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PLAN TO EVALUATE ACID-DEPOSITION
ISSUES IN THE STATE OF TEXAS
VOLUME I

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TEXAS ENERGY
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PLAN TO EVALUATE ACID-DEPOSITION ISSUES

IN THE STATE OF TEXAS^{3#}

VOLUME I

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FINAL REPORT

January 15, 1982

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EDF

EXECUTIVE SUMMARY

It has been demonstrated that rain and snow in certain sections of the United States (most notably in the East and Northeast) are more acidic than would be theoretically expected to occur from natural causes. It has been alleged that this "acid rain" produces a variety of adverse environmental effects, including increased acidification of lakes, reductions in aquatic floral and faunal populations, and decreases in forest and crop productivity. Some of the collected evidence seems to support the allegation that acid rain is responsible for the observed effects; however, much of this evidence is circumstantial. In reality, there are actually several causes that could explain the observed deleterious effects, acid rain being only one of them. In light of the allegations concerning acid rain and the emphasis placed on it in the public media, acid rain (more appropriately, "acid deposition") has become a controversial topic. It is a very complex scientific problem involving a wide variety of disciplines, the outcome of which may have potentially great consequences on both the environment and the economy.

Cognizant of the complexity of the issue and its potential importance, the Texas Energy and Natural Resources Advisory Council (TENRAC) has undertaken the development of a coherent, organized plan to investigate acid deposition in Texas. As a prerequisite to the plan, a preliminary evaluation of the acid deposition problem nationwide and its relevance to the State of Texas has been completed.

The available body of knowledge suggests that acid deposition is not a problem of immediate concern throughout most of Texas. The potential for a problem in the future may exist, however, in parts of east Texas where acid precipitation has been monitored and where the areas most sensitive to potential acid-deposition effects are found.



Monitoring of precipitation chemistry is currently being conducted at several sites in Texas, primarily in the eastern part of the state. A variety of sampling programs have been initiated by several governmental agencies, university researchers, and private concerns. Coordination is needed in this effort and much of the data are either unreliable, intermittent, or unreported.

Texas differs significantly with respect to acid deposition from more thoroughly investigated areas of the U.S. (the eastern and northeastern parts of the country and the Los Angeles Basin). There is no predominant category of anthropogenic emissions sources in this state. The meteorology of the state is substantially different from that of other parts of the country where acid precipitation has been monitored. The physical environment in Texas is different from and generally less sensitive to potential acid deposition effects than that found in the northeastern U.S. These differences make it impossible to confidently extrapolate to Texas the results of studies conducted in other areas of the country without in situ verification.

There is a variety of natural and anthropogenic sources of airborne material important to the process of acid deposition in Texas. In general, these sources are different in character than those found in other, more thoroughly investigated, areas of the country. Two of the primary acid deposition precursors are emissions of nitrogen oxides (NO_x) and sulfur dioxide (SO_2). The most recently available data on anthropogenic emission sources have shown that NO_x emissions far exceed SO_2 emissions in the state, which is the reverse of the situation found in the northeastern U.S. No single source category has been found to be a predominant SO_2 or NO_x producer. Impacts on Texas from anthropogenic sources in adjacent states and Mexico are possible but are undetermined at this time. Natural sources of airborne material can, possibly, be important in determining local and regional impacts. These natural sources include sea salts from the coastal areas of the state, biogenic sulfur emissions from soils and vegetation, and alkaline particles raised by wind erosion of west Texas soils.



Once acidic material and acid precursors enter the atmosphere, they are subjected to various transport, transformation, and removal phenomena. The process which governs these phenomena is the state's characteristic meteorology. Texas exhibits a wide range of meteorological regimes, on both a regional and a local scale. Due to the state's unique physiography and its location with respect to overlying atmospheric circulation patterns, the meteorological regimes pertinent to acid deposition in Texas are quite different from those found in other regions of the country where acid deposition has been studied more extensively.

These differences suggest that the chemistry associated with the formation and removal of acid deposition in Texas is probably unlike that investigated in other areas. Although the same general chemical mechanisms are present in Texas, the reaction, transformation, and deposition rates differ and the relative importance of individual mechanisms may likewise be different. In particular, the dry deposition of acidic substances (particulate matter or gases deposited in the absence of atmospheric moisture) appears to be of equal or greater magnitude than acid precipitation.

The probable impact of acid deposition on Texas lakes and streams, aquatic ecology, vegetation, soils, and the human environment have also been examined. In general, it is determined that the only region of the state which may be vulnerable to the deleterious effects of acid deposition in the foreseeable future is east Texas, and more especially, the timberlands of northeast Texas. This area is most susceptible due to the low buffering capacity of the soil and the vulnerability to acidity of the dominant vegetative species in the region. The remainder of the state is dominated by less susceptible vegetation and calcareous (alkaline) soils.

In west Texas (defined as that area of the state west of a line drawn approximately from Corpus Christi through Dallas-Fort Worth to the Red River), soils have sufficient natural alkaline buffering capacity to neutralize any acid deposition which may occur. Precipitation in this part of the state is generally non-



acidic and there have been no effects of acid deposition observed. Strongly acidic deposition, should it occur, could potentially cause isolated damage to vegetation. It is expected, however, that acid deposition would more commonly be beneficial to west Texas by providing needed sulfate and/or nitrate fertilization.

In east Texas, along and north of the upper Texas Gulf Coast, the precipitation is predominately acidic, with some samples in the Houston-Galveston area being as acidic as vinegar ($\text{pH} \leq 3.0$). Based on preliminary and incomplete data, most of this acidity appears to be due to the presence of sulfuric and nitric acids. No trend in precipitation chemistry has been detected nor have deleterious effects from acid deposition been observed. A preliminary analysis suggests that most of the soils and streams in this region, with the possible exception of those in the area around Longview, are generally resistant to purported acid deposition effects. No effort has been made to monitor specifically for acid deposition effects in this part of the state.

Based on this preliminary evaluation, the four areas of primary concern for the state are the following:

- 1) A single authority is needed to coordinate and direct acid deposition research in the state.
- 2) Monitoring of precipitation chemistry within the state should be continued and, in some areas, expanded in order to determine whether acid precipitation is occurring in Texas, to determine its severity and areal extent, and to establish a baseline for future reference.
- 3) A survey of potential effects of acid precipitation should be conducted in two critical areas of the state where acid precipitation has already been monitored. These areas are the Longview area and the Houston-Galveston area.



- 4) Advances in the state of the art of monitoring dry deposition should be closely tracked with the intention of establishing a dry deposition monitoring network as soon as a reliable, accurate monitoring methodology is developed.

A work plan has been developed consisting of a sequence of tasks directed toward these primary areas of concern. These tasks have been delineated by specification of objectives, rationale, and methodology, and have been assigned a relative priority based upon present understanding of the acid deposition problem in Texas.



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1.0 INTRODUCTION

It has been demonstrated that rain and snow in certain sections of the United States (most notably in the East and Northeast) are more acidic than would be theoretically expected from natural causes alone. This "acid rain" has been linked to a variety of adverse environmental effects, including increased acidification of lakes, reductions in aquatic flora and fauna populations, and decreases in forest and crop productivity. Although there is some evidence indicating that certain of the observed effects could be caused by acid rain, in general, there may be several causes for the observed effects, and the evidence linking the effects to acid rain is frequently only circumstantial. Similarly, evidence germane to the determination of the origin of acid rain is either circumstantial or based on preliminary studies.

The issue of acid deposition¹, a class of phenomena including acid rain, is becoming increasingly controversial, because the outcome has potentially major consequences for both the environment and the economy. The controversy is not easily resolved since acid deposition is a very complex scientific problem and its investigation involves a wide variety of scientific disciplines. Cognizant of the complexity of the issue and of its potential importance, the Texas Energy and Natural Resources Advisory Council (TENRAC) has undertaken the development of a coherent, organized work plan to investigate acid deposition in Texas, as a first step in organizing existing information and in planning future activities.

¹The phrases "acid rain," "acid precipitation," and "acid deposition" are often used interchangeably. In this document, "acid deposition" refers to the deposition upon the surface of the Earth of any acidic material by any process. "Acid precipitation" refers specifically to wet deposition associated with rain, snow, sleet, or hail. The phrase "acid rain" is avoided as being technically incorrect and misleading. A more complete discussion of terminology is presented in Sec. 3.1.

The three primary objectives of the project are (1) to qualitatively evaluate the probable severity of an acid deposition problem, if any, in Texas and to place it into its proper perspective relative to other areas of the country, (2) to evaluate critical aspects of the acid deposition question as they relate specifically to Texas, and (3) to formulate a plan of specific, prioritized tasks which must be accomplished in order to resolve critical issues and to quantify the magnitude of any acid deposition problem, if one exists. The project was not conceived with the intent to conduct original research nor to actually execute any of the tasks developed as part of the plan. Rather, the concept was to review the existing body of information, determine what questions remain to be answered concerning acid deposition in Texas, and develop a series of tasks which would enable the state to respond to those questions.

This report presents the methodology used to accomplish the project objectives and the conclusions which have been reached concerning acid deposition in Texas. The information used to support these conclusions and to develop the work plan is summarized in Sec. 3.0 of this report and is presented in detail in a separate source document entitled "Acid Deposition in Texas: Technical Summary and Perspective." The plan objectives and the tasks required to achieve these objectives are presented in Sec. 5.0 of this report.

2.0 PROJECT METHODOLOGY

The first step in developing the work plan was to conduct an extensive search of the existing literature. This task began with an automated search of computerized bibliographical abstracts files. The abstracts were reviewed by experts in various scientific disciplines to ascertain which references would be most useful for the study.

The pertinent literature was perused to determine important mechanisms and issues associated with acid deposition. Experts in each discipline determined which important questions remained to be answered and who in the scientific community was best qualified to answer these questions. Key researchers in acid deposition were interviewed for the dual purposes of obtaining the most up-to-date information concerning acid deposition and of getting answers, if they existed, to important questions generated by the literature review.

The timing of this work was particularly opportune as three important conferences dealing with various acid deposition issues were held during the period of this study. The Conference on the Effects of Acid Precipitation on Ecological Systems in the Great Lakes was held April 1-3, 1981. "The Challenge of Atmospheric Deposition" was held in Chicago on May 19-20 of this year. Most recently, the annual meeting of the Air Pollution Control Association was held June 21-26 in Philadelphia. Several technical sessions at this meeting dealt exclusively with acid deposition or atmospheric chemistry. Each of these conferences was attended by a member of the project team.

The results of the literature review and the investigator interviews were applied to the situation in Texas insofar as possible. This extrapolation of research conducted in other geographic areas to the Texas environment was based primarily on the experience of each team member with regard to his or her discipline in Texas.

The conclusions for each discipline formed the basis for the synthesis of a single coordinated plan. This effort consisted of prioritizing individual recommendations, developing a brief summary of the rationale for each recommendation, and describing the scope of work needed to accomplish each of the recommended tasks.

3.0 THE NATURE OF ACID DEPOSITION IN TEXAS

3.1 CHARACTERISTICS OF ACID DEPOSITION

Natural precipitation contains carbonic acid due to the absorption and dissolution of atmospheric carbon dioxide (CO_2). When in equilibrium with the atmospheric concentration of CO_2 , a pure water-carbonic acid solution is mildly acidic ($\text{pH} = 5.6$ at 77°F). By convention, precipitation which is more acidic than this is termed "acid precipitation;" precipitation which is less acidic than this is termed "alkaline precipitation." "Wet deposition" is a more general term which includes acid precipitation as well as any other process which deposits aqueous acidic solutions at the surface of the Earth (e.g., fog or dew). "Dry deposition" refers to a group of processes which introduce acidic substances to the environment in the absence of atmospheric moisture. It includes the deposition of acidic particulate matter and gases. It also includes the deposition of gases which react with substances at the surface to form acids. All deposition terms are used to denote both the process involved and the amount of material deposited.

Acid deposition is a complex and, as yet, incompletely understood phenomenon involving emissions, chemical conversion, transport, and removal mechanisms. Acidic substances originate either as primary acids or acid precursors. Primary acids are acidic substances transported and deposited without undergoing any chemical transformation. Acid precursors are substances (primarily gases) which can be converted to acids either during transport or subsequent to deposition. The acids formed from precursors are called secondary acids.

The net acidity formed in precipitation can be viewed as the result of the neutralization of strong acids by bases. The two strong acids which account for the majority of the measured acidity are sulfuric acid (H_2SO_4) and nitric acid (HNO_3). Hydrochloric (HCl) and other acids may also be present. The principal

alkaline components found in acid precipitation are carbonaceous substances (e.g., calcium carbonate), soil-derived material, and ammonium. Dry deposition consists of particles of sulfates and nitrates and of gases, such as HNO_3 . Dry deposition also includes the deposition of acid precursor gases such as sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) which are oxidized and hydrolyzed after deposition to form H_2SO_4 and HNO_3 , respectively. These and other precursors (e.g., hydrogen sulfide) are also converted to secondary acids during transport .

Catalysts are thought to play an important role in the formation of both primary and secondary acids. Catalytic reactions within the combustion zones of spacing industrial boilers, for example, accelerate the formation of primary acids. Hydrocarbons and hydrogen peroxide accelerate the conversion of acid precursors to secondary acids during transport.

Once acids, acid precursors, and alkaline substances are emitted into the atmosphere, their motions are dominated by the motion of the air itself. Three scales of transport can be defined. Short-range transport includes distances less than approximately 25 km, over which primary acids dominate. Medium-range transport is a region of transformation and occurs over distances of 10-500 km. Secondary acids dominate at long range distances in excess of 100 km. The distances associated with these scales overlap, depending on the meteorology and the concentration and number of reactants present. In Texas there are very few data concerning the rates of chemical transformation available, making the specification of ranges difficult.

