that increased particulate exposure increases health risk (Dockery et al. 1993). Characterizing the relationship between particulate concentration and health impacts is complicated by contributions of weather, other co-occurring environmental pollutants, and a lack of extensive measurements of particle sizes other than 10 microns. It has been difficult to identify a single causal factor when several air pollutants are elevated at the same time.

A fine-particulate standard is now being considered for particles less than or equal to 2.5 microns. Available monitoring data suggests that large areas of the country would not be in attainment with such a standard.

In addition to possible health effects, the Environmental Protection Agency's draft criteria document also addresses the contribution of secondary particles to regional haze. Title I of the 1990 Clean Air Act Amendments authorizes the development of control strategies to mitigate visibility impacts. The Environmental Protection Agency could use Title I provisions to respond to the federal land managers' findings of visibility impairment in Class I areas. The Environmental Protection Agency could alternatively use the ambient standard process to set a visual range goal.

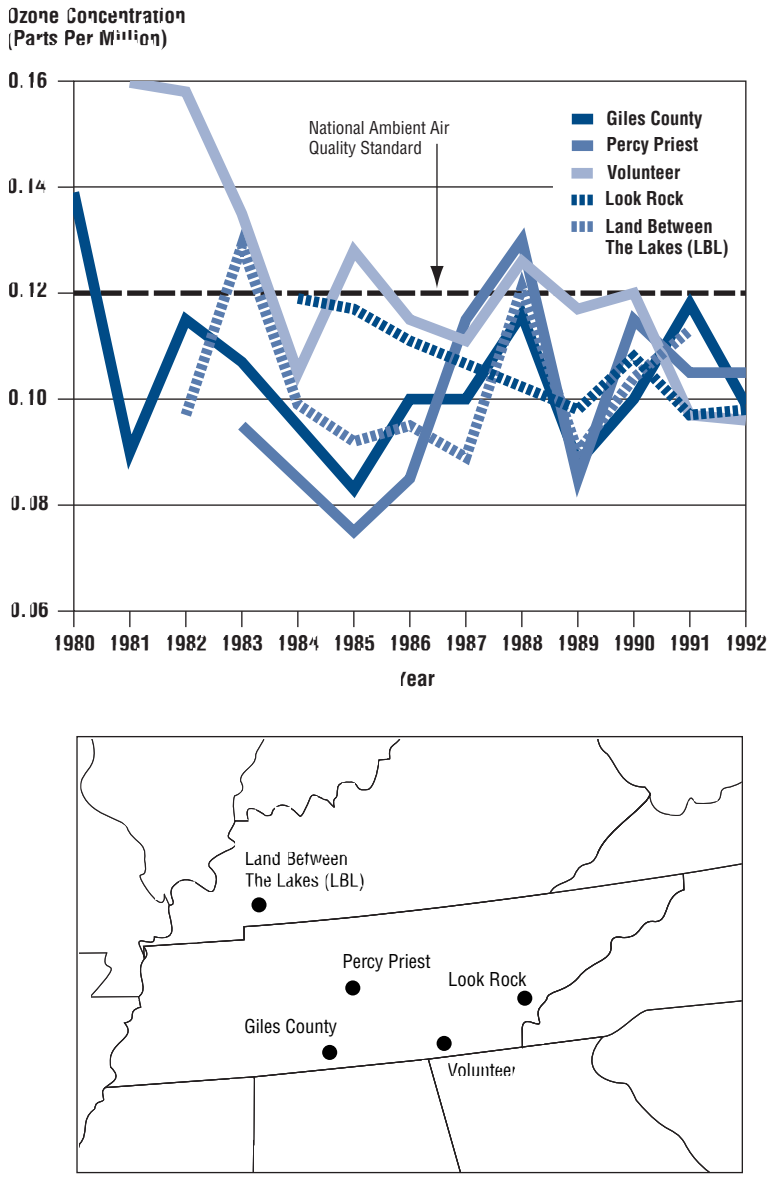
If the ambient standard were revised to limit fine particles (less than 2.5 microns in size), TVA would likely install higher efficiency electrostatic precipitators and add filters to coal-handling areas. Factors to differentiate among energy strategies do not include those to comply with uncertain future regulations of fine particles.

TROPOSPHERIC OZONE

Health and Welfare Concerns

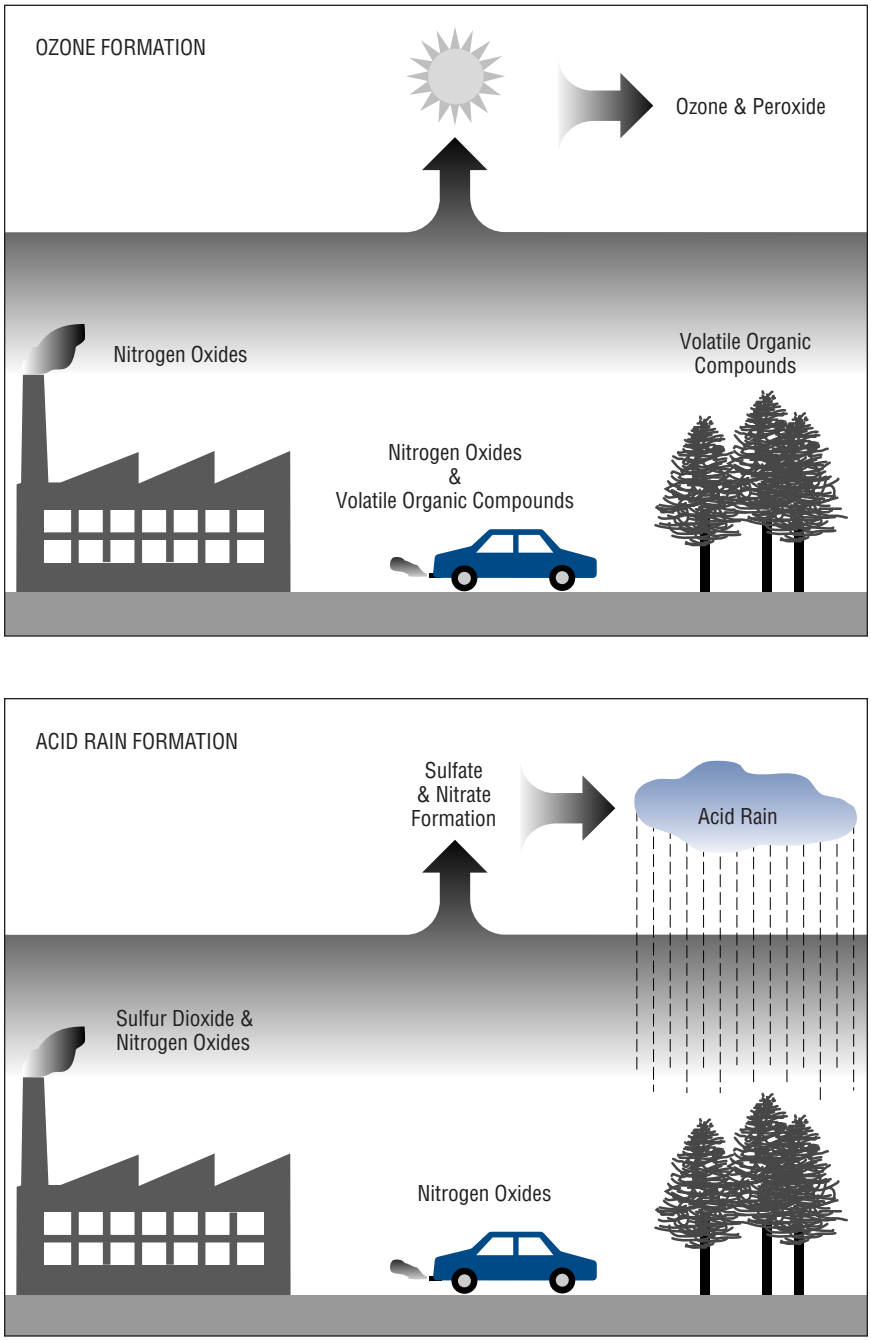
Ozone is a secondary air pollutant produced in the presence of sunlight from the primary emissions of nitrogen oxides and volatile organic compounds in the lower atmosphere (troposphere). In some areas of the southeastern United States, ambient levels of ozone exceed levels demonstrated to impair human respiratory function and to impact crops, forests, and materials. Several urban areas in the Southeast do not attain the current National Ambient Air Quality Standard (maximum one-hour average concentration not to exceed 0.12 parts per million more than three times in three years). The Environmental Protection Agency is considering revisions to the current standard to address health impacts from extended exposures and cumulative impacts to crops and forests. The National Park Service has reported that ambient levels of ozone are adversely

FIGURE T1-29. **Maximum Hourly Ozone Concentrations at Five Monitoring Sites in the Energy Vision 2020 Study Area Have Shown Little Improvement**



impacting resources in park and wilderness areas protected as designated Class I areas under the Clean Air Act (Shaver et al. 1994). For all these reasons, ozone is a major consideration for environmental consequences of energy strategies.

FIGURE T1-30. **Ozone and Acid Rain Formation**



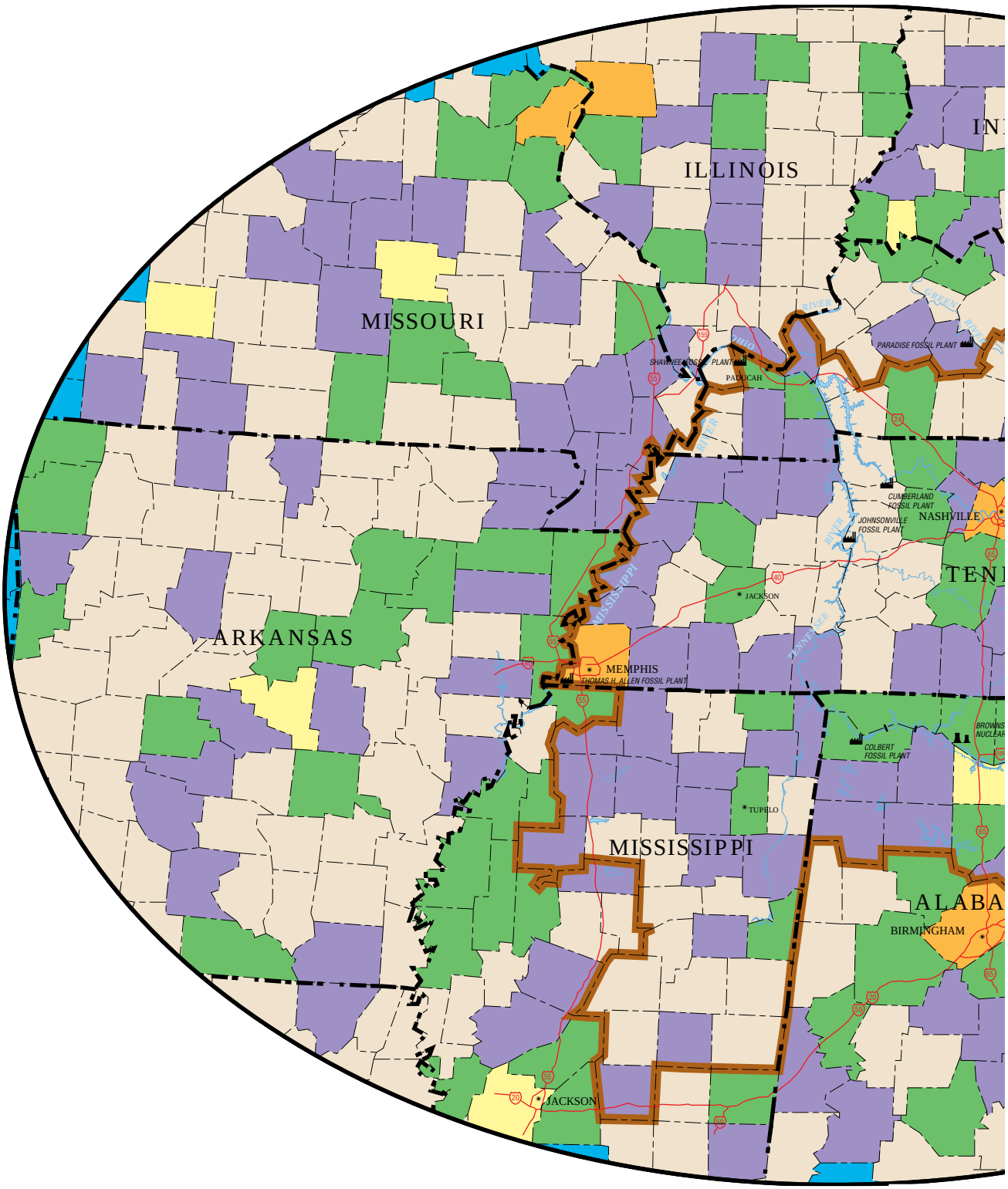
Ozone Formation

Sunlight is required for ozone formation. The rate of formation increases with increasing solar intensity and temperature. Thus, ozone levels are greater in the summer than in the winter and tend to be greater in drier years. The frequency and magnitude of ozone episodes is a function of meteorologic variables such as wind speed and direction, solar radiation, and humidity. The southeastern United States is particularly susceptible to elevated ozone exposures, due to its warm, sunny climate; the high frequency of air stagnation episodes; and the large contribution of natural emissions sources. *Figure T1-29* illustrates the maximum ozone concentration at five monitoring sites in the Tennessee Valley. *Figure T1-30* illustrates the way in which ozone is formed.

Sources of Contribution

Human-produced and natural sources of nitrogen oxides were discussed previously. Human-produced sources of volatile organic compounds include motor vehicles, petrochemical storage and transport, chemical and industrial processing, and smaller sources such as dry cleaners and bakeries. The map in *Figure T1-31* illustrates human-produced point, area, and mobile sources of volatile organic compounds. Vegetation, microbial activity, and forest fires are natural sources of volatile organic compounds. Comparing *Figures T1-31* and *T1-32* shows that in many areas of the southeastern United States, natural sources can equal or exceed human-produced sources. *Figure T1-33* illustrates that TVA's emissions of volatile organic compounds are insignificant when compared to its emissions of other pollutants and to other sources of volatile organic compounds.

