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ACID RAIN IN ASIA

by

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ACID RAIN IN ASIA

1. INTRODUCTION

Acid rain has been an issue of widespread concern in North America and Europe for more than fifteen years. As a result of heavy utilization of fossil fuels in the second half of this century in the industrial countries, the acidity of rain has increased markedly in many areas, and damage to lakes, forests, and materials in many countries has been attributed to this cause. In response to this perceived problem, and to assist decision makers in designing rational control policies, a variety of monitoring, assessment, and modeling programs have been developed in the United States, Canada, Austria, West Germany, and Sweden. There is an emerging feeling that the problem in Europe and North America is nearing solution, largely as a result of existing and newly enacted legislation, decreased energy use due to conservation and efficiency improvements, and/or trends in energy policy away from fossil fuels. Of particular relevance is the passage of the Clean Air Bill in late 1990 in the U.S. which legislates the halving of U.S. acid rain precursor emissions by the year 2000.

The situation in Asia appears much bleaker. Fossil fuels are already used in large quantities, such that local air pollution is becoming a serious problem and high deposition levels are being measured. Emission regulations in most countries (with the notable exception of Japan) are not very stringent. Energy plans in many countries (particularly PRC, India, Thailand, and South Korea) call for very large increases in coal combustion in the future. Finally, there is not presently a strong scientific or public constituency for action to mitigate the potential effects of acid deposition. These factors imply potentially serious problems in the future for long-range transport and deposition of sulfur and nitrogen species and consequent damage to ecosystems and materials. The political ramifications of transboundary environmental pollution in this region are also potentially serious.

It is time to consider applying model-building experience gained in the West to this emerging issue in Asia. A predictive tool could be built to help decision makers project future trends in emissions, estimate the regional consequences for acid deposition levels, evaluate the vulnerability of natural and man-made systems, and determine the costs and effectiveness of alternative mitigative actions that might be taken. Such a policy analysis exercise can start to raise environmental awareness in the region and begin a dialogue that could help ameliorate (or prevent the worsening of) an environmental problem in its early stages. The purpose of this paper is to provide background information on the acid deposition situation in Asia, with the intention of laying the foundation for the development of a possible research program for this region.

2. SOCIOECONOMIC AND ENERGY SYSTEM OVERVIEW OF THE REGION

2.1 The Region

For the purposes of this paper the definition of Asia will not strictly conform to the definitions used by various geographers or political institutions. The geographical focus of this paper must be constrained by the financial and human resource limitations on scope of coverage. Because climates and atmospheric transport do not respect political boundaries, we will need to refer to both political and various meteorological/geographical maps.

The political map in Figure 1 includes South, Southeast, and East Asia. The map covers all of the countries which will be discussed in this report. At latitude 30 degrees north, the region shown in Figure 1 stretches approximately 8500 km east to west; and at the longitude of Bangkok (101 degrees east of Greenwich), it extends north-south more than 9000 km. A glance at the air movement maps such as shown in Figures 3 and 4 later in this paper quickly reveals the incentive to focus on this particular region.

2.2 Population Indicators

Population indicators of the major countries in East, South, and Southeast Asia are shown for 1960 and 1985 in Table 1, including population, population growth rate, and percent of urban population. Also shown are scenario values for the year 2010 based on United Nations medium variant projections. The total population of these countries in these three years is estimated to be 1,583 million, 2,649 million, and 3,646 million, respectively. They currently account for more than 55 percent of total world population and by year 2010 could reach 4 billion people.

2.3 Economic Indicators

An understanding of emissions-related energy consumption and supply systems of the region requires a knowledge of the structure of the economy and what its growth characteristics will be in the future. Although it is no longer considered axiomatic that increases in economic growth and energy consumption march in lock step, nevertheless economic activity is one of the key parameters used in analyzing energy consumption. For the past decade and a half, there has been considerable advancement in our knowledge of the relationships between energy use and activity in the various sectors of the economy, e.g., manufacturing, agriculture, commerce, etc. These activities are the determinants of final energy use, which is the driving force behind the need for combustion of fossil fuels. This, ultimately, is responsible for the emissions leading to acid deposition.

In fact, one of the bases for the concern about the potential for increased acid deposition in Asia is the very high economic growth of this area. Its average level of economic performance is far higher than for any other world region. If foreseeable trends continue through the end of the century, the western Pacific rim countries in aggregate would have an economy comparable in size to those of North America or Western Europe.

Table 2 shows some of the key economic indicators for the countries in the region, including Gross Domestic Product (GDP) for the years 1960 and 1983, average annual growth rates during the period, per capita income, average annual growth rate of per capita income, and commercial energy consumption. It should be noted that Japan is responsible for more than half of the region's income. However, as is well known, the economic growth rates of several of the industrializing countries of the region are very high, and one could anticipate that several countries will rank as developed industrialized economies early in the next century, if not before.

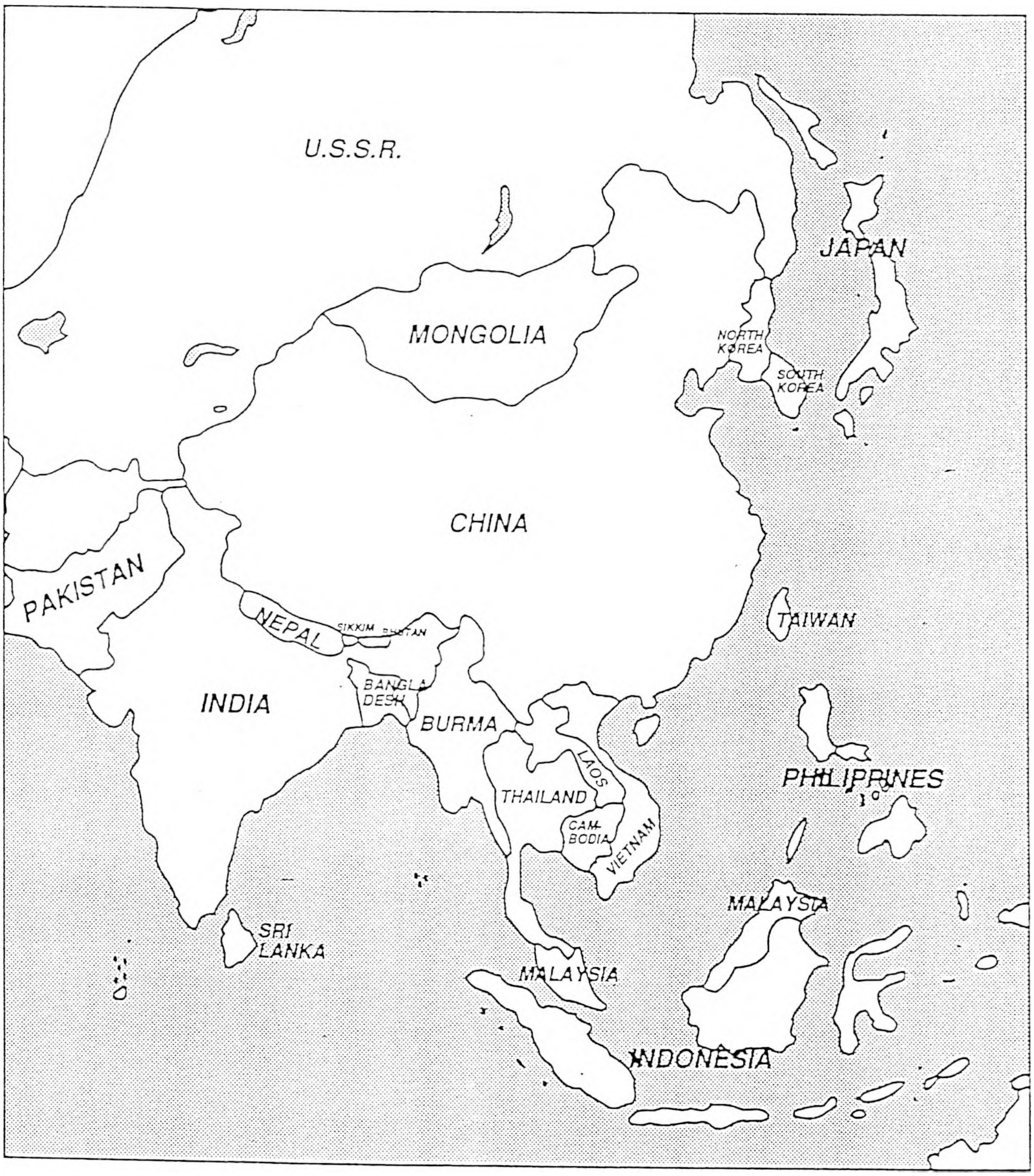

FIGURE 1 Political Map of Asian Region under Consideration

TABLE 1 Population Indicators for Major Asian Nations (from East-West Center, 1986)

Subregion/Country	Population (million)			Population Growth Rate			Urban Population (%)		
	1960	1985	2010	1960–1965	1985–1990	2010–2015	1960	1985	2010
EAST AND SOUTHEAST ASIA									
Brunei	0.1	0.2	0.3[e]	NA	2.7	NA	NA	59.4	NA
Burma	21.8	39.5	66.5	2.3	2.4	1.6	19.3	30.0	48.8
China: Mainland	656.7	1044.1	1362.3[f]	1.8[f]	1.0[f]	0.5[f]	16.8[f]	21.0[f]	33.6[f]
Taiwan	10.6	19.1	NA	3.3[b]	1.9[a]	NA	11.0[c]	15.0[d]	NA
Hong Kong	3.0	5.6	7.4	3.6	1.8	0.5	89.1	90.8	93.8
Indonesia	96.7	165.5	229.0	2.1	1.6	0.9	14.6	25.3	44.5
Japan	98.9	120.0	130.0	1.0	0.4	-0.1	62.5	76.5	82.3
Kampuchea/Cambodia	5.4	7.4	10.8	2.4	2.5	1.1	10.3	15.6	31.0
Korea, North	10.5	20.1	31.7	2.8	2.2	1.3	40.2	63.8	77.2
Korea, South	25.0	40.9	53.5	2.6	1.4	0.6	27.7	65.3	84.3
Laos	2.3	4.4	7.5	2.4	2.4	1.6	7.9	15.9	32.6
Malaysia	8.2	15.5	23.5	3.0	2.2	1.1	25.2	31.5	49.5
Philippines	27.9	54.7	86.6	3.0	2.3	1.3	30.3	39.6	56.4
Singapore	1.6	2.6	3.1	2.8	1.2	0.3	77.6	74.2	81.9
Thailand	27.0	51.6	75.6	3.0	1.7	1.0	12.5	15.6	30.4
Vietnam	33.9	59.5	90.0	2.2	1.9	1.2	14.7	20.3	34.8
SOUTH ASIA									
Bangladesh	51.6	101.1	177.0	2.5	2.6	1.6	5.1	11.9	24.6
Bhutan	0.9	1.4	2.2	1.8	2.0	1.4	2.5	4.5	11.4
India	431.5	761.2	1065.2	2.5	1.8	0.9	18.0	25.5	41.9
Nepal	9.4	16.5	27.6	1.9	2.3	1.5	3.1	5.8	14.1
Pakistan	50.0	101.7	173.0	2.7	2.2	1.6	22.1	29.8	45.4
Sri Lanka	9.9	16.4	23.3	2.4	1.8	0.9	17.9	21.1	30.7
Total	1,583	2,649	3,646						

[a]1958–66; [b]1976–80; [c]1970; [d]1980; [e]2000; [f]includes Taiwan.

