been added to the production base of nearly 2185 ha (5400 acres). This, in turn, has resulted in a 60% increase in the consumption of aquifer water. Earth Sciences Associates (1982a) estimated th. total consumption in 1980 to have been 3 x 10^7 m^3 (24,363 acre-ft), an overdraught of 1.8 x 10^7 m^3 (14,563 acre-ft) in excess of the 1.2 x 10^7 m^3 (9800 acre-ft) of annual recharge. This level of withdrawal intensifies the historical overdraught which has gradually reduced well levels and stream base flow.

Continuing deficit withdrawals from the aquifer create the potential for a particularly serious environmental confrontation. Close to the VAFB boundary the aquifer is dissected by an upwarp of consolidated rock which forms an underground barrier and diverts groundwater to the surface. The continuous presence of surface water confined by clay beds in turn sustains a 222-ha (550-acre) marshy area to the east of the bedrock high known as Barka slough. Such features are rare in the region, and, as might be suspected, the slough contains unique plants and animals. In fact, the pristine marshlands of the slough are known or believed to be inhabited by at least nine "regulated," threatened or endangered species of wildlife. The effect of long-term deficit withdrawals from the aquifer has been to reduce the base flow of San Antonio Creek and therefore the water available to Barka slough. This represents a long-term problem at VAFB.

The unreliability of present water supplies and the concern for future water options represent a continuing challenge to staff at VAFB. The has resulted in numerous studies and investigations in the past 15 years. These studies have revealed growing competition for a finite and limited resource, the reduction of the water resource base through deficit withdrawals, and a precarious legal position for VAFB. Over time, VAFB has gradually increased its withdrawals, its pumpage growing from 5.4 x 10^6 m^3 (4438 acre-ft) in 1970 to 5.9 x 10^6 m^3 (4800 acre-ft) in 1980. Future expansion is expected to increase pumpage to 9.2 x 10^6 m^3 (7500 acre-ft) by 2000.

The following analysis demonstrates the uncertainties facing Vandenberg in procuring increased quantities of water. The situation relative to present and future use of water from the various aquifers of interest to VAFB is illustrated in Table 6. Note that the table lists consumptive use, that is, pumpage minus returns to the aquifer. For VAFB this is roughly 35% of its pumpage. Because VAFB's wastewater is transferred to the city of Lompoc for treatment, the table credits the Lompoc plain with the recharge of this treated water coming primarily from the San Antonio Creek Basin.

Since the San Antonio Valley aquifer is a primary water source for VAFB, it is listed first. Unfortunately, it is also the most heavily overdrawn of the four aquifers. Like most western aquifers, low regional precipitation produces relatively small recharge and limited potential for sustained yield despite huge amounts of water in underground storage. The cumulative loss in storage of the aquifer over the 20-year period preceding 1977 was 3.8 x 10^7 m^3 (31,000 acre-ft) or less than 2% of the storage available above sea level. Even this small reduction, however, resulted in

Table 6. Comparison of consumptive use and overdraught of aquifers in the Santa Ynez River and the San Antonio Creek watersheds [Quantities are in acre-ft/year (1 acre-ft = 1233 m³) and are compiled from the various references listed for this chapter]

Aquifer	Annual recharge	Annual consumptive use (1980)	Annual deficit (1980)	Projected annual consumptive use (2000)	Annual deficit (2000)
San Antonio Valley	9,800	24,363[a]	14,563	30,760[b]	20,960
Lompoc plain	15,000	14,367[c]	-633	16,380[d]	1,380
Lompoc upland	2,650	3,100[e]	450	3,500[f]	850
Lompoc terrace	450	600[g]	150	600	150
	27,900	42,430	14,530	51,240	23,340

[a]Consumptive use = 290 (municipal) + 3,861 (Vandenberg) + 16,212 (agriculture) + 3,000 (evapotranspiration) + 1,000 (stream base flow).

[b]Based on a 25% increase in agricultural in use by VAFB.

[c]Consumptive use = 520 (city of Lompoc) - 125 (effluent import from Mission Hills) + 612 (Vandenberg to FCI) + 9,910 (agriculture) + 3,200 (evapotranspiration) + 250 (stream base flow).

[d]Based on a 25% increase in agricultural recharge and an additional recharge of 945 acre-ft from increases in Vandenberg wastewater treatment.

[e]Consumptive use = 100 (Mission Hills) + 100 (Vandenberg Village) + 1,600 (agriculture) + 1,300 (underflow to Lompoc plain).

[f]Based on a 25% increase in use by cities and agriculture.

[g]Consumptive use = 200 (Vandenberg) + 400 (underflow to Lompoc plain).

an average decline in groundwater levels of 1 m (3 ft) over the 20-year period. Base flow also diminished as a result of lowered groundwater levels in response to pumping.

Between 1977 and 1980, an even more serious threat to the long-term availability of San Antonio Valley Aquifer water developed in the form of increased irrigation. The combined impact of increased irrigation and VAFB's shift from the Lompoc plain aquifer to the San Antonio Valley aquifer caused consumptive use to move from 1.7×10^7 to 3×10^7 m³ (14,138-24,363 acre-ft), more than a 72% increase. Besides lowering well levels and threatening the quality of aquifer waters, the dramatic increase in consumptive use poses a serious threat to the continued existence of the Barka slough and its wildlife. The relationship between lowered groundwater levels or base flow reductions and potential drawdown at the Barka slough have been demonstrated by Hutchinson (1980) and indicate the slough could be eliminated in a few years at current pumping levels.

Reaction to the possible loss of the Barka slough ecosystem could jeopardize VAFB water supplies, because concerned environmentalists or governmental units might force adjudication (allocation of aquifer waters by the courts), to ensure conservation of the endangered species. Hatch (ESA 1982) studied the legal issues involved in such an action and found that VAFB is likely to be in a very weak position, at best, securing only a portion of its current withdrawals in the settlement.

In light of the need to both maintain current consumption and to increase consumption by 36% by the year 2000, it is clear that VAFB must take immediate steps to acquire secure water sources suitable for future expansion. Table 6 contains an estimate of demand by 2000. A rather conservative increase of 25% or 5×10^6 m^3 (4053 acre-ft) in agricultural consumption and an increase of 2.9×10^6 m^3 (2344 acre-ft) by VAFB were assumed in creating the figures shown. As can be seen, the total consumption of San Antonio Valley aquifer water rises to 3.8×10^7 m^3 (30,760 acre-ft) by the year 2000. The drawdown associated with this level of consumption will be quite noticeable and is likely to lead to adjudication.

All three aquifers of the Santa Ynez River Basin experienced deficit withdrawals prior to 1980. For instance, the chief aquifer, the Lompoc plain aquifer, was overdrawn in every year of the decade between 1970 and 1980, except 1980. Shifting its supply away from the plain in 1977 caused VAFB to lose its prescriptive rights. Under California law, if VAFB were to return to the withdrawal o. Lompoc plain waters, it would have to continue to do so for five years to establish prescriptive rights. Thus, it would have little chance of acquiring reliable future water supplies from the aquifer before the close of the 5-year period necessary to fix prescriptive rights, as long as adjudication remained a possibility.

The position of VAFB relative to water can be summarized as follows. VAFB is only one of a number of users of a regional water resource which is not adequate to meet demand over the long term. Furthermore, projected growth will only increase competition for limited supplies. Because VAFB must transport water outside of aquifer boundaries to meet its needs, it must prove prescriptive rights to ensure continued supplies in the event of adjudication. Doing so may prove difficult. Furthermore, since adjudication is likely to reduce the withdrawals allowed for all rightful users, VAFB faces the very real prospect of having its water supply reduced at some point in the future. VAFB officials are well aware of this possibility and have supported a number of unrealized solutions in the past, including the delivery of state project water and the construction of various dams and reservoirs. Each of these proposals could be described with the aid of the ROI concept, but, for demonstration purposes, only one option and its associated ROI will be described. This is the interim solution proposed by Earth Sciences Associates (ESA 1982a), known as the Groundwater Option.

3.3.3 Determining a Region of Influence—The Groundwater Option

As the name implies, the Groundwater Option promotes better utilization of the existing aquifers to secure water supplies for VAFB expansion through the year 2000. In contrast, most other options propose importing water or capturing runoff by means of dams in tributaries. Two projects and a proposed management program make up the groundwater option. The projects consider the purchase and removal of agricultural land use and the development of spreading grounds to retain flood runoff in percolation ponds. Both projects have been considered for the Lompoc Plain and the San Antonio Basins and would be placed within the boundary of these aquifers.

The spreading grounds facilities would consist of a series of small off-channel basins 2- to 3-m (8- to 10-ft) deep and perhaps 4 ha (10 acres) in size into which storm flows normally wasted to the ocean would be diverted from the main streambed. During the 6 months that the basins retain water, percolation would occur into the aquifer providing artificial recharge. Possible recharge from the Lompoc Plain facility has been estimated at 2.5 x 10^6 m^3 (2000 acre-ft) per year. The total capital expenditure would be close to $3 million and annual operating costs about $39,000. Although no comparable set of cost estimates is available, a spreading-grounds project located above the Barka slough and below San Antonio Creek might capture between 1.2 x 10^6 and 2.4 x 10^6 m^3 (1000 to 2000 acre-ft) per year of runoff.

The project to remove irrigated agricultural production would have the federal government purchase land. To save 2.4 x 10^6 m^3 (2000 acre-ft) per year, 385 ha (1200 acres) would have to be purchased at a cost of $7.1 million.

The management program outlined by Earth Sciences Associates consists of the above projects plus increased monitoring, analytical modeling and studies, and conservation. It should be recognized, however, that the Groundwater Option does not eliminate the growing competition for the water resource and the associated long-term problem of aquifer depletion, nor does it produce reliable water supplies for VAFB. For example, retiring a block of farmland cannot ensure that other areas will not be developed. Furthermore, the total recharge anticipated from the projects is not quite enough to cover the increased pumpage of 9.2 x 10^6 m^3 (7,500 acre-ft) needed for VAFB expansion and cannot replace the increased consumption by other users. Adjudication would remain a very real possibility under this option.

Although the groundwater option may not secure long-term, reliable water supplies for VAFB, but it has merit as an interim measure until other programs can be implemented. It offers flexibility and is immediately available, reasonably cost effective, and will not require a large capital investment. It can also function as an emergency supply or as a back-up supply for meeting peak demands.

With this background we are in a position to consider the ROI that best captures the complex water supply problem facing VAFB. Figure 17 shows the ROI constructed in this analysis. The guidelines presented in the introduction to this section tell us that all users with a legal claim to a water resource shared by the Air Force should be included in the ROI. The initial placement of the ROI would logically include all aquifers underlying any part of VAFB (Guidelines 1 and 4). This would push the ROI beyond VAFB installation boundaries and incorporate the San Antonio Creek, Lompoc Plain, and Lompoc terrace aquifers. However, we should also incorporate the Lompoc uplands aquifer, based on the second guideline, because underflow from the uplands aquifer recharges the Lompoc plain aquifer, and any depletion of uplands affects VAFB indirectly.