FIGURE T1-31. **Total Volatile Organic Compound Emissions from Point, Area, and Mobile Sources in the Greater Source Area for Energy Vision 2020**



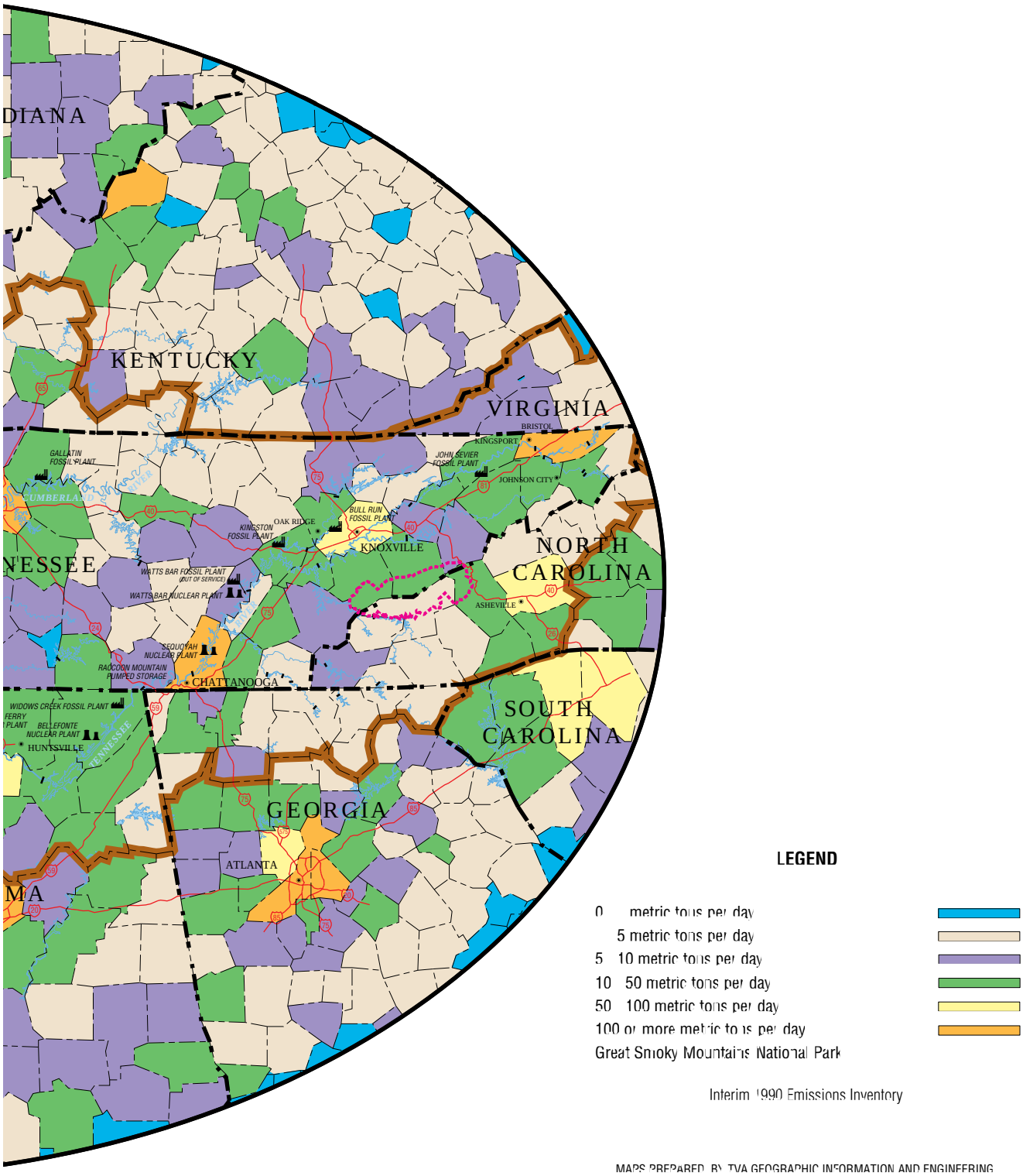
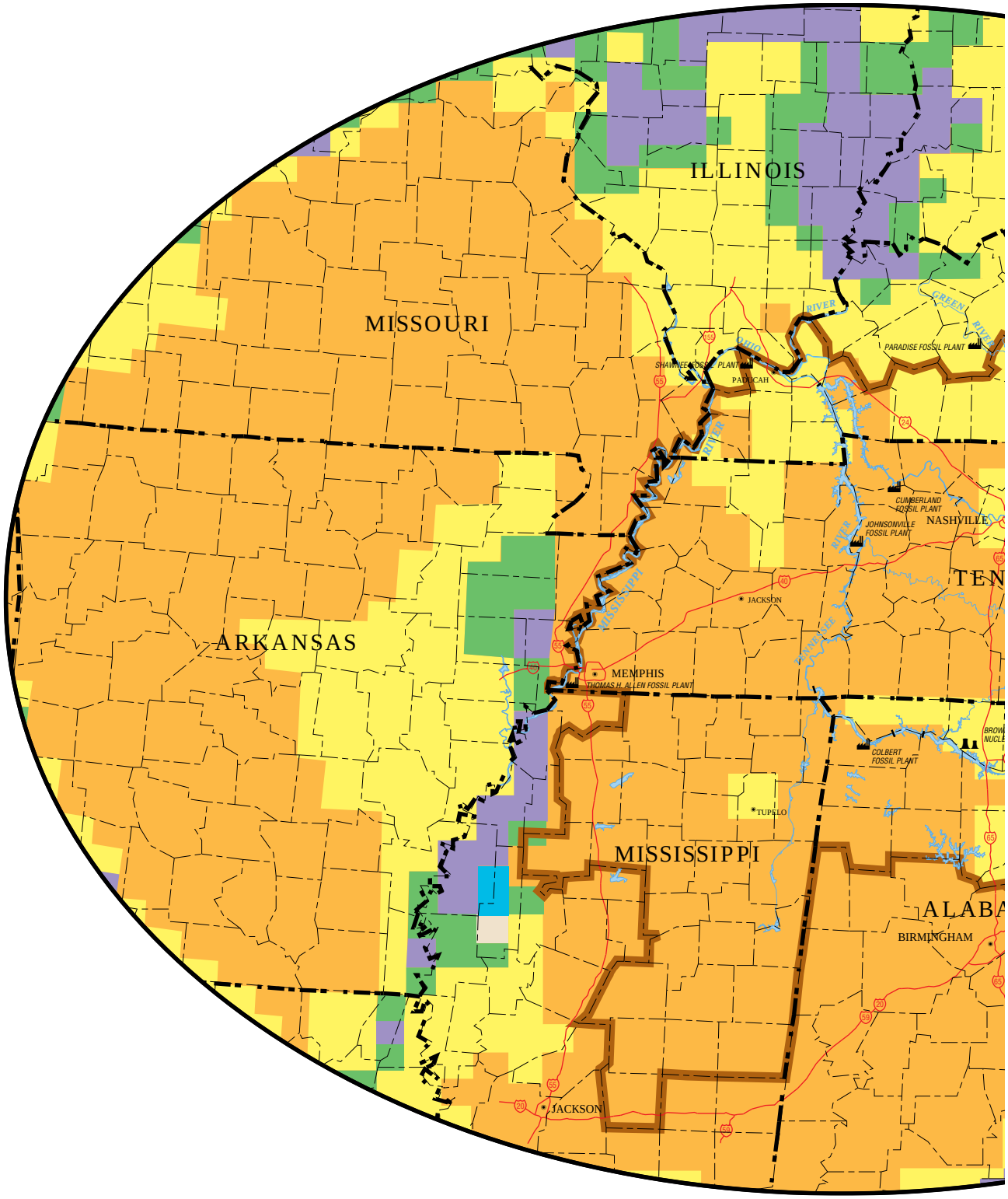
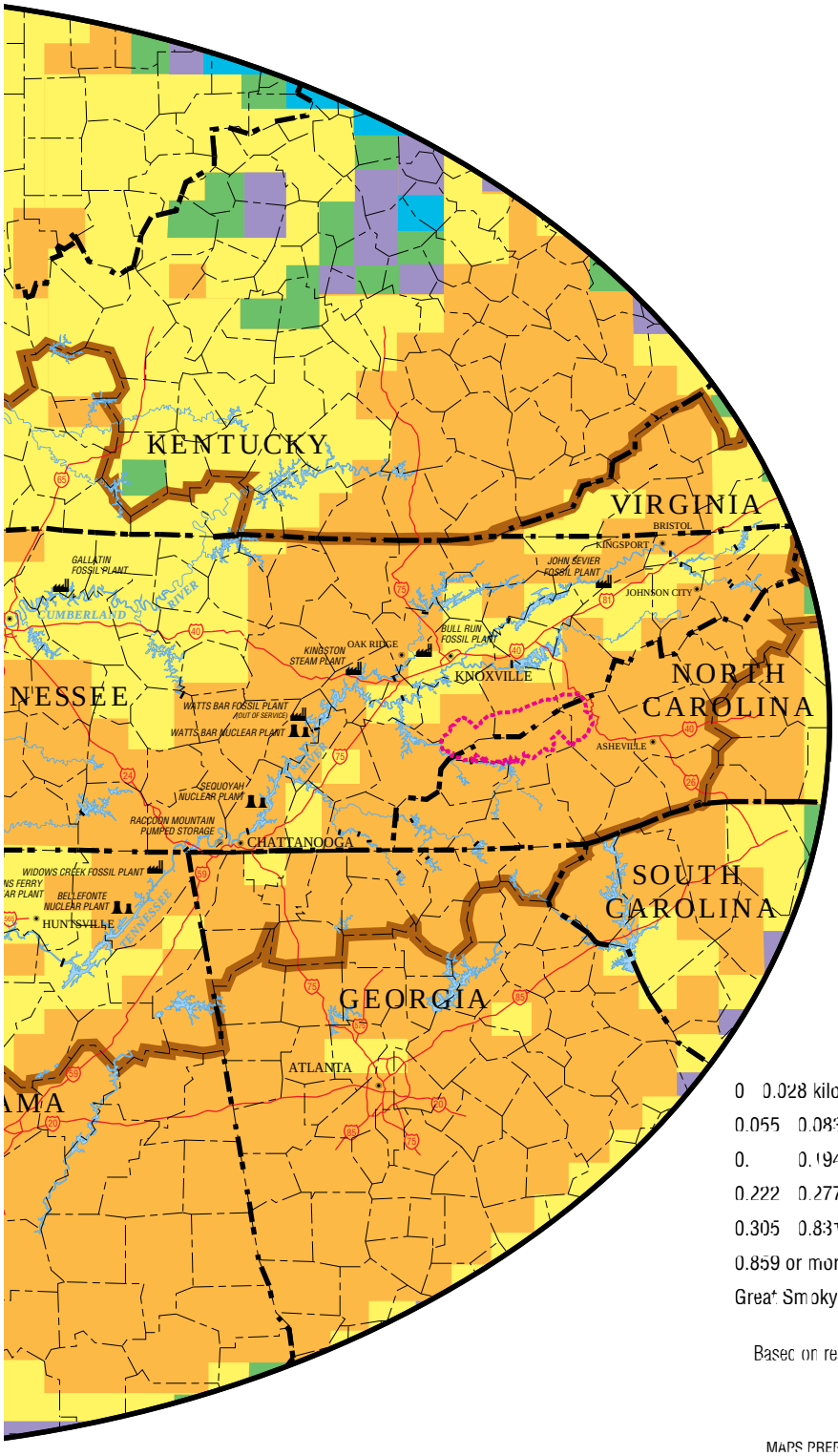

DIANA
KENTUCKY
VIRGINIA
BRISTOL
KINGSPORT
JOHNSON CITY
GALLATIN FOSSIL PLANT
JOHN SEVIER FOSSIL PLANT
CUMBERLAND
OAK RIDGE
BULL RUN FOSSIL PLANT
KINGSTON FOSSIL PLANT
KNOXVILLE
NORTH CAROLINA
NESSEE
WATTS BAR FOSSIL PLANT (OUT OF SERVICE)
WATTS BAR NUCLEAR PLANT
ASHEVILLE
SEQUOYAH NUCLEAR PLANT
RACCOON MOUNTAIN PUMPED STORAGE
CHATTANOOGA
WIDOWS CREEK FOSSIL PLANT
BELLEFONTE NUCLEAR PLANT
HUNTSVILLE
TENNESSEE
SOUTH CAROLINA
GEORGIA
ATLANTA
MA
LEGEND
0 metric tons per day
5 metric tons per day
5 10 metric tons per day
10 50 metric tons per day
50 100 metric tons per day
100 or more metric tons per day
Great Smoky Mountains National Park
Interim 1990 Emissions Inventory
MAPS PREPARED BY TVA GEOGRAPHIC INFORMATION AND ENGINEERING

FIGURE T1-32. **Summer Volatile Organic Compound Emissions from Natural Sources in the Greater Source Area for Energy Vision 2020**





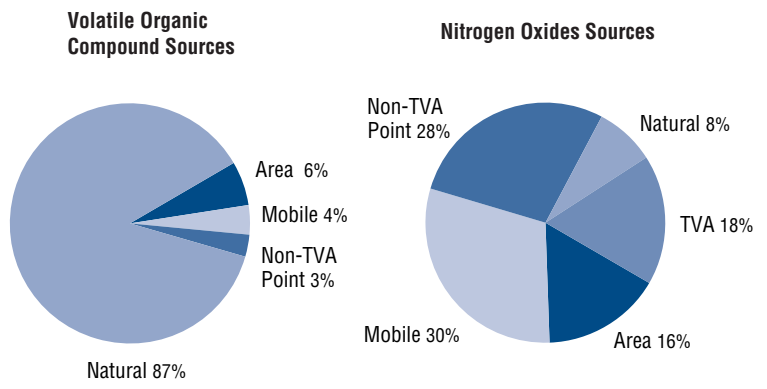
LEGEND

0 0.028 kilogram per hectare per day	
0.055 0.083 kilogram per hectare per day	
0. 0.194 kilogram per hectare per day	
0.222 0.277 kilogram per hectare per day	
0.305 0.831 kilogram per hectare per day	
0.859 or more kilograms per hectare per day	
Great Smoky Mountains National Park	

Based on results of EPA Biogenic Emissions Inventory System II Model

MAPS PREPARED BY TVA GEOGRAPHIC INFORMATION AND ENGINEERING

FIGURE T1-33. **Source Contributions to Ozone in Great Smoky Mountains National Park**



Ambient Trends

Progress on ozone exposures has been mixed, despite the expenditure of billions of dollars on emission reductions in the Southeast over the past decade and a half. In the Tennessee Valley, the cities of Chattanooga, Knoxville, Memphis, and Huntsville have attained the ozone standard. However, Nashville and other cities in the southeastern United States (Atlanta, Charlotte, and Birmingham) remain in nonattainment status. (See nonattainment map in *Figure T1-15*.) Other measures of ozone exposure have not shown an improvement that is discernible above the annual variability in trends due to weather patterns.

Figure T1-34 shows trends during the ozone season (April to September) from 1980 to 1992 at five sites selected to represent urban and rural exposures in the Tennessee Valley.