During transport, particles and gases undergo a variety of chemical and physical transformations. These include homogeneous and heterogeneous conversions of acid precursors to secondary acids. Some of these are photochemical and/or catalytic in nature. A major gap in the current understanding of acid deposition is the mechanism of conversion which take place in clouds. Physical transformations include changes in state (e.g., from a gas to a liquid), dissolution of gases and solids

in condensed atmospheric water, and the coagulation of small particles. The rates at which these transformations occur depend on the concentration and variety of reactants present and on the meteorological conditions encountered. Texas appears to have a different meteorological regime and mix of sources than that encountered in other parts of the country (Sec. 3.2). Coupled with a lack of in situ measurements, these conditions make it difficult to specify transformation rates in this state or to extrapolate results concerning transformation rates from studies in other areas to Texas.

Acidic materials are removed from the atmosphere during precipitation by rainout and washout. Rainout is the process of collecting reactants into cloud droplets which then grow to precipitable size. Washout occurs when raindrops collect gases and particles as they fall below cloud base.

Dry deposition may be a more active removal mechanism in Texas than wet deposition. This is due in part to the large proportion of anthropogenic nitrogen oxides (NO_x) emissions in the state. NO_x is converted to HNO_3 , which is removed primarily by dry deposition mechanisms. The climatology of Texas, with less frequent precipitation events, more sunshine, and higher temperatures than those of the northeastern U.S., also enhances the relative contribution of dry deposition.

3.2 ATMOSPHERIC EMISSION SOURCES

There are four categories of sources of airborne material important to the study of acid deposition in Texas. These include: in-state anthropogenic sources, out-of-state anthropogenic sources, natural sources along the coastal plain, and windblown soils.

The 1973 Texas Air Control Board (TACB) emissions inventory, although somewhat outdated, is the most accurate estimate available of acid deposition impacts from Texas emission sources. It indicates that statewide annual emissions

of NO_x were almost 75% greater than SO_2 emissions in 1973. This value was even higher in major metropolitan areas. These data imply that Texas has a significantly different emissions character than that found in the Northeast, where SO_2 emissions are dominant. Tables 3-1 and 3-2 indicate the ranking of SO_2 and NO_x emission sources in Texas by source category. The leading contributor to SO_2 emissions in 1973 was petroleum industry process losses, with 35% of the statewide total. Industrial fuel combustion accounted for 39% of the state's NO_x emissions in 1973, just slightly more than the contribution from transportation sources. Approximately half of the state's SO_2 and NO_x emission sources are located east of a line from Corpus Christi, through Dallas-Fort Worth to the Red River. It is expected that a more recent inventory would show an increased contribution to statewide SO_2 emissions by electric power generation and industrial fuel combustion. The category of transportation has probably demonstrated the greatest increase in NO_x emissions. Changes in relative quantities of anthropogenic SO_2 and NO_x emissions may occur in the future as a result of the development of lignite-based industry in Texas.

The impact on Texas of acidic emissions from neighboring states and Mexico is generally undetermined. It is doubtful that emissions from New Mexico and western Oklahoma contribute significantly to acid deposition in Texas, since the density of anthropogenic sources in those areas is low and since the soils in those regions are alkaline in nature. States to the east and northeast (eastern Oklahoma, Arkansas, and Louisiana) probably do contribute to the acid deposition burden in Texas, because of the proximity of industrialized areas and the lack of buffering material in east Texas soils. This contribution is ameliorated by the less frequent occurrences of east and northeast winds in Texas. Emission sources in Mexico may also affect acid deposition in Texas, due to the less stringent pollution controls applied to emission sources there.

Two important natural sources of acidic material also have a potential impact on acid deposition in the state. The first of these sources is sea salt aerosols from the Gulf of Mexico and coastal marshes. There is some disagreement

TABLE 3-1
 RANKING OF 1973 SO₂ EMISSION SOURCES
 BY SOURCE CATEGORY

Rank	Source Category	Total 1973 SO ₂ Emissions (1000 tn/yr)	Percent of Total SO ₂ Emissions for the State (%)
(1)	Petroleum Industry Losses	425	35
(2)	Metallurgical Industry Process Losses	279	23
(3)	Electric Power Generation	146	12
(3)	Industrial Fuel Combustion	146	12
(5)	Chemical Industry Process Losses	109	9
(6)	Transportation	49	4
(7)	Mineral Industry Process Losses	24	2
(8)	Area Source Fuel Combustion	12	1

Source: Texas Air Control Board (TACB). 1973. A Summary of Air Pollution Emissions in Texas. Austin, Texas.

TABLE 3-2
 RANKING OF 1973 NO_x EMISSION SOURCES
 BY SOURCE CATEGORY

Rank	Source Category	Total 1973 NO _x Emissions (1000 tn/yr)	Percent of Total NO _x Emissions for the State (%)
(1)	Industrial Fuel Combustion	823	39
(2)	Transportation	739	35
(3)	Electric Power Generation	443	21
(4)	Area Source Fuel Combustion	63	3
(5)	Industrial Process Losses	42	2

Source: Texas Air Control Board (TACB). 1973. A Summary of Air Pollution Emissions in Texas. Austin, Texas.

regarding their actual contribution to the overall acid budget. The second potentially important natural source of acidic material is that of biogenic sulfur emissions from the coastal marshes and mud flats.

The alkaline soils of west Texas play an important role in determining the significance of acid deposition. First, they tend to neutralize acidic material deposited directly on the west Texas surface. Second, soil dust from west Texas is often entrained into the atmosphere by the wind and transported across the state. The distance over which it is transported depends on wind speed, atmospheric stability, and the occurrence of precipitation. Additional alkaline material associated with soils, such as lime, fertilizer dust, and ammonia, can also be entrained into the atmosphere and transported in the same manner as soil dust.

3.3 ACID DEPOSITION MONITORING EFFORTS

Acid deposition monitoring in Texas on a consistent basis has begun only within the past few years. At present, there is still a need for coordination in monitoring techniques among the several researchers and government agencies collecting acid deposition data.

Historically, precipitation pH was first monitored in Texas in 1959. Precipitation chemistry was monitored at Amarillo, Brownsville, and San Angelo between 1959 and 1964. The annual average pH for the monitoring period was approximately 6.1 at all three sites. Minimum monthly values were below 5.0. The TACB sampled precipitation pH in Houston and Austin in the early 1970's. The values monitored were 6.0 and 6.5, respectively. The WMO/NOAA/EPA network operated two sites in Texas during the 1970's: one at the Victoria NWS station and one at San Angelo. The average precipitation pH measured at Victoria indicated the presence of slightly acidic to neutral rain, while the San Angelo readings indicated alkaline rain. Other precipitation pH values were recorded in 1975 in Austin (mean pH of 6.1) and Laredo (single pH measurement of 6.5). These early monitoring

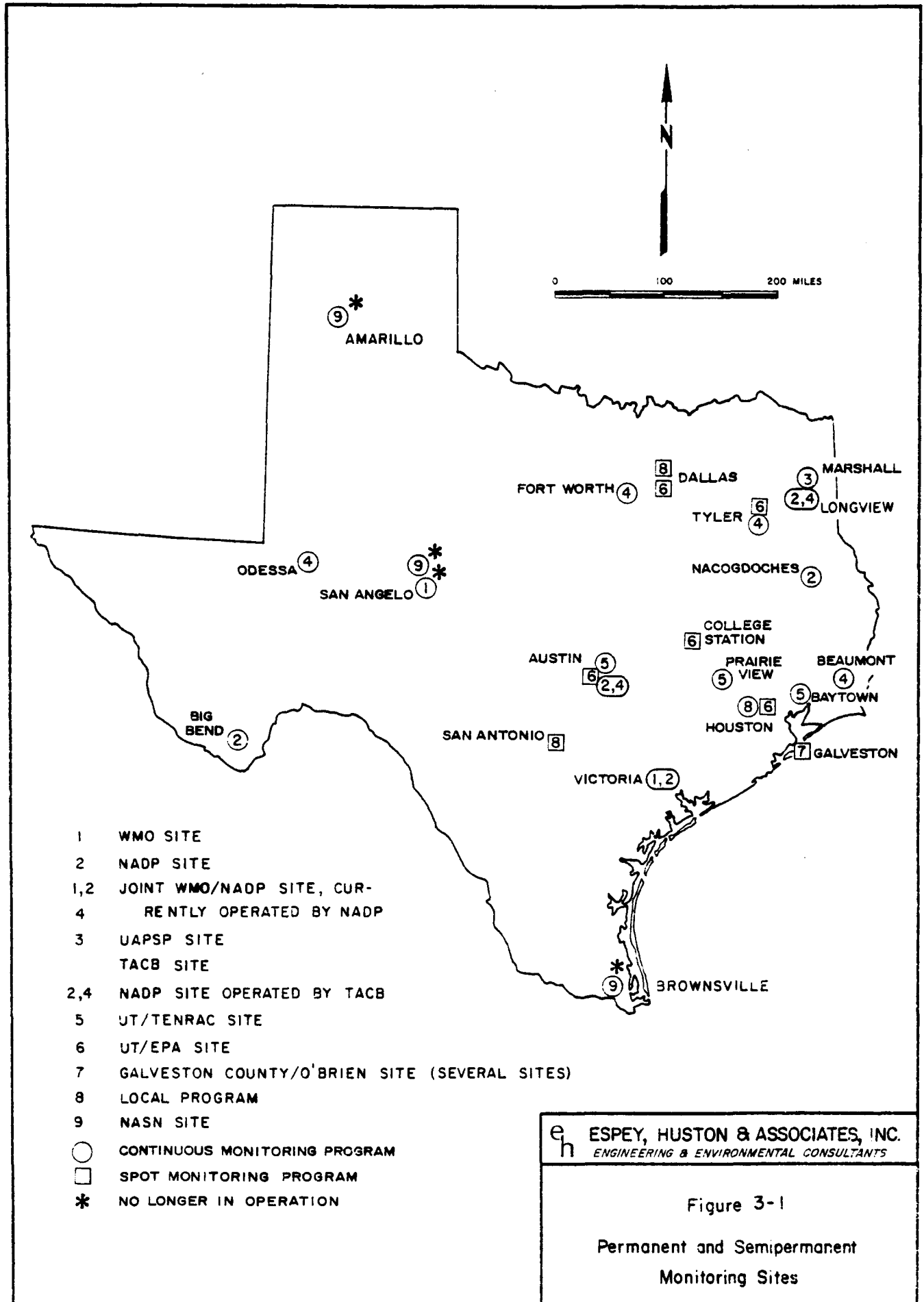
efforts produced data of questionable validity due to the use of unproven or undocumented sampling methodologies, inappropriate or inconsistent sampling frequencies, and/or insufficient quality assurance.

At present, a number of distinct acid deposition monitoring programs are either in operation, or are about to commence operation within the state (Fig. 3-1). A variety of collection equipment is used, with most of the emphasis being on the collection of wet-only samples. Most of the programs have only recently begun routine operation and thus much of the data are yet unavailable, unreported, and/or unverified. A summary of wet deposition data from Texas monitoring programs is shown in Table 3-3.

Preliminary data results indicate the presence of routinely acidic precipitation along the upper Gulf Coast and throughout most of east Texas. On the other hand, the precipitation in west Texas appears to be predominately alkaline. The dividing line appears to pass through Victoria, Austin, and Dallas-Fort Worth.

The National Atmospheric Deposition Program (NADP) will eventually operate five sites in Texas at Big Bend National Park, Victoria, Nacogdoches, Longview, and Austin. The first three stations are in operation at present. Each is or will be equipped with an Aerochem Metrics wet/dry deposition monitor, a Belfort recording rain gauge with event marker, a balance, a pH meter, and a conductivity meter. All samples are sent to the Illinois State Water Survey for analysis. During the past six months, precipitation pH measurements have averaged 5.8 at Big Bend National Park and 4.9 at Victoria. Initial pH readings at the newly-operational Nacogdoches site have ranged from 4.5 to 4.7.

The TACB has been operating its own network of rainfall collection monitors since 1979. The network consists of four sites located at Beaumont, Tyler, Odessa, and Fort Worth. Sampling is strictly on an event basis, and only during the 40-hour work week. The sampler is a funnel-and-bottle device. Samples are



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Figure 3-1
 Permanent and Semipermanent
 Monitoring Sites

TABLE 3-3
SUMMARY OF WET DEPOSITION DATA
FROM TEXAS MONITORING PROGRAMS

Sponsor	Location	Dates of Operation	Mean pH*	pH Range
NASN	Amarillo	1959-1964	6.1	4.8-7.4
	Brownsville	1959-1964	6.0	4.6-6.9
	San Angelo	1959-1964	6.3	4.7-7.3
WMO	San Angelo	1972-1980	6.4	N/A-7.8
	Victoria	1972-1980	5.7	N/A
NADP	Big Bend	1980-current	5.8	N/A-7.5
	Victoria	1980-current	4.9	4-7
	Nacogdoches	1981-current	4.6**	NP
	Longview	N/O	—	—
	Austin: McKinney Falls State Park	N/O	—	—
UAPSP	Marshall	1981-current	N/P	N/P
TACB	Beaumont	1979-current	5.6	3.6-6.6
	Tyler	1979-current	4.8	3.5-5.8
	Odessa	1979-current	N/A	5.2-6.8
	Fort Worth	1980-current	N/A	4.7-6.6
UT/TENRAC	Prairie View	1980-current	NP	NP
	Baytown	1980-current	NP	NP
	Austin Municipal Airport	1980-current	NP	NP
UT/EPA	Austin	Spot Monitoring	NP	3.9-7.0
	Houston	Spot Monitoring		4.0-4.5
	Dallas	Spot Monitoring		3.8**-6.8
	Tyler	Spot Monitoring		4.4-7.6
	College Station	Spot Monitoring		3.6-6.2
Galveston County/ O'Brien	Galveston County (Several Sites)	1979-1980	4.1	3.0-6.2
Local Programs	Houston	1979-current	NP	NP
	Dallas	Spot Monitoring	NP	NP
	San Antonio	Spot Monitoring	NP	NP

* Representative value. May be arithmetic mean pH, weighted mean pH, or other measure of the mean value.