TABLE 2 Key Economic Indicators for Asian Nations

Subregion/Country	Gross Domestic Product: Dollars (millions) 1960	Dollars (millions) 1983	Average Annual Growth Rate 1965–1973	Average Annual Growth Rate 1973–1983	Per Capita Income 1983	Average Annual Growth Rate of Per Capita Income 1965–1983	Commercial Energy Consumption (MTOE) 1986
EAST AND SOUTHEAST ASIA							
Brunei	NA	4,160	NA	NA	20,800	NA	
Burma	1,280	6,190	2.9	6.0	180	2.2	
China: Mainland	42,770	274,630	7.4	6.0	300	4.4	558.90
Taiwan	1,600	49,500	10.3	7.4	2,670	6.2[a]	33.80
Hong Kong	950	27,500	7.9	9.3	6,000	6.2	7.87
Indonesia	8,670	78,320	8.1	7.0	560	5.0	39.36
Japan	44,000	1,062,870	9.8	4.3[d]	10,120	4.8	400.00[e]
Kampuchea/Cambodia	NA	NA	-2.7	NA	NA	NA	
Korea, North	NA	18,100[b,c]	NA	NA	923	NA	41.00
Korea, South	3,810	76,640	10.0	7.3	2,010	6.7	59.60
Malaysia	2,290	29,280	6.7	7.3	1,860	4.5	13.18
Philippines	6,960	34,640	5.4	5.4	760	2.9	11.04
Singapore	700	16,640	13.0	8.2	6,620	7.8	12.14
Thailand	2,550	40,430	7.8	6.9	820	4.3	16.78
Vietnam	NA	9,000[b]	NA	NA	160[c]	NA	5.02
SOUTH ASIA							
Bangladesh	3,170	10,640	0.0	5.2	130	0.5	5.07
Bhutan	NA	120[b]	NA	NA	90	NA	
India	29,550	168,170	3.9	4.0	260	1.5	154.09
Maldives	NA	70	NA	NA	400	NA	0.03
Nepal	410	2,180	1.7	3.0	160	0.1	0.33
Pakistan	3,500	25,880	5.4	5.6	390	2.5	21.50
Sri Lanka	1,500	4,770	4.2	5.2	330	2.9	1.76
Total	153,710	1,939,730					

[a]1971–1983; [b]GNP; [c]1982; [d]1973–1982; [e]total energy consumption

References: East-West Center, 1986; Asian Development Bank, 1989; International Energy Agency, 1989; World Resources Institute, 1988; Institute of Energy Economics, Japan, 1989.

2.4 Energy Overview of Countries and Region

In both assessing and forecasting acid deposition, it is important to have a good picture of both current and future energy use patterns as well as energy consumption and supply technology. In this introductory overview paper there is neither adequate space nor time to treat the countries in detail. However, a summary of some of the key energy indicators and statistics will serve to develop the key issues related to acid rain. Since the information is derived from several different sources, there may be some inconsistencies among the data for a given country.

Table 3 presents the contributions of different energy sources to total energy supply in Asia, based upon United Nations statistics for 1986. The energy system in Asia is striking in many respects. First, it is almost completely dependent on fossil fuels (more than 95% of its commercial energy). Second, approximately 60% of the consumed fossil fuel is in the form of coal, with most of the remainder being fuel oil. Both of these fuels contribute significantly to the emissions of acid rain precursors in Asia. Equally important from an environmental perspective are the extremely high growth rates and relatively low utilization efficiency of Asian energy systems. During the past decade annual growth rates have greatly exceeded (by factors of 2 to 4) those in Western industrialized countries, which are now relatively stable at a few percent or less. There is little reason to expect that per capita energy use in the developing countries of Asia will stabilize anywhere near its present level of approximately 0.5 tons of oil equivalent per year, which is approximately ten percent of the per capita use in North America and Europe.

Of particular concern in terms of the acid rain issue is the continued growth of coal use in the region. In 1987, coal use totaled approximately 1360 million metric tons with the three largest users being China, India, and Japan. Preliminary data suggests that regional coal use in the year 2000 could be as high as 2,300 million metric tons, with very large growth increments in China and India, and significant growth rates in several other countries, including Indonesia, Thailand and the Koreas.

3. OVERVIEW OF CURRENT AND FUTURE EMISSION PATTERNS

Emissions patterns are an important piece of information in the evaluation of existing and potential acid deposition problems. However, information on actual emissions is available for only a few of the Asian countries. These are given in Table 4. Therefore, in order to obtain emission values for the entire region under study, it is necessary to develop a calculational approach to estimate such emissions from all the nations in Asia.

Because emission patterns are heavily dependent on energy consumption and fuel type used and because the Asian region has on average a very high economic growth rate, a long-term strategy dealing with emerging acid deposition problems will need to address the implications of a growing and changing pattern of energy consumption and supply systems. The high economic growth rates shown in Table 2 imply major increases in energy consumption, and, thus, emissions, although the rates of increase depend strongly on a wide range of economic and technical factors, including policies and measures for energy conservation. It is a demanding task to develop energy/economic scenarios for all of the major countries in the region. However, it is possible to make estimates of future energy use under simplified alternative assumptions and a number of studies have carried these out.

TABLE 3 Contributions of Different Energy Sources to Total Energy Supply (1986) (million tons coal equivalent - MTCE) (from United Nations, 1988)

Subregion/Country	Solid	Liquid	Gas	Total Fossil	Non-Fossil Electricity	Total Commercial
EAST AND SOUTHEAST ASIA						
Brunei	0.000	1.077	0.529	1.606	0.000	1.606
Burma	0.258	1.398	1.444	3.100	0.132	3.232
China: Mainland	609.340	102.406	18.671	730.417	12.427	742.844
Taiwan						
Cambodia/Kampuchea	0.000	0.218	0.000	0.218	0.008	0.226
Hong Kong	4.891	5.215	0.000	10.106	-0.148	9.958
Indonesia	2.247	34.909	9.435	46.591	0.891	47.482
Japan	104.220	247.930	56.527	408.677	31.497	440.174
Korea, North	49.720	4.585	0.000	54.305	3.562	57.867
Korea, South	31.132	32.970	0.099	64.201	3.971	68.172
Laos	0.000	0.099	0.000	0.099	0.032	0.131
Malaysia	0.402	12.987	2.791	16.180	0.500	16.680
Philippines	1.802	10.631	0.000	12.433	1.306	13.739
Singapore	0.009	10.739	0.000	10.748	0.000	10.748
Thailand	2.431	15.914	4.447	22.792	0.773	23.565
Vietnam	5.013	2.039	0.000	7.052	0.246	7.298
SOUTH ASIA						
Bangladesh	0.106	2.261	3.978	6.345	0.055	6.400
Bhutan	0.001	0.015	0.000	0.016	0.002	0.018
India	142.550	53.276	7.152	202.978	7.211	210.189
Nepal	0.153	0.240	0.000	0.393	0.053	0.446
Pakistan	2.219	10.672	10.991	23.882	1.739	25.621
Sri Lanka	0.002	1.575	0.000	1.577	0.325	1.902
Total	956.496	551.156	116.064	1623.716	64.582	1688.298

TABLE 4 Literature Values of Estimated Annual Emissions of SO_2 and NO_2 in Various Asian Countries (in 10^6 tons/yr)

	Year									
Country	1975	1977	1979	1980	1981	1982	1983	1985	1989-1992	2000
Japan										
SO_2	2.69 (1)	2.21 (1)	2.07 (1) 1.8 (2)	1.63 (1)	1.2 (1)	0.95 (1)	1.2 (2)	1.1 (3)		
NO_2	2.0 (2)	1.8 (1)		1.3 (3)	1.2 (1)		1.3 (2)	1.4 (3)		
China										
SO_2			15 (2)	12 (4)	13 (5)		18 (2)		18 (4)	
India										
SO_2			3.2 (4)						7.0 (4)	
S. Korea										
SO_2					1.5 (1)	1.4 (1)				
NO_2					0.7 (1)	0.7 (1)				
Hong Kong										
SO_2					0.23 (1)					
NO_2					0.05 (1)					

References: (1) IEA (1984)
(2) Institute of Energy Economics, Japan (1989)
(3) World Resources Institute 1988-1989
(4) McCormick (1985)
(5) Zhao and Xiong (1988)

One of these studies is that conducted by Foell and Green (1990). In this analysis, current and future sulfur dioxide (SO_2) and nitrogen oxides (NO_x) emissions were calculated from estimates of fossil fuel consumption in the base year (1986) and for two future years, 2000 and 2010. The emissions for each country were calculated through the application of emission coefficients to annual end-use and supply sector energy consumption for each of the relevant fossil fuels. All fuel consumption was expressed in terms of million tons of oil equivalent (MTOE). Emission coefficients were expressed in terms of tons of emissions per ton of oil equivalent.

The energy consumption scenarios which were developed for this analysis were in general derived from one of two approaches: 1) directly from scenarios taken from the literature (used mostly for the base scenario) or 2) through appropriate assumptions and supplementary analysis. The supplementary analysis was based as much as possible on historical data, international comparisons, and socioeconomic/technological assumptions appropriate to that country. Wherever possible, both the assumptions and the resulting energy consumption patterns were compared with available related studies.

The results from this study for SO_2 emissions for a number of scenarios and for a number of Asian countries are given in Table 5. The base case (1986) emissions indicate that the total SO_2 emissions from fossil fuel use in the Asian region were in the order of 28 million tonnes. Of these, two-thirds are from China and 11% from India. The majority of the 1986 emissions result from coal-based facilities. For comparison, the estimated SO_2 emissions from the U.S. in 1987 were 27 million tonnes.

Table 5 also illustrates the dramatic increase in SO_2 emissions expected from this region of the world in the next few decades. In the year 2000, emission estimates range from 45 to 53 million tonnes, depending on the particular scenario, and in 2010, emission estimates range from 56 to 76 million tonnes. Again, China is responsible for the majority (62% to 66%) of the emissions from the Asian region and in 2010, would emit more than today's combined emissions from western and eastern Europe.

It is interesting to note that the efficiency scenario, S2, leads to an annual regional emission reduction (compared to the base case) of approximately eight and sixteen million tonnes in the years 2000 and 2010, respectively, i.e., reductions of approximately 15 and 21 percent, respectively. The low carbon scenario, S3, yields a reduction of approximately 20 million tonnes, i.e., 26 percent in 2010. Finally, the sulfur control strategy, S4, (in which SO_2 controls, with 90% efficiency, are assumed to be implemented on 50% of all new power generation units installed between 1986 and 2000 and on all plants installed after 2000) leads to a reduction (compared to the base case) of three million and twelve million tonnes in 2000 and 2010, respectively. Interestingly, this pollution control strategy, although quite ambitious in its rate of implementation, does not ultimately lead to the magnitude of reduction achieved by efficiency improvements and fuel shifts.

This study also estimated NO_x emissions from the Asian region. These are given in Table 6 for 1986 (base case), 2000, and 2010 under various scenarios. As was the case for SO_2, China and India are by far the largest contributors to NO_x emissions in this region. The growth rate of emissions of this pollutant is also substantial; in the base case, regional NO_x emissions grow at rates of 4.5% to 5% over the period in question. The low-carbon scenario results in an approximately 29% reduction in NO_x emissions by 2010.

TABLE 5 - Scenarios of Total SO_2 Emissions in Asia

All Figures in Million Tonnes of SO_2

Country	1986	2000			2010			
	ACTUAL	S1	S2	S4	S1	S2	S3	S4
EAST AND SOUTHEAST ASIA								
China: Mainland	18.972	34.036	28.552	32.882	48.802	38.861	37.152	41.933
Taiwan	0.850	1.738	1.398	1.563	2.217	1.676	1.500	1.797
Hong Kong	0.274	0.397	0.343	0.377	0.588	0.480	0.318	0.532
Indonesia	0.780	1.850	1.669	1.687	3.184	2.485	2.395	2.411
Korea, North	0.587	0.920	0.735	0.920	1.275	0.892	0.794	1.275
Korea, South	1.224	2.721	2.455	2.641	3.308	2.781	2.456	3.162
Malaysia	0.298	0.441	0.404	0.435	0.753	0.596	0.595	0.705
Philippines	0.403	0.815	0.727	0.742	1.339	0.988	0.973	1.036
Singapore	0.061	0.107	0.093	0.085	0.151	0.110	0.094	0.088
Thailand	0.627	2.616	2.349	1.979	2.999	2.313	1.994	1.866
SOUTH ASIA								
Bangladesh	0.150	0.204	0.173	0.202	0.270	0.202	0.171	0.245
India	3.181	5.386	4.761	5.035	8.796	6.656	6.294	7.112
Pakistan	0.748	1.675	1.426	1.617	2.486	1.892	1.592	2.295
Total	28.155	52.904	45.085	50.164	76.167	59.932	56.327	64.456

Scenario Key

S1 Base Case Scenario
S2 Energy Efficiency Scenario
S3 Low Carbon Scenario
S4 SO_2 Control Scenario

Reference: Foell and Green 1990.