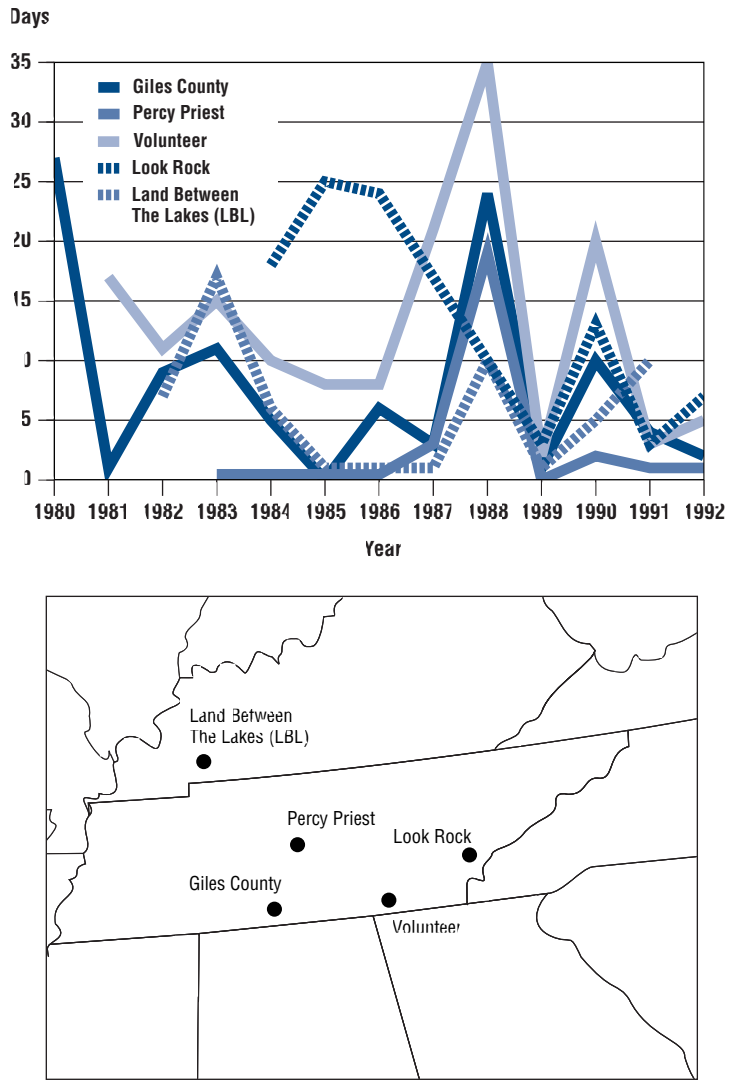
The maximum hourly ozone exposure shown in the graph in *Figure T1-29* provides insight into the annual variability in ozone trends. There has not been a demonstrable improvement over the past decade in maximum hourly ozone at these sites except at the Volunteer site located near Chattanooga. There can be annual variation in exposure that can occur simply as a function of weather patterns. The driest year on record in the Tennessee Valley was 1988; 1989 was the wettest *(Figure T1-11)*. While the maximum one-hour exposure at these sites was similar in 1988 and 1989, the frequency of hours of elevated ozone was much greater at all sites in 1988 than in 1989. During the 1988 ozone season, elevated exposures occurred much more frequently at urban sites (Volunteer site near Chattanooga, and Percy Priest site within Nashville) than at rural sites.

Since ozone formation is dependent on sunlight, the pattern for daily ozone exposure typically is lowest before dawn and builds over the day to peak in late afternoon and evening, as shown in the graph in *Figure T1-35*. In the presence of nitric oxide, ozone is consumed in the formation of nitrogen dioxide. Ozone consumed during evenings and nighttime hours is not replaced by ozone formation. In areas where nitric oxide is plentiful, ozone levels are commonly depleted during evening and nighttime hours. Monitoring at 40 stations in rural areas of the Southeast indicates that ozone levels are similar in daily cycles and timing of peaks as urban exposures (Lee and Ekles 1993). At high elevation (more than 2,500 feet) or remote sites, absence of local sources of nitrogen oxide emissions can cause ozone levels to remain elevated throughout the evening. Exposures at remote sites can also exhibit peaks later in the afternoon, evening, and night hours than nearby urban areas, indicating regional transport of ozone formed outside the remote areas (Mueller 1994; LeFohn 1994). *Figure T1-35* illustrates that ozone exposures can be greater at high elevation sites than at low elevation sites in the Valley.

Current Regulatory Issues

The National Ambient Air Quality Standard for ozone was initially set at 0.08 rather than 0.12 parts per million for the maximum one-hour standard. The level was raised in 1978 because the stricter standard was an unattainable goal for many urban areas in the country. Ozone nonattainment areas are classified as marginal, moderate, serious, severe, or extreme. Classifications are based on the frequency of episodes that exceed the standard. Nashville is currently classified as moderate. If meteorological conditions are mild in 1995, Nashville could achieve the requirement for three consecutive years without a violation of the 0.12 parts per million maximum one-hour standard, and would be designated as being in attainment with the ozone standard. If there is a violation of the standard this year, the current regulation requires that the Nashville area be reclassified as serious. A redesignation would require the State of Tennessee to consider additional emissions reductions to reduce ozone. Past emissions strategies have focused on reducing emissions of volatile organic compounds. Future strategies could consider sources of nitrogen oxides emissions, including TVA's Gallatin, Cumberland, and/or Johnsonville Fossil Plants. TVA is participating in the Southern Oxidants Study to better understand sources contributing to ozone formation in the Nashville area and the southeastern United States. (See discussion in section on cooperative research and assessment programs.)

FIGURE T1-34. **Frequency of Occurrence of 8-Hour Average Ozone Concentration Above 0.08 Parts per Million for Five Selected Sites in the Tennessee Valley**



gent. An Environmental Protection Agency staff paper released for review in spring 1995 (Environmental Protection Agency 1995a) summarized the human health risks and proposed alternative forms for a revised primary standard to protect human health. The revised primary standard could take the form of an eight-hour mean not to exceed 0.08 parts per million. An allowance of one to five exceedances per year are being considered.

The Environmental Protection Agency is also considering a separate secondary ozone standard to better protect crops and forests. In the draft 1995 ozone criteria document (Environmental Protection Agency, 1995b), the Agency suggests a cumulative ozone exposure, calculated as the sum of all hours exceeding 0.06 parts per million (SUM06) during the maximum three-month period between April and October, that does not exceed 26.4 parts per million-hours would protect 50 percent of agricultural crops from a 10 percent yield reduction. Because plants respond more severely to the peak exposures, the frequency of hours greater than 0.10 may also be considered in the future in evaluating potential impacts of ozone exposures. This threshold is based on evidence from crop exposure studies. The threshold for damage to trees may be lower than that suggested for crops because trees have longer lives than annual crops and are therefore exposed to ozone for a greater period of time. (See discussion under crop and forest impacts.)

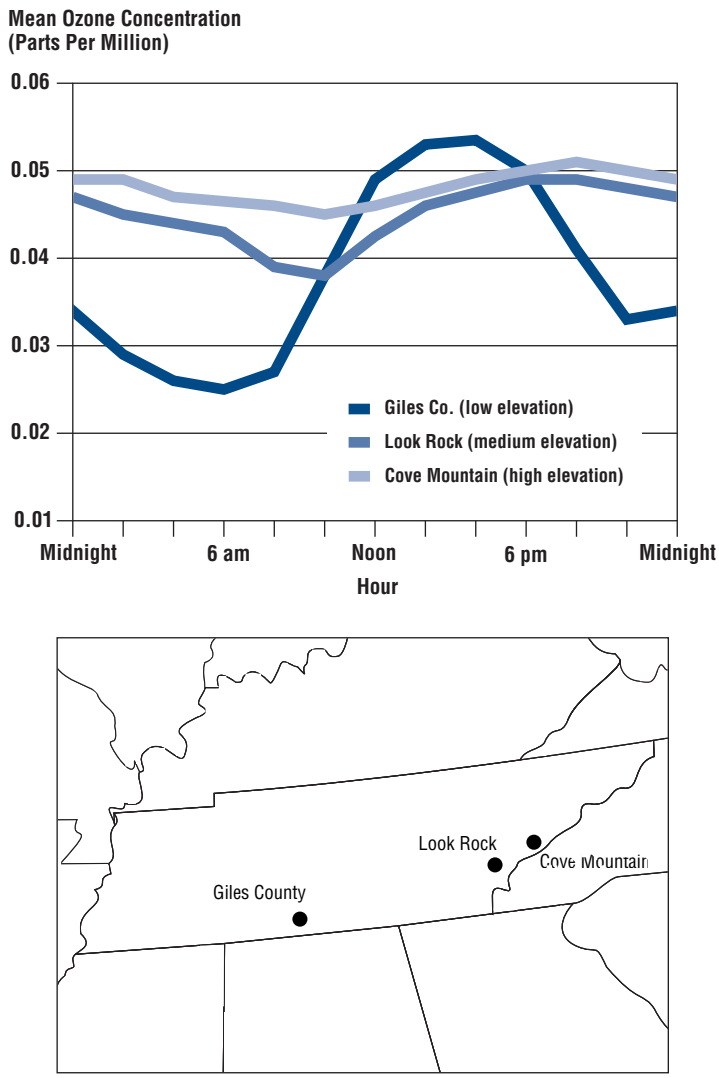
Further emissions reductions to reduce ambient ozone exposures in Class I areas of southern Appalachia are being recommended. The National Park Service has asked for emissions offsets from existing sources as a condition for new source permits. The Southern Appalachian Mountain Initiative, discussed earlier in this section, is considering emissions management options and could make recommendations to the states for emissions reductions that would go beyond the 1990 Clean Air Act Amendments.

The State of New York has petitioned the Environmental Protection Agency to consider states outside the Northeast Ozone Transport Region in its efforts to attain the ozone standard within New York. Research under the North American

Future Regulations

The Environmental Protection Agency is currently reviewing the adequacy of the one-hour maximum standard of 0.12 parts per million ozone to protect human health and welfare. While the Environmental Protection Agency has indicated that it expects to complete its review in 1997, the American Lung Association has sued the Environmental Protection Agency to complete its review by the end of 1995. The Environmental Protection Agency could decide to make the ozone standard more strin-

FIGURE T1-35. **Daily Ozone Trends at Different Elevations**



Research Strategy on Tropospheric Ozone will help define sources contributing to ozone in the northeastern United States Results will assist development of regulatory policy.

Ozone Trends Under Revised Standards

The Environmental Protection Agency's proposed primary standard for ozone is more rigorous than the current maximum one-hour standard. The historical (1980-1992) frequency of occurrence of 8-hour average ozone concentrations greater than 0.08 parts per million for five selected Valley sites are shown in *Figure T1-34*. Depending on the number of occurrences above 0.08 parts per million allowed in one year, all five sites could be classified as nonattainment under a revised standard (currently only one of the sites, Percy Priest, is located in a nonattainment area). Notably, the Look Rock site, located on the western boundary of Great Smoky Mountains National Park, has a high frequency of 8-hour means greater than 0.08 parts per million. Data from 40 rural and urban monitoring stations in 1992, the year with the greatest number of rural monitoring stations, indicates that large areas of the southeastern United States would likely not be able to meet a revised standard of 8-hour mean not to exceed 0.08 parts per million. *(See Figure T1-36.)* The year 1992 was a comparatively mild ozone season. Sites where data is also available for 1990 and 1991 show that the number of days exceeding the 8-hour mean of 0.08 parts per million were greater in the earlier years than in 1992.

Most of the ozone monitoring in the United States has focused on establishing exposures in urban areas. The available data base for examining ozone trends in rural areas in the Southeast where crops and forests occur most frequently is limited prior to 1990. In 1990 the Southern Oxidants Study integrated existing rural sites and established new sites in a network to provide spatially representative coverage of ozone exposure in the rural Southeast. *Figure T1-37* presents the maximum three-month sum of hours exceeding 0.06 parts per million (SUM06) in 1992 at 40 urban and rural monitoring stations. The SUM06 ozone statistic was lowest in Middle Tennessee and highest in northeastern and southwestern Tennessee. Higher values in rural and high elevation areas reflect the higher evening and nighttime ozone exposures at sites removed from sources of nitric oxide.

The number of hours greater than 0.10 parts per million is a useful measure to describe the severity of ozone exposure, since both humans and plants are sensitive to peak exposures. Because nighttime ozone levels can be greater in rural than in urban areas, the SUM06 statistic may be equal to or greater at a rural site compared to an urban site, yet experience fewer hours greater than 0.10 parts per million. *Figure T1-38* illustrates that few areas in the Tennessee Valley experienced more than five hours greater than 0.10 parts per million of ozone during the period from April through September in 1992. The summer of 1992 was cooler than average. Analysis of Southern Oxidant Network data for 1990 and 1991 indicated these years

had higher cumulative exposures and greater numbers of hours exceeding 0.10 parts per million than occurred in 1990.

Understanding Emissions Contributing to Ozone

Ozone control strategies to date have focused on control of human-produced volatile organic compounds. Controls of volatile organic compounds have been less effective in reducing ozone levels than expected for several reasons:

- Natural organic compounds comprise more than half of total emissions of volatile organic compounds in the Southeast.
- Many human-produced sources were underestimated in early strategies.
- Vehicles and vehicular miles traveled have increased in number over the past decades.
- Nitrogen oxides levels were not considered.

The National Academy of Science in its 1991 review, "Rethinking the Ozone Problem in Urban and Regional Air Pollution," recommended reexamination of the strategy (National Research Council 1991). Past experience has demonstrated that the most effective strategy to reduce ozone depends on the relative concentrations of nitrogen oxides and volatile organic compounds in ambient air. In areas where nitrogen oxides concentrations exceed those of volatile organic compounds, ozone formation is limited by levels of volatile organic compounds. This means that reductions in volatile organic compound emissions will reduce ozone levels. These conditions occur most frequently in and downwind of large urban areas such as Nashville.

In an area where volatile organic compound emissions exceed nitrogen oxides, ozone formation is limited by levels of nitrogen oxides. This means that nitrogen oxides reductions will likely result in decreases in ozone. Given the high levels of natural volatile organic compounds, especially in forested areas, ozone production in much of the rural Southeast is limited by levels of nitrogen oxides (Fehsenfeld et al. 1994).

Exposures in rural and urban areas are closely interdependent. Studies in 1992 indicated that a large portion of ozone measured in the Atlanta urban nonattainment area was transported there from the surrounding region (Fehsenfeld et al. 1994). An extensive field study of rural and urban ozone formation was conducted in the Nashville area in summer 1995 by the Southern Oxidants Study. (See discussion of cooperative research and assessment programs on page T1-70.) Results will allow more accurate analysis of TVA emission contributions to regional ozone formation.