** Preliminary data.

NP - Not published.

N/O - Not operational.

N/A - Not available.

NASN - National Air Sampling Network

WMO - World Meteorological Organization.

NADP - National Atmospheric Deposition Program.

UAPSP - Utility Acid Precipitation Study Program.

TACB - Texas Air Control Board.

UT/TENRAC - University of Texas/Texas Natural Resources Advisory Council.

UT/EPA - University of Texas/Environmental Protection Agency.

chemically analyzed at the central laboratory. The results of observations measured thus far show a general occurrence of acid precipitation at Beaumont and Tyler, alkaline precipitation at Odessa, and both at Fort Worth.

The Utility Acid Precipitation Study Program (UAPSP) is scheduled to initiate monitoring in October 1981 at a site near Marshall. The monitor will be sponsored by Southwestern Electric Power Company. Collection of wet-only samples will be on an event basis, using an Aerochem Metrics sampler. Precipitation rates will be measured with a NWS-type recording rain gauge.

The University of Texas at Austin (UT) is currently operating a monitoring program under the sponsorship of TENRAC. Data are being collected at Prairie View, Houston Highlands (Baytown), and Austin. Results of this monitoring effort have not been officially reported yet, but preliminary findings show the occurrence of acid precipitation at all three sites.

A second UT program, sponsored by the EPA, is also being conducted. The program is designed to monitor areal variations in precipitation chemistry in Texas and to evaluate temporal changes in precipitation chemistry during single storm events. Samples are collected with a van-mounted Lopez sequential collector. Data from this program have not been released pending completion of the study.

A one-year study during 1979-80 using funnel-and-bottle samplers has been conducted in Galveston County. Preliminary unpublished results show the occurrence of very acidic precipitation. The cities of Houston, Dallas, and San Antonio have also conducted intermittent precipitation monitoring. Generalized results have shown the occurrence of predominately acidic precipitation in Houston, mildly acidic precipitation in Dallas, and non-acidic precipitation in San Antonio.

3.4 VEGETATION IMPACTS

There are both positive and negative effects of acid deposition on vegetation. Plants may derive benefits from acid deposition in the form of sulfate and nitrate fertilization. However, if the acidity of the deposited material is too great (i.e., if the pH is too low) or if the soil cannot sufficiently buffer the acid, there are negative effects.

Nearly all plants derive at least a portion of their nutritional requirements from the atmosphere by exchanging gases, particulate matter, and moisture through plant surfaces. Because of this, vegetation is actively involved in the deposition process. Airborne acids and acid precursors enter plant systems through a variety of pathways. Gaseous acid precursors, such as SO_2 and NO_x , are absorbed through plant stomata and converted internally to sulfuric and nitric acid, respectively. Gaseous nitric acid is also absorbed directly from the atmosphere. Acidic particulate matter is deposited on plant surfaces where it enters the plant after being dissolved in water transpired by the plant or derived from the atmosphere. Acid precipitation reacts directly with plant surfaces and is absorbed by plant roots. Precipitation also washes the upper canopy cover of previously deposited dry acidic material, which is then deposited on lower plant surfaces or the soil. Acids in the soil can release aluminum and other heavy metals, which are absorbed by the root system.

Short-term deleterious effects may be observed as foliar lesions. Other effects, such as erosion of protective surfaces, alteration of exudation processes, disruption of guard cell functioning, and metabolic changes, can affect the health of a plant indirectly. Indirect effects may be in the form of reduced nitrogen fixation, decreased photosynthesis, reduced gas exchange, increased penetration by pathogens, or premature aging. Any of these effects can reduce plant productivity. Ironically, acid deposition tends to have a greater effect (either positive or negative) on healthy plants because of their greater gas exchange rates.

Acid deposition may also induce long-term deleterious effects involving subtle interactions of vegetation with soil and hydrology. Increasing the acidity of poorly buffered soils can cause direct injury to roots, reduce the nutrient uptake efficiency of roots, and increase the absorption of toxic metals, especially aluminum. The long-term exposure of ecosystems to acid deposition can disrupt the recycling of nutrients upon which plant productivity depends. Chronic exposure to short-term stress leads to increased plant susceptibility to pests and disease and to a general decline in productivity.

Northeast Texas is probably the area of the state most prone to negative acid deposition effects due to the potential sensitivity of both the native vegetation and some soils in that region. The oak-pine forest association, the dominant native vegetation type in the region, has been found to be particularly vulnerable to negative effects. Boggy wetlands are also thought to be sensitive to acid deposition. Timberlands on poorly buffered sandy soils in northeast Texas are prone to both short- and long-term acid deposition effects. So long as the acidity is not extreme, effects on croplands in the area are probably overshadowed by the use of artificial fertilizer and lime. Long-term effects on crops in northeast Texas are possible, however, due to soil degradation, decreased nutrient recycling, and increased susceptibility to other stresses.

3.5 SOILS IMPACTS

The acidification of soils is a natural weathering process which occurs continuously. The formation of soils from parent material is an acidifying process. Natural mechanisms which contribute acid to the soil include biological nitrogen fixation, precipitation which is naturally acidic (due to the absorption of nitrates and nitrites generated by lightning and released from biological decay, and to the absorption of atmospheric CO_2), decomposition of dead plants, and oxidation of pyrite and other metal sulfides. The acidification of crop soil is greatly accelerated by the addition of fertilizers. Acid deposition is an additional mechanism which contributes acid to the soil and accelerates soil acidification.

In excessively alkaline soils, acid deposition has a beneficial effect in that it reduces the native alkalinity and contributes sulfate and nitrate fertilizer. Fertilization due to acid deposition is also a benefit to well-buffered soils in which the increase in acidity is mitigated or overshadowed by existing soil conditions. In poorly buffered soils, acid deposition accelerates the natural acidification process, leading to two deleterious effects. The soil loses nutrient cations due to a reduction in the cation-exchange capacity of the soil. Calcium ions and co-ions (e.g., bicarbonate) are the primary cations lost, but magnesium, potassium, and sodium ions are also leached. Acidification also increases the mobility and availability to plants of toxic metal species present in the soil (e.g., aluminum, manganese, and iron). In the extreme cases, this process leads to soil contamination, phytotoxicity, and, ultimately, heavy metal contamination of ground water. In less extreme cases, nutrient recycling is reduced because the leaching of metal cations reduces the number and variety of soil organisms.

Within Texas, soils in all but the eastern part of the state are not expected to suffer any deleterious effects from acid deposition for the foreseeable future. Combinations of soil types and organic matter throughout most of the state provide a high buffering capacity. Acid deposition is probably of benefit to soils with excessively high lime concentrations, such as those found in west Texas.

Only soils in the East Texas Timberlands resource area, in the vicinity of Longview, appear to be susceptible to negative effects of acid deposition. These are sandy soils, particularly at the surface, are acidic in nature, and are low in subsurface organic matter. As a result, these soils are low in alkaline material and have low buffering capacity.

3.6 SURFACE WATER IMPACTS

Acidic substances enter surface water systems either through atmospheric deposition or as surface runoff. Runoff may contain organic acids from the

natural decomposition of detritus or a variety of inorganic acids from acid deposition and anthropogenic processes. Whether or not these acidic substances adversely affect water quality depends upon the existing alkalinity of the surface water which, in turn, depends primarily on the carbonate and bicarbonate present. Weak acids entering alkaline surface waters high in calcium tend to precipitate calcium carbonate; such waters are generally immune to acidification and to adverse acid deposition impacts.

In lakes and streams subject to acidification, water quality suffers from increased acidity and decreased carbonate or hydroxide concentrations. This leads to increased concentrations of heavy metals, especially aluminum. Aluminum is toxic to fish at relatively low levels and can render phosphate unavailable for aquatic biota. Early changes in water quality are usually very slow and may be imperceptible until the buffering capacity of the soil and water is depleted. Once the buffering capacity is gone, however, a rather abrupt change in water chemistry can occur.

Three indicators can be used to follow trends in surface water acidification. Of these, the calcite saturation index (CSI) is probably the most useful, as it can be used to assess the future susceptibility of a given body of water based on its current alkalinity and calcium and hydrogen ion concentration. The sulfate-to-bicarbonate ratio can be used to follow trends in sulfuric acid deposition damage. Finally, the pH is a useful measure of the existing water quality. As the pH of a lake or stream may reflect the sum of several acid input mechanisms (one of which being associated with acid deposition), it cannot be used alone as a trend indicator for wet or dry acid deposition.

Lakes and streams in west Texas are not subject to acidification due to acid deposition. Calcium carbonate, abundant in the soils, lakebeds, and streambeds of the region, will be able to mitigate any adverse effects which could be induced by acid deposition. A preliminary analysis of four east Texas streams indicates that

deleterious effects of acid deposition have not been observed and are probably unlikely to occur in the near future in most rivers. This preliminary analysis indicates that at least one river (the Angelina) could be susceptible to acid deposition effects in the future.

3.7 AQUATIC ECOLOGY IMPACTS

Aquatic biota cannot be affected by acid deposition until changes in water quality occur; however, once water quality begins to change, significant stress is placed on many organisms in the aquatic system. High concentrations of strong acids and heavy metals affect all links in the food chain: bacteria, phytoplankton, zooplankton, invertebrates, some vertebrates, and macrophytes. There are effects from acidity, an imbalance in the cation/anion ratio (particularly with regard to sulfur), and heavy metals, as well as secondary effects from reduced nutrient input and alterations in predator-prey relationships.

Algae are impacted by both acidification per se and reduced nutrient input due to lower decomposition rates. A decline in phytoplankton biomass poses severe food limitations for algal grazers such as zooplankton. Effects of acidification observed in fish include: failure to spawn, low serum calcium in females, spinal deformities, changes in average sizes of age classes, and disappearance of sensitive predator species while less sensitive prey species increase. Most fish species eliminations appear to be gradual, a result of reproductive failure rather than direct mortality of adults.

Deleterious acid deposition effects on aquatic systems in west Texas are highly unlikely since soil and bedrock geology in that region effectively prohibit surface water acidification. In northeast Texas, damage to aquatic biota is possible if the rate of lake and stream acidification is increased. Because initial changes in water quality may be imperceptible until buffering capacity is depleted, changes in aquatic species may be used as indicators of potential future acidification problems.

3.8 HEALTH AND MATERIALS IMPACTS

There are no confirmed direct or indirect effects of acid deposition on human health. Indirect health effects have been postulated to exist due to the release of toxic metals. Metals can enter the body by consumption of contaminated fish, plants, or water. Acidic water, free of heavy metals, can become contaminated by leaching metals from household plumbing. These effects do not appear to be of immediate concern in Texas because of the general resistance of soils and surface waters to acidification.

A variety of materials used by man are affected by acid deposition. The most pronounced effects are observed on stone and metal surfaces. Marble, limestone, concrete, calcareous sandstone, and lime plaster suffer both surface and structural damage from acid deposition. SO_2 reacts with calcite in these materials to form gypsum which then dissolves in rain. The gypsum is visible as an unsightly brown to almost black crust. The effects of wet and dry deposition may frequently be differentiated by the location of damage. Wet deposition effects are observed primarily on surfaces exposed to precipitation, while dry deposition effects are most easily observed on sheltered surfaces, such as underneath cornices.

Acid deposition accelerates corrosion of copper, zinc, brass, and bronze. Effects on iron, steel, and lead surfaces are also observed. Automobile finishes degenerate when exposed to acid deposition and may become pitted in extreme cases. Oil-based paints can suffer similar damage.

If adverse effects of acid deposition are ever observed in Texas, the first to be seen would be damage to stone and metal surfaces, since these surfaces react directly with airborne acids and acid precursors. There is a problem, however, in whether or not the cause of potential damage is actually due to acid deposition. Damage to stone under dry conditions, for example, is due to the absorption of SO_2 , a gas which can be classified as either a criteria pollutant or an acid precursor.

Although its classification has no bearing on its effects on stone, the way in which SO₂ is classified could have a bearing on the way an observed effect is handled from a regulatory point of view.

4.0 CONCLUSIONS

Important preliminary conclusions have been reached in the course of developing this plan. First, and most important, acid deposition is not a problem of immediate concern throughout most of Texas. Measurements of precipitation chemistry in east Texas and a preliminary analysis of the sensitivity of that part of the state demonstrate a need for an ongoing monitoring and research effort. Second, the situation concerning acid deposition in Texas differs in several ways from that found in other parts of the country. Third, dry deposition is probably at least as important as wet deposition in Texas. Fourth, existing acid deposition monitoring and research efforts in the state lack coordination and unified direction.

4.1 EXISTENCE AND SEVERITY OF AN ACID DEPOSITION PROBLEM IN TEXAS

Based on existing data, acid deposition is not a problem and does not pose a problem of such magnitude that immediate regulatory attention is required. The potential for a problem in the future is sufficiently real, however, that additional monitoring and research are warranted.