TABLE 6 - Scenarios of Total NO_x Emissions in Asia

All Figures in Million Tonnes of NO_x

Country	1986	2000		2010		
	ACTUAL	S1	S2	S1	S2	S3
EAST AND SOUTHEAST ASIA						
China: Mainland	7.671	15.316	12.748	21.864	17.221	16.279
Taiwan	0.298	0.648	0.520	0.828	0.612	0.515
Hong Kong	0.111	0.162	0.139	0.249	0.201	0.122
Indonesia	0.712	1.701	1.474	3.131	2.359	2.262
Korea, North	0.628	0.938	0.751	1.249	0.874	0.753
Korea, South	0.663	1.302	1.173	1.641	1.360	1.098
Malaysia	0.296	0.582	0.501	0.982	0.741	0.704
Philippines	0.202	0.438	0.377	0.734	0.546	0.534
Singapore	0.166	0.252	0.216	0.338	0.252	0.247
Thailand	0.495	1.508	1.292	3.523	2.662	2.482
SOUTH ASIA						
Bangladesh	0.025	0.039	0.032	0.052	0.039	0.035
India	2.830	5.516	4.813	9.252	6.924	6.358
Pakistan	0.119	0.274	0.232	0.405	0.309	0.260
Total	14.216	28.677	24.268	44.249	34.101	31.650

Scenario Key

S1 Base Case Scenario
S2 Energy Efficiency Scenario
S3 Low Carbon Scenario

Reference: Foell and Green 1990.

It is obvious that the magnitude of SO_2 and NO_x emissions in the Asian region is large and likely to get larger. However, the density of emission sources will also play a significant role in determining the severity of the impacts that acid deposition may have in this region.

Emission estimates of the type determined by Foell and Green are one starting point for the development of an integrated acid rain policy model. They need to be linked with transport and impact analysis as described in later sections of this paper. In addition, they need to be conducted in a manner that can permit the assessment of the impact of a variety of future systems characteristics such as technology substitutions and changes, fuel shifts, emission controls, changes in economic and energy demand structure, etc. Such analysis would permit the examination and design of appropriate policies for acid rain control.

4. METEOROLOGY OF THE ASIAN REGION

Many of the critical issues concerning acid deposition involve its impacts on natural and man-made systems. In order to assess these impacts, a determination of not only the magnitude of emissions of acid deposition precursors but also the distribution of these substances and the sensitivity of anthropogenic and natural systems to them, must be made. The former aspect of the acid deposition phenomenon was discussed in the previous section; this section deals with the distribution of acid deposition in the Asian region and the following section addresses the latter issue.

Because acid deposition is basically a secondary pollutant (i.e., is not emitted in the same form as it is deposited) and its precursors can travel long distances before reaching the surface, an identification of the transformation and transport processes is critical to an understanding of this phenomenon, particularly in delineating its extent and magnitude in Asia. This necessitates an assessment of the meteorology of the Asian region.

4.1 Local vs. Regional Air Pollution

Most of the air pollution problems identified in the nations of Asia are confined to localized areas of high emissions, which are usually associated with the densely populated cities of this region, such as Beijing, Bombay, Calcutta, Shenyang, Seoul, Bangkok, Hong Kong, Manila, and Kuala Lumpur. These high levels of pollutants are due to a combination of factors including high emission rates, lack of control measures, and unfavorable meteorological and topographical conditions. Pollutant concentrations in most of these cities regularly exceed the World Health Organization (WHO) recommended limits for SO_2, ozone, particulates, and lead. The few attempts to address air pollution issues in the developing world have, therefore, focused on these localized urban pollution problems.

In recent years, however, it has become evident that with the rapid growth in population, energy consumption (with much of this from highly polluting fuels such as coal), and industrialization, the potential for serious and widespread regional-level air pollution, particularly of acid deposition and ozone, has greatly increased in the developing nations. The existence of acid deposition and/or the conditions that can lead to its occurrence have already been discovered in some Asian countries, and additional monitoring in this area may uncover a more widespread presence of this phenomenon.

As discussed in the previous section, emissions of the precursors of acid deposition (SO_2 and NO_x) are high (particularly SO_2) in many Asian nations and are expected to increase significantly in the near future. However, because these substances are released at or near the ground (emitted by individual households and industries and powerplants with low smokestacks) and stable air masses are prevalent in this region, the emissions are highly concentrated and confined to local areas. Because of this, regional, secondary pollutants such as acid deposition, have historically been considered a problem only in Europe and North America where tall smokestacks and unstable air masses are common and greatly increase the residence time and transport of air pollutants. Thus, almost all our information on the acid deposition phenomenon is based on conditions found in the industrialized countries of the temperate zone. Only recently has the region thought to be under potential threat from acid deposition been extended to include the developing world, especially Asia. This extension is due to a number of reasons:

1. Emissions of acid deposition precursors, especially SO_2, have been projected to increase substantially in many Asian nations due to rapid modernization and industrialization, population growth, and the transfer of polluting industries from the developed world, which may have strict pollution control laws, to the developing world, which may not require the same level of control (McCormick 1985). [For example, emissions of SO_2 in China are expected to increase from 13 x 10^6 tons in 1980 (Zhao and Xiong 1988) to 18 x 10^6 tons by 2000 (McCormick 1985). In India, SO_2 emissions have tripled since the 1960s (Khemani et al. 1989b) and are expected to be double the present rate by the end of the next decade.] In addition, due to the seriousness of local air pollution problems, the increased use of energy (and electrification) will likely be accompanied by larger coal-fired power plants and factories having taller smokestacks. This will result in increased residence time and greater potential for long-range transport of acid deposition precursors.
2. The higher temperature and sunlight intensity present in most Asian nations increases the efficiency of atmospheric chemical reactions particularly those transforming SO_2 and NO_x to acidic sulfates and nitrates (Rodhe et al., 1988).
3. Stable air masses in Southeast Asia during large portions of the year increase the residence time of pollutants, thereby allowing greater opportunity for conversion to secondary pollutants. In addition, the strong vertical mixing of the lower portion of the atmosphere characteristic of much of the tropics and subtropics would transport pollutants to higher altitudes (thus mimicking tall smokestacks) where they would have longer residence times and be carried farther afield (Chatfield and Crutzen 1984).
4. High rainfall rates (at least seasonally) in much of the Asian region (except the central deserts) would increase the proportion of SO_2 and NO_x that is converted to sulfates and nitrates by aqueous-phase reactions. These sulfates and nitrates can then be coupled to large-scale precipitation-producing weather systems and be deposited farther from emission sources than the same acidic substances produced via gaseous-phase (dry) processes. Also, the greater amounts of rainfall in these regions would contribute to larger total H^+ deposition than that predicted on the basis of precipitation pH alone (McDowell 1988).

Thus, there appears to be considerable potential for the occurrence of regional-scale acid deposition in many of the Asian nations, and this is likely to increase significantly in the future.

4.2 Specific Features of the Meteorology of the Asian Region

In addition to the factors discussed above that facilitate the formation of acid deposition in Asia, the climate of this region has a number of unique features that could further influence its magnitude and extent. Furthermore, the specific topography of the region could significantly affect the geographic distribution of this phenomenon.

The predominant weather pattern over much of Asia is the monsoon system. In the summer, it affects almost all of the region. In the winter, when its winds are reversed, its range of influence is reduced to Southeast Asia. Along with abundant rainfall, especially in the summer (up to 25 in./month), the monsoon is associated with unidirectional, seasonal winds. In the summer, the prevailing winds blow in a northeasterly direction from the western Indian Ocean to the South Asian low pressure system centered over the Indus River basin in northwestern India. These winds bring heavy rain to India, the southern Himalayas, and Southeast Asia. In eastern Asia, moisture-laden winds blow from the Pacific Ocean northwestward into China, Japan, and northern Asia.

In the winter, these wind patterns reverse themselves, due primarily to the presence of a high-pressure system located in central Asia. Winds flow clockwise out of this Siberian High blowing cold, dry air south-southwestward toward the Himalayas and southeastern Asia, north-northeastward to northern Asia, and southeastward to China, Korea, and Japan. On the islands of Southeast Asia, this cold air is warmed and saturated by passing over the warm Pacific waters thereby bringing winter rains to these islands (Encyclopedia Britannica 1979).

Superimposed on these regional climate patterns is the persistent Northern Hemisphere westerly air drift. In the summer, this westerly air flow affects mainly northern Asia, carrying moist air from eastern Europe into southern Siberia. In the winter, in addition to influencing northern Asia, these westward-moving cyclonic storm systems can flow through the Mediterranean Basin across southwestern Asia. They are then deflected by the Himalayas across northern India and southwestern China where they turn northeastward to eventually join their northern counterpart (Encyclopedia Britannica 1979). Figures 2 and 3 illustrate the mountain ranges and generalized wind flow patterns in Asia in the summer and winter, respectively.

4.3 Potential Distribution of Acid Deposition in Asia

The possibility that acid deposition could occur in the countries of Asia has only been realized relatively recently. Thus, there have been very few long-term measurements of deposition acidity, and even now organized monitoring endeavors are rare. A few global precipitation pH monitoring networks with stations in Asia have been in operation for a number of years, and projections have been made regarding precipitation acidity distribution in the Northern Hemisphere based on these. One of these projections is given in Figure 4. Most of the monitoring efforts have, however, been concentrated in North America and Europe and the spatial resolution in Asia is extremely low. Thus, the pH ranges for Asia shown in Figure 4 must be regarded as very speculative. Nevertheless, this broad-scale map suggests that precipitation acidity in the

SUMMER

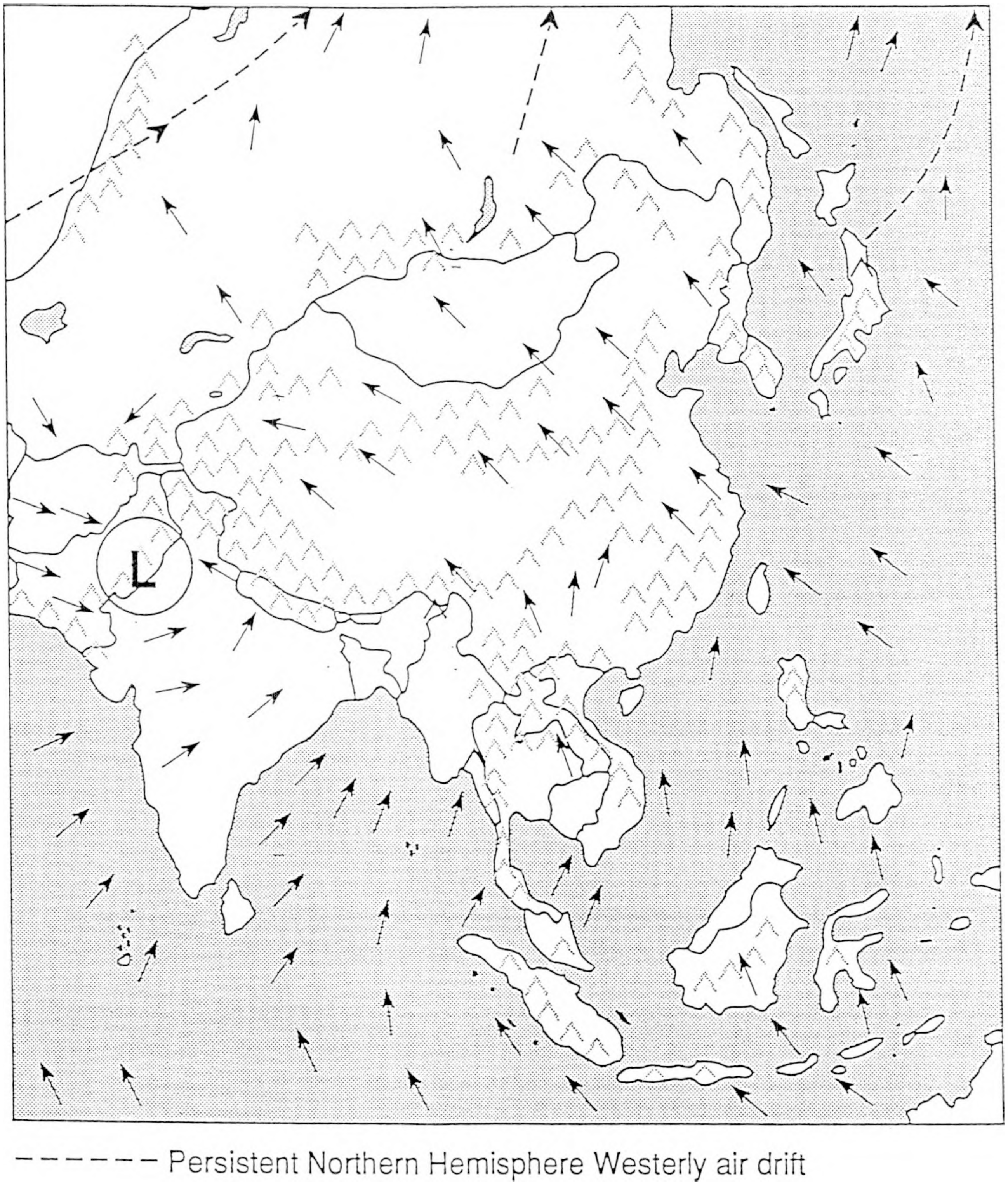

FIGURE 2 Mountain Ranges and Summer Wind Flow Patterns in Asia (adapted from Encyclopedia Britannica 1979 and MacKinnon & MacKinnon 1986)