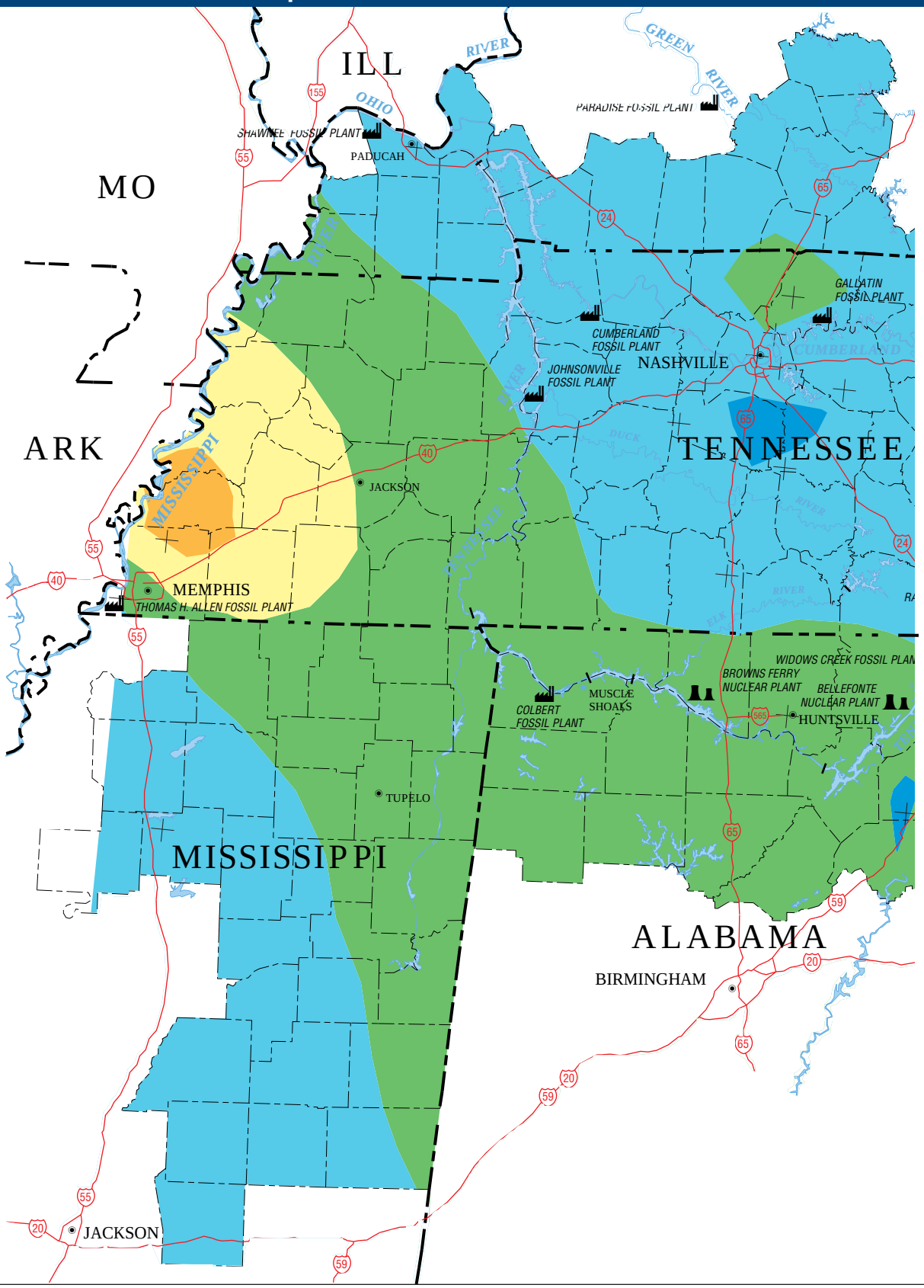
Nitrogen oxide emissions from a coal-fired power plant can either decrease or increase ambient ozone levels, depending on the local atmospheric mix of nitrogen oxides and volatile organic compounds. Within the first 20 kilometers of the source, nitric oxide emissions in a power plant plume will react with ozone to form nitrogen dioxide. Ambient ozone levels can be significantly decreased in this area. If the atmosphere is limited by concentrations of nitrogen oxides, nitrogen dioxide in a power plant plume will react photochemically with volatile organic compounds to form ozone. Ozone formation begins roughly 20 kilometers downwind of the emissions source.

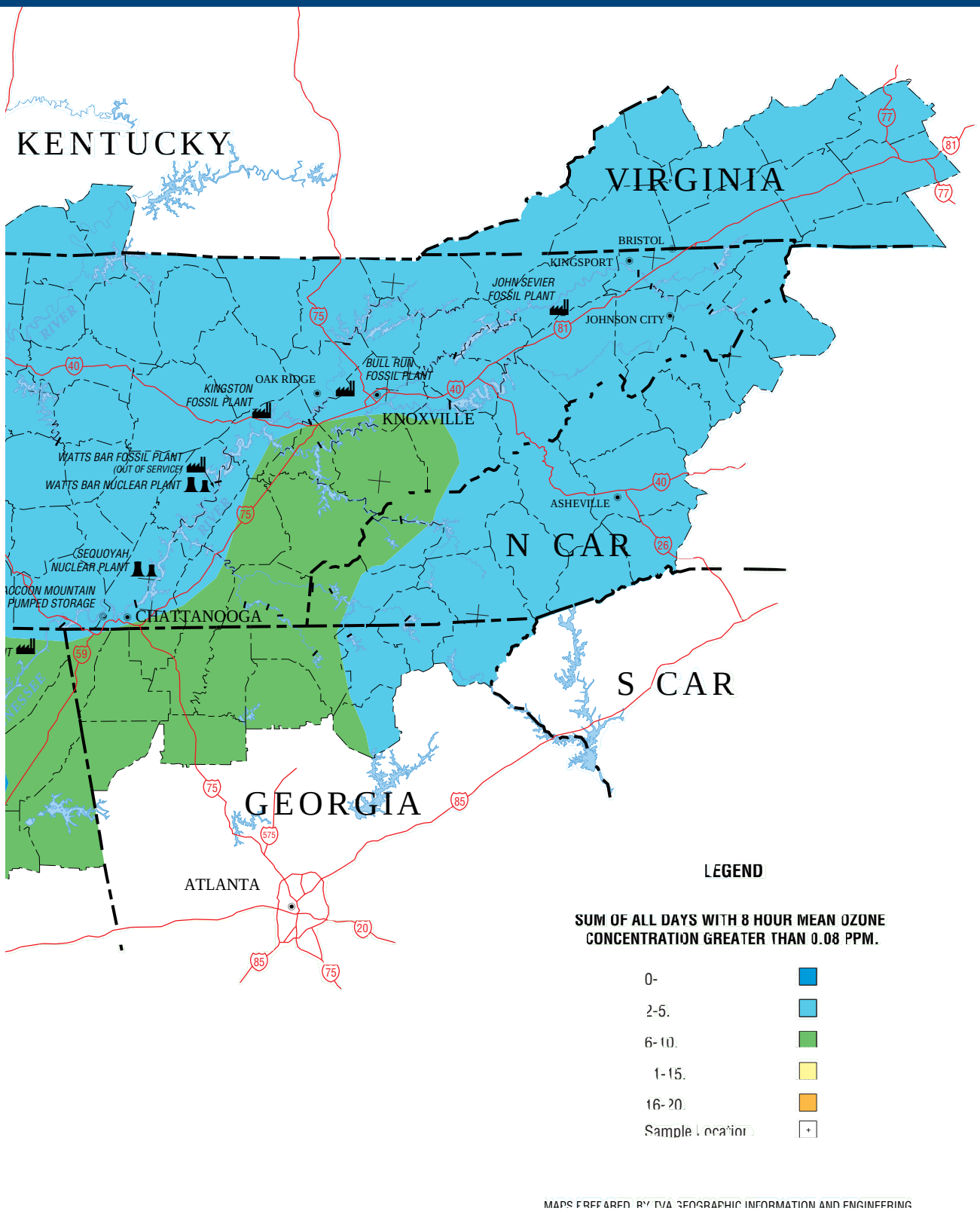
Nashville is currently classified as a "moderate" nonattainment area for ozone. TVA's Gallatin coal-fired power plant is located 15 kilometers east to northeast of the city. Depending on the prevailing weather pattern, nitrogen oxides emissions from Gallatin could reduce ozone in the metropolitan area to the southwest or contribute to ozone exposures in areas downwind. TVA's Johnsonville and Cumberland Fossil Plants are located west of Nashville and, depending on meteorology, could contribute to ozone exposures in the Nashville area. As part of TVA's compliance with the acid rain provisions (Title IV) of the 1990 Clean Air Act Amendments, TVA has already reduced nitrogen oxides emissions from Gallatin and Johnsonville and may reduce nitrogen oxides emissions from Cumberland prior to 2000.

Reliable assessment of source contributions requires detailed meteorological and atmospheric modeling that is beyond the scope of the current analysis. Simplifying assumptions can be made to estimate the source area contributing to ozone exposures in the Tennessee Valley. Ozone formation generally occurs within 12 hours after nitrogen oxides are emitted, depending on sunlight and levels of volatile organic compounds in the atmosphere. Once formed, ozone can be consumed in atmospheric reactions with other pollutants or transported hundreds of kilometers downwind.

Ozone transport is controlled by wind patterns both near the ground and aloft. Elevated power plant stacks emit nitrogen oxides hundreds of feet above the ground. Winds at this level are predominantly from the west through west-southwest directions in the Tennessee Valley *(Figure T1-12)*. Point sources emissions are generally elevated. Mobile and area source emissions and natural source emissions of nitrogen oxides occur near ground level. Surface winds that transport pollutants from near-ground sources usually flow from the south through southwest directions *(Figure T1-12)*. Winds from other directions also contribute to ozone transport. Average wind speeds and directions over the summer months would suggest that sources of nitrogen oxides 200 to 400 kilometers away could contribute to ozone levels in the Tennessee Valley *(Figure T1-24)*. During air stagnation episodes, local sources of nitrogen oxides and volatile organic compounds can predominate. Relative contributions of specific sources to specific receptors vary day to day as a function of

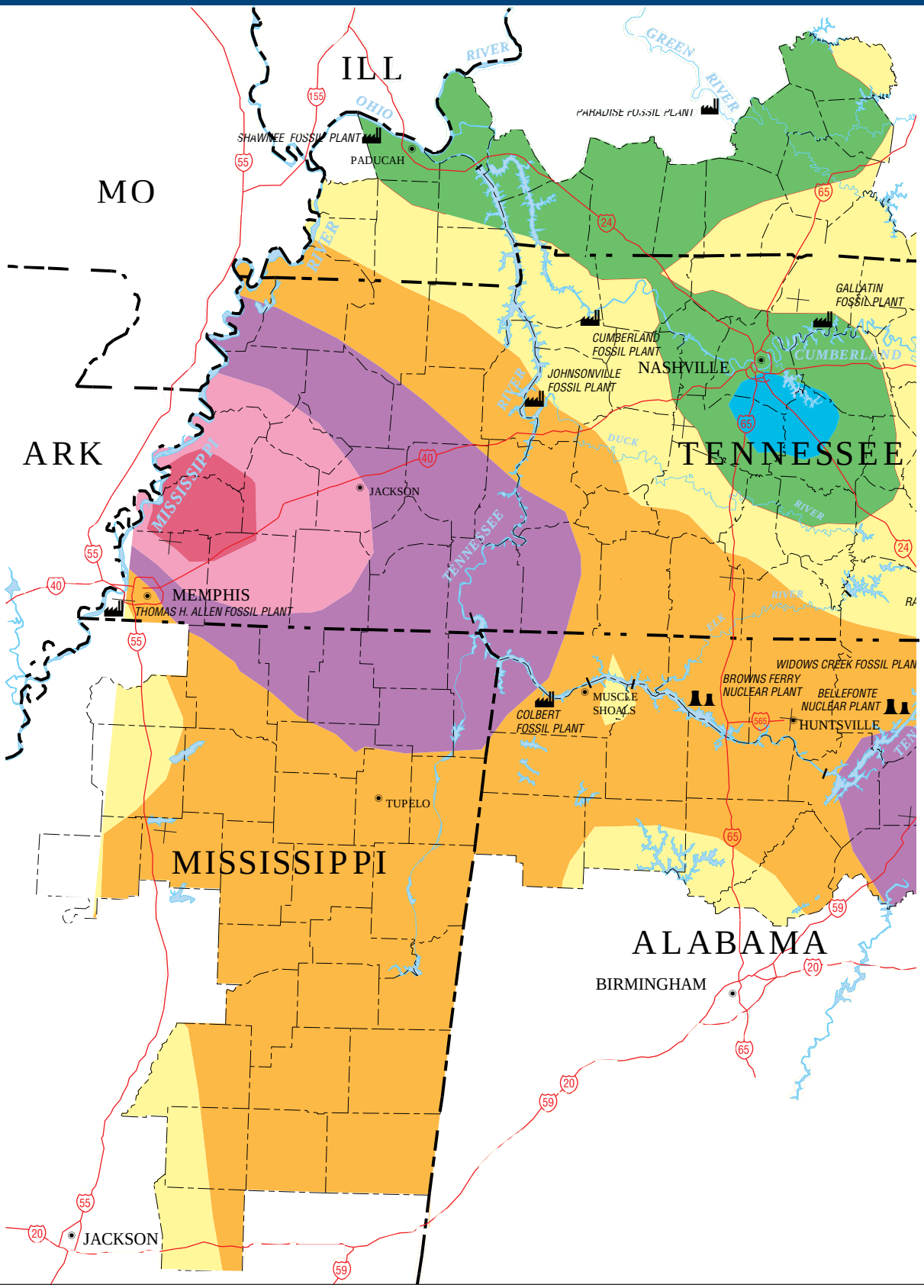
FIGURE T1-36. **Sum of All Days with 8-Hour Mean Ozone Concentration Greater Than 0.08 Parts per Million**





MAPS PREPARED BY TVA GEOGRAPHIC INFORMATION AND ENGINEERING

FIGURE T1-37. **Cumulative Ozone Exposure Greater Than 0.06 Parts Per Million in a 3-Month Period**