Guideline 3 states that areas likely to be affected by Air Force water withdrawals should be included within ROI boundaries. The most serious impact of water withdrawal from VAFB's major water source, the San Antonio Valley Aquifer, would be the possible destruction of the Barka slough and its endangered biota. The existing ROI completely encloses the Barka slough and no modifications are needed to integrate it. A second potential environmental problem could result from the construction of spreading grounds on the Lompoc Plain. The Santa Ynez lagoon, located at the mouth of the Santa Ynez River, is the largest wetland community on the north coast of Santa Barbara County and contains the rare and endangered California bird, the least tern. The stability of the lagoon ecosystem, which occupies a complex transitional zone between freshwater and saltwater environments, depends the periodic influx of freshwater to flush out the system and maintain a water-quality gradient. A reduction in base flow and flood peaks may upset the freshwater-to-saltwater balance and limit the diversity of the area, perhaps affecting the least tern's use of the area. The lagoon is also located within the boundaries we chose and no modifications are necessary to portray the impact area.

Finally, applying guideline 2, areas used by water development projects should be incorporated into the ROI. In the case of VAFB, this involves the areas associated with the two projects described and any wells that might be needed to monitor aquifer parameters. The spreading grounds projects are shown (Fig. 17) in their approximate locations within the ROI, while the other entities have been excluded because their locations are not yet known. When specified, they will be located within the aquifers and will not, therefore, affect the selected boundaries.

This completes the development of the ROI. A comprehensive understanding was gained, without gathering new data, by systematically examining the physical basis of the water supply, historical water use, future needs, institutional relationships, possible impacts, and possible solutions. Furthermore, we applied the basic tenet of the ROI concept that spatial parameters of complex planning problems can be usefully portrayed on a map. The exercise of creating the ROI forced us to review all the important aspects of our problem and integrate them visually. We now have a way of communicating our understanding to others, and we are in a better position to do the hard job of weighing the option examined against others.

The usefulness of our ROI would be improved by digitizing its boundary and various symbols and attributes on a map base and entering this information into a computer. Having this information in digital form would facilitate updates for modifications and various analytical procedures. Such capability can be made a part of computer-aided design (CAD) or GIS with different primary missions, such as facilities management. As these systems find their way into the operations of Air Force installations, the planner should insist that they include the capability to process spatial information and to create graphics useful in planning, such as in the ROI.

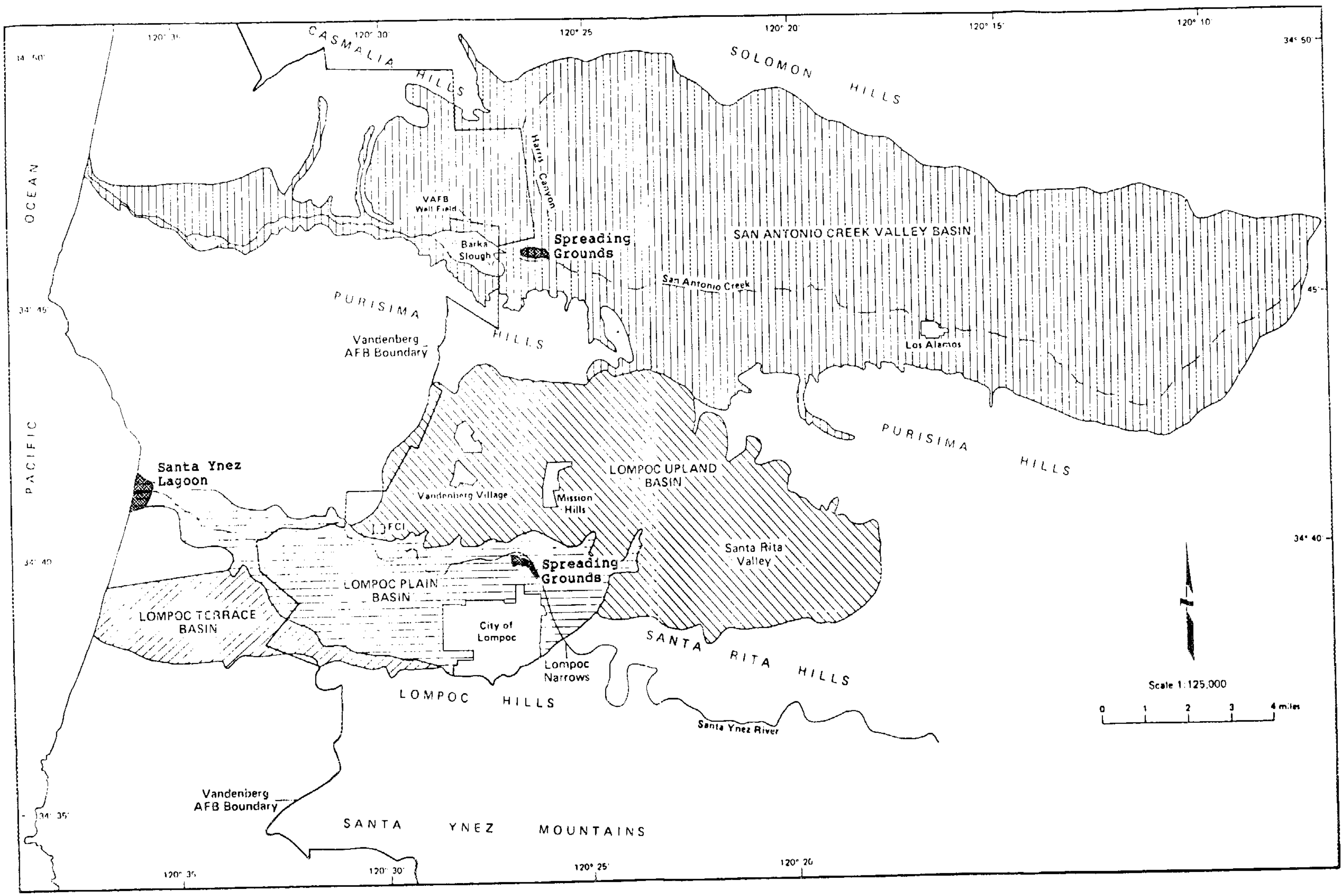

Fig. 17. The ROI for water availability at VAFB determined by management plan discussed in Section 3.3. The cross-hatched areas represent the geographic area of the ROI.

4. BASE-LINE DATA BASE FOR VANDENBERG AIR FORCE BASE

The development of the BDB for VAFB and the surrounding region was a major task in the prototype test of the ROI methodology. The computer systems at ORNL were used as a tool for numerical and statistical modeling and display of the dynamic and static data bases of the BDB. The BDB also demonstrated automated bookkeeping (e.g., managing large files of data from water quality monitoring stations) and the use of computer graphics to display spatial data in understandable map formats. Automated data-base management provides the tools to input, update, and analyze dynamic data sets, such as water-quality monitoring information. In addition, a geographic information system (GIS) provides the necessary hardware and software for manipulating spatial data sets required for regional environmental analysis. Durfee (1985) provides detailed information on the GIS hardware and software used in the prototype test at VAFB.

Static and dynamic data are used to demonstrate the data-base management and GIS framework developed for VAFB. All data sets have been structured to be cross-compatible within the BDB so that data can be merged, analyzed, and displayed in a common format. In addition, this format allows new spatial data to be incorporated with data already in the BDB. This is critical if the BDB is to be useful in applications at a variety of locations, each with its unique set of environmental issues and data needs. All the data described below are available on request to Air Force staff; however, to manipulate the data requires the appropriate hardware and software, discussed in Durfee (1985).

4.1 STATIC DATA BASES

Included in the static data base developed for this project are attributes that incorporate the environmental pattern of key physical and biological attributes in the regional landscape. The low temporal but high spatial variability of these attributes makes them ideal as a source of base-line information. Included in the static data base are aquifer boundaries, land use/land cover, Landsat satellite thematic mapper data, terrain, freshwater streams and ponds, the Vandenberg Environmental Planning System (EPS), monitoring stations for surface and subsurface water quality and quantity, and waste disposal sites. All the spatial data are stored in the computer by latitude and longitude (except the EPS) and, thus, all data sets are spatially compatible (e.g., one-to-one locational mapping of different data sets is possible).

4.1.1 Aquifer Boundaries

Figure 18 shows the spatial boundaries of the primary aquifers used to supply water to VAFB. The information was digitized from water-quantity maps available from the USGS and the state of California. The mapped output demonstrates the usefulness of the GIS for presenting spatial information in a form that can be used to illustrate the data and present the information to decision makers unfamiliar with the background of an analysis.

4.1.2 Land Use/Land Cover

The USGS has developed a spatial data set of land-cover attributes based on aerial photographs (Fageas et al. 1983). The data sets are available in both polygonal and grid cell format

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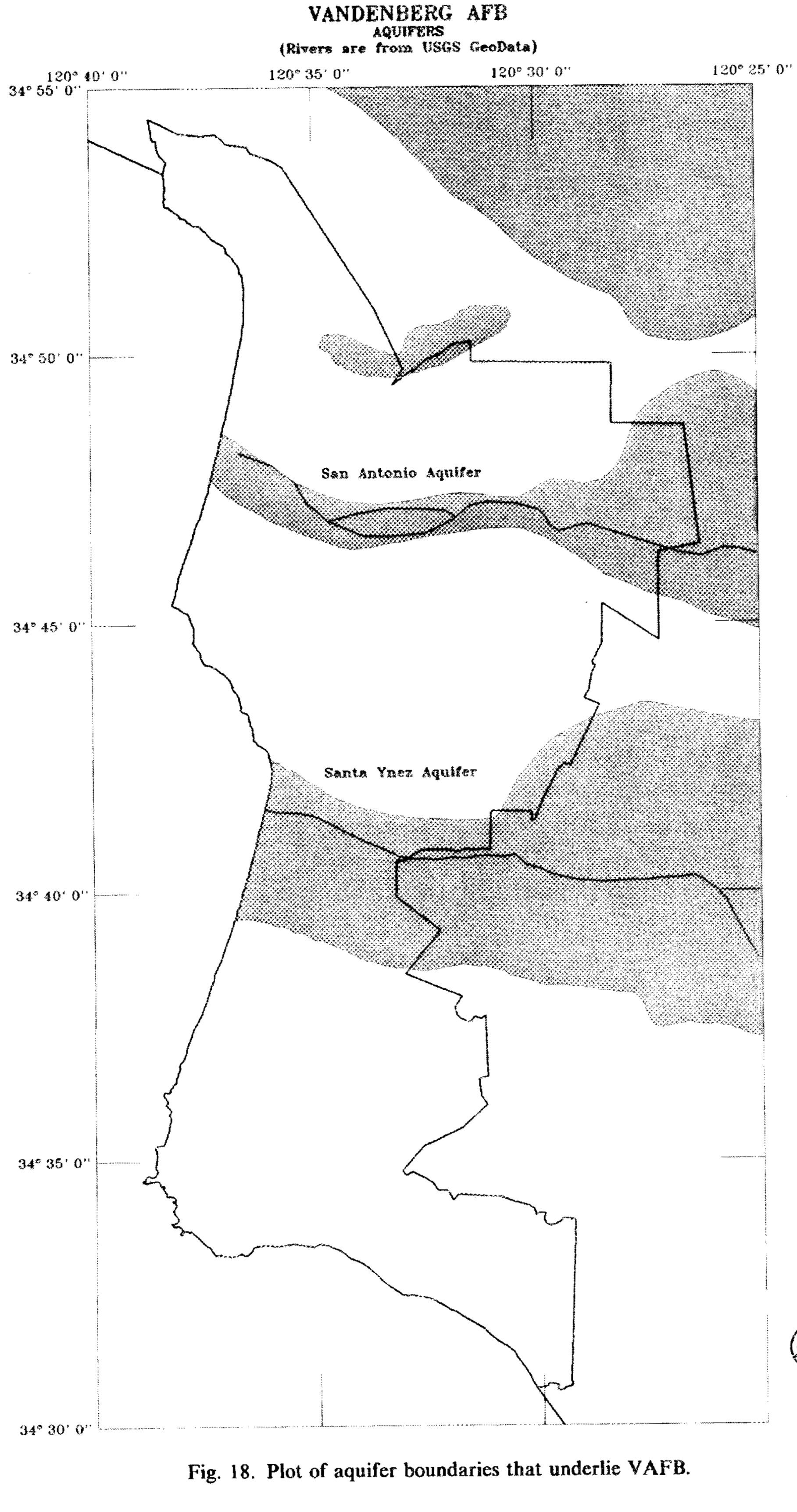