WINTER

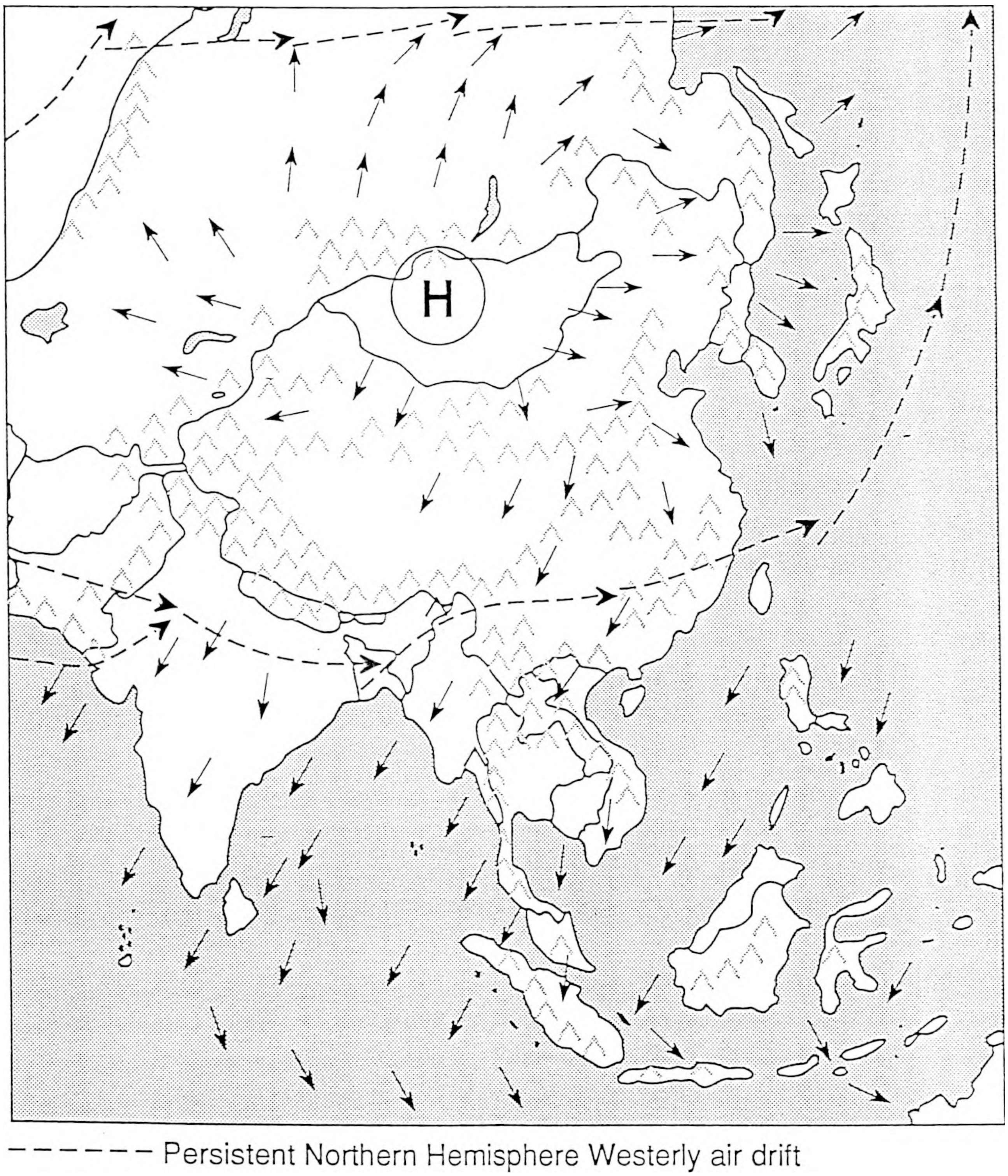

FIGURE 3 Mountain Ranges and Winter Wind Flow Patterns in Asia (adapted from Encyclopedia Britannica 1979 and MacKinnon and MacKinnon 1986)

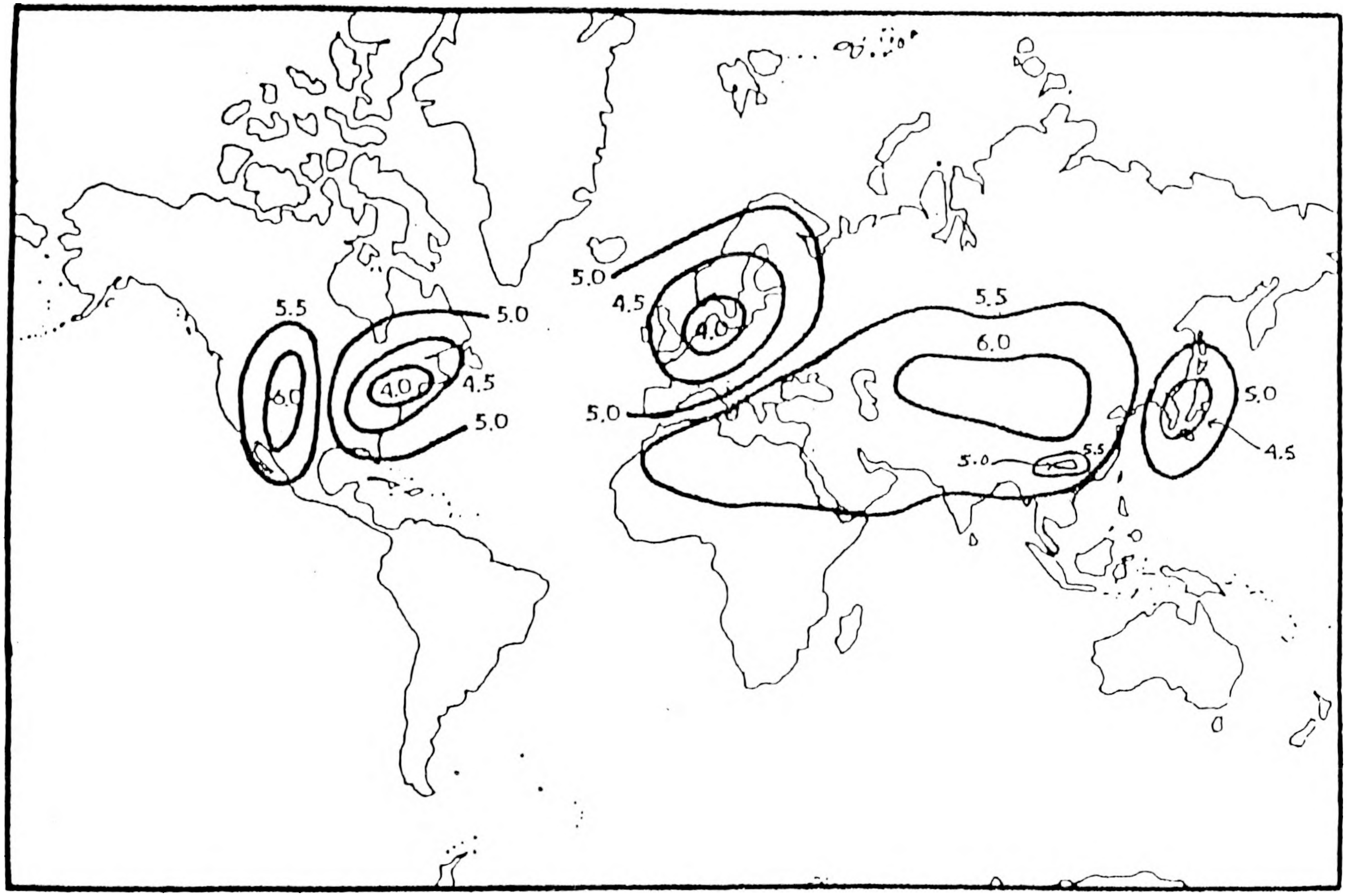

FIGURE 4 Global Mean Rain pH Values (adapted from McCormick 1985)

eastern parts of Asia can approach the kinds of levels found in eastern North America and central Europe.

In reaction to the growing concern over acid deposition in the industrialized world, a number of attempts have been undertaken in some Asian countries (China, Japan, India) in recent years to measure precipitation acidity. In China, isolated surveys of acidity levels and chemical composition of rainwater were begun in the 1970s, and nationwide acid rain measurements have been conducted since 1982 (Zhao and Sun 1986). The results indicate that precipitation in southern regions of China (south of the Yangtze River) often has pH values below 5.6, with average levels in some areas reaching 4.0. In northern regions of China, pH is usually greater than 6.0, in spite of the fact that most of the coal combustion takes place here, and SO_4^{--} concentration in rain water and SO_2 levels in many towns and cities in this region are often much higher than those in the south. The reason for this relatively high precipitation pH is that, in the north, the proximity of the central Asian deserts with their highly alkaline, saline soils increases the neutralizing capability of the atmosphere. It has been observed that NH_4^+ and Ca^{++} concentration in rain water in northern areas is much higher than in the south and in the U.S. and other industrial nations (Wenxing and Quan 1990). It is estimated that if the soil-derived bases ($CaCO_3$ and NH_3) were eliminated from the atmosphere, the precipitation pH in these northern sites would average approximately 3.5 (Galloway et al., 1987).

This implies that, if long-range transport of acid deposition precursors were to intensify (for example, due to the building of tall smokestacks) into areas, such as southern China, where such alkaline substances were not present, this could substantially increase the incidence of acidic deposition. A study of precipitation pH in the remote eastern Tibetan plateau of Qinghai Province revealed pH levels as low as 2.25 (in the largest town in the region) and as high as 8.9 (Harte, 1983). The low pH events were associated with high nitrate levels that may have been the result of long-range transport and/or the combustion of high-N coal found in this region. The high pH values were associated with areas with very alkaline, loose soils.

Another study of acid rain has been carried out in the southwestern Chinese province of Guizhou, which is surrounded by mountains on the north and southwest and therefore isolated from the prevailing winds in both the summer and winter. Precipitation acidity and composition has been measured at 14 urban and rural sites in this region since 1981. The pH of precipitation has been found to be lowest in urban areas (where most high-sulfur coal burning occurs), reaching as low as 3.4 (Zhao and Xiong, 1988). In rural areas, mean precipitation pH is approximately 4.6. It is generally believed that acid rain in Guizhou is mainly a local phenomenon (as most emissions are released at ground level) as evidenced by a significant difference in precipitation acidity levels between rural and urban areas that are only a few hundred kilometers apart, and even between urban and suburban parts of the same city. However, remote parts of this province do receive acidic precipitation, thus suggesting that some long-distance transport does occur.

In summary, it appears that acid deposition in China is not always controlled by SO_2 concentrations. In fact, the pH of precipitation seems to be as dependent on the amount of alkaline dust and cation content of the air as it is on SO_2 emission levels.

In India, precipitation chemistry and pH have been measured at a number of sites since the 1960s. Most of the pH values are in the range of 6.5 to 7.0, with some found below 5.18 (Varma, 1989a). Most of the lower pH events were observed in southern (especially along the east coast) and northeastern India and the southern Indian islands. As in China, the high pH events in India are associated with the presence of soil particulates rich in Ca^{++}, Mg^{++}, Na^{+}, and K^{+}, and are located in or near the Rajasthan desert. If suspended particulate matter is removed from precipitation samples, the pH in these high pH regions would average 5.57 (Varma 1989b). It has been observed that over the 10-year sampling period from 1974 to 1984, the trend in precipitation pH has been decreasing towards the acid range in the majority of the areas studied. Another study compared the ionic composition of rainwater samples from the monsoons of 1963 and 1965 to that of 1984 at Delhi and Agra. In both these cities, the pH value decreased over this time period -- at Delhi, pH declined from 7.0 to 6.1 and at Agra, from 9.1 to 6.3 (Khemani et al., 1989a). This decrease is likely due to the increase in industrial activity during the 1970s and 1980s leading to increased emissions of SO_2 and NO_x. In addition, at both these sites, Ca^{++} concentrations were found to have declined.