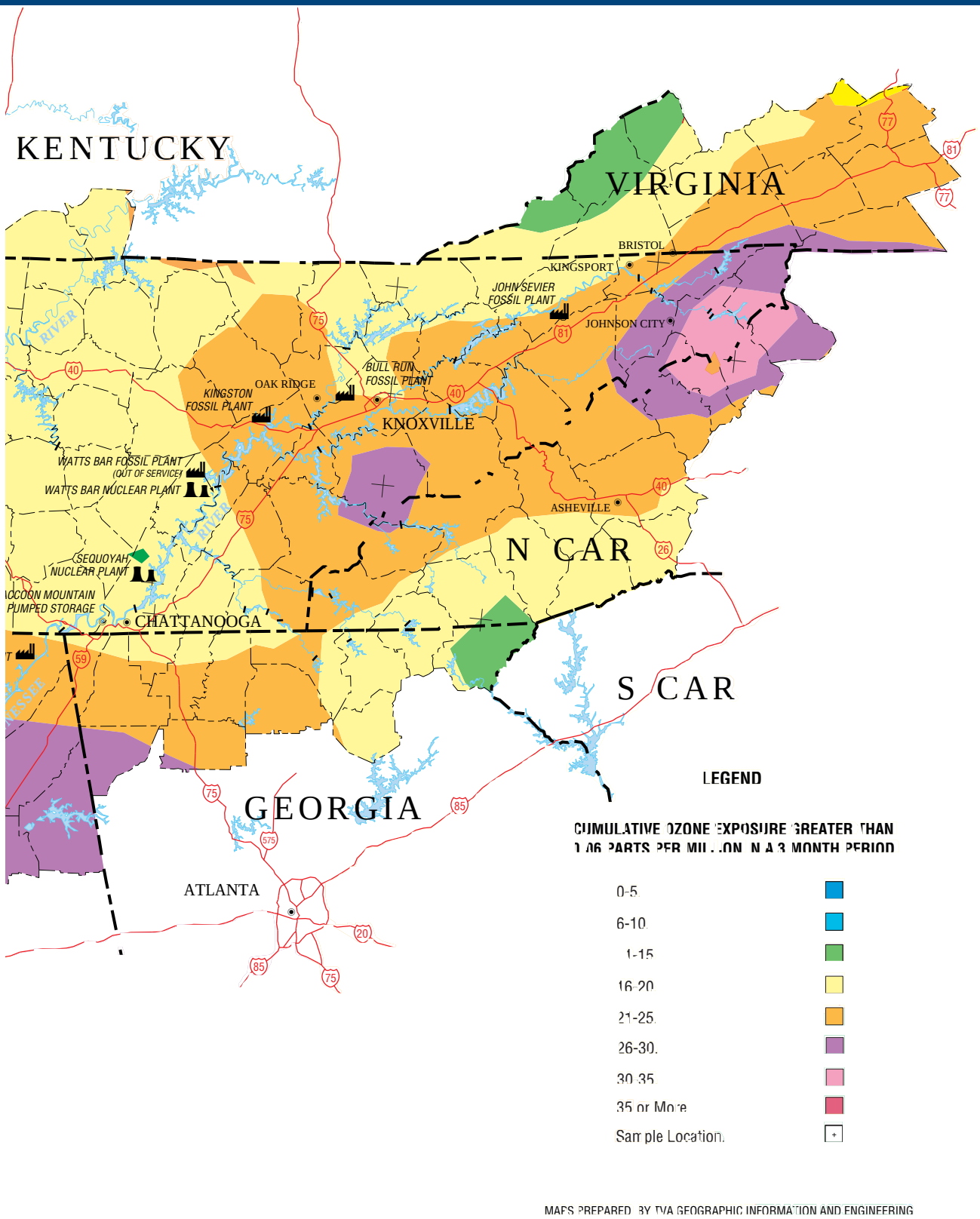
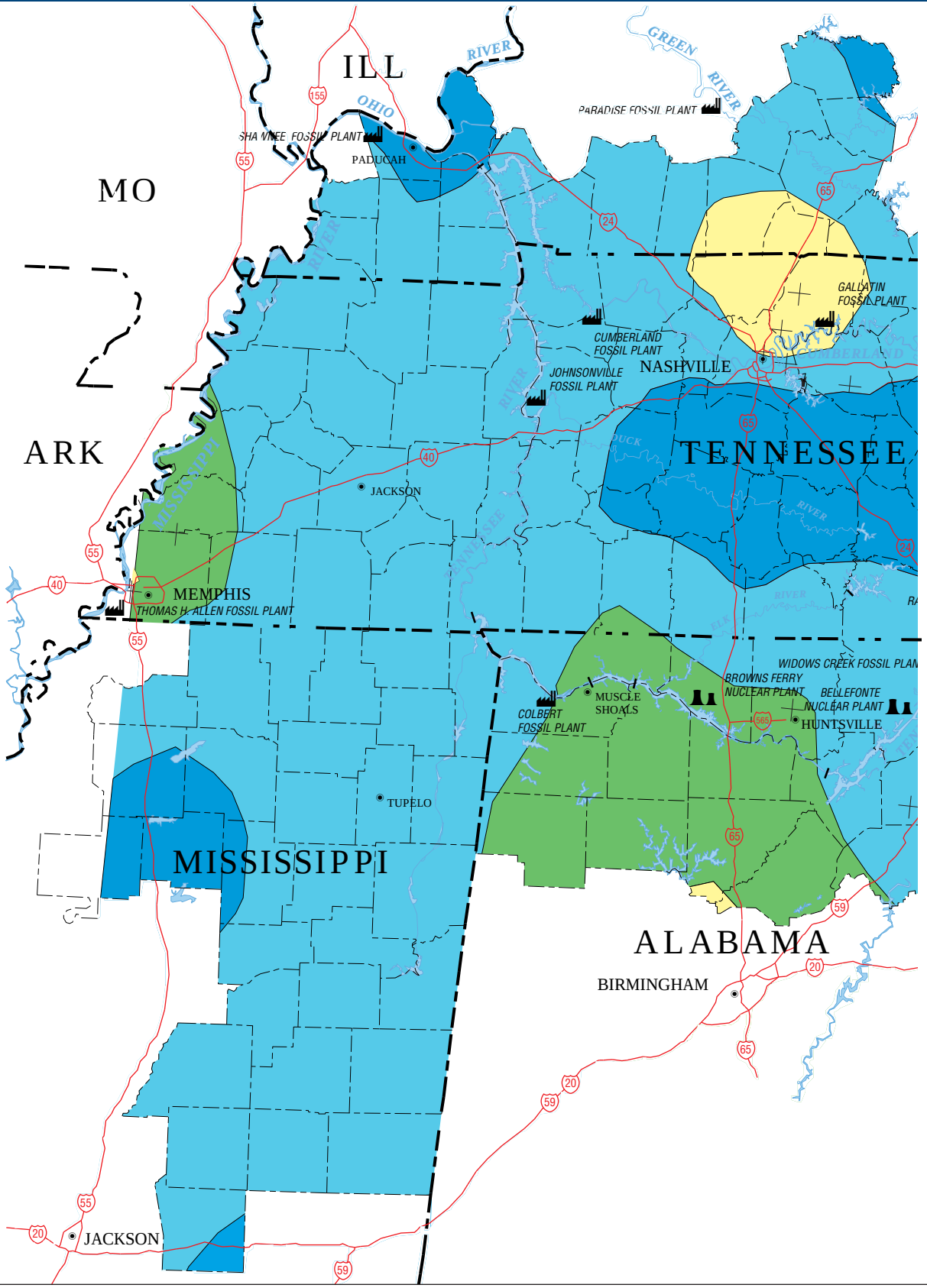
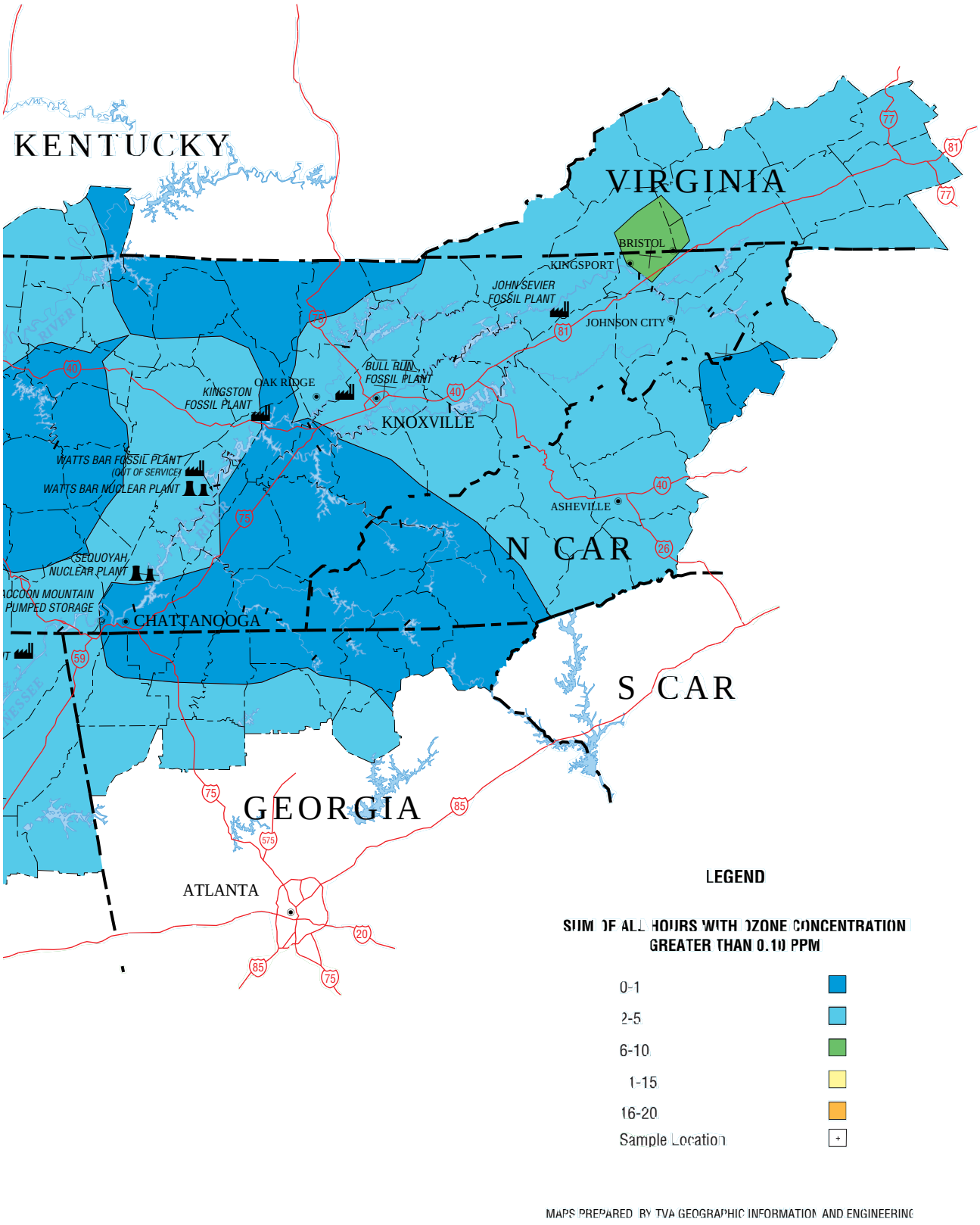

KENTUCKY
VIRGINIA
BRISTOL
KINGSPORT
JOHN SEVIER FOSSIL PLANT
JOHNSON CITY
BULL RUN FOSSIL PLANT
OAK RIDGE
KINGSTON FOSSIL PLANT
KNOXVILLE
WATTS BAR FOSSIL PLANT (OUT OF SERVICE)
WATTS BAR NUCLEAR PLANT
ASHEVILLE
N CAR
SEQUOYAH NUCLEAR PLANT
OCOON MOUNTAIN PUMPED STORAGE
CHATTANOOGA
S CAR
GEORGIA
ATLANTA
LEGEND
CUMULATIVE OZONE EXPOSURE GREATER THAN
0-5
6-10
1-15
16-20
21-25
26-30
30-35
35 or More
Sample Location
MAPS PREPARED BY TVA GEOGRAPHIC INFORMATION AND ENGINEERING

FIGURE T1-38. **Sum of All Hours with Ozone Concentration Greater Than 0.10 Parts per Million**




KENTUCKY
VIRGINIA
BRISTOL
KINGSPORT
JOHN SEVIER FOSSIL PLANT
JOHNSON CITY
BULL RUN FOSSIL PLANT
OAK RIDGE
KINGSTON FOSSIL PLANT
KNOXVILLE
WATTS BAR FOSSIL PLANT (OUT OF SERVICE)
WATTS BAR NUCLEAR PLANT
ASHEVILLE
N CAR
SEQUOYAH NUCLEAR PLANT
OCOON MOUNTAIN PUMPED STORAGE
CHATTANOOGA
S CAR
GEORGIA
ATLANTA
LEGEND
SUM OF ALL HOURS WITH OZONE CONCENTRATION GREATER THAN 0.10 PPM
0-1
2-5
6-10
1-15
16-20
Sample Location
MAPS PREPARED BY TVA GEOGRAPHIC INFORMATION AND ENGINEERING

weather atmospheric mixing and transport. Similarly, TVA emissions of nitrogen oxides can contribute to ozone exposures at distances 200 to 400 kilometers downwind of specific sources. Percentage contribution cannot be accurately predicted without atmospheric modeling.

Based on prevailing wind speeds and direction, the source area for nitrogen oxide emissions contributing to ozone levels in the Great Smoky Mountains National Park is assumed to be a circle with a 300-kilometer radius and centered 150 kilometers west of the park. Within this source area and on a seasonal average basis, TVA emissions are estimated to be 18 percent of the total. Mobile, non-TVA point, area, and natural sources are estimated to contribute 30, 28, 16, and 8 percent, respectively, to ozone levels in the park *(Figure T1-33)*. Depending on the receptor and specific meteorologic conditions, TVA emissions may contribute 15 to 30 percent to ozone exposures in the TVA region.

ACID DEPOSITION

Acid deposition, acid rain, and acid precipitation are all terms used to describe the atmospheric input of acidic molecules, particularly sulfate and nitrate, to terrestrial and aquatic systems. Often this occurs as rainfall which is below natural pH levels. The term pH expresses the acidity or alkalinity of a concentration on a scale from 0 to 14, with 7 being neutral. Numbers less than 7 mean a concentration is acidic, while numbers greater than 7 mean the solution is alkaline. In the absence of human influence, precipitation would still be acidic due to the contribution of naturally occurring acids. Carbonic acid is formed when carbon dioxide is absorbed into cloud droplets. With other sources absent, precipitation would be weakly acidic with a pH of 5.2 to 5.6. Chloride, sulfate, and nitrate ions from natural sources such as sea salt, volcanic activity, and biological decay can further acidify precipitation. Alkaline substances in the atmosphere, particularly soil particles containing calcium, can have a neutralizing effect on cloud and rain water acidity. Acid deposition is of concern because human-produced emissions of sulfate and nitrate can acidify precipitation at levels well below that which would otherwise occur.

Acid deposition occurs in three forms: wet, dry, and cloud water.

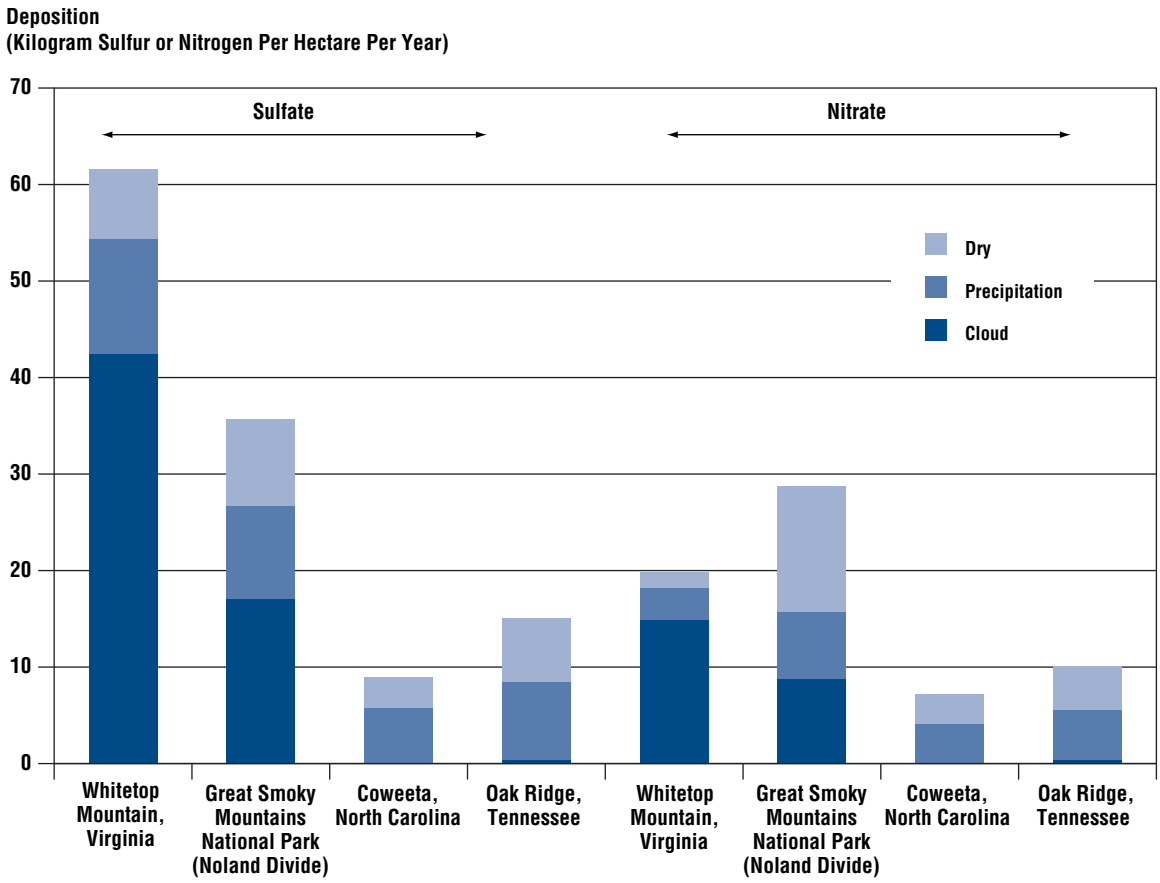
- Wet deposition is liquid or frozen precipitation. The concentration of acidic gases and particles in the atmosphere where clouds are formed determines the acidity of precipitation. Precipitation can deposit acidic pollutants hundreds of kilometers from the sources of origin.
- Dry deposition occurs when acidic aerosols such as sulfuric acid or acidic gases such as nitric and hydrochloric acids react with and deposit directly to surfaces without the presence of precipitation. Dry deposition processes occur constantly. The rate of deposition at any given location depends on the air concentrations of acidic gases and particles, the type of surface to which the deposition occurs, and the relative turbulence of the atmosphere just above the ground. Dry deposition is often greater near major sources of acidic pollutants.
- Cloud water deposition occurs when cloud droplets directly deposit their contents on surfaces. This phenomenon occurs primarily over elevated topography where clouds are intercepted. Acidic species are more concentrated in cloud water droplets than in rainwater. Forest canopies are especially efficient surfaces for cloud water interception. In areas such as the southern Appalachian Mountains, where immersion in clouds occurs frequently, cloud water deposition can be the predominant pathway for acidic deposition.