Fig. 18. Plot of aquifer boundaries that underlie VAFB.

and contain 37 categories of land-use/land-cover attributes. Although seven of the categories pertain to the built environment (e.g., transportation corridors, residential and commercial developments, and mining activities), the natural environment is categorized by 30 attributes that define the location and spatial extent of forest-cover types, agricultural and pasture land, wetlands, rangelands, lakes and rivers, and other natural land-cover types. With this data set, the complex patterns of land-cover types can be mapped and the data analyzed. For example, the perimeter and area of evergreen, deciduous, or mixed forest types on Air Force bases can be quantified for evaluating animal habitat availability.

Figure 19 is a mapped representation of the land cover types found on and around VAFB, based on the information in this data set. Managed areas (i.e., agricultural or urban) have a minimum delineation of 4 ha (10 $miles^2$), while natural vegetation has a minimum mapped area of 16 ha (40 $miles^2$). Major vegetation classes represented include the plant associations found on the coastal sand dunes and on irrigated agricultural land in the Lompoc Valley and the rangeland vegetation that supports cattle-grazing northwest of the base. This data set provides easy access to the location and spatial extent of land-cover classes that could occur within an ROI. Unlike the Landsat data, the land-cover categories have already been classified, and basic quantitative data on the attributes, such as the perimeter of each evergreen forest patch, are incorporated into the data-base structure.

4.1.3 Terrain

The terrain data for VAFB was obtained from the Defense Mapping Agency's TOPOCOM digital topography data base of elevation contours found on USGS 1:250,000 base maps. Figures 20 and 21 show the different ways these data can be presented in a map format for Vandenberg and its vicinity. The different formats allow an investigator to illustrate the terrain in the ROI of interest. However, terrain data are most useful as quantitative variables associated with other attributes of interest in an ROI study. In the terrain data base, topography can be represented as slope, elevation, or aspect. The representation chosen would depend on the particular question asked by the investigator. For example, elevation data may be needed in a meteorological study of stack emission dispersal, while evaluating the impact of cattle-grazing on erosion would require computer overlays of vegetation cover and percentage of slope.

4.1.4 Landsat Thematic Mapper

A Landsat thematic mapper scene was obtained for 19 February 1983. This scene includes all of VAFB, the coastal range, part of the Central Valley of California, and the Channel islands. (This particular scene was chosen to represent a wet-season image of the midcoastal area of California.) A cloud-free, high-quality scene was unavailable to represent the dry season along midcoastal California. The Landsat thematic mapper provides 30-m^2 resolution, with seven spectral bands for use in the analysis of land-cover patterns. To date, the best use of these data has been in the analysis of vegetation changes (especially for the wetland areas on the base) and as a receptor data base for evaluating the air-quality impacts from shuttle launches. To use the data analytically, an installation must have access to image processing hardware and software.

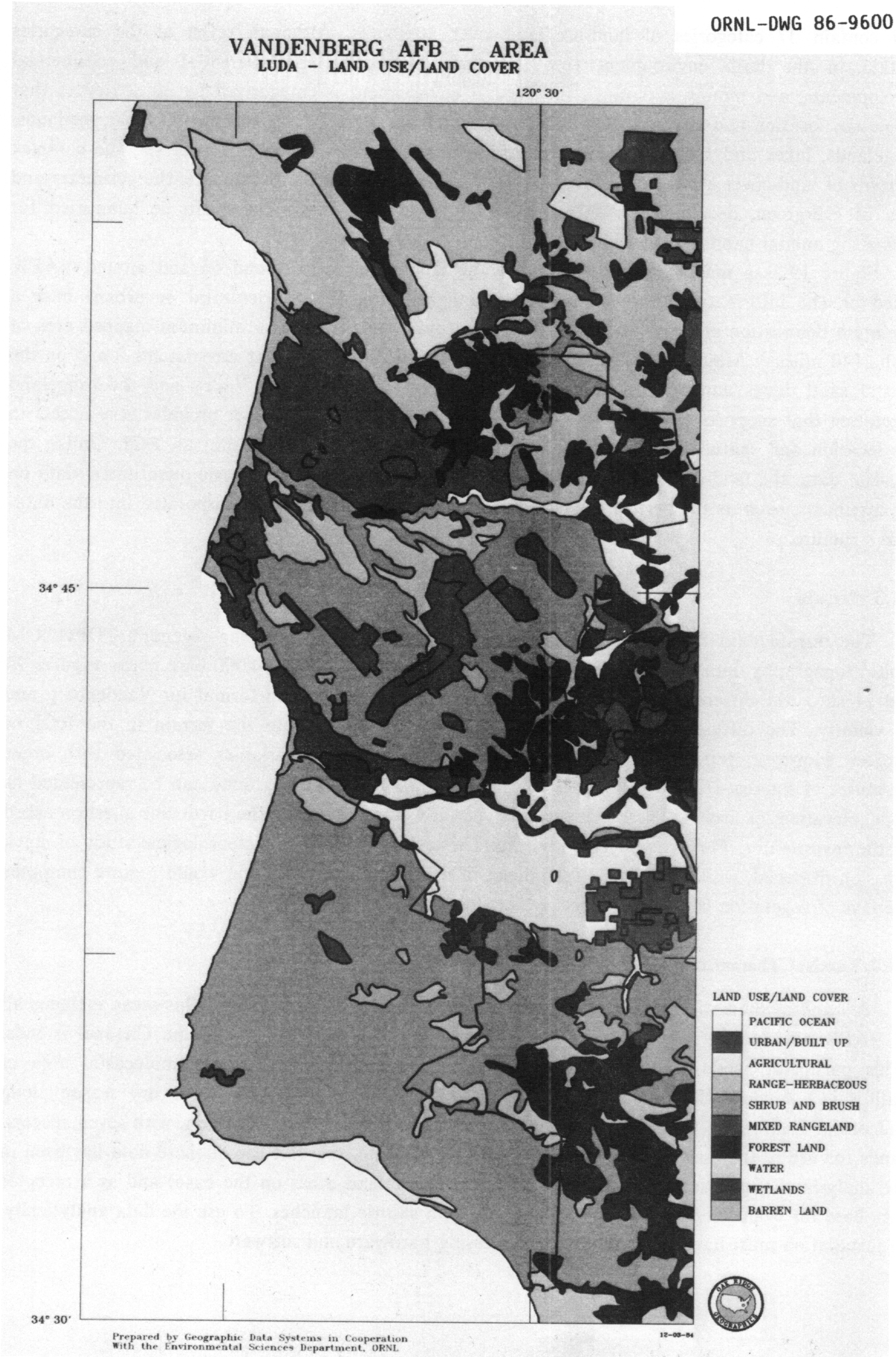

Fig. 19. Mapped representation of land-cover associations on VAFB and the surrounding area.