At present, it appears that Texas can be roughly divided into three geographic regions, based on each region's susceptibility to potential acid deposition impacts. The region west of a line drawn approximately from Corpus Christi through Dallas-Fort Worth to the Red River appears to be immune to virtually all documented or hypothesized impacts of acid deposition. Soils, vegetation, and climatology will mitigate or eliminate postulated impacts of acid deposition. In general, vegetation in this region, and to some extent soils, may derive a beneficial effect from acid deposition, due to a decrease in soil alkalinity and an increase in nitrogen and sulfur availability. However, some native vegetation in very specific locales in west Texas may be adapted to high alkalinity and could possibly suffer damage from increases in acidity.

The southeast portion of the state (roughly, the area south and east of a line drawn from Corpus Christi to Waco to the Toledo Bend Reservoir) appears to be susceptible to some of the acid deposition impacts mentioned in the literature. An increase in atmospheric water content, a general shift in predominant winds from southwest to southeast, and changes in soil and plant characteristics contribute to this increased susceptibility. This area is of major importance in the overall acid deposition issue, however, due to the high density of air pollutant emission sources and the levels of precipitation acidity found there. According to the 1973 emissions inventory, this area accounted for more than one-fourth of all SO₂ emissions and one-third of all NO_x emissions in the state. This area, or portions of it, may have relatively high natural emissions levels of acid precursors. Acid precipitation has been monitored consistently in the area by several researchers using a variety of sampling techniques. The most acidic precipitation monitored in the state has been observed in the Houston-Galveston area, with some very acidic samples having pH values as low as 3.0.

The northeast corner of Texas appears to be the region most susceptible to potential acid deposition impacts. This region can be approximately defined as being north of Lufkin and east of Dallas. At this time, the most sensitive area in the region appears to be located in the vicinity of Longview. Vegetation in the region, particularly that found in sandy pinelands and boggy wetlands, is potentially sensitive, to acid deposition. Soils in this region are also potentially sensitive, due to their naturally acidic nature. Regional meteorological conditions tend to enhance any acid deposition impacts, due to a generally abundant supply of atmospheric moisture as well as the mean wind flow. Acid precipitation has been observed at every monitoring site in the area.

While acid precipitation has been monitored in east Texas, there is no discernible trend in precipitation chemistry. There have been no effects due to acid deposition reported and preliminary evidence suggests that surface waters have not been adversely affected. Thus, it appears that the potential for acid deposition

impacts exists in east Texas but no damage has yet occurred. This situation indicates a need for additional monitoring and research.

4.2 DIFFERENCES IN THE ACID DEPOSITION SITUATION IN TEXAS RELATIVE TO OTHER AREAS OF THE U.S.

There are several significant differences concerning acid deposition in Texas relative to other more thoroughly investigated areas of the U.S. Some of these differences will tend to increase while others will tend to decrease the rate of formation and the effects of acid deposition. Together, these differences make it difficult to apply to Texas, either directly or through extrapolation, the results of studies conducted in other areas of the country.

Texas has a significantly different mix of anthropogenic air pollutant sources than that found in the East and Northeast. In those areas of the U.S., several studies have found that a correlation exists between sulfur emissions from the utility industry and increased acid deposition. The utility industry has been frequently implicated as the source of acid deposition in those areas, in spite of the fact that no clear causal relationship has been established. In Texas, the utility industry does not appear to be the dominant contributor to the total atmospheric air pollution burden. Petrochemical and other industrial emitters appear to emit much more sulfur on a statewide scale than do electric utilities. Similarly, the utility industry appears to account for only about one-fifth of the total nitrogen emissions in the state, with most of the remainder originating from transportation, the petrochemical industry, and other industries. These statements are based on outdated emissions inventory data and a soon-to-be-released revision will undoubtedly require some modifications, but the overall concept is expected to remain intact. No single class of source is responsible for the majority of acid deposition precursors in Texas.

Most of the present volume of work on acid deposition in the United States addresses the area east of the Mississippi River and is concentrated in the

Northeast. This is the area from which most of the air flow egresses the continent. Thus, the Northeast is exposed to air into which much of the nation's industrial air pollutants have been emitted. Additionally, this air has had a sufficiently long trajectory to allow the primary air pollutant emissions to age into acid substances. Much of the air flowing over Texas (particularly during non-winter months) is of maritime origin or enters the state after having passed over less industrialized areas of the American West or Mexico. Although this air is certainly not free of air pollution, there is much less potential for it to be significantly polluted than air found over the Northeast.

The climate in Texas is obviously different from that in the Northeast. A greater abundance of sunshine and higher mean temperature in Texas tends to accelerate the photochemical conversion of precursor pollutants to acidic substances when compared to the Northeast. Damage to vegetation may be increased due to higher evaporation rates in Texas. A lower frequency of rain will tend to reduce the relative importance of acid precipitation in the state when compared to that of dry deposition. The lack of sustained snow cover in Texas essentially eliminates the potential for an acid shock due to spring thaw. Except for areas in east Texas and along the coast, the state has a lower mean relative humidity and a lower frequency of fog and dew than the Northeast. Differences in these and other meteorological parameters indicate the potential for error in attempting to use data collected in one area of the country and applying the implications of those data to Texas.

Texas has a huge reservoir of alkaline buffering capacity in the form of west Texas soils. This means that much of the acid deposition pollution will be neutralized either before deposition can actually occur (due to the interaction of entrained soil) or after deposition to an alkaline surface. No such reservoir exists for the northeastern U.S. Thus, the potential for the deposition of low pH substances is significantly reduced in Texas, particularly in the western part of the state, when compared to the northeastern U.S. Note, however, that this buffering

capacity may not reduce the effects of chemical radicals, such as sulfates and nitrates, present in acid deposition.

These differences, considered jointly, indicate that the chemistry of acid deposition formation is probably different in Texas than in other areas. It is not expected that different chemical mechanisms are to be found in Texas. Rather, chemical transformation rates are expected to be different, accelerated in some ways and retarded in others when compared to the northeastern and other parts of the country. It is also probable that the relative importance of individual chemical conversion mechanisms may be different in Texas.

Other differences exist, but it is difficult to quantitatively or even qualitatively establish their importance to acid deposition in Texas. This difficulty results from a lack of solid scientific evidence concerning the effects of acid deposition on Texas ecosystems. Vegetation in west Texas is probably fairly immune to most acid deposition impacts because of the existence of protective coatings on leaves, but this has not been proven. Species of vegetation present in east Texas have been shown to be sensitive to acid deposition in other areas of the country, but it is unclear whether these species are as sensitive when grown in Texas soils and climatic conditions. Similar statements can be made concerning Texas fauna and aquatic systems.

Since acid deposition is being monitored consistently in east Texas, it is of paramount importance that the state determine if any adverse effects are occurring. Differences between the acid deposition situation in Texas relative to other areas of the country make it impossible to apply the results of studies in other areas to Texas without in situ verification. Thus, the state must institute an effects monitoring program for the purposes of confirming the validity of existing information within the context of the Texas situation, establishing new data where required, and determining whether any trends in acid deposition effects exist.

4.3 RELATIVE IMPORTANCE OF DRY DEPOSITION IN TEXAS

A major conclusion suggested by the scientific evidence evaluated in the course of developing this plan is that dry deposition is probably as important in Texas as is wet deposition. Wet deposition, in the form of acid precipitation, is the deposition mechanism most frequently discussed in the public media. Wet deposition is roughly equivalent to "acid rain." In Texas, however, it is probable that at least as much acidic material is deposited in the absence of precipitation as is deposited in the presence of precipitation. "Dry deposition" includes the deposition of dry particles, particulate matter wetted by the absorption of water vapor from the atmosphere at higher relative humidities, and gases. It also includes the deposition of non-acidic substances which can be converted to acidic substances after having been deposited.

The importance of dry deposition is suggested both by the weather and by the air pollution emission characteristics found in Texas. First, the weather in the state tends to enhance dry over wet deposition, since much of the state is relatively arid, with little precipitation on an annual basis and thus, an infrequent opportunity for wet deposition to occur. East Texas and much of the Gulf Coast have annual precipitation amounts comparable to those found in the eastern U.S., but precipitation events in these areas of the state tend to be more intense and occur less frequently. Again, there are fewer opportunities for wet deposition to occur. In addition to less frequent precipitation, Texas has higher evaporation rates, higher mean and maximum temperatures, more sunshine, and equivalent or lower relative humidities than the eastern U.S. All of these conditions will enhance the importance of dry deposition in Texas when compared to the eastern U.S.

The second condition in Texas suggesting the importance of dry deposition is its mix of air pollutant sources. According to the TACB emissions inventory conducted in 1973, annual emissions of nitrogen oxides (NO_x) are almost 75% greater than annual emissions of sulfur dioxide (SO_2). This is in marked contrast to

the eastern U.S., where SO₂ emissions exceed NO_x emissions. Recent evidence suggests that as much as three-fourths of the airborne nitric acid thought to be derived from NO_x emissions undergoes dry deposition. This, coupled with the potential one-third sulfur acidity removed by dry deposition, could mean that more than half of the acid deposition in Texas occurs through the dry mechanism.

The significance of dry deposition has important implications for the state. On the positive side, dry deposition of nitric acid is believed to be much less damaging to the environment than the deposition of sulfuric acid. Nitric acid is probably beneficial to most plants and soils in Texas in the form of fertilization as long as supplies of available cations are adequate. On the negative side, however, there is currently no accurate means of monitoring dry deposition. This means that a deposition mechanism which potentially contributes more than half of the overall acid deposition occurring in the state cannot be evaluated. The effects of dry deposition (particularly of sulfur compounds) may be observed, but the actual deposition rates and mechanisms can only be deduced indirectly.

4.4 NEED FOR COORDINATION AND DIRECTION OF ACID DEPOSITION MONITORING AND RESEARCH EFFORTS IN TEXAS

There are currently at least nine different governmental agencies, university researchers, and private concerns monitoring precipitation chemistry in the State of Texas. A different sampling procedure is generally used by each program. There is little or no communication among researchers, with many individual researchers unaware of the existence of any other research or monitoring programs. There is little coordination with federal acid deposition research efforts. As a result, there is no uniformity of purpose or direction with the state.

If the state is to achieve consistent and steady progress toward the resolution of acid deposition issues in an efficient manner, a single governing entity should be designated. This entity should coordinate research and monitoring

activities within the state, act as a clearinghouse for acid deposition information, and be the authority responsible for ensuring that the elements of this work plan are accomplished in sequence. This entity must, at the same time, provide a forum for the expression of divergent viewpoints concerning acid deposition and ensure that acid deposition issues are resolved in an impartial manner. Without a single governing entity, acid deposition monitoring efforts within the state will continue to be disjointed and uncoordinated, and progress toward resolution of acid deposition issues will continue to be haphazard.

5.0 RECOMMENDATIONS AND WORK PLAN

5.1 PLAN OBJECTIVES

The plan is designed to achieve four general objectives, namely:

- I. Determine if acid deposition is occurring in Texas;
- II. Determine if acid deposition is causing any impact on the Texas environment;
- III. Determine what mechanisms are causing the observed impacts; and,
- IV. Determine the origin or origins of the reactants causing the observed impacts.

A fifth general objective, the development of appropriate control strategies, if required, is deferred for the present. This objective must be implemented if a deleterious impact due to acid deposition is discovered. The task elements comprising control strategies are intrinsically dependent upon the characteristics, scale, and geography of the problems they address, hence it is premature to formulate such work elements at this time. They should include, at a minimum, an evaluation of each alternative control strategy, the costs/benefits of each, and the possible secondary environmental, economic, and energy impacts of each. Although it is premature to formulate these task elements now, it may be appropriate to conduct low-cost long-term basic research on acid deposition control strategies because of the long lead times needed to implement research results.

The successful achievement of each general objective is dependent upon the successful achievement of several specific objectives. To achieve each specific

objective, it will be necessary to complete one or more tasks. The entire objective structure is presented in Table 5-1, in which general objectives are denoted with Roman numerals and specific objectives are denoted with capital letters.

The work plan is composed of a series of tasks of varying priorities that comprise four primary activities considered to be of immediate importance to the interests of the state:

- 1) Monitoring of precipitation chemistry within the state will be continued, modified, and/or expanded, as appropriate, to determine the severity and areal extent of acid precipitation in Texas and to establish a baseline for future reference.
- 2) A survey of potential effects of acid deposition will be conducted in two critical areas of the state where acid precipitation has already been monitored. These are the Longview area and the Houston/Galveston area.
- 3) Advances in the state of the art of monitoring dry deposition will be closely tracked with the intention of establishing a dry deposition monitoring network as soon as a reliably accurate monitoring methodology is developed.
- 4) Studies of the ultimate causes of acid deposition in Texas will be implemented, with particular attention given the role of anthropogenic sources and the attendant chemical conversions.

The need for implementing additional elements of the work plan is contingent upon the results of the first three activities.

TABLE 5-1

STRUCTURE OF OBJECTIVES WHICH MUST BE ACHIEVED
TO DESCRIBE AND CONTROL ACID DEPOSITION IN TEXAS

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- I. DETERMINE IF ACID DEPOSITION IS OCCURRING IN TEXAS.
 - A. Select instrumentation and establish proper quality assurance procedures for wet deposition monitoring.
 - B. Design and implement a wet deposition monitoring network to establish a precipitation chemistry baseline and track projected or potential changes in precipitation chemistry.
 - C. Establish a means of tracking and testing advances in dry deposition monitoring. Once monitoring methodologies are determined to be adequate, select instrumentation and establish proper quality assurance procedures for dry deposition monitoring.
 - D. Design and implement a dry deposition monitoring network to establish a baseline and to track projected or potential changes.