In general, acid precipitation in India currently exists only in highly industrialized areas, such as Bombay, and in regions where acid soils are prevalent, such as in the southern and northeastern parts of the country.

In Malaysia, a limited precipitation monitoring program has revealed rainfall pH to range from 4.4 to 4.8 in the area around Kuala Lumpur and 4.9 to 5.5 in Perak (Sahabat Alam Malaysia, 1983). A significant number of episodes of acid deposition (pH <4.5) have also been observed in Korea where a sampling network of 46 stations has recently been initiated (Hong 1990). In Bangladesh, an air quality monitoring program was initiated in 1990 in the capital city of Dhaka. Preliminary results reveal very high levels of SO_2 and particulates (levels greatly exceeding U.S. and WHO standards) and moderate levels of NO_x and carbon monoxide (Bangladesh Environmental Newsletter 1990).

Precipitation monitoring has also been conducted in Japan, particularly in the Tokyo area. During each of the rainy seasons of 1981 to 1983, rain pH was measured for 12 consecutive days and it was observed that pH levels were less than 4.0 for 5 of these days in 1981, 4 days in 1982 and 9 days in 1983 with levels reaching below 3.0 on one occasion in both 1982 and 1983 (IEA 1984). Monitoring in other major cities in Japan often revealed rain pHs between 3.7 and 4.2. In general, it has been observed that concentrations of sulfur and nitrogen oxides in precipitation on the west coast (facing the Japan Sea) are higher in the winter when the prevailing winds are from the Asian mainland (Swinbanks 1989). In Japan as a whole, precipitation pH has averaged between 4.5 and 5.5 over the past several years (Institute of Energy Economics, Japan 1989).

In 1983, the Japan Environment Agency initiated a five-year, 29-site field study to determine the extent and effect of acid deposition throughout Japan (JEA 1990). The results of precipitation monitoring at these sites revealed that annual SO_4^{--} and NO_3 deposition equaled or exceeded that received in affected areas of North America and Europe. This study also indicated that many sites in Japan receive precipitation with a pH of 5 or below.

Due to the general paucity of empirical measurements of current deposition pH and of long-term data on the chemical composition of precipitation in the Asian region, it is difficult to determine which areas are experiencing acid deposition and if there are any trends toward increasing deposition acidity in this region. However, based on the geographical distribution of present and/or future emissions of acid deposition precursors, the transformation processes of these precursors, and the specific weather patterns and topography of this area, it may be possible to make projections of which locations would be most likely to receive acid deposition either now or in the future.

Figure 5 provides the locations of the areas of largest emissions of acid deposition precursors and suggests that most of these emissions occur in fairly localized areas, i.e., northeast China, the Kelan Valley of Malaysia, and in the vicinity of large cities in India and other Asian countries. The majority of these emissions result from uncontrolled coal combustion and motor vehicle use.

In the summer, when the moisture-laden winds of the monsoon dominate the weather pattern of much of southeast Asia and the Indian subcontinent, the SO_2 and NO_x emitted in localized areas (along with the sulfates and nitrates produced from these) would likely be carried farther from their source than in the winter. This is due to the fact that the residence time of the aqueous-phase products of SO_2 and NO_x is greater than the corresponding gas-phase reaction products. Due to the predominant south-southwest winds during this period, most of the acidic substances would be wet deposited in areas north-northeast-northwest of emission sources as follows:

Source	Receptor (Summer)
NE China	Mongolia, Siberia
SE Asian cities	SE Asian highlands (mainland)
Indian cities	Himalayas, Assam, Bangladesh

Due to the presence of the Himalayas between India and China, there is unlikely to be much transport of acidic pollutants from India into Tibet and southern China except for that portion of China bordering on the northeastern edge of India. Also, the mountain ranges in western Burma may limit the influx of pollutants from India into Burma and Southeast Asia. Similarly, the mountains of southeast Asia may preclude long-range transport of pollutants from the polluted cities of this region into the northern reaches of southeast Asia and into southeastern China.

In the winter, the transport pattern of acidic pollutants and their precursors would be completely different. Most of Asia (except the southeastern and parts of the eastern portion) would now be in the dry season. Thus, gaseous-phase reactions and dry deposition would dominate during this period. Since dry deposition processes occur closer to the source of emission than wet deposition, transport distances would be reduced.

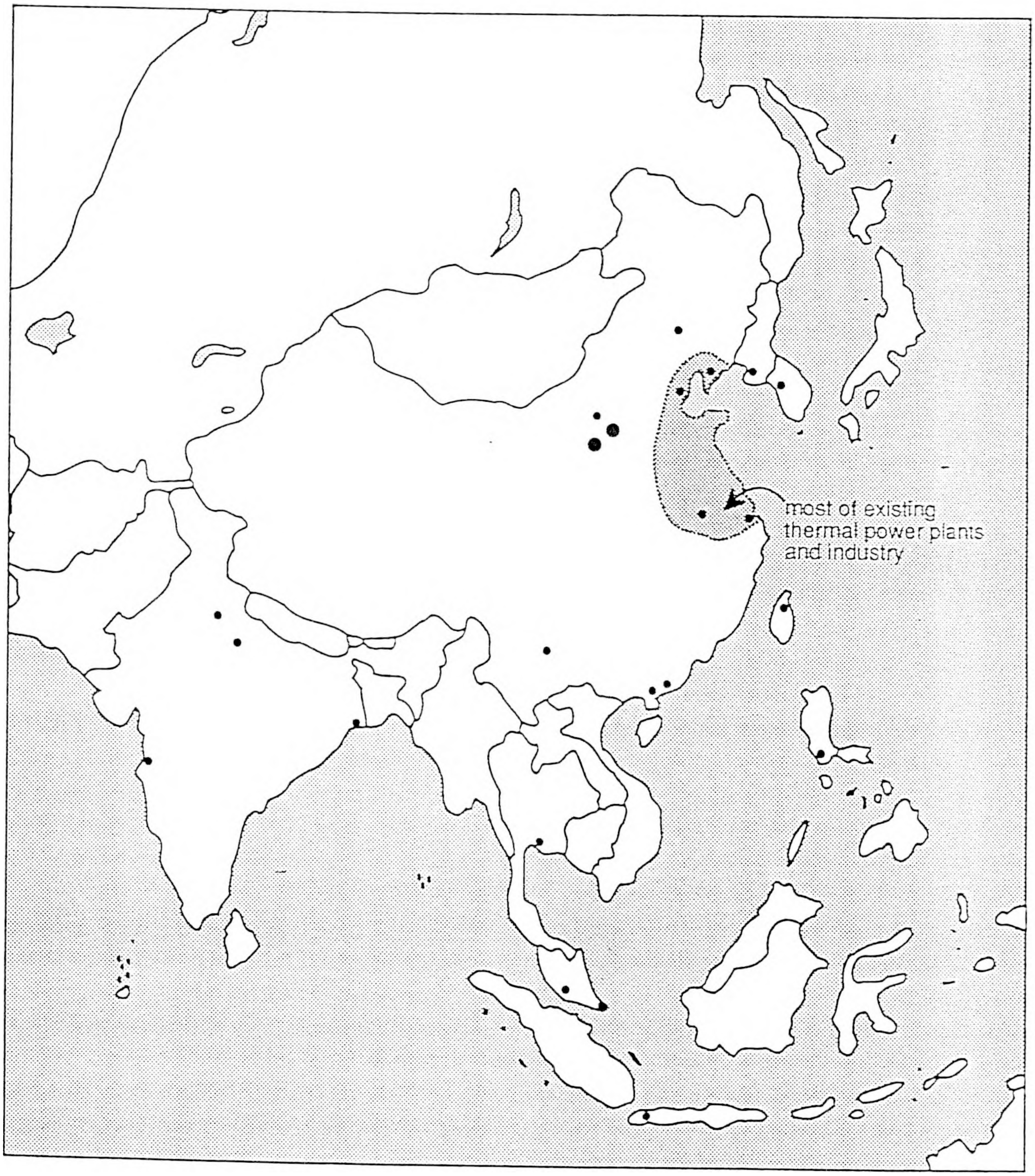

FIGURE 5 Main Emission Sources of Acid Deposition Precursors in Asia

This fact, coupled with the prevalence of north-northeast-northwest winds during this season and the topography of the region, suggests that the likely areas of acidic deposition in winter are as follows:

Source	Receptor (Winter)
NE China	Japan, Korea, southern China
SE Asian cities	SE Asian islands
Indian cities	Sri Lanka, southern India

In addition to these simplified source/receptor relationships, it is likely that the persistent westerly drift of the northern hemisphere could transport air pollution from the northern Indian subcontinent to that part of China bordering on India's extreme northeastern edge.

It appears that the most severe episodes of acid deposition are likely to occur in the winter downwind from the northeastern Chinese emission sources. This is due to the fact that much more coal is used during this season than any other, particularly for heating purposes. The receptor areas most severely impacted by this increase in emissions would be Japan, Korea, and southern China.

The mountainous portions of the above-mentioned receptor areas would likely receive some of the highest levels of acid deposition because they are located in the path of moisture-laden air masses which must rise over them, condensing out their moisture as they do. In addition, mountain areas are often enshrouded in fog and mist, both of which have been observed to contain higher acidity concentrations than other forms of precipitation.

The complexities of the meteorology of the Asian region and the considerable gaps in our knowledge of the acid deposition phenomenon, especially under tropical conditions -- coupled with the uncertainties in projecting future economic growth, energy efficiency improvements, and energy consumption -- make it extremely difficult to predict the magnitude and extent of the threat that acid deposition poses to the nations of this region. However, as long as these countries continue to pursue their goals of rapid economic and industrial development without implementation of control measures, it is a virtual certainty that emissions of SO_2 and NO_x will increase, thereby enhancing the formation of acidic pollutants and their potential to damage the environment.

5. POTENTIAL IMPACTS OF ACID DEPOSITION

Ultimately, it is the impacts that acid deposition has on the natural and man-made environment that are of greatest concern to society. Thus, the most important issue from a public policy perspective is not whether or not acid deposition does or can occur but whether the environment of the area under consideration is vulnerable to its potential effects. In the countries of Asia, where recognition of this phenomenon is just beginning, there is very limited information available on the possible consequences of acid deposition.

It is well known that acid deposition has the capacity to damage a number of components of the environment. These include freshwater aquatic ecosystems; terrestrial systems, including crops and forests; man-made structures; and human health. In the absence of research and empirical evidence on this aspect of acid deposition in the Asian countries, the determination of the potential of this pollutant to cause damage to the various anthropogenic and natural environments of this region requires an analysis and assessment of the vulnerability of these systems to elevated acid inputs.

5.1 Potential Vulnerability of Terrestrial Ecosystems

Some of the ecosystems of the Asian region (particularly those of the temperate zone) are very similar to those found in areas of North America and Europe where the majority of the research on acid deposition impacts has been conducted. Thus, in some cases, it should be possible to extrapolate the potential effects found in these western nations to the corresponding ecosystems of Asia. However, many other environments in Asia are very different from those for which acid deposition impacts have been studied, and any attempt to deduce potential effects based on observations in other parts of the world would involve a considerable degree of speculation. Nevertheless, based on a knowledge of the various components (i.e., soils, flora, fauna, climate) of the ecosystems in question, their relative vulnerability to acidic inputs, and their distribution in the Asian region, certain predictions can be made.

5.1.1 Soils

The soils of a given region, through their differing ability to process and neutralize acidic inputs, determine, to a large extent, how acid deposition will affect the overall terrestrial and aquatic ecosystems. Thus, an analysis of the characteristics of the soil and its sensitivity to acidification would permit a preliminary determination of the potential for acid deposition to impact a given environment.

The sensitivity of soils to acidification is known to be based on a number of factors, the most important of which are texture, base saturation and cation exchange capacity (CEC), organic matter content, anion mobility, thickness, vegetative cover, and rainfall rate of the area.