ORNL-DWG 86-9601

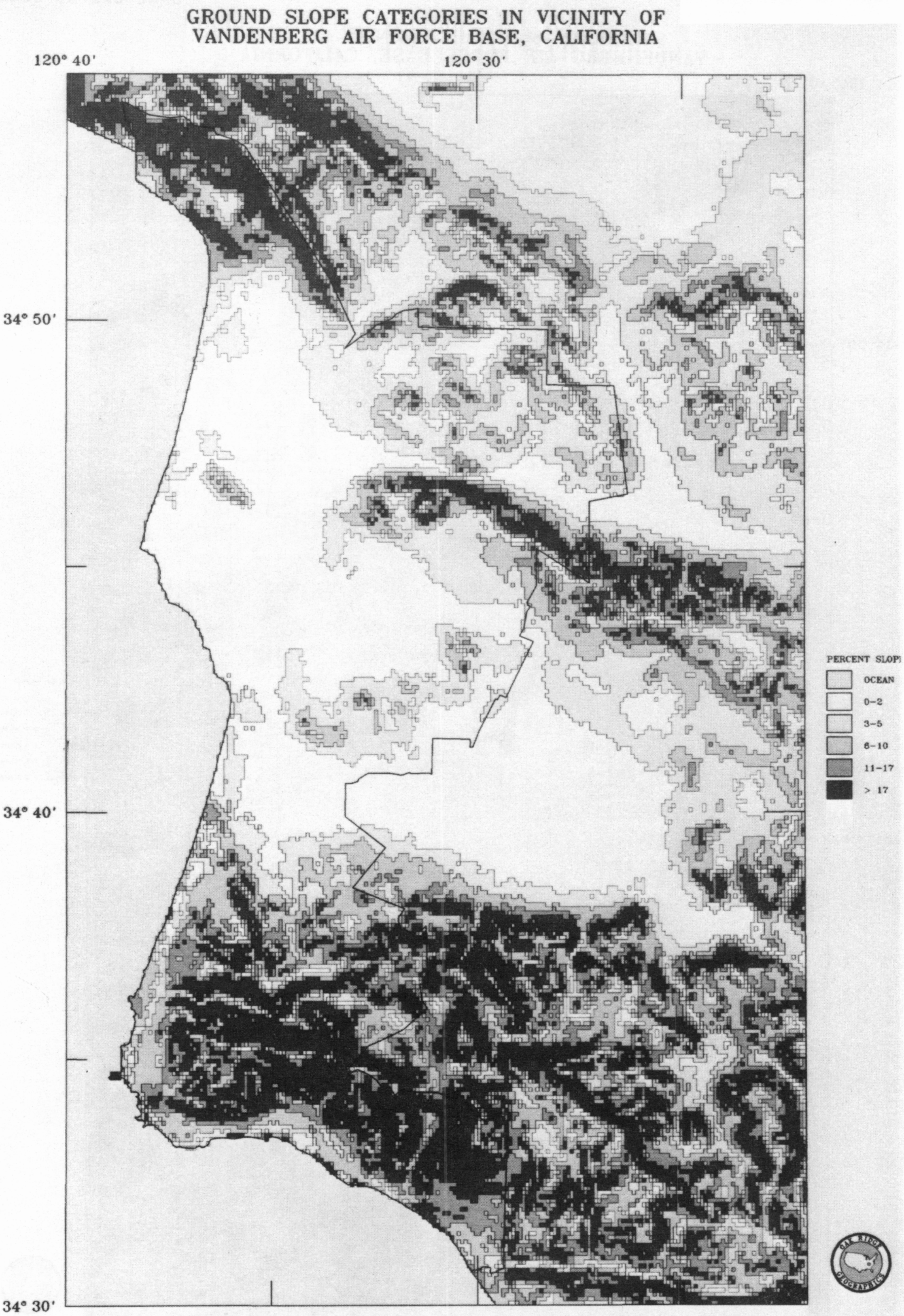

Fig. 20. Percentage-slope categories based on digital terrain data at VAFB and the surrounding region.

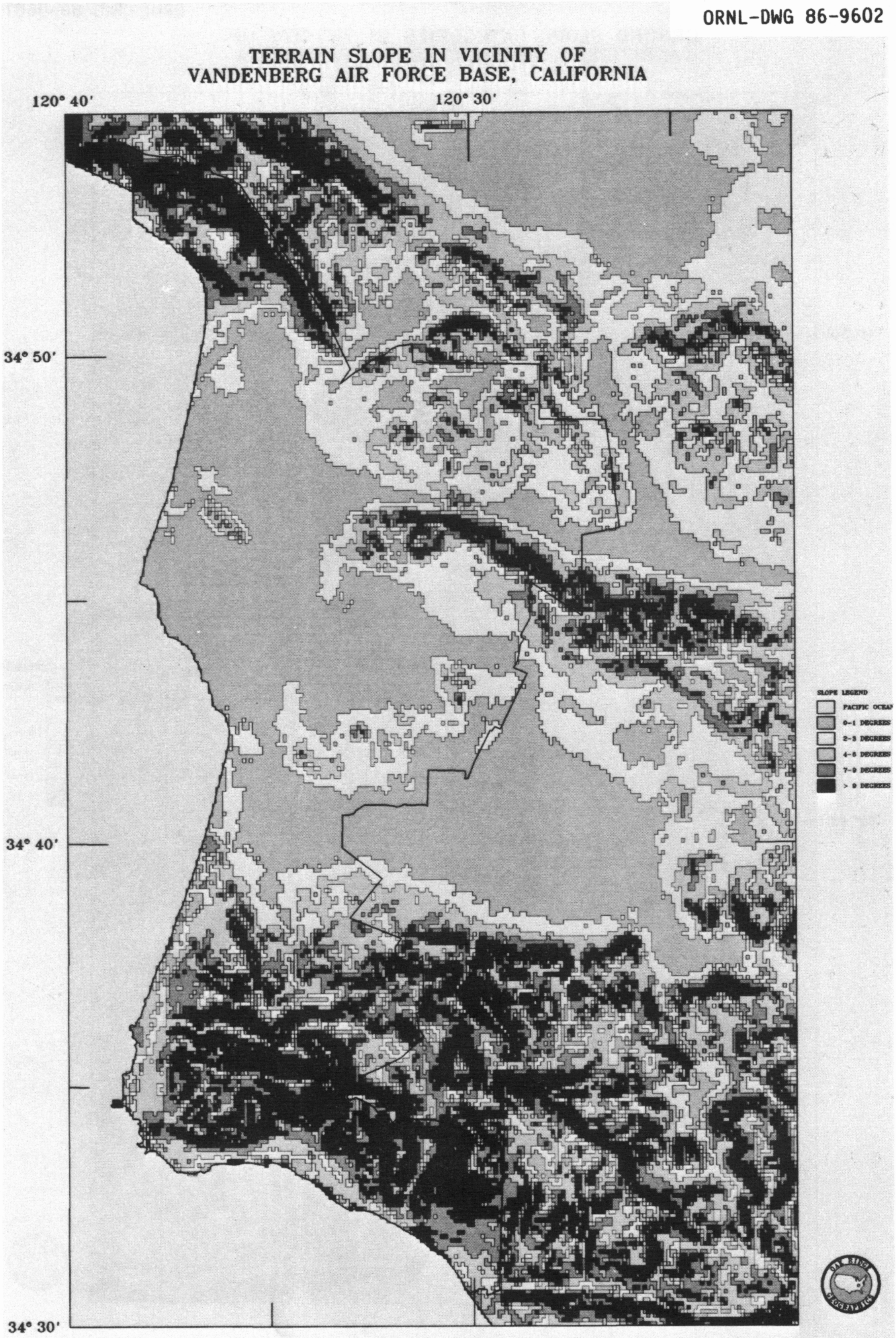

Fig. 21. Degree-slope categories based on digital terrain data at VAFB and the surrounding region.

4.1.5 Vandenberg Environmental Planning System

The EPS developed for VAFB (Reilly, Stutz, and Cooper 1976) has been incorporated into the prototype BDB. The data in the EPS are structured around a computer-mapping program developed by researchers at Harvard University. Soil and vegetation data are maintained in this data base, with a resolution of either 1.1 or 9.3 ha (2.7 or 22.9 acres). Figures 22, 23, and 24 show examples of the different vegetation communities stored in each grid cell and the aggregation levels available to an investigator. Data in the EPS can be linked using different algorithms to display overlay results. For example, vegetation cover and soil types can be combined under a set of general rules to display areas sensitive to erosion.

Because of the internal grid structure of the spatial attributes, the EPS is extremely difficult to use with other static data in the BDB. The EPS does not use map coordinate values to provide the locational information; instead, it uses an arbitrary grid superimposed over a VAFB map. This makes one-to-one locational mapping of these data with data from other sources very uncertain. [see Durfee (1985) for details of this problem.) As a practical example, the vegetation data in the EPS can not be used with a high degree of certainty to provide ground truth information for Landsat scenes.

4.1.6 Monitoring Stations

The location and type of all surface-water and well-monitoring stations maintained by VAFB have been incorporated into the BDB (Fig. 6). The information was obtained from the comprehensive water-quality monitoring plan developed by Air Force staff at VAFB to monitor activities on the base that could adversely affect water quality. The monitors are located around waste holding ponds, launch sites, and aquifers used to supply water for the base (Fig. 6). The development of a dynamic data set that utilizes the water monitoring data associated with these sites is presented below.

4.2 DYNAMIC DATA BASES

As a demonstration of data-base management and analysis that links the spatial data in the GIS to location-specific, but temporally varying, data a prototype dynamic data base for water quality was developed based on data collected from monitoring stations on and around VAFB. The data-base management system is based on the Statistical Analysis System® (SAS), which is maintained on the IBM mainframe computers at ORNL. The SAS system is well documented and currently runs on IBM 370,30XX,43XX-compatible machines. SAS combines file management, statistical analysis, and graphic display in an interactive environment. Because water-quality data at VAFB show high temporal variation within and between the fixed monitoring locations, a relational data-base concept that links specific locational information with temporally varying thematic data (e.g., changes in water quality) provides an important analytical component for the BDB. Section 3.3 of this report (water quality) presents some analytical results obtained from this data base. Here we describe the structural components of this data base.

The data sets created for this prototype test are shown in Table 7. All of the surface-water data were entered into SAS data sets from data logs supplied by staff at VAFB. It is assumed that the user of this data base has a working knowledge of SAS and will become familiar with the SAS Full Screen Product (FSP). The SAS reference manuals, SAS Users Guide: Basics (1982a) and

ORNL-DWG 86-9603

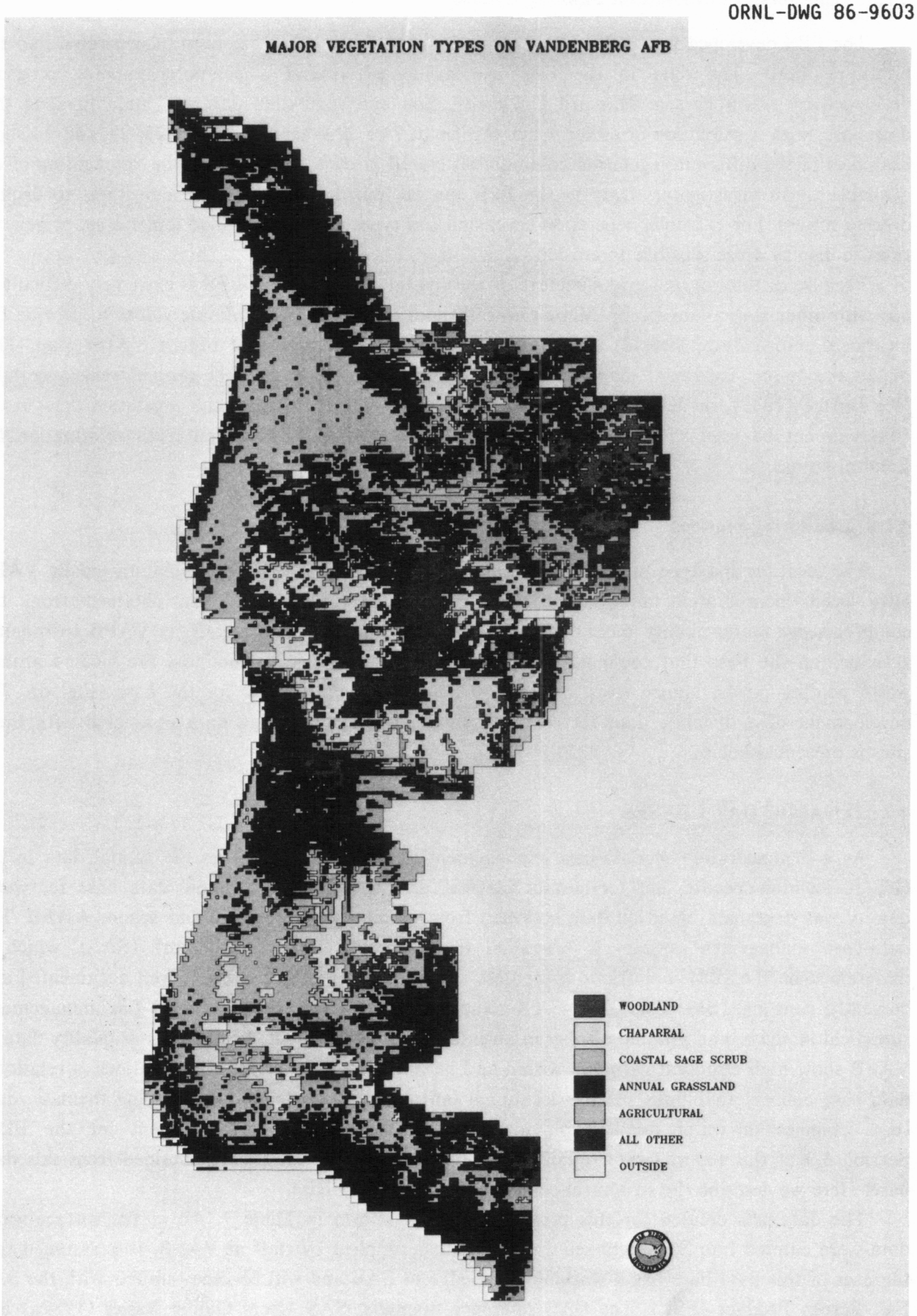

Fig. 22. Major vegetation types found on VAFB, plotted from data contained in the EPS.