 - II. DETERMINE IF ACID DEPOSITION IS HAVING ANY IMPACT ON THE TEXAS ENVIRONMENT.
 - A. Identify potentially sensitive Texas ecosystems.
 - B. Determine whether acid deposition impacts are occurring or are likely to occur on Texas surface waters.
 - C. Determine whether acid deposition impacts are occurring or are likely to occur on Texas vegetation.
 - D. Determine whether acid deposition impacts are occurring or are likely to occur on Texas soils.
 - E. Determine whether acid deposition impacts are occurring or are likely to occur on Texas aquatic biota.
 - F. Determine whether acid deposition is having or is likely to have any direct impact on the human environment in Texas (health, paint, building masonry, etc.)

 - III. DETERMINE WHAT MECHANISMS ARE CAUSING THE OBSERVED IMPACT(S).
 - A. Determine how the acidic substance is entering the affected system (e.g., deposition of airborne acidic material, surface runoff, etc.).
 - B. Determine whether the impacts are the result of chronic and/or acute acid deposition events.
 - C. Determine the physical state of the acid deposition (i.e., wet and/or dry; solid, liquid, or gaseous).
 - D. Determine the chemical composition of the impact-causing acid deposition.
 - E. Determine acid deposition dosage rates required to produce observed impacts.
 - F. Determine the typical weather patterns associated with impact-causing acid deposition events.

 - IV. DETERMINE THE ORIGIN OR ORIGINS OF THE REACTANTS CAUSING THE OBSERVED IMPACT(S).
 - A. Preliminarily determine whether the impact-causing acid deposition could originate from natural and/or anthropogenic sources; preliminarily determine whether interstate or international transport could be involved.
 - B. Establish an up-to-date emissions inventory of the potential origins of impact-causing acid deposition.
 - C. Determine the transport mechanisms involved (i.e., long vs. short range, photochemistry, in-cloud conversion processes, etc.).
 - D. Locate the specific origin or origins of the impact-causing acid deposition.

 - V. DEVELOP APPROPRIATE CONTROL STRATEGIES TO EFFECTIVELY REDUCE ACID DEPOSITION TO ACCEPTABLE LEVELS, IF REQUIRED.
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5.2 PLAN SUPERVISION AND FUNDING METHODOLOGY

Overall implementation of the plan is to be supervised by a single entity. This is considered to be absolutely essential, based on experience in the coordination of existing monitoring programs and in view of the number and diversity of participants likely to be involved in the completion of individual tasks. This entity is to have the following duties and responsibilities:

- 1) Ensure adherence to the work plan;
- 2) Review and modify the work plan periodically and as needed;
- 3) Ensure that acid deposition issues are treated impartially;
- 4) Ensure that proper scientific methods are used in conducting acid deposition research;
- 5) Act as a vehicle for funding of acid deposition research;
- 6) Coordinate the efforts of state agencies and researchers within Texas and act as a clearinghouse for the dissemination of data and information;
- 7) Coordinate, to the extent necessary, Texas' efforts with those of other states and of the Federal Government; and
- 8) Make recommendations concerning acid deposition to state regulatory agencies and the state legislature.

The supervising entity should be constructed such that it meets four criteria. First, it must have the primary state responsibility for directing and

overseeing the implementation of the plan. Second, the entity must have expertise in all relevant environmental disciplines. Third, it must be able to utilize a variety of funding mechanisms. Fourth, the supervising entity must provide a means for public and private contributors to participate in formulating decisions concerning the disbursement of their contributions.

An entity meeting these criteria could take several forms, including a lead state agency, a non-profit corporation, or a state task force. The most obvious lead state agency would be the TACB since it will almost certainly have the responsibility of regulating acid deposition in the event it is found to be a problem in the state. The TACB would act to implement the work plan on the advise of a policy decision group having the dual responsibilities of making recommendations concerning the funding of projects and of providing a forum for the participation of concerned parties. The group would be composed of approximately ten members, with four representatives from state government, four representatives from the industrial and business community, and two representatives from the public at large. Each governmental representative should have expertise in either air, water, soils, or vegetation and should have sufficient authority within his agency to commit it or its funds when necessary. Other state governmental agencies may have representatives serve on a temporary basis for specific projects. Project funding could be facilitated by the participation of TENRAC.

As an alternative, the supervising entity could be in the form of a non-profit corporation consisting solely of a board, composed of no more than 12 members. Approximately one-half of the Board's members would come from state government (with at least one board member from the Texas Air Control Board), one-fourth of the members from the industrial and business community, and one-fourth from environmental groups and the public at large. Board members would be appointed by TENRAC for terms of three years, staggered so that approximately one-third of the board would be reappointed each year. Members would receive no financial compensation other than appropriate travel expenses. Administrative

functions of the corporation would be handled by the staff of TENRAC. The TENRAC staff, with the support of the TACB and other state agencies, would execute the responsibilities of the corporation until the corporation could be established.

The third potential form the supervising entity could take would be that of a state task force. This would be essentially the same as the non-profit corporation, but with the distinction of being completely under state control. It would operate in a manner similar to that of the corporation and would be composed of similar membership.

The supervising entity is to have overall responsibility for the plan and is to assign to governmental agencies, or to contract to university researchers or private parties, the execution of individual tasks. Supervision of each task is generally to be accomplished by the state agency responsible for regulating the associated environmental or material resource. Each task description contains a recommendation of the appropriate supervising agency.

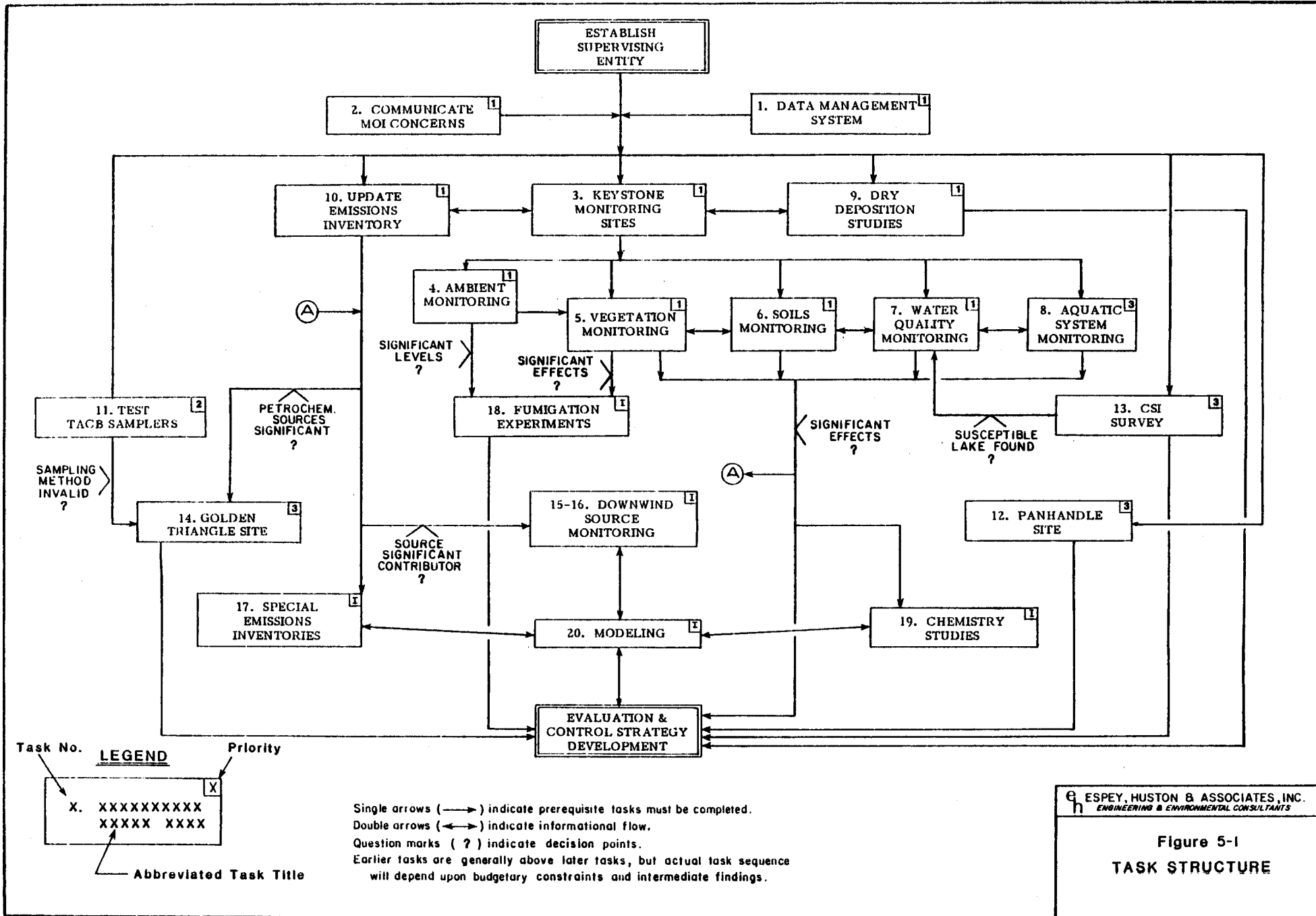
The funding of tasks is to be accomplished by a combination of state and federal contracts or grants and contributions from the industrial and business community. If the TACB is to be the lead agency, the operating expenses of the policy decision group would be funded by the TACB. If a corporation or task force is established, its operating expenses would be underwritten by TENRAC. The supervising entity can use a variety of methodologies to fund individual tasks. It is to seek blind contributions from affected individual industrial sources as well as from industrial trade associations and research groups. For example, if a monitoring site is required in the immediate vicinity of an isolated major refinery (Task 16), the corporation would seek contributions for that purpose from individual refining companies, the American Petroleum Institute, and the Gas Research Institute. The supervising entity would have the authority to spend these monies in the manner which it deemed to be the best means of accomplishing the task. This could be by

means of one or more contracts and/or grants to state agencies, university researchers, and/or private concerns.

The supervising entity is also to utilize public monies to accomplish specific tasks. State or federal agencies may contract with the entity to direct a specific task, with the performance of the task handled as a subcontract. Other tasks may be funded by a state agency directly, with agency employees performing the work in a manner consistent with the objectives of the plan. The supervising entity may also support university researchers by encouraging federal research agencies (e.g., the National Science Foundation) to approve specific grants which are consistent with the work plan. It may be necessary to combine public monies and private contributions to fund some tasks. Potential sources of funding are suggested in each task statement.

5.3 TASK STATEMENTS

The statements which conclude this section describe the tasks comprising the plan. The task structure should be viewed as being flexible, since an understanding of acid deposition is still evolving. The organization and flow of the task structure is shown in Fig. 5-1. The initial tasks of the work plan will produce scientific evidence specific to Texas concerning the existence and severity of an acid deposition problem in the state. If no problem or only a minimal problem is found, no further tasks would be implemented immediately. If a significant problem is uncovered, the work plan delineates an extended course of action which will enable the state to better define and isolate cause-effect relationships. The task number and title are given for each element. As the work effort matures, the results must be evaluated and the work elements reprioritized as appropriate. If an acid deposition problem becomes manifest, the evaluation task must also incorporate the development of control strategies. Although this evaluation is in fact a continuing process, it is indicated schematically on Fig. 5-1 as the culminating effort.



Three specific priority levels are employed: "1" indicates uppermost priority for the interests of the state; "2", important priority, but secondary to that regarded as uppermost; "3", lacking the urgency of 1 and 2 but nonetheless of potential significance to the state. In addition, some tasks are designated as "indeterminate" (I) since their urgency will be dictated by the results of other tasks.

The determination of priority level is based upon the importance of a particular task to the resolution of acid deposition issues within the state. The tasks which must be undertaken to resolve these issues are given Priority 1 rating. Priority rating is, in a sense, related to schedule because the most important tasks will generally be undertaken first. There is no one-to-one correlation, however, between priority and schedule. For example, three Priority 1 tasks (nos. 5, 9, and 10) have quite different schedules. Task 10 (Emissions Inventory) should be initiated immediately, Task 5 (Vegetation Monitoring) should be initiated 6 months after precipitation chemistry monitoring is begun, and Task 9 (Dry Deposition Studies) should be viewed as an ongoing effort. In spite of different schedules, each of these tasks is assigned Priority 1 because each must be accomplished in order to resolve the acid deposition issue.

The objective of each task is described and is referenced to one or more of the objectives listed in Table 5-1. Tasks or objectives which must be achieved prior to the implementation of a specific task are given under "Prerequisites for Implementation." The purpose and reason for each task are described in "Rationale". "Methodology" describes the procedure to be used to accomplish each work element. Tasks with lower priority ratings have more general methodology descriptions, in anticipation of their being changed as a result of the findings of earlier tasks. Finally, the recommended funding and supervising agencies for each task is given.

Task: 1. Establish a uniform data management and reporting system.

Priority: 1

Objective (I-A): Establish a uniform system of data management and reporting to facilitate the coordination of results from various monitoring programs. This system is to include methods for presenting the following:

1. Monitored data and summary data parameters (e.g., means, extremes, measures of the data distribution, and trends);
2. Quality assurance data and measures of data validity (e.g., reliability, accuracy, reproductibility, etc.); and
3. Site and operational information.

Prerequisites for Implementation: None

Rationale: In the course of developing the work plan, it has been difficult to conduct adequate intercomparisons of the results from various monitoring programs because each has a different monitoring protocol and data reporting procedure. In the future, this problem of data compatibility can be minimized by standardizing the reporting of data and other pertinent program parameters.

Methodology: The probable uses of acid deposition data are to be reviewed with the purpose of determining the best means of managing and reporting the data. Particular attention is to be paid to the methods used to calculate mean values, to the need for precipitation weighting, to units of measurement, and to measures of data validity. Variations between monitoring techniques which could affect data compatibility are also to be reported. To the extent possible, the data management system is also to be compatible with that used by federal acid deposition programs.