In general, the more acid-sensitive soils are those which (a) are underlain by hard granite or gneiss bedrocks (which do not weather easily and, thus, have low base saturation and CEC), (b) are located in areas of moderately high rainfall (20-40 in/yr or 500-1000 mm/yr), (c) have high organic matter content and/or low sulfate adsorption capacity, or (d) are in areas undergoing rapid deforestation and/or agricultural intensification. Soils with all or some of these characteristics include the podzols of the temperate zone and podzolized soils of the subtropical monsoon region. Both of these are moderately acid without much sulfate adsorption and acid neutralizing capacity due, in part, to the fact that they are often located in areas of moderate precipitation. This is enough to leach away basic cations but not great enough to produce a substantial iron and aluminum sesquioxide layer which would adsorb the incoming sulfates, and thus, prevent acidification.

Given the distribution of these sensitive soil types in Asia as shown in Figure 6, and the precipitation distribution patterns [with areas of moderate rainfall (20-40 in/yr or 500-1000 mm/yr) outlined] illustrated in Figure 7, a prediction of the areas with soils most likely to be sensitive to acidic inputs can be made. Those areas at high risk of

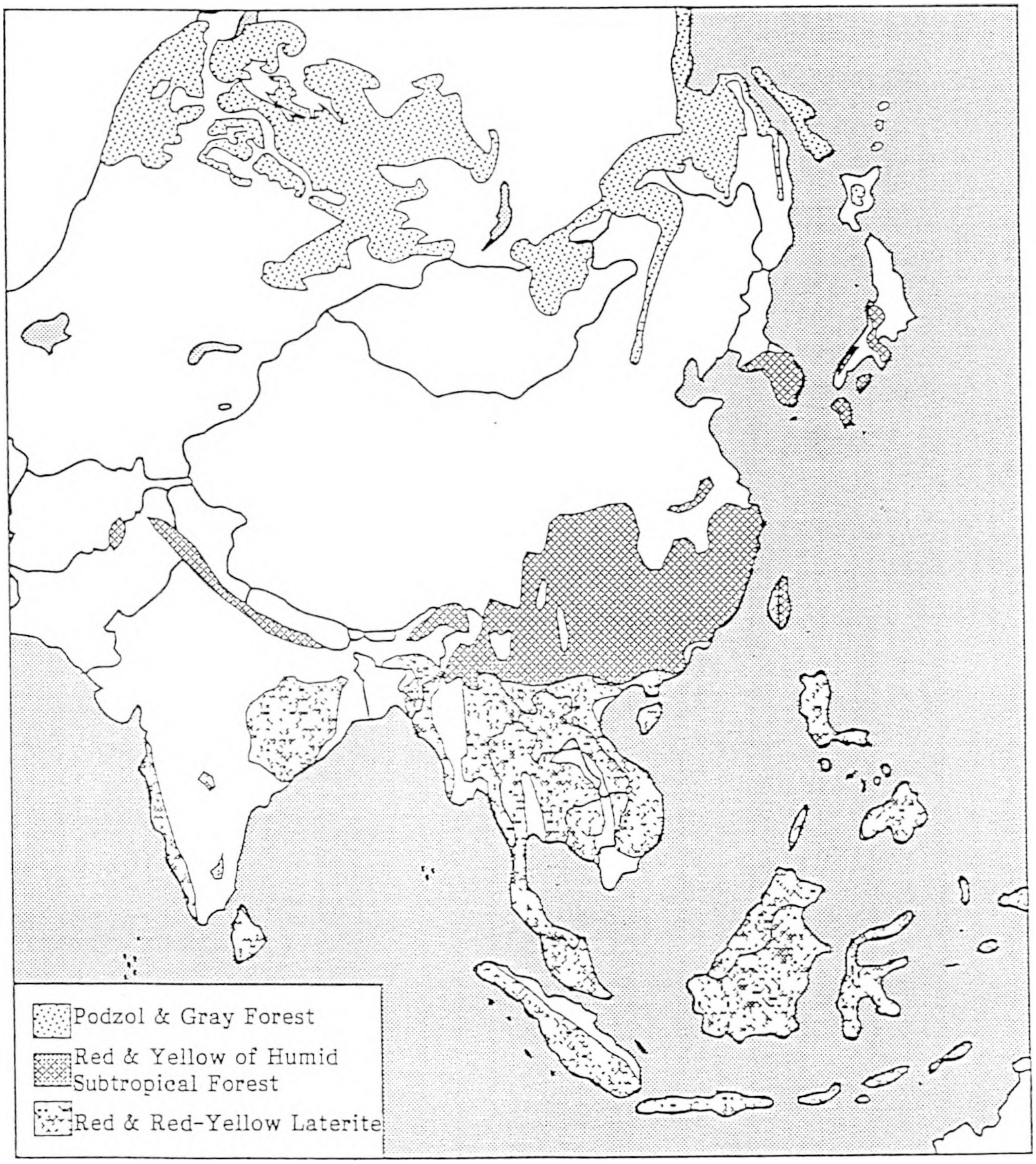

FIGURE 6 Sensitive Soil Zones in Asia (modified from Encyclopedia Britannica 1979)

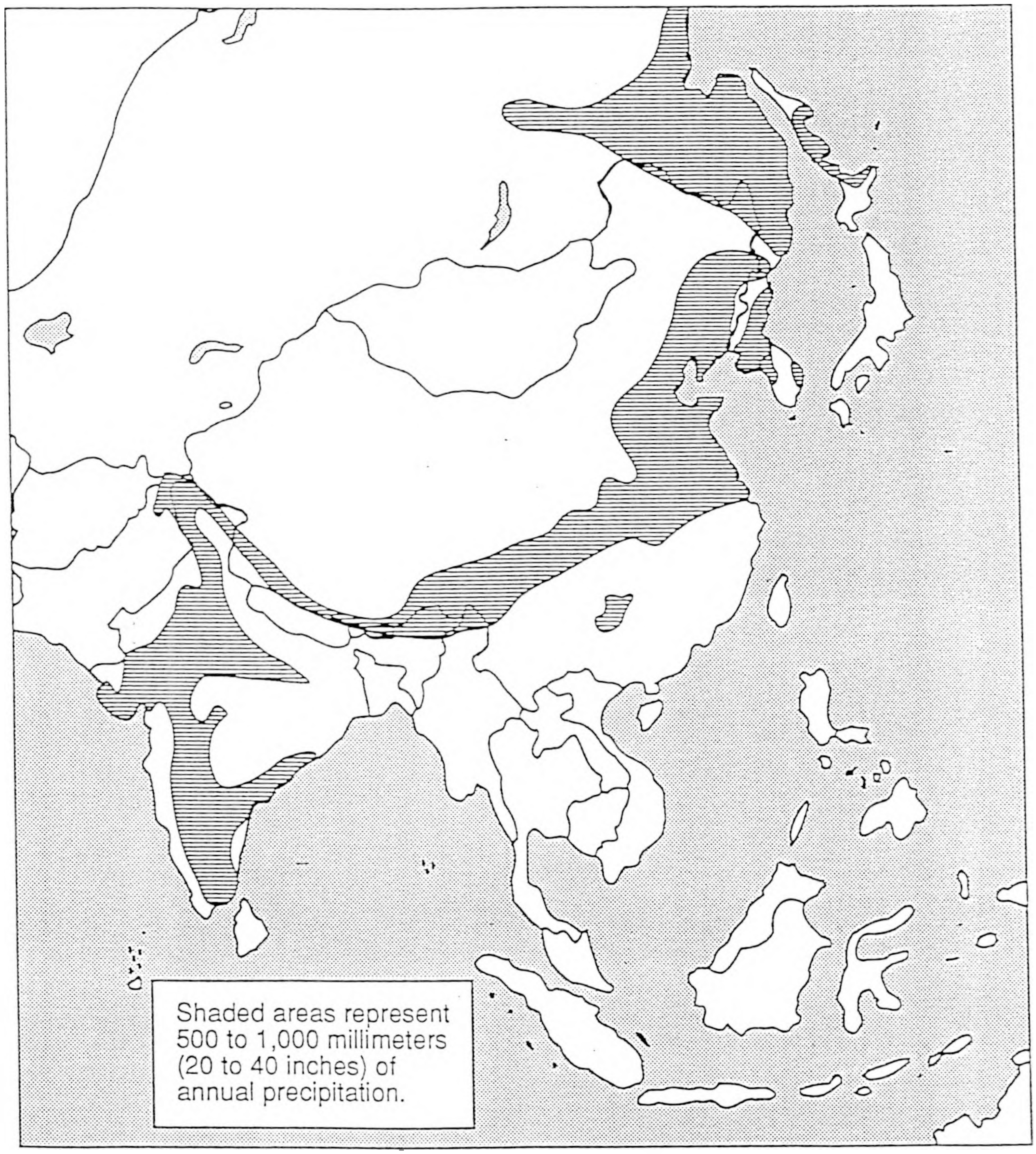

FIGURE 7 Regions Receiving Precipitation Between 500 to 1,000 mm/yr in Asia (adapted from Encyclopedia Britannica 1979)

acidification based on soil and precipitation characteristics, as well as on limited empirical measurements, are the following:

1. Southern China, Korea, and Southwestern Japan -- many areas of southern China have acid-sensitive podzolized soils with low cation exchange capacity and low acid-buffering capacity. Soil pH in this region is usually between 5.0 and 6.0 with a few areas having soil pH below 5.0 (Zhao and Xiong 1988, Zhao and Sun 1986, JEA 1990). Inputs of acid precipitation in these areas could rapidly lead to increased soil acidification and mobilization of toxic metals such as aluminum, due to the absence of buffering systems. It should be noted that some areas in this region have yellow soils with strong sulfate adsorption capacity due to the presence of iron and aluminum sesquioxide layers in the soil. This would allow these soils to maintain a stable pH regardless of the pH of the incident precipitation.
2. Southeast Asia -- some nonvolcanic, montane portions of this region have thin, highly weathered, lateritic soils that are close to the end of the weathering process and, thus, have few basic cations remaining (McCormick 1985). These soils are already acidic and have high levels of aluminum that could be mobilized with additional acid inputs (Rodhe et al., 1988). Most of the basic cations that exist in the ecosystems of these regions are locked up in the biomass; if vegetation is removed through whole tree harvesting and agricultural processes, these areas could become acidified rapidly. These activities are increasing in southeast Asia and, thus, the potential for soil acidification is large.
3. Southwest and Northeast India -- The southwestern portion of India has been observed to have acidic, lateritic soils with pH between 4.8 and 5.3 (Khemani et al. 1989b). In the northeastern part of the country, soils are also acid, with pH varying between 4.0 and 6.0. Most of these areas receive high levels of precipitation, which leaches out nutrients and increases soil acidity. Usually, such soils are accompanied by substantial amounts of aluminum and iron sesquioxides that can buffer incoming acids via their sulfate adsorption capacity. However, in these areas, further weathering is limited, and agricultural and deforestation activities are accelerating thereby reducing the buffering potential of the soil. Thus, exogenous inputs of acidity would further increase soil acidity and mobilize aluminum. In addition, some of the Himalayan foothills have podzolized soils characteristic of the subtropical monsoon zone. These soils are sensitive to acidification as discussed above; furthermore, such mountain soils are thin and deforestation is common in these areas, further increasing the susceptibility of these soils to acidic inputs.

5.1.2 Flora and Fauna

Even if a region is receiving high levels of acidic deposition and has soils sensitive to acidification, this phenomenon will only have an impact on terrestrial and aquatic ecosystems if the flora and fauna of the region are sensitive as well. Due to the large population of the Asian region, most of it directly dependent on these resources for its existence (much of it at a marginal level), any change in the productivity of these ecosystems could have severe consequences. In addition, many of these nations depend primarily on the export of their crop and forest species to earn foreign exchange. Thus, an assessment of the sensitivity of the vegetation and fauna of the Asian region is urgently required to determine the potential risk of acid deposition to this area.

The vegetation of the Asian continent is extremely diverse, ranging from the alpine and polar tundra to the tropical forests of the equatorial region. In many parts of Asia, the natural vegetation has been replaced by cultivated croplands and forestlands. Given the variety of vegetative cover in Asia, it is impossible to easily determine the potential impact of acid deposition in the region as a whole, especially in light of the fact that very little research on the effect of acidity on Asian species has been conducted.