ORNL-DWG 86-9604

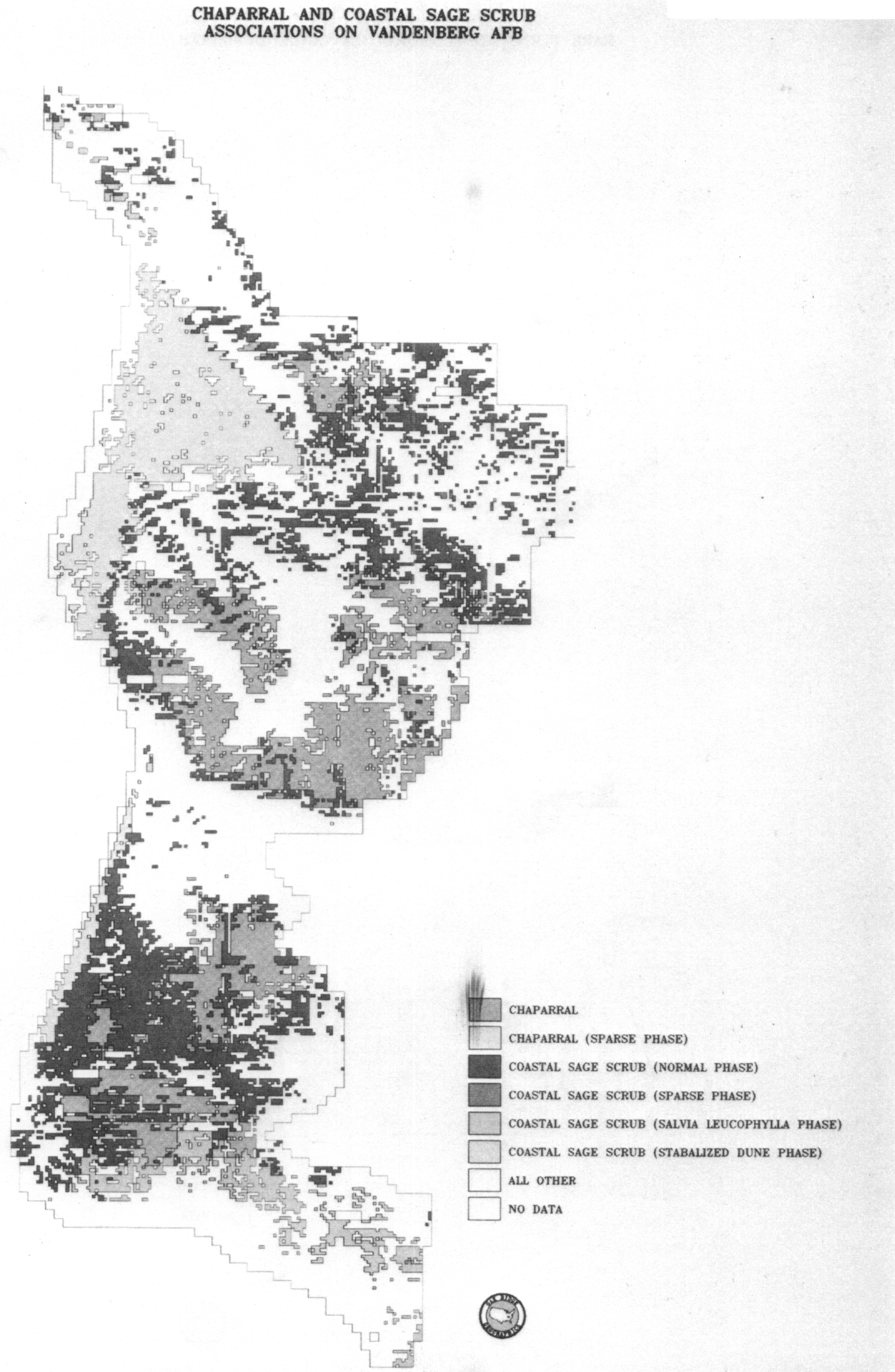

Fig. 23. Chaparral and coastal page scrub associations on VAFB, plotted from data contained in the EPS.

ORNL-DWG 86-9605

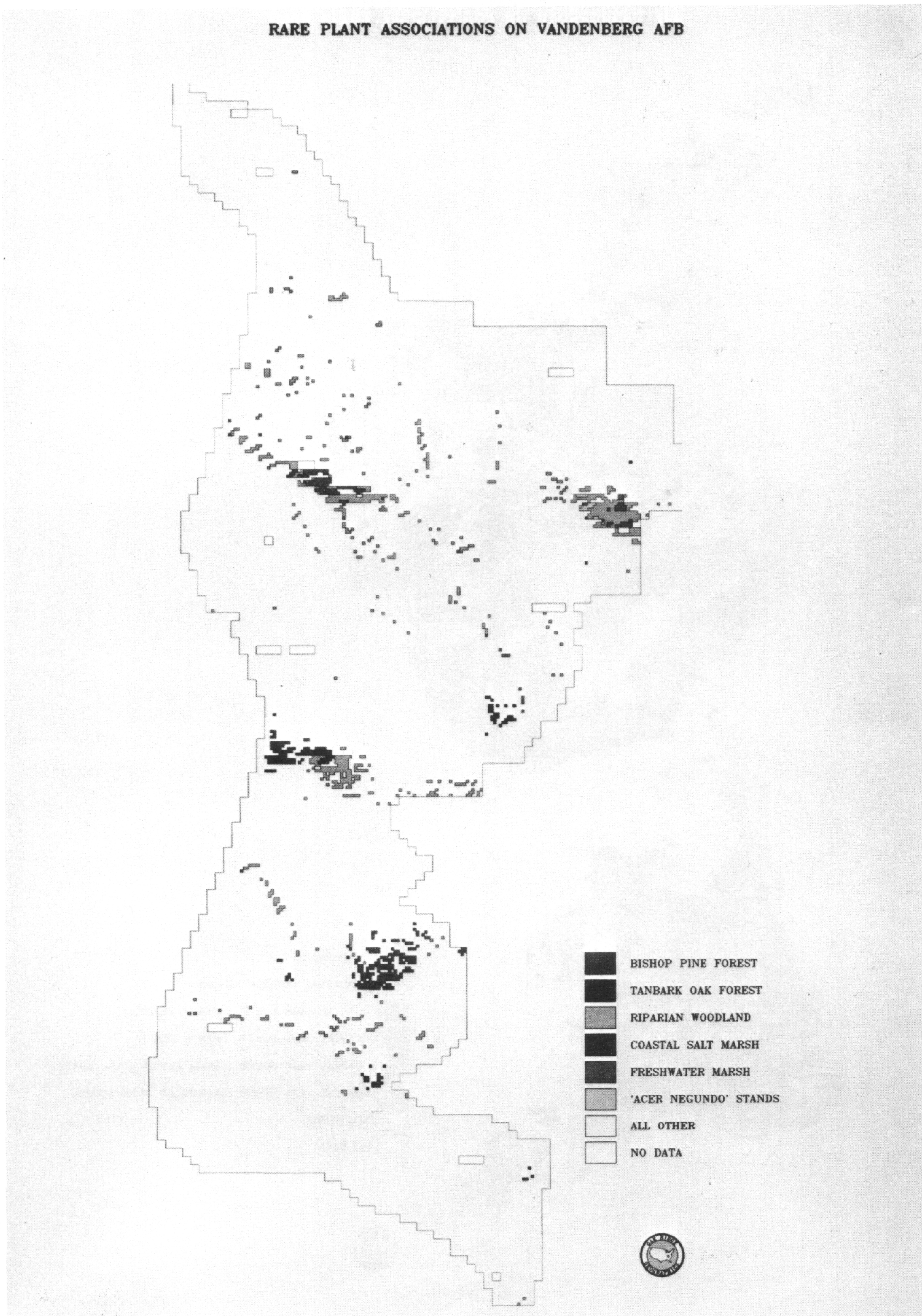

Fig. 24. Rare plant associations on VAFB, plotted from data contained in the EPS.

Table 7. File names for Vandenberg surface-water data

Raw data set	Screen data set	Contents
VANDY.AMB	VANDY.SAMB	Ambient water data—nonorganics
VANDY.AMB_ORG	VANDY.SAMB_ORG	Ambient water data—organics
VANDY.IMP	VANDY.SIMP	Impoundment water data—nonorganics
VANDY.IMP_ORG	VANDY.SIMP_ORG	Impoundment water data—organics
VANDY.SITES	N/A	List of monitoring locations
VANDY.PARMS	VANDY.SPARMS	List of parameters monitored

SAS/FSP Users Guide (1982b) provide documentation. The data sets can be accessed either through SAS directly or through SAS/FSP. Figure 25 shows examples of three terminal display screens with water-quality data from different data sets that can be edited using SAS/FSP. The data set VANDY.ABM contains a single monitoring station's data (9 March 1981) for the San Antonio Creek entry. The data sets VANDY.PARMS and VANDY.SITES respectively contain information on the type of water-quality data collected and the type of monitor and its location. In the SAS/FSP mode, data can be easily entered or edited, a necessary condition for dynamic data sets. Groundwater data can be entered into the SAS data sets in the same format as the surface-water data. Appendix B provides information on user access to these data bases.

The use of this data-base management system will increase quality control, decrease manpower needs associated with manual data entry and editing, provide statistical support for decision making, and support graphic output of the data essential to communicating results. Based on the joint work of Air Force and ORNL staff who implemented this system, the authors strongly recommend that the Air Force utilize some form of the above dynamic data-base management scheme for all air- and water-quality-monitoring data. Because the water-quality data are on the ORNL computers, it is relatively easy to use this data set as a demonstration and teaching tool for Air Force personnel located at Air Force bases.