Ambient Trends

The relative importance of each deposition mechanism depends on site elevation, vegetation cover, and the location of a site relative to major human sources. At sites in the eastern United States where cloud deposition is not important, wet and dry depositions are about equal. In high elevation forests of the Appalachian Mountains, studies have found that cloud water can account for 50 percent or more of the total sulfate and nitrate deposition *(Figure T1-39)*. Cloud water pH, which averages about 3.6 in many areas, is typically lower than that of rainwater, which averages about 4.2 in the Appalachian region. Some sites may experience cloud interception more than 30 percent of the year (Mueller and Weatherford 1988; Lindberg and Lovett 1992; Lovett and Lindberg 1993). At these same sites, precipitation is often enhanced by the effect of the mountainous terrain lifting and cooling the air above it. Thus both the volume of precipitation and the total wet, dry, and cloud deposition at high elevation sites in the southern Appalachian Mountains can be greater than that of other areas of the Valley.

The trends for annual mean pH in precipitation for six low-elevation sites in the Tennessee Valley are presented in *Figure T1-40*. Annual mean pH generally increased over the period. The most acidic (lowest pH) precipitation in the Tennessee Valley region occurs in portions of Kentucky and east Tennessee, with slightly lower acidity to the east and south. Lowest annual pH values are near 4.2. Ranges of measured sulfate and nitrate concentrations at these sites are representative of all but the highest elevations of the Tennessee Valley. Loadings of sulfate are roughly twice loadings of nitrate in the Tennessee Valley and nationally according to data collected under the National Acid Deposition Program. This is the basis for targeting greater reductions in sulfur dioxide than in nitrogen oxides in the 1990 Clean Air Act Amendments. The Environmental Protection

FIGURE T1-39. **Growing Season Deposition of Sulfate and Nitrate Deposition by 3 Pathways at 4 Locations in the Eastern Part of the Tennessee Valley (1986 and 1987)**



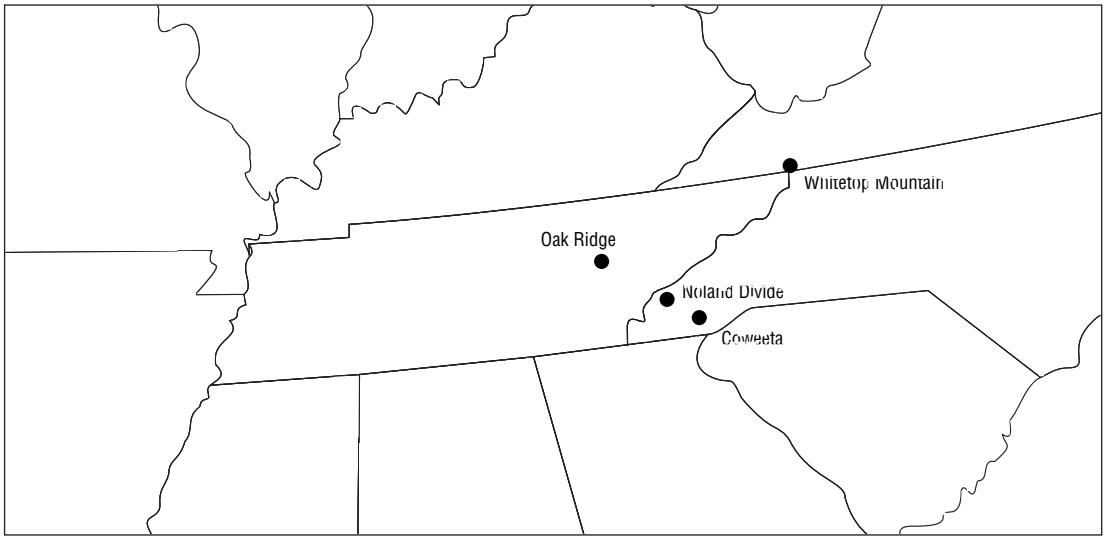
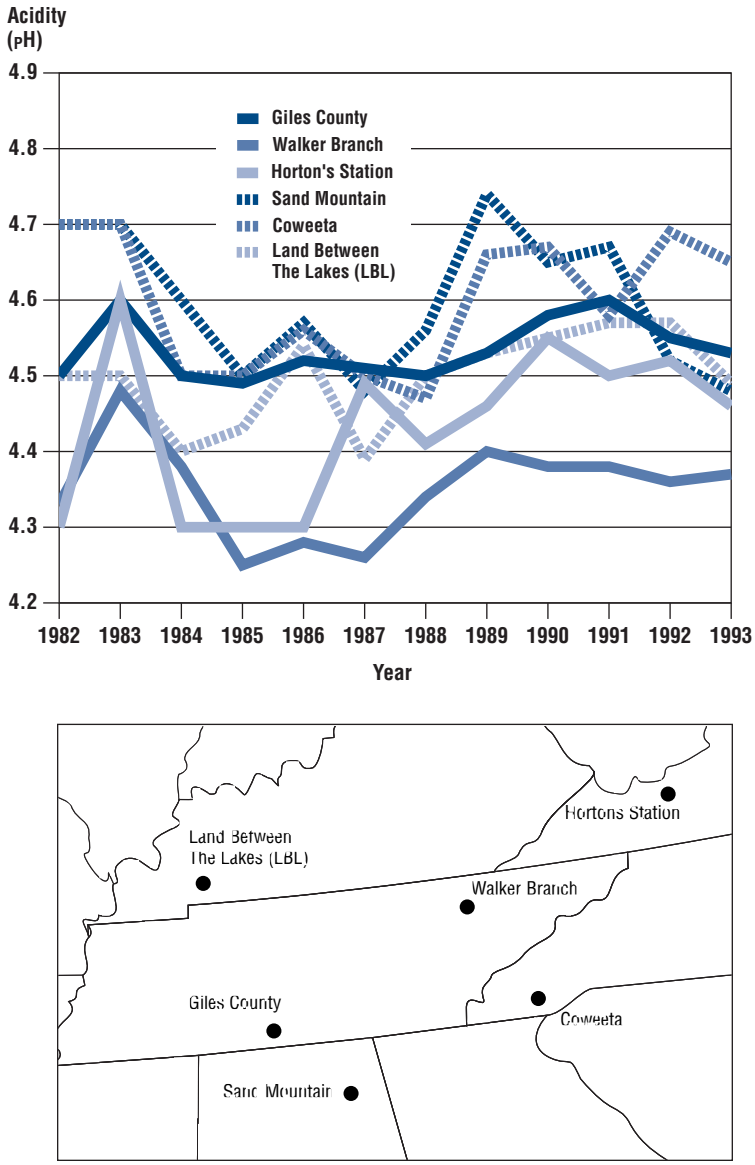


FIGURE T1-40. **Annual Mean Acidity (pH) of Precipitation at Six Monitoring Sites in the Energy Vision 2020 Study Area**



Agency is currently evaluating whether the reductions will be sufficient and is considering an acid deposition standard.

Some of the highest acidic inputs in the country are found in mountaintop forests of the southern Appalachians (Mueller and Weatherford 1988; Lindberg and Lovett 1992; Lovett and Lindberg 1993). Comparison of sulfate and nitrate deposition in 10 forest locations across the country indicates the highest loadings of sulfate and nitrate were measured at the Great Smoky Mountains site. Measurements at Whitetop Mountain and Mount Mitchell under the Mountain Cloud Chemistry Program (Vong 1990) support the same conclusions. However, because levels of cloud water deposited can vary twofold within a single forest stand, results from these specific sites cannot be generalized to be representative of all high elevation forests.

Understanding Emissions Contributions to Acid Deposition

The probable source region for nitrate in deposition is similar to that for ozone (200 to 400 kilometers). *(See Figure T1-24.)* The probable source region for sulfate deposition is larger than for nitrate and ozone because the rate of sulfate formation is slower. Oxidants, particularly peroxides, are required for sulfate formation. Summertime conversion of sulfur dioxide to sulfate occurs at a rate of roughly 1 percent per hour in the absence of clouds. Within clouds, conversion can reach 100 percent. In wintertime, oxidant levels, and thus rates of sulfate formation, are low. Assuming 24 to 48 hours for summertime formation and transport, sources 400 to 800 kilometers away are likely contributing to sulfate deposition in the Tennessee Valley *(Figure T1-20)*. As with ozone, local sources could predominate under some meteorological conditions, such as air stagnation episodes or favorable cloud chemistry. Sources within the assumed source area are not suggested to have equal contribution to deposition. Detailed atmospheric modeling would be required to determine contributions of specific sources to specific episodes. Based on the assumptions stated above, on a seasonal average basis, TVA sulfur dioxide emissions could contribute 18 percent to sulfate and 19 percent to nitrate deposited in the Great Smoky Mountains National Park. *(See Figure T1-41.)* TVA emissions could be greater under specific meteorological events.

Modeling results specifically linking TVA emissions with sulfate or nitrate deposition do not exist. The only modeling that has been done has grouped sources within geographic areas.

FIGURE T1-41. **Emission Comparisons for the Ozone Impact Source Region and the Acid Rain/Visibility Source Region**

SOURCE REGION FOR OZONE IMPACTS

POLLUTANT EMISSIONS (ca. 1990) [4,5]

	Carbon Monoxide		Nitrogen Oxides [6]		Volatile Organic Compounds	
Sources	**Tons/Day**	**% of Total**	**Tons/Day**	**% of Total**	**Tons/Day**	**% of Total**
Human Produced [1]	14,574	100.0	2,659	92.0	3,441	13.0
Natural [2]	0	0.0	237	8.0	23,273	87.0
Total	14,574	100.0	2,896	100.0	26,714	100.0
TVA Portion of Human Produced [3]	24	0.2	512	18.0	3	0.0

SOURCE REGION FOR ACID RAIN VISIBILITY IMPACTS

POLLUTANT EMISSIONS (ca. 1990) [4,5]

	Nitrogen Oxides		Sulfur Dioxide [7]		Volatile Organic Compounds	
Sources	**Tons/Day**	**% of Total**	**Tons/Day**	**% of Total**	**Tons/Day**	**% of Total**
Human Produced [1]	5,841	87.0	15,177	100.0	6,767	10.0
Natural[2]	873	13.0	10	0.1	63,234	90.0
Total	6,714	100.0	15,187	100.0	70,001	100.0
TVA Portion of Human Produced [3]	598	9.0	2,736	18.0	4	0.0

[1] Based on annual values in Environmental Protection Agency 1990 Interim Inventory/365.

[2] For NO_X and VOC: based on BEIS2 model, ROM/SUPROXA domain land use data and "typical" ozone meteorology (max. temperature=35 C and full sun). For equivalent SO_2: estimated from data presented in (Placet, 1990).

[3] Portion of 1990 Inventory allocated to TVA sources.

[4] All rates are in metric tons.

[5] TVA estimates that its 1990 emissions in this region were within 2-6% of the 1990 inventory values.

[6] Emissions expressed as equivalent NO.

[7] Natural SO_2 emissions are assumed to be negligible; estimates represent biogenic sulfur emissions expressed as equivalent SO_2.

Thus, National Acid Precipitation Assessment Program modeling results using the Regional Acid Deposition Model cannot distinguish between TVA emissions and those from other nearby sources.

TVA emissions of sulfur dioxide will be reduced significantly under Title IV requirements of the 1990 Amendments to the Clean Air Act. New emissions controls, such as the sulfur dioxide scrubbers recently installed on the two boilers at the TVA Cumberland power plant, further reduce TVA contributions to downwind sulfur deposition. TVA's future energy options project further reductions in sulfur dioxide emissions that are discussed in Volume 2, Document 2, Environmental Consequences.

VISIBILITY IMPAIRMENT

Visibility impairment refers to atmospheric conditions in which the ability of an observer to discern form, color, or texture of a distant vista is reduced from that which would have existed under natural conditions, causing the scenic value of that vista to be diminished. An adverse impact on visibility is defined by 40 CFR 51.301 federal regulation (Federal Register 1977) as "…visibility impairment which interferes with the management, protection, preservation or enjoyment of the visitor's visual experience of the Federal Class I area." *Figure T1-42* contains the pollutants causing visibility impairment, emissions, and control technologies.

Visibility impairment can be considered in two categories:

FIGURE T1-42. **Pollutants Causing Visibility Impairment, the Primary Emissions, and Their Control Technologies**

Secondary Pollutant	Primary Emission	Control Technology
Primary Fine Particulate Matter	Primary Fine Particles	Electrostatic Precipitator, Baghouse, Venturi Scrubber, Cyclones
Particulate Nitrates	Nitrogen Oxides	Low Nitrogen Oxides Burners
Particulate Sulfates	Sulfur Dioxide	Low Sulfur Coal, Coal Washing, Scrubbers, Fluidized Bed Combustion
Acid Mist	Sulfite	Ammonia Addition, Low Sulfur Coal
Nitrogen Oxides	Nitrogen Dioxide, Nitrogen Oxide, Nitrous Oxide	Low Nitrogen Oxides Burners, Selective Catalytic Reduction

- Regional haze that occurs over a wide geographical area and often persists for a few days
- Plume opaqueness that occurs when emissions from a specific source are observable, usually within 100 kilometers of the source and for shorter duration than a regional haze episode.

In the TVA region, both types of visibility impairment may occur.

Regional Haze

Visibility is affected by the concentrations of gases and particles in the air, the angle of the sun, the object being viewed, and the viewer. Gases that affect visibility include water vapor and nitrogen oxides.

The light that contributes to our perception of an image can be altered by three mechanisms:

- Light is scattered out of the sight path between the viewer and the object (vista).
- Light is absorbed in the sight path.
- Ambient light is scattered into the sight path and competes with the image—forming light to reduce the clarity of the image.

The sum of scattering and absorption of light is referred to as atmospheric light extinction.