From research on temperate zone vegetation in North America and Europe, it appears that acid deposition can affect plants in two ways -- directly on leaf and other plant surfaces (e.g., leaching of nutrients from leaves, erosion of protective surface layers) and indirectly through soil-mediated effects. However, even in temperate areas receiving the highest levels of acid deposition, there is little conclusive evidence of widespread direct foliar damage to trees and crops (McDowell 1988). It is possible that in the tropics and subtropics, where the average leaf life is greater than in the temperate zone, the cumulative effects of acid deposition could be large enough to cause direct damage. This needs further investigation. Also, much of the forests of the Asian region are located in mountainous areas where exposure to acidic species is potentially higher than at lower levels. It should be noted that although precipitation pH in many parts of Asia is currently high, this is due not to low sulfate and nitrate levels but to high levels of alkaline dust. However, ecosystem vulnerability depends not only on the acidity of the deposition impinging on it but also on the total quantity of sulfates and nitrates it receives; these latter cations can contribute to surface acidification after they are deposited even if they are not acidic at the time of deposition (Galloway et al. 1987). In many parts of China and India where deposition is not currently acidic, the quantity of sulfates and nitrates deposited is more than that being received in areas where acid deposition damage is suspected in North America and Europe.

On the other hand, it is possible that since many tropical and subtropical ecosystems are nutrient-limited, especially in nitrogen and sulfur, atmospheric deposition of these substances through acid deposition could have a fertilizing effect on these areas. This could also lessen the need for fertilizers for agricultural lands. Again, conclusions are hindered by the absence of research information.

Given our understanding of the impact of acid deposition on temperate zone vegetation in North America and Europe, supplemented with the few such studies in the Asian region and on tropical and subtropical species, the vegetation (both crops and forests) in the areas given in Table 7 are likely to be at highest risk from acid deposition (the location and vegetation types involved are illustrated in Figure 8).

Acid deposition could also affect the terrestrial fauna of the Asian region, particularly those species which have an aquatic phase in their lifecycle. This would include frogs and salamanders, mosquitos and flies, and soil microorganisms. Many of these species have important roles in the terrestrial ecosystem, particularly in pollination and soil nutrient cycling and aeration. These activities are especially significant in tropical and subtropical ecosystems where most pollination is carried out by animals (Baker et al. 1983), nutrients are extremely limited, and nutrient cycling is very tight. No information currently exists on the potential vulnerability of Asian fauna to acid deposition.

TABLE 7 Areas with Vegetation at Highest Risk from Acid Deposition

Area	Vegetation Type	Comments on Effects
Siberia, northern Mongolia, extreme northeast China	Taiga -- coniferous forests (pine, spruce) with some deciduous species (birch, aspen, larch)	This area is comparable to the boreal forest of North America and Europe that is considered to be sensitive to acid deposition.
Northeast China, mountain regions of southern China, Korea, Japan, Himalayan slopes in India and Nepal, upper mountain region of southern India	Temperate -- broad leaf and mixed forests of spruce, pine, fir, birch, aspen, oak, and cedar	This vegetation type is similar to that of the mixed forests of North America. Some of the species in these forests appear to be sensitive to acid deposition. Some evidence of forest decline has been observed in the mountainous areas of southwestern China where precipitation with pH < 4.5 is common. A large-scale pine reforestation program has been initiated in this region and approximately 50% of the planted trees withered within a few years and net productivity of the surviving trees was half that of similar trees in areas receiving rain with pH > 4.5 (Chuying 1985).
Himalayan foothills in India, Montane regions of southeastern Asia, southern China, and southern India	Subtropical montane -- evergreen forests of conifers (fir, pine, cedar, spruce) and deciduous species	This is unlike vegetation zones found in North America and Europe where acid deposition is prevalent. However, due to their long leaf life and existence of related, sensitive conifer species, these forests could be susceptible to high levels of acid deposition, especially to its cumulative effects.

TABLE 7 (Cont'd)

Area	Vegetation Type	Comments on Effects
Upper mountain regions of India, China, and Nepal	Alpine -- coniferous forest (spruce and fir) with birch	Similar to high elevation forests of eastern N. America and Central Europe that are particularly susceptible to acid deposition.
Various areas of China, India, Japan, Korea	Crops -- mostly rice, wheat, soybean Timber -- pine	Rice has shown susceptibility to rain events of pH 4.5 (Zhao and Xiong 1988). Wheat yields and growth has been observed to decrease with rain of pH < 4.5. However, no significant growth declines have been conclusively proven to have been caused by rainfall with ambient pH even in most severely impacted areas of North America and Europe. It is possible that interaction of acid deposition with other air pollutants (especially ozone) could cause yield declines in some crops. Of timber resources, the pines and spruce of Japan and China are at highest risk.

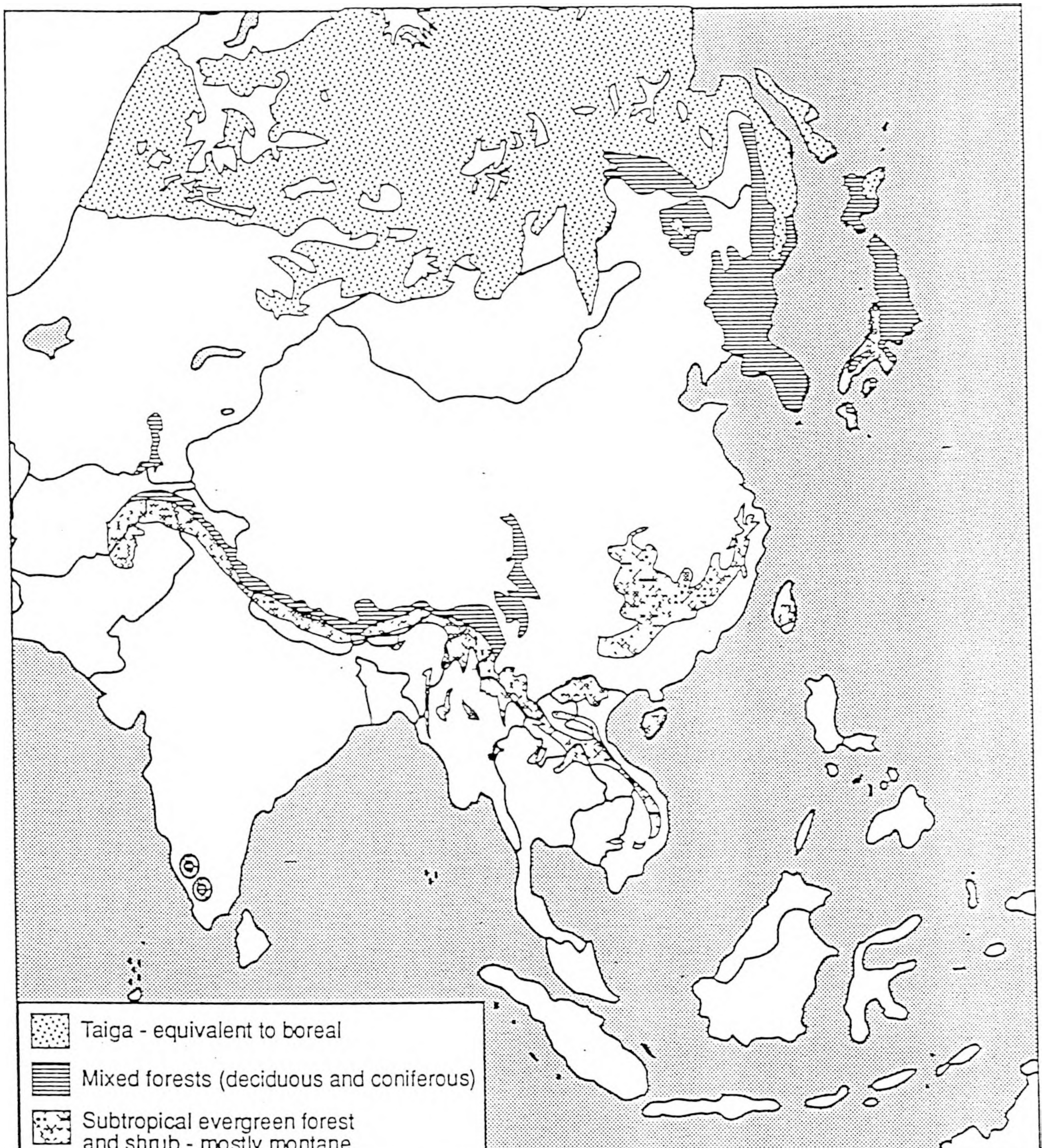

FIGURE 8 Sensitive Vegetation Zones in Asia (modified from Encyclopedia Britannica 1979 and MacKinnon and MacKinnon 1986)

5.2 Potential Vulnerability of Aquatic Ecosystems

Much of the threat of acid deposition was brought to world attention by its potential impacts on aquatic ecosystems and, even today, its effects on these systems remain the best documented and convincing evidence of this phenomenon. The connection between terrestrial and aquatic ecosystem acidity is well-established and implies that the area surrounding a water body (i.e., the watershed) controls, to a large extent, the input of acids into the lake, stream or river system. Once acid deposition enters a water body, either directly or via the watershed, it can undergo further changes via interaction with the water. The ability of a water body to neutralize incoming acidity is referred to as the alkalinity or acid neutralizing capacity (ANC), which is derived mainly from the long-term interaction of the watershed with precipitation (Schofield et al. 1985). Lakes and streams with low ANC are more likely to become acidified with acid inputs.

In general, aquatic ecosystems most at risk from acid deposition are those which are located in watersheds that have little carbonate bedrock; have thin, compacted, acidic soils; contain coniferous vegetation; receive high levels of acid deposition; and/or are ultraoligotrophic (have few nutrients and buffers). This characterizes many aquatic ecosystems found in the boreal/temperate zone of eastern North America and Northern Europe. In Asia, aquatic ecosystems in these climatic zones are found in northern China, Korea, Japan, and the mountainous regions of northern and southwestern India and southern China. However, most of these areas have watersheds containing alkaline soils due to their proximity to the central Asian and western Indian deserts and, thus, are probably resistant to acidification. This has been confirmed in the eastern Tibetan plateau where surface water pH ranges from 7.9 to 9.3 (Harte 1983). In Japan, a survey of 133 lakes showed that most have a pH of approximately 7.0 (JEA 1990). Thus, of the temperate-zone aquatic ecosystems, only those in Korea and the mountain areas of southern China and southwestern India are associated with acid soils and thus are potentially at risk from acidification. This needs further verification.

It should be noted that nontemperate/nonboreal aquatic systems can also be vulnerable to acidification. Many tropical areas have highly weathered, acidic soils making the aquatic ecosystems contained within them susceptible to acidification due to low alkalinity levels (Galloway 1988).

In addition to changes in growth and productivity of terrestrial and aquatic ecosystems, long-term acid deposition can also result in shifts in species composition and abundance. These shifts could have serious economic implications for many Asian nations. Such changes in species composition are thought to be currently in progress in some forests of eastern North America and central Europe and could also occur in areas of Asia, especially if acid deposition intensifies. However, in tropical and subtropical ecosystems, where biological diversity is extremely high, changes in species composition and abundance would be very difficult to detect and assess (McDowell 1988). Here, more basic research into growth and productivity changes of individual species is required.

In summary, it appears that there is considerable potential for ecosystem impact from acid deposition in the Asian nations. Further study and monitoring is urgently needed to establish baseline values, as well as to detect and warn of possible changes at an early stage (McCormick 1985). In addition, accelerated research on tropical flora and fauna and increased knowledge of the future emission patterns of acid deposition precursors in this region are needed before a more accurate assessment of the risk of the ecosystems of Asia to acidification can be made. However, in spite of the potential risk of the ecosystems of this region to acidification (as outlined above), it should be realized that air pollution in general, and acid deposition in particular, is only one of many threats to the environment in a region exposed to the heavy pressures of accelerating human settlement, urbanization, industrialization, and agricultural intensification.

5.3 Potential Vulnerability of Man-made Systems and Human Health

The potential of acid deposition to corrode and damage man-made surfaces such as those of statues, monuments, buildings and vehicles is now well-established. In fact, it was this property of acid precipitation that led to its discovery in 1852 by Robert Angus Smith. The constituents of acid deposition can react with the surface of various materials thereby causing damage. It should be realized that other air pollutants as well as normal weather processes can also lead to similar damage. Therefore, it is often difficult to separate the effects of acid deposition from those of other processes, even in areas where extensive research on this aspect of acid deposition has been conducted (i.e., in North America and Europe). In Asia, where concentrations of other air pollutants are often very high, and humidity, precipitation and temperature are greater, assessing the specific impact attributable to acid deposition is very difficult.