ORNL-DWG 86-9608

```
                         Edit SAS data set: VANDY.AMB              | Screen  1
Command ===>                                                       |----------
                                                                   | Obs     1
------------------------------------------------------------------------------
LOCID:     0195NA110                          DATE: 09MAR81  YEAR:    1981
LOCNAME:   SAN ANTONIO CREEK ENTRY            TIME: 0935     SEASON: WET
BASEID:    GN810184
OEHLID1:   9792-95
BERKID:    _________
COMMENTS:  ___________________


STRMFLO:                      ____   WTRTEMP:    13.0     PH:          7.63
DO:                           10.6   TURBIDITY:  ____     AIRTEMP:     ____
COD:                          ____   NITRATE:     1.9     OILGRES:     -0.3
ORGANIC CARBON (TOC):         ____   PHOSPHORUS: ____     CHROMIUM:    ____
IRON:                         ____   LEAD:       __       SODIUM:     171.9
ZINC:                         ____   ALUMINUM:    573     ALKAL TOT:  264.0
CHLORIDE:                    160.0   TDS:        1400     SULFATES:   550.0
SPEC COND:                    ____   VLAUNCH:    YES
```

```
                         Edit SAS data set: VANDY.PARMS            | Screen  1
Command ===>                                                       |----------
                                                                   | Obs     1
------------------------------------------------------------------------------


                    PCODE:    39730

                    PNAME:    2,4-D

                    SASNAME:  _24D

                    UNITS:    UG/L

                    QDL:              0.06
```

```
                         Edit SAS data set: VANDY.SITES            | Screen  1
Command ===>                                                       |----------
                                                                   | Obs     5
------------------------------------------------------------------------------


          REMARKS:   CONTINUOUS, COAST RD

          LOCID:     0195NA141

          LOCNAME:   CANADA HONDA CREEK

          LAT_LONG:  N343622/W1203737

          HYDROCOD:  18060013
```

Fig. 25. Three CRT terminal display screens that show SAS® data observations from data sets VANDY.AMB, VANDY.PARMS, and VANDY.SITES.

5. CONCLUSION

This prototype test of the application of the ROI methodology and BDB at VAFB demonstrates the usefulness of incorporating spatial information into the analysis of environmental issues. The regional approach used in this demonstration incorporates base-line information on the geographic boundaries of a potential disturbance, characterizes the ambient conditions within the boundaries, and provides information on the potential magnitude of a disturbance within the ROI boundaries. The discussion of the different ROIs quantified in this report clearly demonstrates the dependence of a potential ROI on the type of disturbance and the questions asked by the investigator. Thus, the ROI methodology provides the context or framework within which to analyze the questions or issues. As such, the ROI methodology should be viewed as a technical management tool that allows one to incorporate spatial, as well as temporal, analyses in environmental impact analyses.

As the first step in an environmental impact analysis, the determination of a biophysical ROI aids the analyst in planning the location of monitoring stations and the selection of more detailed, site-specific study areas. In the past, a priori site selection of areas for intensive field work has not benefited from prior landscape or regional studies. This has often resulted in inappropriate data collection or the failure to link the study to other changes that occur in the environment. As an example of the need to relate regional-scale issues to potential site-specific problems, monitoring vegetation changes in the Barka slough, independent of agricultural irrigation, will not provide the information necessary to develop mitigation strategies (Section 4.3.). By first determining the ROI for water quantity at VAFB, the system linkages that affect water yield at the Barka slough become apparent, potential environmental problems are clearly defined, and appropriate mitigation strategies can be developed. This demonstration also shows the spatial links in environmental systems that can only be addressed in the context of the ROI.

The strength of a GIS tool in environmental problem solving is the automated bookkeeping for spatial data. The best analogy would be a comparison with an automated spreadsheet on a personal computer. The data are entered in cells or polygon; different types of spatial information (based on simple algorithms) can be merged; and simple "what if" scenarios can be developed. More importantly, complex spatial data can be displayed in understandable map formats. Because many maps need periodic updating, a computerized GIS, like a spreadsheet, eliminates the time-consuming chore of manual input and output of the mapped data.

To date, commercially available GIS systems do not support the array of statistical and numerical tools needed to analyze environmental problems. However, these links are critical if spatial analyses are to be truly integrated into environmental analyses. As a demonstration of this link, ORNL developed a dynamic data base for water quality that links a powerful data-base management and statistical program to the spatial data base of water-monitoring locations. The development of this data base allowed use of the extensive water-quality data that exists at VAFB. The term "relational data base" describes the links between the relatively static locational data in the GIS and the dynamic thematic data in the SAS® data base. By developing links between static and dynamic data sets, a flexible computing tool is then established for problem solving.

It is apparent from this prototype test that determining biophysical ROIs requires input from professional experts in a variety of different fields. Because the ROI concept is driven by careful issue definition and the application of specialized information and knowledge, it is fundamental for both technical and quality-control purposes to incorporate expert knowledge into the ROI process.

At present, there exists no "menu-driven" system to draw ROI isopleths. However, the generic rules that compose the ROI methodology are extremely useful for setting up a technical management plan to analyze various Air Force actions. Indeed, the actions investigated in this report illustrate the step-by-step processes needed to determine the ROI. Also, the BDB and data-base management activities discussed here can be used directly by Air Force personnel in their work environments. This should result in increased efficiency, cost savings, and timely input for management purposes.

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APPENDIX A

AIR-QUALITY IMPACTS OF A MODIFICATION TO AN EXISTING COAL-FIRED HEATING SYSTEM AT CHANUTE AIR FORCE BASE

Because the shuttle launch represents a unique disturbance that is not representative of most air-quality disturbances from sources at Air Force installations, the ROI methodology was also applied to a more common occurrence, the point source pollution associated with coal-fired boilers. The action investigated in this Appendix is an upgrade of the coal-fired heating system at Chanute AFB.

In this retrofit existing boilers were replaced by new, coal-burning boilers. The fuel characteristics used for the study were: an average heating value of 2.5 x 10^3 MJ/kg (10,830 MBtu/lb) and an assumed sulfur content of 3.7%. A permitting strategy for this facility is reported based on the material contained in Jacks and Woessner (1982). The common technique is demonstrated by determining the ROI affected by changes in air quality as a result of the operation of this facility.

use the facility was designed to replace existing uni units, the air-quality unit effects in question were based on the incremental increase in pollutant ncentrations as a resultlt of replacing the existing units, not on the total effects of the new unit. However, the methods used to determine the regions affected by the modifications were identical to those used for a new facility. The added complexity was due to determining the appropriate credit for reducing the emissions from the present facilities, which offset a significant portion of the emissions from the new facility.

These values were input to a dispersion model, CRSTER (U.S. EPA 1977), suitable for predicting the effects, both short and long term, from coal-fired facilities. The CRSTER model is approved by permitting authorities for use in analyses of facilities such as the one proposed for Chanute and is acceptable for the terrain surrounding the base. Full details of the input to the code are detailed in Jacks and Woessner (1982) and are not included in this study. The code is commonly used in dispersion studies, and is designed to use airport meteorological data and the nearest upper-air soundings.

Air-quality regulations can require compliance with both emission and ambient standards. Present regulations require compliance with strict emission limitations and proof of no significant deterioration in air quality following facility operation. Due to the size of this proposed modification and the emission offsets gained by replacing the older facilities, a major new source review was not required. Flexibility on the part of the state allows the modification to occur without resorting to a full-scale permitting exercise. The air-quality analysis in this study demonstrates the ROI based on a level of degradation in ambient air quality projected to occur during the operation of the new coal-fired facility. The ROI boundaries with concentration levels in the ROI show projected air-quality changes compared with the standards.

Ambient concentrations of regulated pollutants contain the contribution of the present coal-fired units. Therefore, the incremental increases in pollutants emitted are of interest, assuming that operating parameters affecting dispersion, such as stack height, gas flow rates, and exit temperatures, remain unmodified. The predicted increases in pollutant concentrations are compared with predicted concentrations resulting from operating the present units. The difference between the modeled concentrations of the present and proposed units can then be compared with regulations governing allowable increases for each of the pollutants of interest and can be added to present background concentrations to determine compliance with ambient air-quality standards.

The increased emissions over current conditions is presented in an ROI format for a representative strategy that should meet both permitting and heat-load requirements. In addition, a worst-case scenario, representing the maximum load that could be placed on the proposed facility, is analyzed. These cases may not represent the actual plant modification performed, but they do serve to bracket the impacts likely to occur and provide a reasonable estimate of the region affected by the modification. Emissions for these two scenarios are presented in Tables A.1 and A.2, and the assumed base-line emissions are presented in Table A.3.

Increases in pollutant concentrations predicted to occur for each of the scenarios are presented in Table A.4. These concentrations are the maximum ground-level increases calculated to occur anywhere in the vicinity of the facility. These values indicate that the only pollutant of concern is SO_2. Increases in SO_2 concentrations for each averaging time for the proposed modification minus

Table A.1. Proposed plant scenario[a]

Month	Coal consumption (Mg)	Coal consumption (Mg/h)	Average heat input (MBtu/h)	SO_2 emissions (lb/h)	Flow rate acem
January	6915	9.28	201	1195	61,908
February	5803	8.62	187	1110	57,596
March	6055	8.12	176	1046	54,208
April	4263	5.91	128	761	39,424
May	3425	4.59	99	591	30,492
June	3376	4.68	101	603	31,108
July	3852	5.17	112	666	34,496
August	3792	5.09	110	656	33,880
September	2488	3.45	75	444	23,100
October	3425	4.59	99	591	30,492
November	4734	6.56	142	845	43,766
December	6669	8.94	194	1152	59,752

[a]Based on 54,797 Mg/year of coal with an average heating value of 10,830 MBtu/h and a sulfur content of 3.38%.

Table A.2. Worst-case scenario based on maximum coal consumption per month

Coal consumption (Mg/month)	Average heat input (MBtu/h)	SO_2 emissions (lb/h)	Flow rate acem
12,133	300	1947	92,250

Table A.3. Representative base-line scenario[a]

Month	Coal consumption (Mg)	Coal consumption (Mg/h)	Average heat input (MBtu/h)	SO_2 emissions (lb/h)	Flow rate acem
January	6247	8.40	182	1181	56,056
February	5241	7.80	169	1097	52,052
March	5469	7.35	159	1033	48,472
April	3850	5.35	116	752	35,725
May	3094	4.16	90	585	27,720
June	3048	4.23	92	595	28,336
July	3481	4.68	101	658	31,108
August	3426	4.60	100	547	38,800
September	2246	3.12	68	439	20,944
October	3094	4.16	90	585	27,720
November	4278	5.94	129	835	39,732
December	6023	8.10	1175	1139	53,400

[a]Based on 1977 coal consumption of 49,497 Mg, with an average heating value of 10,830 MBtu/h and a sulfur content of 3.7%.

the present level are presented as Figs. A.1-A.3. Because the worst-case 24-h predicted concentrations are relatively high, these values are plotted in Fig. A.4. All incremental values are determined by subtracting predicted concentrations resulting from the operation of the present units from the predicted values for the scenario under study. The area enclosed by the dashed line represents the area affected by significant increases in pollutant concentrations, assumed to be 30% of the Prevention of Significant Deterioration (PSD) increment for this analysis. This area represents the ROI influenced by the modification. Because SO_2 is the pollutant that will have the largest impact region due to the amounts emitted, the ROI for SO_2 is the maximum area affected by the plant modification.