Funding Agency: TACB.

Supervising Agency: Acid deposition supervising entity.

Task: 2. Study and maintain an awareness of the federal authorities' work in progress to implement and extend the Memorandum of Intent (MOI) on Transboundary Air Pollution between Canada and the U.S.

Priority: 1

Objective: Ensure that agreements reached in accordance with the MOI could not adversely affect any possible similar agreements which may be reached between the U.S. and Mexico in the future.

Prerequisites For Implementation: None

Rationale: The U.S. and Canadian governments are currently negotiating a treaty on transboundary air pollution. The conditions of this treaty could serve as model conditions for other international treaties concerning air pollution, including any which might be negotiated with Mexico in the future. For this reason, it is important for Texas to be aware of the Canada - U.S. negotiations and to make known any concerns the state may have.

Methodology: The state is to request that Texas be kept abreast of developments. The state is to review treaty conditions insofar as they could impact any future Mexico - U.S. treaty. U.S. Senators from Texas are to be informed of the state's potential interests.

Funding Agency: TACB.

Supervising Agency: TACB.

Task: 3. Site two keystone acid deposition monitoring sites.

Priority: 1

Objective (II, I-B, III-D): Establish two multipurpose "keystone monitoring sites", one in the vicinity of Houston and another in the vicinity of Longview. These sites are to be used for both operational and research-oriented monitoring of acid deposition and of its potential effects. Data from these sites are to be used to accomplish the following objectives, in whole or part:

1. Determine acid deposition baseline conditions and trends;
2. Determine whether there are any discernible effects from acid deposition on the Texas environment;
3. Establish relationships between acid deposition, acid precursors, and meteorological parameters; and
4. Verify acid deposition models.

Prerequisites for Implementation: None in Houston; verification of acid precipitation in Longview.

Rationale: Acid precipitation has been monitored at several locations in Texas, but it is not known if this acid precipitation has had or will have any deleterious effects on the Texas environment. Further, it has not been established that the results of investigations into acid deposition effects in other parts of the country can be applied directly to Texas. The central issue in determining the need for regulation concerning acid deposition is whether or not it is significantly affecting the Texas environment. Thus, it is imperative that monitoring for potential effects be implemented.

If it is found that acid deposition is having a deleterious effect on the environment, it will be necessary to ascertain the sources of the acidic material and acid precursors. Information concerning transport and chemical transformation

rates will be needed to devise appropriate models. Again, it is not known whether this information can be extrapolated from existing studies in other parts of the U.S. It will be necessary to monitor relevant parameters in Texas to determine if this information is correct in Texas and, if not, to develop new data concerning transport and chemical transformation rates which are specific to Texas.

The need to locate the keystone sites near Houston and Longview is based on the probable contribution and sensitivity of these areas, respectively, to acid deposition. The Houston-Galveston area is expected to have more emissions of acids, acid precursors, and potential catalysts than any other area of the state. This is expected because of the concentration of industrial (especially petrochemical) and transportation sources in the area. Biogenic sulfur emissions and emissions of sea salt may also contribute to acid deposition in this area. Local meteorological conditions may accelerate the photochemical conversion of precursors to acidic substances and/or may tend to enhance the concentration of acidic substances. The effects of large urban areas on acid deposition have not been adequately investigated to date and, thus, there is no large data base from which conclusions may be drawn. Finally, the most acidic precipitation monitored to date in Texas has been monitored in the upper Texas coastal area.

The Longview area is expected to be the most sensitive area of the state to potential acid deposition effects. If there are any negative effects of acid deposition in Texas, it is likely that they will be observed first in this area. The fact that acid precipitation has been monitored at the nearby Tyler and Nacogdoches sites indicates a high probability that acid precipitation is also occurring in the Longview vicinity. If acid precipitation is monitored at the future Longview NADP site, effects monitoring could help to correlate deposition chemistry to effects.

Methodology: There are or have been four monitoring programs collecting precipitation chemistry data at a number of sites in the Houston-Galveston area. Each program utilizes a different sampling methodology and the results of each have yet to be formally reported. Each program is to be critically evaluated to determine

the validity of the sampling methodology and the data. Site locations are to be assessed for potential bias due to the proximity of large sources. Data are to be reviewed to determine which unbiased site consistently recorded the "worst" precipitation chemistry (defined as the combination of lowest pH, with the highest sulfate, highest nitrate, and lowest alkaline components). The keystone site is to be chosen from the subset, based upon the presence of environmental systems in which effects are likely to be observed.

An NADP site will soon be in operation at the Gregg County Airport near Longview. Precipitation chemistry at this site is to be collected for a period of six months to determine if acid precipitation is occurring. If, after reviewing these data, it is determined that the precipitation is acidic and/or contains significant quantities of sulfates and nitrates, a survey is to be instituted to locate specific areas in the vicinity which are potentially sensitive to acid deposition. While some effects monitoring can be conducted at the NADP site, it is unlikely that the most sensitive soils, vegetation, and surface water will all be found at the Gregg County Airport. Thus, it may be necessary to determine the dimensions of the survey area for which the NADP site can be considered representative. If necessary, this is to be done by assessing the climatology, air pollutant emission source density, and ambient air quality of the area. Part of the survey can be accomplished by a review of existing literature on soils, vegetation, and surface water in the area. Where the literature is insufficient to accomplish detailed siting, screening field studies are to be instituted. The NADP site, together with the most sensitive soil, vegetation, and water site(s), will comprise the Longview keystone "site."

Funding Agency: Acid deposition supervising entity (with support of TACB, local air pollution control agencies in Houston and Galveston, the Texas Departments of Water Resources and Agriculture, Texas Forest Service, U.S. Forest Service, U.S. Soil Conservation Service, and private sources).

Supervising Agency: Acid deposition supervising entity.

Task: 4. Establish ambient monitoring at the keystone sites.

Priority: 1

Objective (I-B): Monitor ambient wet deposition, ambient air pollutant concentrations, and meteorological conditions in the area of greatest source density and in the area most sensitive to potential acid deposition effects. (See Task 3 for the purposes of keystone sites)

Prerequisites For Implementation: Completion of Task 3, establishment of two keystone monitoring sites.

Rationale: See rationale under Task 3.

Methodology: Each site is to be equipped with an Aerochem Metrics wet deposition sampler (or equivalent), an event recorder, and an NWS-approved rain gauge. Sampling is to be conducted on a daily basis, as necessary, and in accordance with NADP guidelines. Continuous monitoring of ambient concentrations of NO/NO_x/NO₂, SO₂, TSP, O₃, and HC is also to be conducted using EPA methods. TSP samples are to be analyzed for sulfate, nitrate, chloride, and carbonate concentrations. Wind speed, wind direction, relative humidity, and insolation are also to be monitored continuously. Much of this equipment is already available at sites in the Longview and Houston areas.

Funding Agency: Acid deposition supervising entity (with support from the TACB, EPA, and private funding sources).

Supervising Agency: TACB (under the direction of the acid deposition supervising entity).

Task: 5. Vegetation impacts monitoring.

Priority: 1

Objective (II-C, III-E): Institute a vegetation monitoring program to establish an effects baseline and to track any future changes in vegetation which may result from acid deposition.

Prerequisites for Implementation: Siting of keystone sites (Task 4).

Rationale: Vegetation impacts are readily determined through established procedures. Because of this, vegetation impacts monitoring may yield a valuable yardstick for measuring potential environmental damages resulting from acid deposition.

Methodology: Many vegetation studies are already underway. Planning for any new studies should include a careful review of existing data and studies to avoid duplication. Vegetation monitoring stations are to be included at keystone air monitoring sites. Features such as topography, prevailing wind direction, and type of vegetational community present are to be taken into consideration during siting studies.

At each site, permanent quadrats, based upon a stratified random design are to be established. These are to be monitored at least twice during the growth season. Number and size of quadrats are to be consistent with sound ecological methods.

Potential indicator species are to be chosen by making a preliminary inventory of the species present at each site using the following selection criteria:

- (a) the species should be sensitive to the pollutant at a level below the sensitivity of vegetation of economic or aesthetic importance;

- (b) it should be widely distributed;
- (c) the pollutant-induced markings should be characteristic and easily observed;
- (d) the species should be present throughout the growing season; and
- (e) the species should grow from a terminal shoot throughout the growing season.

Initial observations of potential indicator species of native and cultivated plants in Texas gathered from each site may be incomplete and inconclusive due either to the inherent variability in susceptibility of the existing plants being studied or to the poor distribution of sensitive receptors within the studied plant community. To interpret such initial results, several study replications incorporating a bioassay technique may be necessary before indicator plants with known specific responses can be selected for monitoring purposes. These further studies should utilize plantings in field plots which meet the following criteria:

- (a) uniformity with respect to genetic background and cultural maintenance;
- (b) planted in sufficient abundance for subsequent statistical analyses;
- (c) located at significant sites in the area with respect to acid deposition;
- (d) composed of plants which will develop fairly specific symptoms to pollutants of interest; and
- (e) sufficient variety of plant species at each site to represent a range of susceptibilities to a particular pollutant or to be specific for the different pollutants present.

Once indicator plants specific to Texas conditions are established in field plots, surveillance studies may commence at keystone air monitoring sites. Field greenhouse studies may be instituted at this time at the keystone air monitoring sites for pollution criterion definition.

Funding Agency: Texas Forest Service, Texas Department of Agriculture, U.S. Forest Service, U.S. Department of Agriculture, private sources.

Supervising Agency: Texas Department of Agriculture.

Task: 6. Soils impacts monitoring.

Priority: 1

Objective (II-D): Institute a soils monitoring program to establish an effects baseline and to track any future changes in soil chemistry which may result from acid deposition.

Prerequisites for Implementation: Siting of keystone sites (Task 4).

Rationale: By establishing a firm baseline and tracking trends in soil pH, the potential effects of acid deposition on soils and dependent ecosystems may be determined. Soil monitoring, in concert with monitoring of other ecological systems, will potentially define many of the impacts of acid deposition in the total natural environment.

Methodology: Soil chemistry at keystone monitoring sites is to be analyzed both to establish a soils baseline and to maintain surveillance of potential changes due to acidification. Sites selected should be free of man-induced disturbances such as liming or the additions of fertilizer. The sites are to be located so as not to receive dust from roads, trails, or railroads. Chemical parameters to be determined include pH, cation exchange capacity, base saturation, and concentrations of sulfate, nitrate, chloride, aluminum, and possibly heavy metals such as molybdenum and selenium. Samples for analysis are to be taken at yearly intervals.

Funding Agency: U.S. Soil Conservation Service, National Science Foundation, private sources.

Supervising Agency: Texas Soil and Water Conservation Board.

Task: 7. Water quality impacts monitoring.

Priority: 1

Objective (II-B): Institute a water quality monitoring program to establish an effects baseline and to track any future changes in water quality which may result from acid deposition.

Prerequisites for Implementation: Siting of keystone sites (Task 4).

Rationale: Water quality impacts from acidification due to acid precipitation or dry deposition may only be determined by establishing clear water quality baselines and monitoring the pH levels of lakes and streams over time. As a result, trends in surface water acidification may be isolated and potential environmental effects determined. USGS records have been sufficient for a preliminary assessment of the impacts of acid precipitation to date and for the purpose of developing this plan. However, because the potential exists for acid deposition to become a problem at some point in the future, USGS sampling should be augmented by a semiannual sampling program which would obtain data not normally collected by the USGS (i.e., hypolimnion and epilimnion samples).

Methodology: In order to determine the short-term impacts of acid precipitation, stream sampling is to be conducted at keystone sites during two to four precipitation events per year. Sampling is to be performed with a water level actuated sampler. Flow is to be monitored continuously during the storm event. A recording rain gauge and rainfall sampler is to be installed at the sample site to monitor rainfall intensity and volume and the water quality of the rain. Analytical parameters to be monitored include pH, alkalinity/acidity, sulfate (SO_4^-), and nitrate (NO_3^-). All analyses are to be performed in accordance with procedures outlined in Standard Methods.

The long-term impact of acid deposition is to be determined by sampling representative lakes. Sampling is to be conducted on a semi-annual basis. Samples are to be withdrawn from the epilimnion and hypolimnion with a kemmer sampler or equivalent. Analytical parameters to be monitored are identical to those previously listed.

Funding Agency: Texas Department of Water Resources, private sources.

Supervising Agency: Texas Department of Water Resources.

Task: 8. Aquatic system impacts monitoring.

Priority: 3

Objective (II-E): Institute an aquatic biosystem monitoring program to establish an effects baseline and to track any future changes in the system which may result from acid deposition.

Prerequisites for Implementation: Siting of keystone sites (Task 4).

Rationale: Changes in water quality may directly affect the dependent aquatic biosystem. Monitoring the system is of critical importance in providing potential insight into the overall and specific impacts of acid deposition on aquatic wildlife.

Methodology: The water bodies selected are to be of substantial size, so that minor or anomalous events will not produce extreme data points. If possible, at least one stream and two impoundments are to be monitored in the vicinity of each keystone site. In addition to size, the availability of data from past monitoring efforts on the candidate water bodies is to be one of the selection criteria.

Differentiation of sources is essential. Unless the contribution from acid deposition can be separated from other sources (e.g., liquid effluents), no rational control program can be established. Therefore all substantial sources of aquatic acidification should be known and characterized.