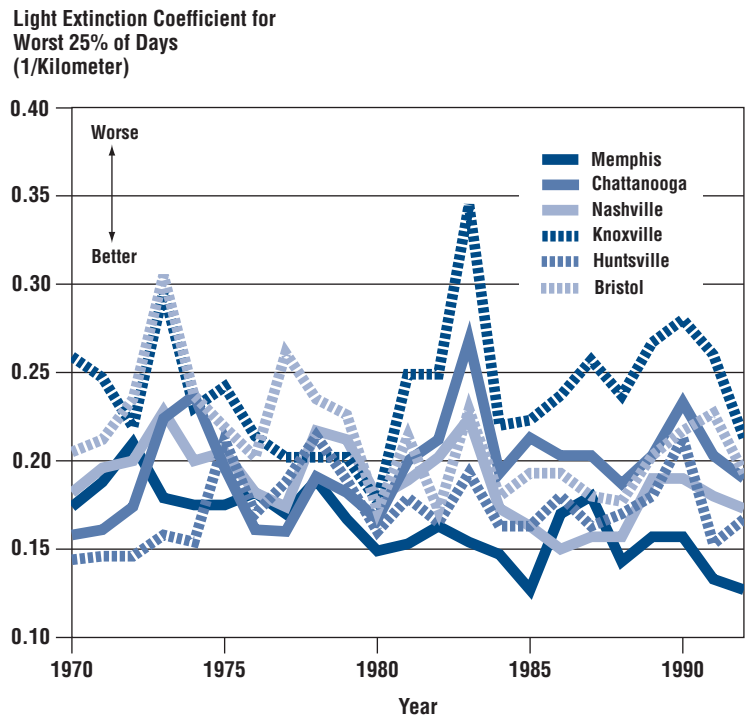
Atmospheric particles that reduce visual contrast and visual range by absorbing and scattering light have their origin in both natural and human-produced processes. Most of the soil components, such as silicates and other inorganic oxides, are of natural origin. Organic aerosols result from photochemical processes involving both natural and human-produced sources. The bluish haze characteristic of southern Appalachia originates from organic aerosols emitted by vegetation. Elemental carbon comes from combustion, including natural forest fires and human-made fires. Sulfates originate from human-produced sources of emissions, such as fossil fuel combustion and industrial processes. Natural sources such as volcanoes and hydrothermal vents, sea salt, and biogenic activity in the oceans and wetlands contribute significantly to global sulfate loadings (30 to 40 percent in the northern hemisphere). In the Tennessee Valley they are of minor importance. Formation of sulfate is seasonally dependent, with the rate of formation greater in the summer months. Compared to sulfate particulate matter, nitrate particulate matter is of secondary importance as a contributor to visibility impairment.

Relative humidity has a significant effect on light extinction, and thus visibility, in the eastern United States. Water vapor in the air provides surfaces for particles, especially sulfate, to bond. These particles grow in size to the size fraction (0.6 micrometers) that is most efficient in scattering light. Higher relative humidity in the eastern United States as well as higher emissions levels, explains why visibility is generally poorer in the eastern than western United States. Differences in relative humidity can also contribute to differences in average summer visibility trends between wetter and drier seasons. For example, visibility in cities in the Tennessee Valley was generally better in the dry summer of 1988 than the wet summer of 1989 *(Figure T1-43)*. Sulfate aerosol levels were 25 percent lower in the summer of 1988 than in the summer of 1989 (Eldred and Cahill 1994).

Ambient Trends

Several methods have been used to measure visibility. The longest record available is from human observations of visual range at airports across the country. Fine-particulate matter and some atmospheric gases scatter light in a phenomenon referred to as light extinction. This scattering causes objects to appear fuzzy or to merge with the background. Light extinction values are calculated from human observations. The measure of visual range is an inverse of the measure of light extinction; smaller extinction values represent clearer air and better visual range. Trends for light extinction at six urban airports in the Tennessee Valley from 1970 to 1992 during summer months (July to September) for the days with the worst 25 percent visibility are presented in *Figure T1-43*. Despite improvements in ambient levels of sulfur dioxide *(Figure T1-19)* and particulate matter less than 10 microns in size *(Figure T1-28)*, vis-

FIGURE T1-43. **Summer Visibility Trends for the Worst 25 Percent of Days in Six Cities in the Energy Vision 2020 Study Area as Shown by the Light Extinction Coefficient Have Shown Little Improvement**



ibility has not improved in the Tennessee Valley over this time period. Based on airport data, analyzes under the National Acid Precipitation Assessment Program concluded that visibility in the Southeast has decreased 60 percent since 1948 when measures were first made (Trijonis et al. 1990). Particulate matter in the fraction less than 2.5 microns would likely be better correlated with visibility, but there is very limited data available in the Southeast for particulates of this size.

Visibility has also been measured in Class I areas of southern Appalachia. Malm et al. (1994) report summertime 1985 extinction coefficients for Great Smoky Mountains National Park between 0.22 and 0.26 per kilometer. These are similar to values for Knoxville. *(See Figure T1-43).* Sulfate is the major contributor to the fine-particulate fraction that impairs visibility. In addition, soil dusts, elemental carbon, and organic aerosols also contribute to visibility impairment. Malm et al. (1994) estimated that sulfate was responsible for 48 percent of the measured light extinction for the 10 percent best summertime days in 1985 in the Great Smoky Mountains, 64 percent of the median days, and 76 percent of the worst days.

The Interagency Monitoring of Protected Visual Environments (IMPROVE) network began measuring visibility and particulate matter in Great Smoky Mountains National Park in 1984 and in Shenandoah National Park in 1982. IMPROVE sites have been established more recently at Mammoth Cave National Park and several national wilderness areas maintained by the U.S. Forest Service. Eldred and Cahill (1994) reported that sulfate concentrations at Great Smoky Mountain and Shenandoah National Parks increased from 1982 to 1993.

In addition to the IMPROVE data, camera images from the Class I areas are available for a longer time frame than are the light extinction measures of visibility. Camera data for the U.S. Forest Service wilderness areas will be published with the final report of the Southern Appalachian Assessment. Based on camera images in six U.S. Forest Service Class I wilderness areas, the median standard visual range in July and August is 25-30 kilometers. In December and January, median standard visual range is between 106 and 244 kilometers (Scott Copeland, unpublished data). The Southern Appalachian Mountain Initiative is also evaluating visibility and is considering emission sources contributing to visibility impairment. TVA's final analysis of environmental consequences may incorporate results from the Southern Appalachian Assessment and Southern Appalachian Mountain Initiative reports. (See discussion under Current Research and Assessment programs section in this document on page T1.70.)

Understanding Emissions Contributions to Regional Haze

The source area discussed for sulfate in acid deposition is also applicable to sulfate aerosols that scatter light and impair visibility. The relationship between sulfate levels and light extinction is not linear. This means that a reduction in sulfate levels may not lead to an equal improvement in light scattering due to sulfate.

In regions with high aerosol loadings, a decrease in the concentration particulate matter may lead to only a small improvement in visibility. The National Acid Precipitation Assessment Program (NAPAP) produced an early assessment of regional visibility impacts expected to result from changes in sulfate emissions. Malm et al. (1994) modeled the expected change in visibility that would result from a 10 million ton per year reduction in sulfur dioxide emission rates in the eastern United States as a result of the Clean Air Act Amendments of 1990. The

greatest improvement in visibility was projected to be in the Ohio River Valley. The emission reductions were projected to have an impact that, when averaged across the eastern United States, would result in a 5 percent (just perceptible) improvement in light extinction on the 15 days in the year having the highest sulfate concentration. Malm et al. projected impacts for three Class I areas, with the Great Smoky Mountains National Park being the one most likely influenced by TVA emissions. The park had a projected decrease in sulfate concentrations of 44 percent, and a net decrease in light extinction of 35 to 45 percent due to implementation of the 1990 Clean Air Act Amendments.

Based on the 1990 emissions inventory for the greater source area *(Figure T1-20)*, and averaged over summer conditions, TVA emissions are estimated to be roughly one quarter of total sources contributing to sulfate particle loadings in the Great Smoky Mountains National Park. TVA emissions could be a greater contributor during specific episodes.

FIGURE T1-44. **Hazardous Air Pollutants Studied at TVA Coal-Fired Power Plants.**

Inorganics	Organics
Antimony (Sb)	Benzene
Arsenic (As)	Toluene
Beryllium (Be)	Formaldehyde [e.g., Benzo-a-Phrene (BAP)]
Cadmium (Cd)	Dioxins/Furans
Chlorine/Hydrogen Chloride (HCL)	Polycyollo Organic Matter (POM) [e.g., Benxo-a-Pyrene (BAP)]
Chromium (Cr)	
Cobalt (Co)	
Fluorine/Hydrogen Fluoride (HF)	
Lead (Pb)	
Manganese (Mn)	
Nickel (Ni)	
Mercury (Hg)	
Selenium (Se)	
Radionuclides	

Plume Blight and Opaqueness

Plume blight is the visual perception of a plume from a large industrial source located at a distance. Because large sources such as coal-fired power plants have elevated stacks, their emissions can sometimes travel great distances before they disperse to the ground. Opacity (or visible emissions) is a measurement of the visibility of a plume. Observations are made at the point of highest opacity in the plume, where condensed water vapor is not present. The visible emissions measure was originally a method for ensuring that the mass emissions from a facility were within the allowable limits. However, at coal-fired power plants, particularly those with flue gas desulfurization, the mass emission rate may be met while exceeding the allowable opacity.

Coal-fired power plants emit fine particles, gases that form fine particles in the atmosphere, and gases that directly absorb light. Fine particles scatter light. Emission controls typically remove more than 95 percent of the mass of fine-particulate matter. Those that escape scatter light and are the primary cause of plume blight and opacity. Secondary sulfate and nitrate particles and acid aerosols can also contribute to plume opacity.

HAZARDOUS AIR POLLUTANTS

Title III of the 1990 Clean Air Act Amendments identified 189 substances as hazardous air pollutants. This greatly expanded the number of chemicals subject to regulation. The Environmental Protection Agency is to develop regulations for each source category (i.e., each type of industrial facility) that emits the listed air toxics. The Environmental Protection Agency was directed to evaluate the hazards to human health and the environment from hazardous air pollutants emitted by electric utilities and to recommend whether emission reductions were warranted for utility plants. The Environmental Protection Agency was given until November 1993 to complete this study, but it is currently behind schedule. The Environmental Protection Agency issued a draft report for review in spring 1995. The final report is expected in November 1995. If the Environmental Protection Agency concludes that emissions reductions are warranted, it must establish necessary and appropriate control requirements. At the earliest, any new regulations would be proposed in 1996 and finalized in 1997. Utilities would have until approximately the year 2000 to bring their plants into compliance.

The Electric Power Research Institute and the Department of Energy have characterized toxic emissions for nearly 100 U.S. utility boilers representing a range of fuels, boiler configurations, and control technologies. Based on these results, the Electric Power Research Institute has estimated emissions and risk to human health from emissions at over 600 utility plants. (EPRI 1994). The Electric Power Research Institute's assessment indicated that no TVA plants and only 3 of the 600 plants posed cancer risks greater than the one-in-one-million identified in the statute and used by the Environmental Protection Agency as an accepted level of minimal risk. Calculated ambient exposures from all plants were below

FIGURE T1-45. **Human Health Risks in the Tennessee Valley Due to Air Concentrations of Heavy Metals**

Metal	Air Concentration at Fort Loudoun, Tennessee Milligram per Cubic Meter	Public Standard Milligram per Cubic Meter	Ratio: Observed to Standard
Arsenic	0.0015	0.3 [1]	1:200
Beryllium	No Data [2]	0.01 [3]	(1:25) [2]
Cadmium	0.007 [2]	50 [4]	(1:7000)
Chromium	0.002 [6]	No Standard [5]	
Copper	Not a Health Hazard by Inhalation Pathway		
Mercury	0.0016	No Standard	

[1] State of Washington standard — only agency to date to establish a standard.

[2] Survey of U.S. cities indicate the highest recorded level in any city was 0.0004 or about 1/25 of the current provisional Environmental Protection Agency standard.

[3] Current standard is a provisional Environmental Protection Agency criterion for a 30-day average (U.S. Public Health Service, 1989)

[4] U.S. Public Health Service standard for occupation exposure; no standard has been established for exposure of general public to ambient air.

[5] No Environmental Protection Agency standard has been set since hexavalent chromium is a carcinogen by inhalation pathway. Cancer risks have been identified for various exposures to hexavalent chromium.

[6] TVA has data only on total chromium, not hexavalent chromium, at the Fort Loudoun site. Approximately 0.2% of power plant emitted chromium is in the hexavalent state. Applying this factor to the measured value for total chromium, and using Environmental Protection Agency data on cancer risk, the cancer risk at this level is estimated to be 1 in 25,000,000.

known threshold levels for human toxicity, even when exposures from multiple sources were considered. TVA is estimating emissions of 19 hazardous air pollutants released from TVA coal-fired plants as part of its reporting requirement under Title V of the 1990 Clean Air Act Amendment *(Figure T1-44)*.

Radionuclides are one of the hazardous air pollutants being evaluated by the Environmental Protection Agency in its study of utility industry hazardous air pollutant emissions. Coal-fired boilers emit trace amounts of radioactive elements (uranium, radium, thorium, and their decay products) found in the fuel. These radionuclides become incorporated into fly ash and are released to the air in the particulate matter emitted from the boilers. Particulate air pollution control equipment, such as electrostatic precipitators limit radionuclide emissions.

Risks to human health due to air concentrations of arsenic, beryllium, cadmium, chromium, and copper in the Tennessee Valley are extremely low. (See discussion under human health impacts section.) *(See Figure T1-45* and *T1-46.)* Environmental impacts from heavy metals are largely confined to aquatic ecosystems where concentrations are highest and organisms are often most sensitive. *Figure T1-47* indicates that water concentrations in Fort Loudoun reservoir would have to increase at least a hundredfold to approach thresholds for organism response to arsenic, beryllium, and chromium. Copper and cadmium concentrations measured at Fort Loudoun approach thresholds where some aquatic invertebrates may be affected. TVA is only one contributor to ambient levels of these metals in the Tennessee Valley. Nationally, electric utilities are estimated to contribute about 50 percent of the beryllium, 30-35 percent of the cadmium, 12-16 percent of the chromium, 2-5 percent of the copper, and less than 3 per-

FIGURE T1-46. **Human Health Risks in the Tennessee Valley Due to Water Concentrations of Heavy Metals**

Metal	Water Concentration at Fort Loudoun Reservoir, Tennessee (Milligrams/Liter)	Public Standard (Milligrams/Liter)	Ratio: Observed to Standard
Arsenic	0.034	50 [1]	1:150
Beryllium	Not a Carcinogen by Ingestion Pathway		
Cadmium	0.10	5 [2]	1:50
Chromium	0.46	50 [2]	
Copper	Not a Health Hazard by Ingestion Pathway		
Mercury	0.0058	No Standard [3]	

[1] Interim Maximum Contamination Level established by both Environmental Protection Agency and World Health Organization.

[2] Environmental Protection Agency drinking water standard.

[3] Standard based on fish concentrations for human consumption rather than water concentration.