Included in Table A.4 are the allowable increases in pollutant concentrations for a major new source under the PSD regulations. Although these regulations may not apply to this modification, they do provide useful guidance as to significant levels of pollutant increases and can be used to bound the region affected by this proposed modification (the new ROI). The values presented in columns 2 and 3 of Table A.4 are for the calculated increases in pollutant concentrations for the two scenarios, without subtracting the concentrations from present base-line operations. Present ambient concentrations of the pollutants of interest were determined to be within ambient standards, and, since projected increases must be subtracted from present emission levels, violations of applicable standards will not result. Since the worst-case scenario represents a realistic upper bound on the emissions following conversion, the ROI bounded by the dashed line in Fig. A.2 represents the maximum area affected by the proposed modification, regardless of the actual conversion scenario that occurs.

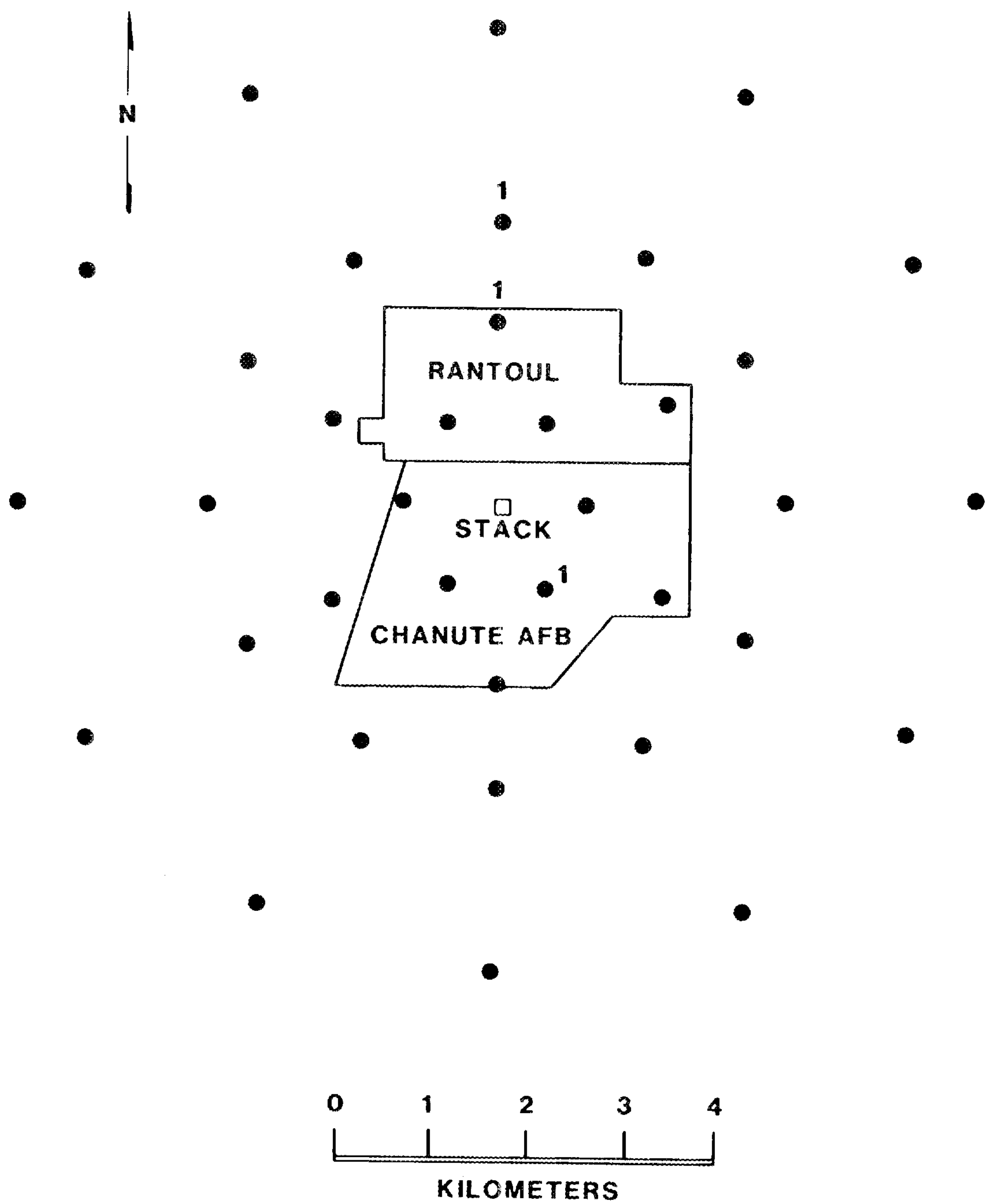
Table A.4. Maximum predicted increases in pollutant concentrations (in g/m^3) for the proposed and worst-case emission scenarios

	Proposed	Worst-case	Prevention of significant deterioration (PSD) increment
SO_2			
Annual average	14	18	20
24-h	107	143	91[a]
3-h	371	482	512[a]
TSP			
Annual average	<1	<1	19
24-h	2	2	37[a]
NO_x			
Annual	1	2	NA[b]
CO			
1-h	9	11	NA[b]
VOC			
3-h	3	3	NA[b]

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

[b]No PSD limits have been established for these pollutants.

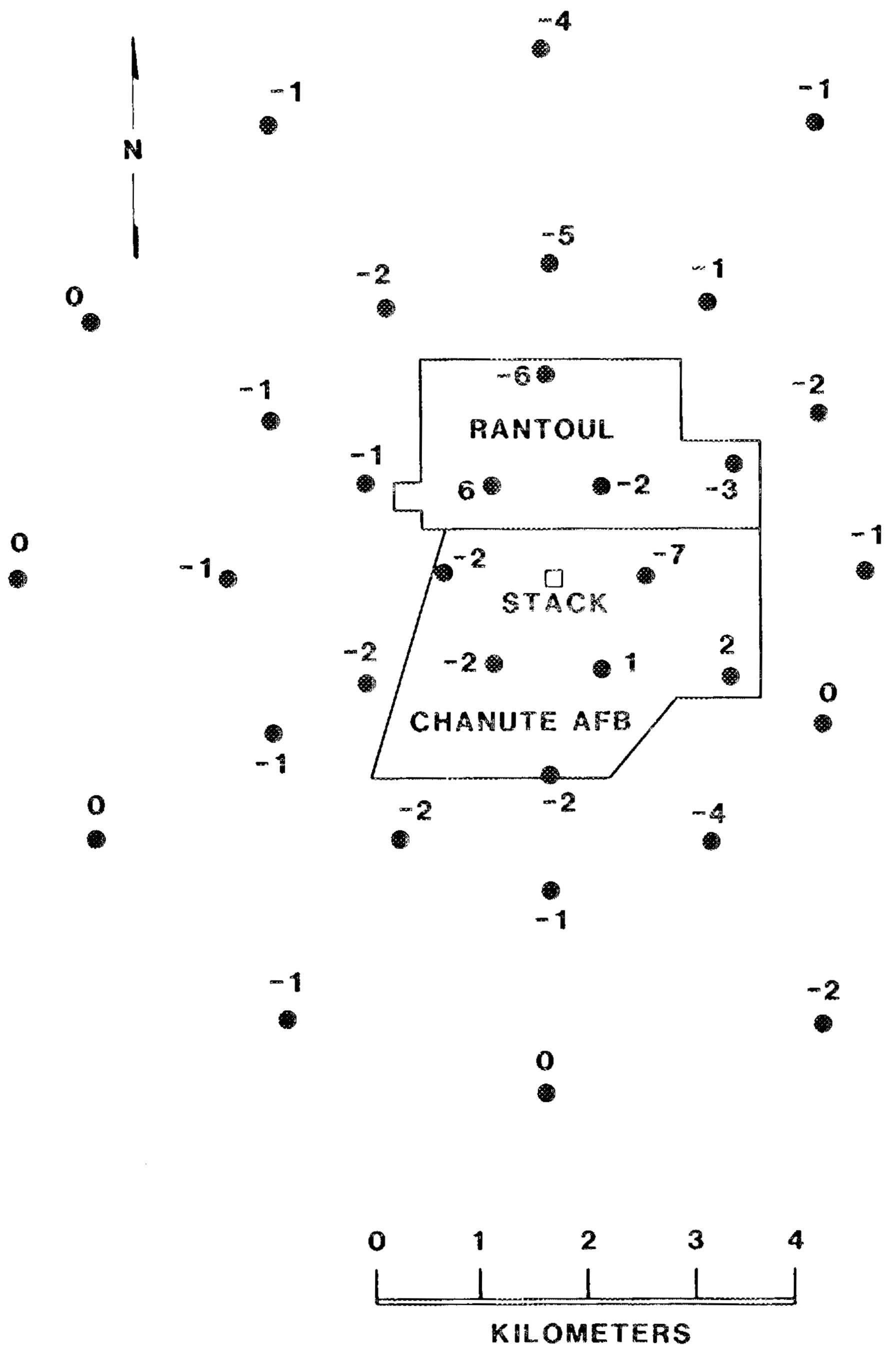
ORNL–DWG 85-1426



NO AREA AFFECTED IN EXCESS OF 30% OF PSD INCREMENT

Fig. A.1. Predicted annual average SO_2 ($\mu g/m^3$) increases over present concentrations, based on proposed modification scenario (proposed minus existing).