Indicator organisms should not be reviewed as indicative of acidification, but, rather, as denoting the evolution of a problem situation. Certain taxa in various trophic levels are known to exhibit threshold responses to chronic pH levels of certain magnitudes. To simply designate, in advance, that the appearance or disappearance of individual species indicates that a problem exists, is of little utility. Rather, what should be done is to periodically sample the water bodies for

phytoplankton, zooplankton, and fish especially, being alert for changes in community structure and abundance that appear to be related to concomitant changes in acidity. Fish communities are already monitored by the Texas Parks and Wildlife Department (TPWD) and their data could be accessed as desired. Particular points of interest are reproductive phenomena, which are likewise a principal concern of TPWD. Shifts in phytoplankton community structure, as indicated in the review of previous studies will aid interpretation of the mechanisms acidification effects. A number of zooplankton taxa exhibit clear tolerance thresholds, and the alterations of trophic interrelationships by the removal of some species would be a significant effect. The macroinvertebrate community shows some clear relationships to pH, but also offers greater difficulty in methods of adequate sampling. The simplest, as well as most useful monitoring, thus, would emphasize routine (at least seasonal) collection of phytoplankton and zooplankton, with cooperative use of TPWD's fish data, especially as it relates to reproductive parameters. Fish data should be carefully correlated with both pH and aluminum concentration data.

Funding Agency: Texas Department of Fish and Wildlife, private sources.

Supervising Agency: Texas Department of Fish and Wildlife.

Task: 9. Investigate ambient dry deposition monitoring techniques.

Priority: 1

Objective (I-C, I-D): Develop accurate, reliable dry deposition monitoring techniques as soon as they become available so that the relative contribution of dry deposition to the total acid deposition in Texas can be assessed.

Prerequisites for Implementation: None.

Rationale: Within the State of Texas, acid deposition is more probably due primarily to dry deposition than to wet deposition. Dry deposition, which includes the conversion of gaseous pollutants to acids upon impaction, absorption, or adsorption at the Earth's surface, has been indicated as being the dominant deposition mechanism for HNO_3 and a major deposition mechanism for $\text{SO}_4^{=}$. Unfortunately, there is no truly adequate methodology for monitoring dry deposition, due primarily to the difficulty in finding a representative collection medium. The collection of poor quality and probably biased data is worse than the collection of no data. For this reason, dry deposition samplers are not to be deployed at this time, but sampling techniques are to be investigated with samplers to be deployed only when reliable data can be obtained.

Methodology: Because of its potential importance to acid deposition in Texas, the subject of dry deposition cannot be ignored or left entirely as the responsibility of others. The state is to coordinate with researchers actively studying dry deposition, to initiate a thorough evaluation of current research on the subject, and to augment existing research with a vigorous research effort of its own. Once an adequate sampling methodology is found, the state is to determine the appropriate number and locations of sites for dry deposition monitoring and to deploy a monitoring network.

Research currently being done concerning dry deposition monitoring is to be assessed. Governmental agencies and private organizations to be contacted include, among others, the U.S. EPA, Canadian Environmental Protection Service, Tennessee Valley Authority, National Science Foundation, Utility Acid Precipitation Study Program, Electric Power Research Institute, Edison Electric Institute, American Petroleum Institute, and various university researchers. Existing and proposed sampling methodologies are to be evaluated for their scientific merit, ease of operation, cost, reliability, applicability to Texas, and accuracy. The state is to encourage the continued support of those research efforts which appear to hold the greatest promise for developing a reliable dry deposition sampler.

Additionally, a vigorous research effort into the problem of how to monitor dry deposition is to be undertaken. This effort is to be closely coordinated with other groups investigating dry deposition in order to minimize redundant efforts and to maximize the effective pursuit of promising collection methodologies. A variety of monitoring techniques is to be investigated at the two keystone sites. The techniques which hold promise are outlined in the following paragraphs. Other techniques may be suggested as a result of the evaluation of current research.

The first technique to be investigated is the use of the Aerochem Metrics dry deposition sampler, modified to use a variety of sampling media and configurations. Modifications to be considered may range from the simple (e.g., changing the color or surface roughness of the collection bucket) to the sophisticated (e.g., using convoluted, baffled collection plates, or using electro- or thermophoretic forces to drive particles to the collection surfaces). Modifications are to be investigated both theoretically and experimentally. Intercomparisons between different modifications are to be made to try to isolate biases and to determine which modifications, if any, are acceptable.

The second technique to be investigated is that of monitoring the total ambient dry aerosol. The ambient dry aerosol can be collected using a high-volume

air sampler, virtual impactor device (e.g., dichotomous sampler) or Nuclepore filter sampler (e.g., streaker). The concept behind this sampling methodology is that since all aerosol particles must eventually be removed from the atmosphere (either by sedimentation, impaction, or wet deposition), collection of the total aerosol will provide data concerning the total acid deposition potential of an air parcel. The method is inaccurate to the degree that future photochemical aging of the aerosol is assumed to be negligible. This may or may not be an acceptable assumption and is to be investigated together with the sampling technique.

The third dry deposition technique to be investigated, the use of indigenous plant species to monitor dry deposition, is an indirect method, but one which holds promise. A simple example will illustrate the use of this technique. Two genetically uniform plants are grown in identical soil and watered artificially (to eliminate the influence of wet deposition). One plant is exposed to clean air; the other, to ambient air. At specified intervals, samples from both plants are chemically analyzed for important anions and cations. An elemental analysis is also possible. The difference between the two samples in the concentration of various chemical species represents the contribution due to dry deposition. This system has the advantage of monitoring the actual impact of dry deposition upon vegetation without the need for theoretical assumptions or corrections. It has the disadvantages of ignoring dry deposition to soils and water and of combining the impacts of absorption and adsorption of gaseous pollutants with the deposition of dry particulate matter.

Once an adequate sampling methodology has been found, a dry deposition monitoring network is to be designed. The highest priority is to be assigned to monitoring at keystone sites, with other wet deposition monitoring sites receiving the next highest priority. The number and locations of additional monitors will depend on cost, ease of operation, and the available results of acid deposition research in Texas.

Funding Agency: Acid deposition supervising entity (with support from TACB, EPA, U.S. Department of Agriculture, Texas Department of Agriculture, NSF, NOAA, and private sources).

Supervising Agency: Acid deposition supervising entity.

Task: 10. Complete the TACB point source emissions inventory of criteria pollutants.

Priority: 1

Objective (IV-B): Establish a reliable emissions data base for the following purposes:

- (1) To ascertain the relative contribution of various categories of emission sources;
- (2) To serve as input to future acid deposition modeling efforts; and
- (3) To determine if the acid deposition monitoring network requires modification.

Prerequisites for Implementation: None

Rationale: The emissions data used, in part, to develop this plan were gathered in 1973. This emissions inventory was updated in 1975 for specific areas of the state. These data are considered too incomplete and too outdated to be used in achieving the objectives stated above. The TACB is finalizing a more current inventory which should serve the objectives of this task.

Methodology: The current TACB emissions inventory effort is to be completed as rapidly as possible. Actual or average emissions of SO₂, NO_x, and HC are to be inventoried. The inventory is to be completed in the following order: the areas of the keystone sites (Houston-Galveston and Longview); along the upper Texas Gulf coast; east and northeast Texas; and the remainder of the state, moving from east to west. The inventory is to include stack parameter data for use in dispersion models. Once the data for each area have been collected and verified, they are to be reviewed in order to place into perspective the relative contributions of various industrial categories to the total atmospheric loading of each pollutant.

Funding Agency: TACB.

Supervising Agency: TACB.

Task: 11. Test the TACB wet deposition sampling methodology.

Priority: 2

Objective (I-A; I-B): Determine the accuracy and reliability of the TACB wet deposition sampling methodology.

Prerequisites For Implementation: None

Rationale: The methodology currently used by the TACB appears to be a simple, inexpensive way of sampling precipitation chemistry. Without an adequate demonstration of the validity of the methodology, there is no assurance that the collected data are valid or comparable to other methodologies used by the NADP and UAPSP.

Methodology: The entire sampling methodology is to be tested. Sampler performance is to be evaluated by collocating a TACB sampler, an Aerochem Metrics sampler, and a National Weather Service (NWS) recording rain gauge. This is to be accomplished at the TACB headquarters in Austin in order to avoid any biases introduced by field operations. Rainfall collection efficiency, field and lab pH and conductivity measurements, and precipitation chemistry measurements are to be compared. Operator performance is to be evaluated by collocating an NWS recording rain gauge at each TACB sampler. (One rain gauge can be used at a site over several rainfall events and then transported to another site.) Precipitation amounts and operating times are to be recorded for comparison with the rain gauge recorded data to determine overall sampling efficiency. Blind samples are to be sent to field operators to test their efficiency in making field measurements. Laboratory performance is to be tested by splitting individual samples, sending half to the Illinois State Water Survey (laboratory for the NADP) for analysis and having the other half analyzed by the TACB. The TACB is also to request the Illinois State Water Survey laboratory to provide blind samples for analysis in the TACB laboratory.

Results are to be evaluated for consistency, to determine if there is a significant bias introduced by workweek sampling, to determine if operators are adequately responding to rainfall events, and for the adequacy of the TACB methodology. If the TACB methodology is found to be adequate for its intended purpose, quality assurance and reporting procedures are to be upgraded. If the methodology is found to be significantly unreliable, biased, or inaccurate, the four TACB samplers are to be eliminated.

Funding Agency: TACB.

Supervising Agency: TACB.

Task: 12. Establish a baseline acid precipitation monitoring site in the Texas Panhandle.

Priority: 3

Objective (I-B): Determine if acid precipitation is occurring in this agriculturally oriented region.

Prerequisites for Implementation: None

Rationale: The only precipitation chemistry data available from the Texas Panhandle were collected during the late 1950's and early 1960's. Sampling was conducted intermittently on a monthly basis. The sampling methodology used is incompatible with current sampling methodologies and quality assurance procedures were not rigorous. These data are, therefore, considered to be inadequate for current planning purposes. Airborne acidic material could be brought into the area by means of long-range transport, and the subsequent potential for crop damage exists. Because agriculture is so economically important in the Panhandle, baseline precipitation chemistry of the area should be determined.

Methodology: A regional acid precipitation monitoring site is to be selected based on NADP siting criteria. The site is to be equipped with an Aerochem Metrics wet deposition sampler (or equivalent), an event recorder, and an NWS-approved rain gauge. Sampling is to be conducted on a weekly basis and in accordance with NADP guidelines. The sampler is to be tested to ensure that windblown dust can not enter the sampler when closed. The sampler is to be modified if dust is found in it. If data from the first year of operation are adequate and show an absence of acid precipitation, the site is to be terminated.

Funding Agency: Acid deposition supervising entity (with support from the regional business community, TACB, U.S. Department of Agriculture, and/or Texas Department of Agriculture).

Supervising Agency: TACB (under direction of the acid deposition supervising entity).

Task: 13. Determine the Calcite Saturation Index (CSI) for a representative sample of east Texas water bodies.

Priority: 3

Objective (II-A, II-B): Conduct a general survey of the susceptibility of east Texas water bodies to acid deposition effects and to determine if any lakes or streams are particularly sensitive to acid deposition.

Prerequisites for Implementation: None.

Rationale: In developing this plan, a preliminary evaluation of the susceptibility of four east Texas rivers was conducted using the Calcite Saturation Index (CSI) and other indicators. This evaluation did not demonstrate the presence of any trends in acidity and only one river showed any susceptibility to acid deposition effects (and that was only for two out of the five years analyzed). A broader scale survey is necessary to extend the results of this preliminary effort.

Methodology: A survey of east Texas water bodies is to be made in order to determine the number and type of water bodies needed to form a representative sample. This sample is to include water bodies of various sizes but is to emphasize water bodies either not subject to upstream contamination or in which upstream contamination can be accurately quantified. The CSI is to be calculated for each water body for every fifth year in the past 25 years. If the CSI exceeds a value of 3.0 for any year, the CSI and sodium-to-bicarbonate ratio are to be calculated for every year in the past 25 years. Trends in CSI, pH, and sodium-to-bicarbonate ratio are to be determined. If a trend in any of these indicators shows that acid deposition is affecting the water body, or if there is a frequent occurrence of high CSI's, low pH's, and/or high sulfate-to-bicarbonate ratios, additional investigation is to be conducted. The nature of this additional effort is to be determined by the acid deposition supervising entity and the Texas Department of Water Resources after a thorough review of the results of the survey.

Funding Agency: TDWR.

Supervising Agency: TDWR.

Task: 14. Establish a baseline/trend acid precipitation monitoring site in the vicinity of the Texas "Golden Triangle" (Beaumont-Port Arthur-Orange).

Priority: 3

Objective (IV-C, IV-D): Determine the chemistry of atmospheric deposition resulting from this industrial area where petrochemical sources are expected to be the primary contributors of airborne acidic substances and acid precursors.

Alternative Objective (I-B): Monitor precipitation chemistry in this area if the TACB sampling methodology is found to be invalid.

Prerequisite for Implementation: Monitoring of acid deposition effects at the Houston keystone site (Tasks 5, 6, 7, and 8), determination that petrochemical and other industrial sources are probably the primary contributors to acid deposition in Houston (Task 10), and confirmation that these sources account for most of the emissions in the Golden Triangle.

Prerequisite for Implementation of Alternate Objective: Determination that the TACB sampling methodology is invalid (completion of Task 10).

Rationale: The Golden Triangle area of Texas is expected to exhibit many of the industrial emissions characteristics found in the Houston-Galveston area, but with a much smaller relative contribution from transportation and area source-related emissions. If effects are observed at the Houston keystone site, it may not be possible to determine the primary cause(s) of these effects due to the source complexity of the Houston area. Observations of precipitation chemistry in the Golden Triangle will provide data important in segregating possible causes. Additionally, acid precipitation (as low as pH 3.5) has been monitored in Beaumont. If the TACB monitor is discontinued at this site, additional monitoring will be required.