Due to the prevalence of structures of cultural, religious and historical significance -- often constructed of limestone, marble or sandstone, and hundreds or thousands of years old -- deterioration from acid deposition could be considerable. Other structures such as buildings, bridges, industrial plants, motor vehicles, electric and electronic equipment, textiles, painted surfaces and dams could also be at risk. Some damage has already been observed in this region in recent years that could be due to SO_2 and/or acid deposition. The Taj Mahal, located downwind of a major oil refinery, and metal, concrete and stone structures in southwestern China in areas of high levels of acid deposition are currently undergoing rapid and severe deterioration (Zhao and Xiong 1988; Gauri and Holdren 1981). Although such damage could be due to other factors, in China it has been shown that cities with similar climatic characteristics but less acid deposition and other pollutants have corrosion rates less than one-half that of areas receiving high levels of acidity (Zhao and Xiong 1988). With accelerating rates of industrialization and greater long-range transport of pollutants, increased damage to man-made structures can be expected.

As research into the acid deposition phenomenon has intensified, it has become evident that it has the potential to affect human health. These effects are caused not only by acid precipitation but also by acidic aerosols (particularly sulfates and nitrates). These substances can affect human health both directly (through contact with the skin, eyes, and respiratory system) and indirectly. At ambient levels of acidity even in North America and Europe, very little direct damage has been observed except through the inhalation of acidic aerosols, particularly sulfate. Asthmatics, those with other respiratory ailments, the elderly, and children are particularly susceptible to these direct impacts, which can result in decreased lung function, increased susceptibility to colds and allergies, bronchitis, and eventually in obstructive lung disease.

Indirect effects of acid deposition on human health may be potentially more serious. These impacts include contamination of drinking water supplies (acid deposition can liberate toxic metals from the soil and water supply systems), and mercury and toxic metal poisoning through ingestion of fish from acidic waters and crops grown in acidic soils. Although the potential exists for such human health damage due to acid deposition, few effects have yet been observed at ambient levels even in the most polluted areas of North America and Europe.

In Asia, where population density is extremely high, the health of a large segment of the population is weakened due to other stresses, levels of SO_2 and $SO_4^{=}$ are very high (especially in urban areas, where, under the higher temperature and humidity conditions of the tropics, sulfur dioxide can rapidly be converted to acid sulfates), and drinking water supplies are not treated and/or are obtained from shallow wells and roof-catchment cisterns, the potential for human health damage from acid deposition is considerable. This threat is greatest in areas currently receiving or expected to receive large quantities of acid deposition, which are underlain by acid soils, and which have high population density. This includes southern China, parts of southeastern Asia, Japan, Korea, and northeastern and southwestern India.

6. OPTIONS FOR DEALING WITH ACID DEPOSITION IN ASIA

A number of options are currently available to reduce the emissions and/or threat of acid rain. Although most of these measures have been developed to fit into the North American and European context, some could be adapted to the situation in Asia.

As mentioned earlier, in most Asian countries coal continues to be the most likely fuel for power generation, industrial use, and, in some cases, for domestic cooking and heating needs. Typically, the coal is burned directly without attempts to limit the emissions of acidifying species. However, options are available to continue the expansion of coal use while minimizing the emissions of sulfur and nitrogen oxides to the environment. Whether such options are affordable by developing countries depends on competing demands for scarce economic resources and the seriousness of the environmental impacts. Ideally, the affordability of emissions controls should be evaluated in terms of costs of damage to the environment. In the power generation sector, which may contribute most of future problems of acidic deposition, current plans in most countries call for the use of tall stacks to disperse the emissions and in a few cases, use of low-sulfur coal or coal preparation. This of course was precisely the strategy adopted in the industrialized nations of Europe and North America prior to the discovery of acid rain and the recognition that tall stacks merely transformed a local pollution problem into a regional one.

Installation of flue-gas desulfurization (FGD) systems on large power stations could certainly control emissions of sulfur oxides (reduction of 90 percent or greater). At present, in the absence of a demonstrated need based on observed damaged, governments and electricity-generating authorities seem to view the additional costs of FGD as prohibitive.

An alternative approach would be to consider utilizing cleaner technology for coal. Technologies such as fluidized-bed combustion and coal gasification are commercially available and can reduce emissions of both sulfur (80-95%) and nitrogen oxides. In addition, they may operate with greater conversion efficiency and, hence, reduce coal consumption and limit the carbon dioxide emissions that contribute to global warming. Costs would be comparable to conventional combustion with FGD.

Some less expensive techniques for emissions control are available, but they are less effective in reducing emissions. These techniques include various levels of physical coal cleaning and limestone injection. Whichever processes are chosen, it would seem advisable to use those that produce useful waste products such as gypsum, elemental sulfur, or sulfuric acid, so as not to add to the mounting problems of solid waste disposal in Asia.

The opportunities for clean coal technology seem to be greater in Asia than in Europe or North America where the acid rain problem is related to emission sources that are already built. In Asia the opportunity exists to anticipate a problem from pollution sources that are planned but not yet constructed. The advantages of clean coal technology may best be achieved in new facilities, rather than in retrofitting existing facilities. Many of these control options, perhaps with the exceptions of FGD and gasification, are equally applicable to industrial-sized facilities. In the commercial sector however, increased costs for pollution control are more difficult to justify, for they may affect the competitive position of companies. In the household sector, if coal cannot be phased out, then conversion of coal to "smokeless" briquettes--possibly with the addition of limestone to absorb some of the sulfur--seems to be a possible option.

A review of technology types applicable to the coal resources of the regions is urgently needed. The review should concentrate on some of the more problematic types of lignite and other poorer quality coals as well as capital and operating costs, pollution removal efficiencies, and other factors affecting the production of electricity or industrial goods.

Another control strategy is to substitute coal with other fuels, or, to delay the development of coal utilization for those countries that currently are not major coal consumers. These measures would, however, require the availability of alternative energy resources that are not only economic and reasonably competitive with coal, but also much cleaner. Considering resource availability in the region, natural gas, geothermal resources, and hydropower would offer feasible options to be promoted as major components of the energy supply system of the region.

The supply of natural gas as a major component of the regional energy supply system would be highly feasible. Australia, New Zealand, Indonesia, Brunei, Malaysia, Thailand, and Bangladesh are natural gas producers in the region. Vietnam could be a potential natural gas producer. A large gas-reservoir in Iran has not been tapped. Given sufficient level of regional cooperation, establishing an Asian gas grid that runs from Iran to the east, passing through Pakistan, India and Burma on one side, and a westward stream originating from Vietnam, Malaysia, and Thailand on the other side, could be an attractive option. Even on a much smaller scale or using different routes, the gas utilization alternative has appealing features.

Of the various known renewable energy sources, geothermal has been proven to be economical. In countries like Indonesia, the Philippines, and others that have sizable geothermal resources, the exploitation of this energy source should be promoted.

Development of large hydropower facilities could also be seen as one of the energy policy options that could help substitute for thermal power generation, especially in South Asia. There is a massive hydropower potential in Nepal (with estimated economically feasible potential of about 30,000MW) which still remains mostly unexploited. Keeping in view the large share of thermal power generation in India and Bangladesh, a regional cooperation in developing the hydro resources in South Asia offers an alternative measure to mitigate the acid rain problem in the year 2000 and perhaps much beyond.

In addition to all of the supply-side options previously mentioned, one must not overlook energy conservation measures in dealing with energy-related emissions of acid precursors. The choice of technology in energy supply systems and the functioning of energy efficient technologies in end-use systems are the important elements in this scheme. As many of the countries in the region are still in the process of developing their industries, the opportunities for choosing energy efficient technologies are very great, both for conservation purposes and for increasing the competitiveness of the industries being developed.

7. CONCLUSION

Thus far, acid deposition has been considered as being a problem only in the industrialized countries of North America and Europe. However, it is becoming evident that the developing nations are not immune to this threat. In fact, given their policy and desire to "catch up" with the industrialized world, which necessitates a significant expansion of energy consumption (most likely derived from indigenous coal reserves), the potential for the formation of, and damage from, acid deposition in these developing countries is very high. This is especially true in many parts of Asia.

From the previous sections, it is clear that in order for a given area to be at high risk from acidification, a number of conditions must be present simultaneously. These are the following:

(1) the area must be receiving (or will receive if future risks are being evaluated) high levels of deposition. This requires that the area be downwind of major emission sources of acid deposition precursors and that the meteorology of the region favors the transformation of these precursors into acidic substances;
(2) the soils of the area must be sensitive to acidification;
(3) the area must have vegetation, fauna, aquatic organisms, man-made materials and/or large human populations vulnerable to increased inputs of acidity.

These have all been discussed and evaluated in previous sections of this paper. From this analysis, it can be deduced that a number of areas in Asia currently fulfill these conditions and some others are likely to do so in the near future given their development strategies. The various regions in Asia and their ability to meet at least some of these conditions are summarized in Table 8. It can be concluded that three areas meet all these requirements at present and thus can be considered to be at high risk from acidification. These are Japan and Korea, southern China and the mountainous regions of Southeast Asia with the montane zones of southwestern India being at marginal risk at present. (Two other areas have the potential for being at risk from this phenomenon as they currently receive relatively high levels of acid deposition and have sensitive ecosystems and man-made structures but do not have vulnerable soils. These include parts of Siberia and northern Mongolia, and the foothills of the Himalayas in northern India.)

TABLE 8 Vulnerability of Various Asian Regions to Acid Deposition Risk Factors

<table>
<tr><th rowspan="3">Region</th><th colspan="7">Risk Factors</th></tr>
<tr><th colspan="2">High Emissions</th><th colspan="2">High Deposition (based on meteorology, emissions and location)</th><th rowspan="2">Sensitive Soils</th><th rowspan="2">Sensitive Vegetation and Materials</th><th rowspan="2">High Risk</th></tr>
<tr><th>Current</th><th>Future</th><th>Current (confirmed through empirical data)</th><th>Future</th></tr>
<tr><td>NE China</td><td>X</td><td>X</td><td></td><td>X</td><td></td><td>X</td><td></td></tr>
<tr><td>Japan, Korea</td><td></td><td></td><td colspan="2">X X
(winter mostly)</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>S. China</td><td></td><td>X</td><td colspan="2">X X
(winter mostly)</td><td>X</td><td>X</td><td>X</td></tr>
<tr><td>SE Asia</td><td>X</td><td>X</td><td colspan="2">X X
(local areas, summer mostly)</td><td>X
(mountain areas)</td><td>X
(mountain areas)</td><td>X
(mountain areas)</td></tr>
<tr><td>SE Asian Islands</td><td>X</td><td>X</td><td colspan="2">X X
(isolated, local)</td><td>X
(mountain areas)</td><td></td><td></td></tr>
<tr><td>N. India</td><td>X</td><td>X</td><td></td><td>X
(summer)</td><td></td><td>X
(Himalayan foothills)</td><td></td></tr>
<tr><td>SW India</td><td></td><td></td><td>(borderline acidity)</td><td>X
(winter)</td><td>X</td><td>X
(montane areas)</td><td>(borderline in mountain areas)</td></tr>
<tr><td>NE India</td><td></td><td>X</td><td></td><td>X
(summer)</td><td>X</td><td></td><td></td></tr>
<tr><td>Sri Lanka, Maldives</td><td></td><td></td><td>(borderline acidity)</td><td>X
(winter)</td><td></td><td></td><td></td></tr>
<tr><td>Siberia, N. Mongolia</td><td></td><td></td><td></td><td>X
(summer)</td><td></td><td>X</td><td></td></tr>
</table>

It should be noted that although much of Asia currently does not appear to be vulnerable to acidic deposition, this could change with the accelerated development initiatives underway in many Asian nations which inherently entail greatly increased emissions of acid deposition precursors, especially from large sources which often have tall smokestacks. This would likely increase the transport of these precursors (and their transformation to acidic substances) to sensitive areas.

It is clear that acid deposition has a significant potential to affect the Asian region. However, empirical evidence is urgently needed to confirm this as well as to increase the awareness of this phenomenon within these nations. Thus, an active deposition monitoring program and intensified research on the meteorology and ecosystems of these regions is required. These would also provide early warning of increases in the magnitude and extent of acid deposition and its impacts.

A variety of control technologies to reduce acid deposition and/or its impacts in Asia are currently available. These include emission abatement strategies, fuel switching, conservation, and energy efficiency. The most effective strategy, however, will depend on the energy and industry mix of each particular country or region in Asia.

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