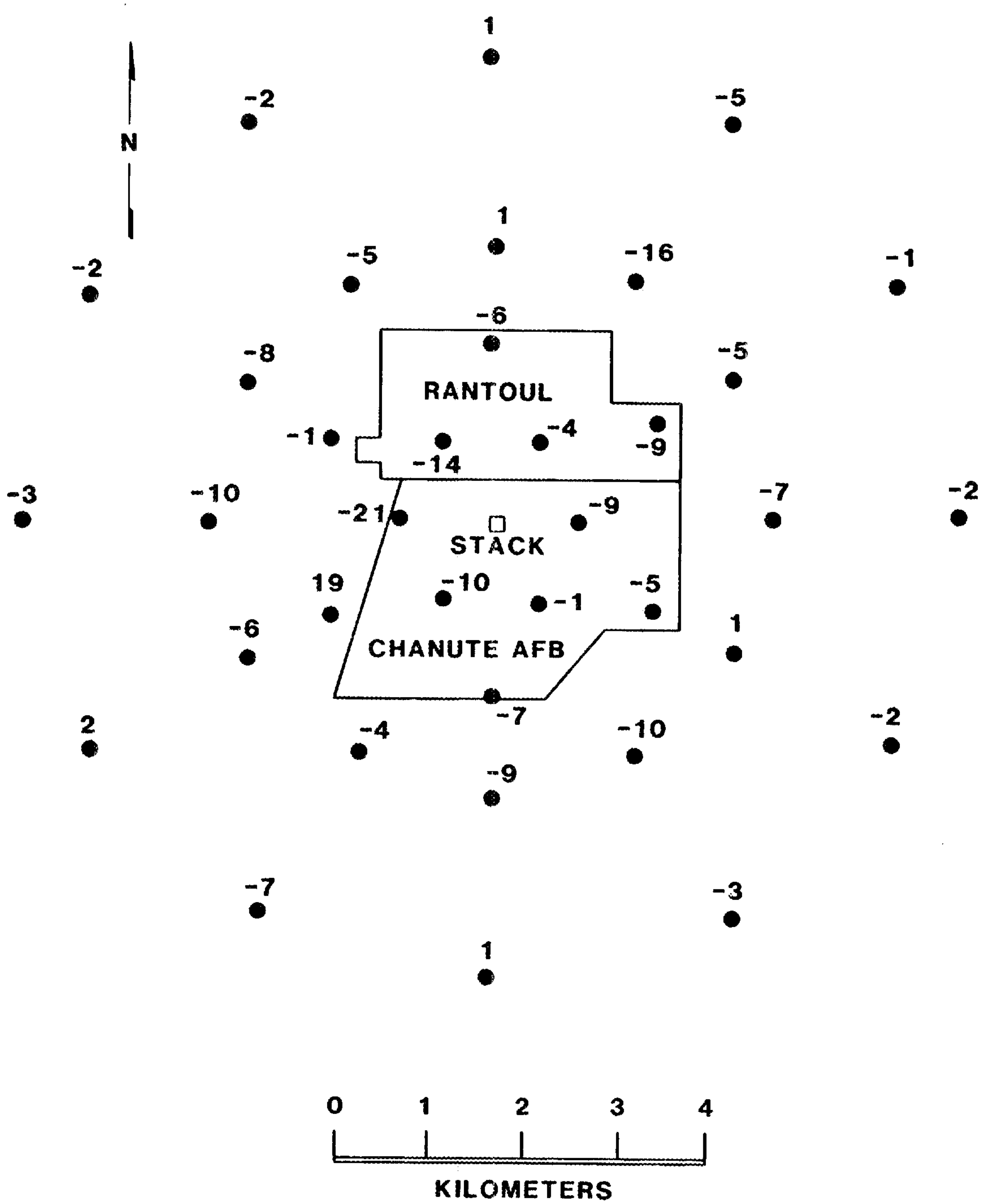
ORNL–DWG 85-1427



NO AREA AFFECTED IN EXCESS OF 30% OF PSD INCREMENT

Fig. A.2. Predicted maximum 24-h SO_2 ($\mu g/m^3$) increases over present concentrations, based on proposed modification scenario (proposed minus existing).

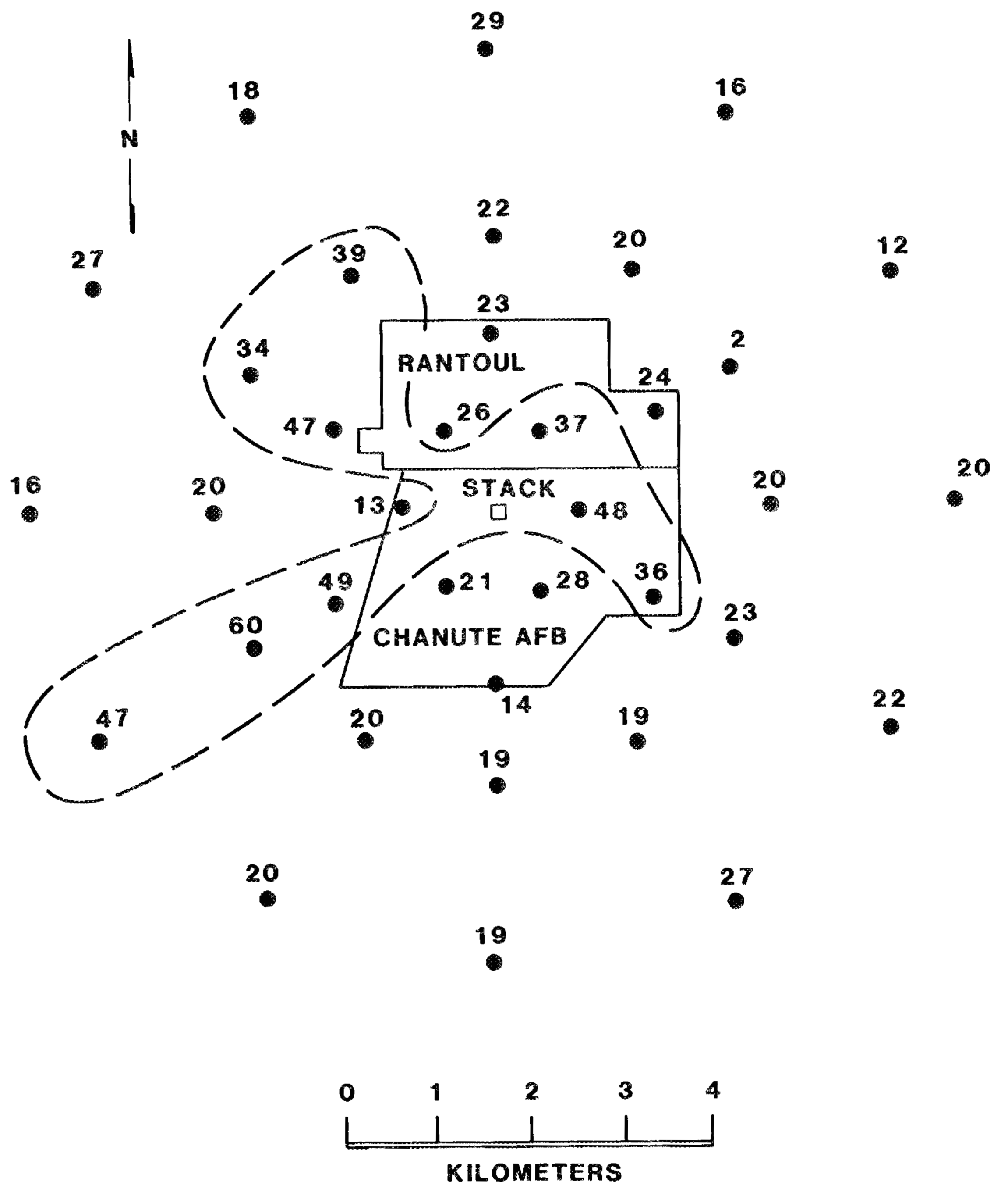
ORNL–DWG 85-1428



NO AREA AFFECTED IN EXCESS OF 30% OF PSD INCREMENT

Fig. A.3. Predicted maximum 3-h SO_2 ($\mu g/m^3$) increases over present concentrations, based on proposed modification scenario (proposed minus existing).

ORNL—DWG 85-1429



—— —— —— REGION AFFECTED BY PREDICTED INCREASES IN EXCESS OF 30% OF PSD INCREMENT

Fig. A.4. Predicted maximum 24-h SO_2 ($\mu g/m^3$) increases over present concentrations, based on proposed modification scenario (proposed minus existing). The ROI is outlined by dashed line.

APPENDIX B

INFORMATION ON USER ACCESS FOR SAS®

To access SAS/FSP the user must have one of the terminals listed on page 25 of the IBM Series/1 manual. After logging on to the Time-Sharing Option (TSO), the system replies "READY." If, for example, you want to access the surface water impoundment data set, VANDY.IMPND, follow this procedure:

NOTE: We will adopt the convention of user response printed in lower case and system response in upper case.

NOTE: A 'return' must be typed at the end of each user response.

READY

alloc f(VANDY) da('ENVSCI.ROI20586.WATER')

READY

alloc f(saslib) da('roi.sas.formats')
READY

sas

NOTE: There will be some introductory messages at this point.

NOTE: SAS will then prompt you with a line number and a '?'. 1? proc fsedit data=VANDY.IMPND; run; SAS now displays the Primary Option Menu, similar to the one shown on page 6 of the SAS/FSP manual (Screen 2-1) (SAS 1982b). The only difference is the data set name, which will be VANDY.IMPND. To edit the data set, or add or delete observations, select option 1. Various function keys (PF keys) necessary for using FSP are described in the FSP User's Guide. The specific keys will depend on the terminal being used. See the IBM Series/1 manual for details.

When finished editing a data set, the user can return to SAS by pressing the PF2 key (consult the IBM Series/1 manual to determine which key on your terminal is PF2).

The logoff procedure is as follows:

2? /*

NOTE: SAS will ask you if you used PROC FORMAT and want to save your formats. You should respond 'n' (no).

READY

logoff

Data values that represent '<' values have been stored as negative numbers. For example, <0.5 is stored as -0.5. This is done so that parameter values could be given a numeric type rather than a character type. A format is associated with all values that are '<' so that they will be printed with the '<' symbol. Future values that contain '<' values are also be entered as negatives.

For statistical analysis of parameters that may have '<' values there are several possibilities. All values with a '<' could be deleted. For example, if NITRATE were to be analyzed, the following SAS statements would create a new data set with all '<' values of NITRATE deleted:

```
DATA TEMP; SET VANDY.IMPND;
 IF NITRATE<0 THEN NITRATE=.;
```

Since '<' values are stored as negative numbers, this would set all negative values for NITRATE to missing values (in SAS a "." indicates a missing numeric value).

Another possibility for analyzing parameters with '<' values is to do a "worst-case" analysis. In this case a <0.5 would be treated as 0.5. The following SAS statements would accomplish this for NITRATE:

```
DATA TEMP; SET VANDY.IMPND;
 NITRATE=ABS(NITRATE);
```

Values that were recorded as ND (not detectable) on the data sheets were coded as '9999' when they were entered into the SAS data sets. They were later changed to the SAS special missing value of ".N.". The data could not be left as '9999' because this value would be included in any numerical analysis, which would be incorrect. An 'N' cannot be entered for a numeric value in full-screen mode, even if it is designated as a special missing value. Therefore, when new data are added to a data set using full-screen mode, to denote 'not detectable,' code a series of 9's, and then in SAS change the 9's to 'N.'

For example:

```
DATA TEMP; SET VANDY.IMPND;
 MISSING N;
  IF NITRATE=9999 THEN NITRATE=.N;.
```

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