Methodology: Siting of this sampler is to be determined by its objective. If the sampler is to replace the TACB sampler that is currently being used in Beaumont, it is to be located at the existing site. If the objective of the site is to monitor the precipitation chemistry resulting from a petrochemical source-dominated area, its location is to be determined based on the location of the maximum source density and on the results of the Houston keystone monitoring effort, as extrapolated to the Golden Triangle area.

The site is to be equipped with an Aerochem Metrics wet deposition sampler (or equivalent), an event recorder, and an NWS-approved rain gauge. Sampling is to be conducted on a weekly basis and in accordance with NADP guidelines. Data from the site are to be evaluated every two years to determine the need for continued sampling.

Funding Agency: Acid deposition supervising entity (with support from the TACB, API, and local refiners).

Supervising Agency: TACB (under direction of the acid deposition supervising entity).

Task: 15. Establish a baseline acid precipitation monitoring site in the immediate vicinity of an isolated major coal- or lignite-fired utility or industrial boiler.

Priority: I

Objective (III-B, III-D, IV-D): Determine if washout (removal of acidic pollutants from a plume by rain falling through it), short-range transport, and/or emissions of primary acids are resulting in high acid deposition rates near a major point source and to obtain information concerning the relative contribution of a single major point source to the total acid deposition budget.

Prerequisite for Implementation: Observation of acid deposition effects at a keystone site (Tasks 5, 6, 7, and 8) and determination that coal- and lignite-fired point sources contribute substantially to acid deposition (Task 10).

Alternative Prerequisite for Implementation: Observation of acid deposition effects in the immediate vicinity of a major coal- or lignite-fired point source (Task 10).

Rationale: All of the long-term acid precipitation monitoring sites in Texas have been located with the intent of minimizing any possible biases due to nearby major point sources. There is no monitoring site within the immediate vicinity of a major coal- or lignite-fired point source and there is no monitoring site located in such a way that the acid deposition contributions of a single point source can be segregated from the contributions of regional sources. The most acute acid deposition may occur in the immediate vicinity of a major point source due to washout, short-range transport, and/or primary acid emissions. Additionally, if major coal- and lignite-fired point sources are implicated as substantial contributors to an observed regional deposition problem, a site in the immediate vicinity of such a source will provide information on the importance of various scales of transport and the total budget of airborne acids and acid precursors.

Methodology: An acid precipitation monitoring site is to be established within 6 km of an isolated major coal- or lignite-fired utility or industrial point source. Existing

and planned sites are to be reviewed to determine if one of these will fulfill the requirements of this task. The site is to be located downwind of the source, in the direction of the most probable precipitation maximum and at least 25 km from any other major source upwind. The site is to be selected on the basis of computer modeling, using precipitation frequency-weighted climatological input data and with the results interpreted by air pollution meteorologists familiar with the area. Computer models designed to assess radiological impacts (e.g., AIRDOS) are to be investigated for this purpose, as these models already incorporate deposition and washout algorithms which may be modified to account for acid deposition in a relatively simple manner.

The site is to be equipped with an Aerochem Metrics wet deposition sampler (or equivalent), event recorder, and NWS-approved rain gauge. Sampling is to be conducted on an event (24-hour) basis and in accordance with NADP guidelines. Plant operating characteristics are to be monitored to assist in determining if any emission-deposition correlation exists. The data are to be evaluated semi-annually to evaluate the need for continued sampling.

Funding Agency: Acid deposition supervising entity (with support from EPRI, EEL, ERCOT, and TACB).

Supervising Agency: TACB (under direction of acid deposition supervising entity).

Task: 16. Establish a baseline acid precipitation monitoring site in the immediate vicinity of an isolated major refinery.

Priority: I

Objective (III-B, III-D, IV-D): Determine if washout (removal of acidic pollutants from a plume by rain falling through it), short-range transport, and/or emissions of primary acids are resulting in high acid deposition rates near a major refinery and to obtain information concerning the relative contribution of a single major refinery to the total acid deposition budget.

Prerequisite for Implementation: Observation of acid deposition effects at a keystone site (Tasks 5, 6, 7, and 8) and determination that refinery emissions contribute substantially to acid deposition (Task 10).

Alternative Prerequisite for Implementation: Observation of acid deposition effects in the immediate vicinity of a major refinery.

Rationale: All of the long-term acid precipitation monitoring sites in Texas have been located with the intent of minimizing any possible biases due to nearby major point sources. There is no monitoring site within the immediate vicinity of a major refinery and there is no monitoring site located in such a way that the acid deposition contributions of a single refinery can be segregated from the contributions of regional sources. The most acute acid deposition may occur in the immediate vicinity of a major point source due to washout, short-range transport, and/or primary acid emissions. Additionally, if major refinery emissions are implicated as substantial contributors to an observed regional deposition problem, a site in the immediate vicinity of such a source will provide information on the importance of various scales of transport and the total budget of airborne acids and acid precursors.

Methodology: An acid precipitation monitoring site is to be established within 6 km of an isolated major petrochemical refinery having significant SO₂, NO_x, and H₂S

emissions. Existing and planned monitoring sites are to be reviewed to determine if one of these will fulfill the requirements of this task. The site is to be located downwind of the source, in the direction of the most probable precipitation maximum and at least 25 km from any other major source upwind. The site is to be selected on the basis of computer modeling, using precipitation frequency-weighted climatological input data and with the results interpreted by air pollution meteorologists familiar with the area. Computer models designed to assess radiological impacts (e.g., AIRDOS) are to be investigated for this purpose, as these models already incorporate deposition and washout algorithms which may be modified to account for acid deposition in a relatively simple manner.

The site is to be equipped with an Aerochem Metrics wet deposition sampler (or equivalent), an event recorder, and NWS-approved rain gauge. Sampling is to be conducted on an event (24-hour) basis and in accordance with NADP guidelines. Refinery operating characteristics are to be monitored to assist in determining if any emission-deposition correlation exists. The data are to be examined semi-annually to evaluate the need for continued sampling.

Funding Agency: Acid deposition supervising entity (with support from API, Gas Research Institute, individual refineries, TACB).

Supervising Agency: TACB (under direction of acid deposition supervising entity).

Task: 17. Extend the TACB emissions inventory for special analyses.

Priority: I

Objective (IV-A, IV-C, IV-D): Obtain more detailed emissions information in specific locations, as needed.

Prerequisite for Implementation: Monitoring of acid deposition effects, definition of the chemical species present in the acid deposition, and modeling which indicates that the point source emissions inventory cannot explain the observed deposition chemistry.

Rationale: If, on the basis of modeling or sulfur/nitrogen budget analyses, it is determined that the point sources listed in the emissions inventory (Task 10) do not emit sufficient quantities of pollutants to account for the observed deposition chemistry, the inventory will have to be extended. This extension may be in any combination of three possible directions: (1) to include non-point sources, (2) to include noncriteria pollutants, (3) to include additional areas.

Methodology: The methodology to be selected will depend on the circumstances encountered. If, for example, point source NO_x emissions are found to be too small to explain the observed quantities of nitric acid downwind of Houston, the inventory is to be extended to include transportation and other NO_x area sources. If hydrochloric acid is found to contribute substantially to the overall acidity of atmospheric deposition in the state, chloride emission sources are to be included in the inventory. If modeling indicates that long-range transport is bringing substantial quantities of acids and acid precursors into the state, the state is to encourage the Federal Government to inventory probable source areas. Other possible extensions of the inventory might include natural emissions of biogenic sulfur, sea salt, ammonium, or alkaline dust emissions; area source emissions due to natural gas home heating and cooking; and emissions of primary acids, H_2S and other reduced

sulfur compounds, hydrocarbon emissions, and/or other reactants and catalysts. In some cases (e.g. area source emissions from traffic, point source emissions of H₂S, etc.) established procedures are to be used in extending the inventory. In other cases, (e.g. biogenic sulfur emissions), research is to be conducted within the state, or research by others is to be encouraged by the state.

Funding Agency: Acid deposition supervising entity (with support from the TACB and other state agencies, agencies of the Federal Government, and private industrial research groups, depending upon the nature of the inventory extension).

Supervising Agency: Acid deposition supervising entity (with TACB support).

Task: 18. Plant fumigation experiments.

Priority: I

Objective (II-C, III-E): Provide dose-response data useful in defining pollutant criteria relative to indicator plants.

Prerequisites for Implementation: Observation at keystone sites of plant damage due to acid deposition (Task 5) or monitoring of precipitation at a keystone site or elsewhere with a level of acidity known to cause damage in indigenous plant species (Task 4).

Rationale: If acid deposition effects are observed in indicator plants, additional effort will be needed to quantify dose-response relationships for use in developing regulatory control strategies. Existing research, conducted in other parts of the country, may not be applicable in the Texas environment due to differences in climate and geography.

Methodology: A thorough literature review of existing fumigation experiments involving affected plant species is to be conducted. Researchers currently conducting such experiments are to be contacted and their research is to be evaluated. The applicability of the existing data to the Texas environment is to be determined, with particular attention being given to effects of differences in climate, soils, and if appropriate, fertilization techniques.

If the results of this initial investigation are inconclusive, or if there is substantial doubt concerning the applicability of existing research to Texas, fumigation experiments are to be initiated. Fumigation experiments at a central laboratory are to be utilized to determine reproducible dose-response relationships specific to Texas between pollutants associated with acid deposition and their effects. Climatic conditions, pollutant concentration, and exposure times are to be

controlled in growth chambers. Both dry and, to the extent possible, wet deposition are to be investigated.

Funding Agency: Acid deposition supervising entity (with support from Texas and U.S. Departments of Agriculture and Forest Service).

Supervising Agency: Texas Department of Agriculture and/or Texas Forest Service (under direction of acid deposition supervising entity).

Task: 19. Investigate the chemistry involved in the formation and removal of airborne acidic substances within the context of the Texas geography and climate.

Priority: I

Objective (IV-C): Determine important chemical conversion mechanisms which contribute to the formation of acid deposition in Texas.

Prerequisites for Implementation: Observation of acid deposition effects in Texas (Tasks 5, 6, 7, or 8).

Rationale: If cause-effect relationships are to be established with respect to acid deposition, it is absolutely essential to have an understanding of the chemistry involved. There is a considerable amount of scientific study currently underway to determine how acid deposition is formed and removed from the atmosphere. The applicability of this work to the Texas environment has not been demonstrated, however. While it is possible that completely new formation and removal mechanisms are present in Texas, it is much more likely that formation and removal rates are different and/or different mechanisms are dominant. This is because, when compared to more thoroughly investigated areas of the country, Texas generally has higher mean temperatures, greater evaporation rates, greater insolation, a different pattern of precipitation, and a different mix of anthropogenic and natural emission sources, as well as other differences in climate, geography, and emissions. If acid deposition effects are observed within the state, the chemistry involved must be correctly understood before the related causes can be found and appropriate regulatory actions taken.

Methodology: A two-phased analysis of atmospheric chemistry is to be undertaken. First, the existing scientific literature is to be reviewed in order to determine whether it is applicable to Texas. Literature is to be reviewed for the proper methodology, to determine if any conditions exist in Texas which would invalidate

the conclusions reached, and to determine if any theoretical corrections could be applied to the conclusions which would make those conclusions valid in Texas. Upon completion of this literature review, an evaluation of potential gaps in the current understanding of the atmospheric chemistry is to be conducted. If there are significant gaps which are universal, the state is to encourage the Federal government, private concerns, and universities to continue research into those areas. If there are significant gaps which relate specifically and only to Texas, the state is to design and implement a program of research to extend the state of the art in those areas.

Funding Agency: Acid deposition supervising entity (with support of TACB, NSF, NOAA, industrial research groups, and universities).

Supervising Agency: Acid deposition supervising entity.

Task: 20. Model of atmospheric deposition.

Priority: I

Objective (IV-C, IV-D): Determine the primary contributors to observed acid deposition effects.

Prerequisites for Implementation: Observations of adverse acid deposition effects on the Texas environment (Tasks 5, 6, 7, or 8), completion of criteria pollutant emissions inventory (Task 10), completion of relevant special emissions inventories (Task 17), and completion of investigation of chemical formation and removal mechanisms (Task 19).

Rationale: If adverse acid deposition effects are observed, it will be necessary to determine the origin of the acids and/or acid precursors. Additionally, it will be necessary to verify that the expected atmospheric chemistry effective in the conversion of acid precursors to acids is applicable to Texas. Both of these tasks must be accomplished in order to develop an effective control strategy. The best means to accomplish these tasks is to use models of atmospheric transport and deposition.

Methodology: Existing literature is to be reviewed and researchers developing acid deposition models are to be contacted. Current modeling methodologies are to be evaluated with respect to their accuracy and applicability to Texas. Gaussian dispersion models, numerical models, and trajectory models are to be analyzed. Within each model, algorithms for treating horizontal and vertical dispersion, transport, washout, rainout, dry deposition, area source emissions, and atmospheric chemistry are to be evaluated individually, so that, if necessary, the best algorithms may be combined into a new model designed for use in the Texas environment. Particular attention is to be given to the chemical transformation algorithms used and to any assumptions of a model which may predetermine its results (e.g., the lack

of an algorithm which accounts for natural emissions if those emissions are important in Texas).

If an existing model is determined to be adequate for use in Texas, it is to be applied to observed problem situations. If model adjustments are required to obtain a good correlation between model projections and observed data, the adjusted model is to be verified by applying it to an area of the state in which no acid deposition problem is observed. Failure to independently verify the model could result in the implication of the wrong origin of the problem.

Funding Agency: Acid deposition supervising entity (with support from EPA, DOE, TACB, and industrial groups implicated as causing the observed problem).

Supervising Agency: TACB.