FIGURE T1-47. **Levels of Metals in Fort Loudoun Reservoir Compared to Threshold Exposures for Environmental Impacts**

Metal	Water Concentration at Fort Loudoun Reservoir, Tennessee (Milligrams/Liter)	EPA Criterion: Biotic Effects (Milligrams/Liter)	Ratio: Observed to Standard
Arsenic	0.34	40[1]	1:100
Beryllium	Not measured (0.02[2])	5.3[3]	(1:250)
Cadmium	0.10	0.05[4]	2:1
Chromium	0.46	100[5]	1:200
Copper	0.8 (0.5 to 5)	5.6[6]	1:7

[1] Threshold for embryo and larvae of vertebrates
[2] Beryllium level of the highly-polluted Rhine River, demonstrating how low river levels of beryllium generally are.
[3] Threshold for crustacean chronic toxicity.
[4] Threshold for larvae and embryos of freshwater fish in water of hardness of 200 Milligram per Liter.
[5] Threshold for freshwater invertebrates
[6] U.S. Environmental Protection Agency criteria for aquatic life.

cent of the arsenic emitted annually to the atmosphere by human sources (Neme 1990).

Mercury

Mercury is used in Energy Vision 2020 as an indicator of hazardous air pollutants. Depending on the degree of concentration and length of exposure, mercury can have toxic effects on humans and wildlife. Organic mercury compounds, such as methyl mercury, are among the most toxic. Mercury salts released into the environment may be converted by bacteria into organic mercury compounds. Mercury accumulates in the environment and is carried through the food chain with ultimate consumption by humans.

Worldwide, approximately 6,000 tons of mercury are released into the air every year. Human activities account for half of this. Estimates vary widely, but United States electric utilities emit about 80 tons per year (EPRI 1993), representing 1.3 percent of the global or 20 percent of United States human-produced emissions. Measurement of the chemical forms of mercury in stacks and in plumes from coal-fired power plants indicate that mercury occurs in both gaseous (elemental) and particulate (oxidized salt) phases.

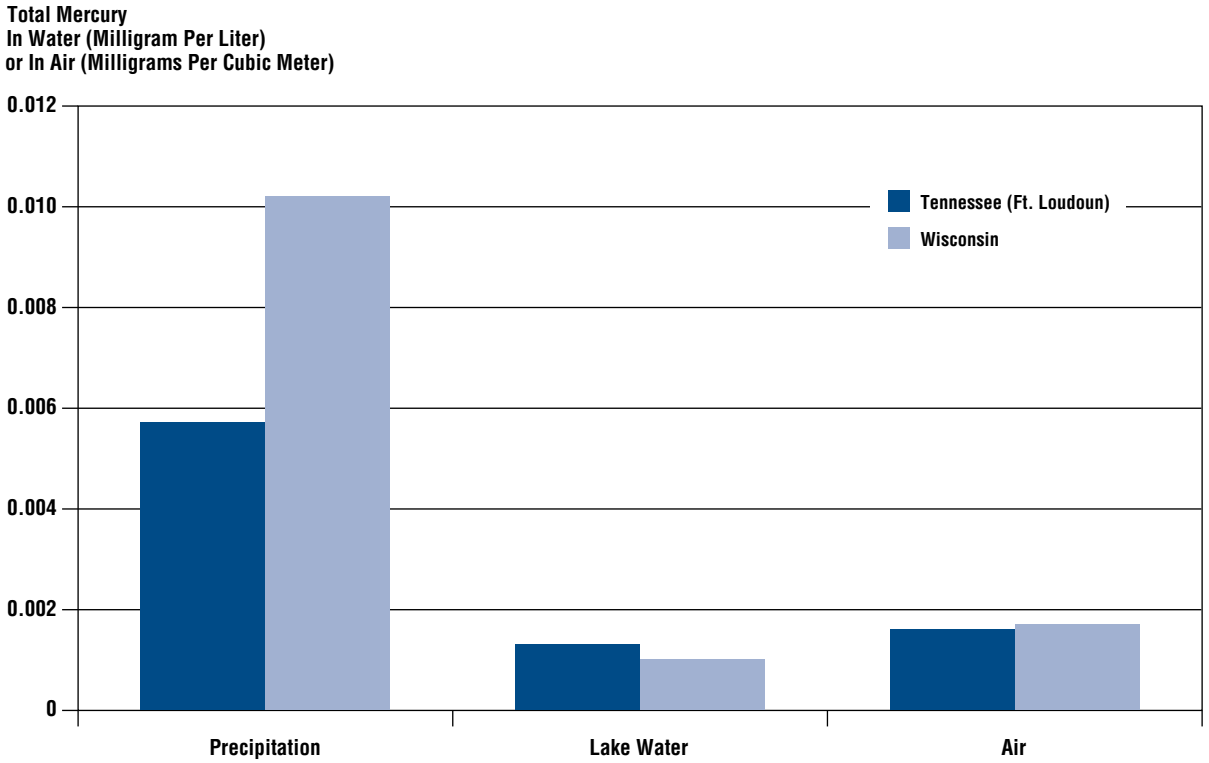
The 1990 Clean Air Act Amendments require the Environmental Protection Agency to study and report on United States mercury emissions. The Environmental Protection Agency's draft mercury study was available for public review in January 1995 with parallel peer reviews and public meetings.

TVA is cooperating in national studies with the Department of Energy and the Electric Power Research Institute to evaluate the efficiency of mercury removal by different control technologies. If the Environmental Protection Agency requires control of mercury emissions, likely controls include wet scrubbers, high efficiency electrostatic precipitators, fabric filters, and/or injection of a sorbent such as activated carbon into the flue gas. Human-produced emission sources are about equally divided among coal combustion, waste incineration, and other facilities.

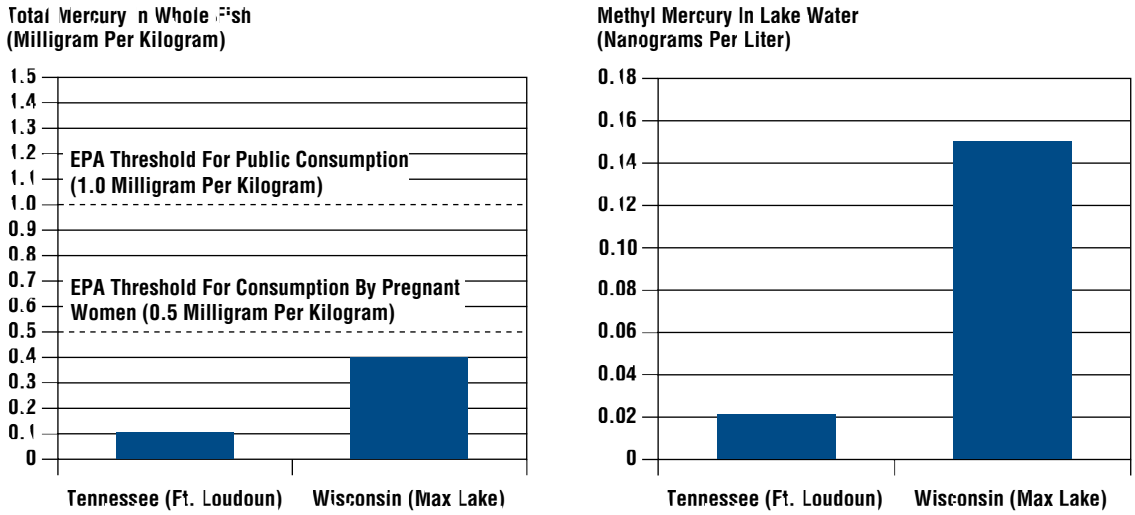
Globally, impacts of mercury are of concern for sensitive invertebrate and vertebrate species in aquatic ecosystems. Watershed characteristics determine whether atmospherically deposited mercury will accumulate in aquatic ecosystems. Dissolved organic carbon and sulfate ions facilitate mobilization and transport of mercury in aquatic systems. The Tennessee Valley has a higher land-to-surface water ratio and comparatively lower levels of dissolved organic carbon and sulfate than those areas of the country that are experiencing impacts (Joslin 1994). *(See Figure T1-48.)* Impacts of TVA's mercury emissions in the Tennessee Valley are likely to be minor, because the watersheds in the Valley are generally well buffered against mercury accumulation.

TVA emissions could contribute a small percentage to overall mercury loading in watersheds in the upper Midwest and Florida that are sensitive to mercury accumulation. Uncertainty regarding the extent to which mercury is deposited locally, regionally, or globally prevents more quantitative estimates of TVA's contributions to mercury loadings. TVA emissions of mercury are very small compared to its other emissions and compared to mercury emissions from other sources. Mercury emissions under TVA's future energy alternatives are tracked in Volume 2, Document 2, Environmental Consequences, as a surrogate for all toxic emissions from TVA's coal-fired power plants.

FIGURE T1-48. Comparisons of Environmental Mercury Concentrations



Concentrations of total mercury in precipitation, lake water, and air at Ft. Loudoun Reservoir, Tennessee, compared to those in northern Wisconsin.



Comparison of total mercury in whole fish and toxic methyl mercury in lake water in Ft. Loudoun Reservoir, Tennessee, and in Max Lake, Wisconsin.

GLOBAL CLIMATE CHANGE

The earth's climate is controlled by the radiative balance of the atmosphere. This refers to the radiant energy received from the sun and emitted by the earth back to space. Greenhouse gases include water vapor, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and chlorofluorocarbons (CFC). With the exception of chlorofluorocarbons, these gases occur naturally. However, human-produced emissions have contributed to the increases in their concentrations. These gases absorb infrared radiation as it passes through the atmosphere and re-emit this energy. This results in a warming of the earth's surface. The greenhouse effect is a natural phenomenon that makes the earth inhabitable. The earth would be cooler by approximately 30 degrees C without the effect of naturally occurring gases. A recent estimate of the contribution by different human-produced activities shows carbon dioxide emissions from energy use and production are the largest contributors to greenhouse gases. The combined effect of the other trace gases presently is equal to that of carbon dioxide.

Globally, atmospheric concentrations of greenhouse gases are believed to have increased dramatically from pre-industrial levels. Atmospheric carbon dioxide has increased from 270 parts per million by volume prior to 1880 to 355 in 1990. The current rate of increase of carbon dioxide is 1.8 parts per million by volume per year or 0.5 percent per year. Fossil fuel combustion and global deforestation are the primary contributors to carbon dioxide buildup. The rate of global increase is projected to accelerate in the next decade as underdeveloped nations, particularly China and India, significantly increase power generation using coal.

Global circulation models predict an average global warming between 1.5 and 4.5 degrees C (2.7 and 8.1 degrees F), changes in precipitation amounts, and distribution (Bretherton et al. 1990; Mitchell et al. 1990) by the middle of the next century. These changes in global precipitation and distribution are also predicted to result in regional changes in crop and forest productivity, land use, water quality and quantity, and possible loss of ecosystems that cannot adapt to these changes. While the general circulation models generally agree that average temperatures in North America will rise, there is a great deal of uncertainty about the magnitude of changes in temperature and whether rainfall will increase or decrease. Current models do not have sufficient spatial resolution to predict magnitude or direction of changes on regional scales. At the current spatial resolutions, the models do not distinguish the southern Appalachian mountains as unique topographic features. Changes in temperature and rainfall within a region such as the Tennessee Valley could have far-reaching impacts on various sectors such as energy, transportation, agriculture, forestry, and socioeconomic factors. However, the science of global warming does not permit reasonable predictions of potential impacts.

The magnitude and scope of the potential climate change impacts are of concern for three areas of TVA operations:

- Those related to power production, including both adjustments to power demand and to power supply operations such as water availability for hydroelectric power production, and water temperature limits for nuclear and coal plant water usage
- Issues related to political or legislative constraints on emissions
- Impacts on the natural resources of the Valley, i.e., forests, water, and agriculture.

Despite the scientific uncertainties, TVA has already agreed, along with some 60 other utilities, to participate in the Department of Energy's Climate Challenge initiative and to voluntarily reduce equivalent TVA carbon dioxide emissions by the year 2000.

Aside from its present activities which seek to reduce equivalent carbon dioxide emissions, TVA is also evaluating how different energy resource options affect greenhouse gas emissions. For example, coal-based technologies emit over 200 pounds of carbon dioxide per million Btu of heat input. Nuclear, wind, solar, and hydroelectric power production essentially emit no carbon dioxide. Biomass fuel options that include burning of wood or herbaceous crops that recycle carbon stored in the vegetation after converting carbon dioxide from the atmosphere have less carbon dioxide emissions than coal-fired options. There may actually be a reduction of carbon dioxide since the root systems of these crops act to store carbon in the soil even after the crop has been harvested for fuel.

The carbon dioxide emissions level is one of the measures used to differentiate among TVA's energy strategies.

Cooperative Research and Assessment Programs

This document summarizes current scientific understanding. Uncertainties in current scientific understanding limit our ability to assess:

- The specific contribution of TVA emissions to regional pollutant loadings
- The relationships between pollutant levels and impacts to human health and the environment
- The expected benefits of specific emission reductions.

TVA is cooperating with several regional air pollution research and assessment programs to improve the scientific

understanding and to design regulatory policy that will be successful in the Tennessee Valley to mitigate present and prevent future impacts. Results of these regional programs will be available between 1995 and 1997. The programs are discussed below.

The Southern Appalachian Mountain Initiative (SAMI) and the Southern Appalachian Assessment (SAA) are two regional assessments being conducted under the public review process to evaluate air pollutant impacts in southern Appalachia. TVA is actively participating in both studies. The assessments summarize existing information on visibility impairment, acid deposition, and ozone impacts in southern Appalachia. The Southern Appalachian Mountain Initiative work is ongoing and may provide information that can be used by TVA. A final report for the Southern Appalachian Assessment is expected early in 1996. TVA's analysis may contribute to the assessments being developed by these groups and to their public information and policy decision-making process.

The Southern Appalachian Assessment considers both ecological and socioeconomic focuses. It is led by seven federal agencies in the southern Appalachian region. The Atmospheric Team of the Southern Appalachian Assessment will report by fall 1995 on visibility impairment, acid deposition, and ozone in southern Appalachia.

The Southern Appalachian Mountain Initiative focuses on policy development and regulatory recommendations for air emissions management. It includes state and federal regulatory agencies, federal land managers, industry, academia, and public interest groups. The Southern Appalachian Mountain Initiative is evaluating emissions management options to mitigate existing or prevent future air quality impacts in Class I areas of southern Appalachia. Existing information on air quality impacts will be evaluated and delivered by the Southern Appalachian Mountain Initiative's Technical Oversight Committee in fall 1995. In its technical assessment of emissions management options, the Southern Appalachian Mountain Initiative's Integrated Assessment Committee is designing a framework to integrate current understanding of relationships among emissions, exposures, and impacts. The technical assessment and recommendations on emissions management options are anticipated to be complete by 1997.

The Southern Oxidants Study is a research partnership between the pubic and private sector to better understand the processes and sources that contribute to regional ozone formation. Several federal agencies, state and local regulatory agencies, industries, and universities are participating in the partnership to study rural ozone exposures and source contributions to urban nonattainment areas in the southeastern United States. In the summer of 1995, the Southern Oxidants Study conducted an extensive field study of rural and urban influences on ozone formation in the Nashville area. TVA is leading the design and implementation of this multi-organizational field study. Results from this field study will allow better understanding of the total biogenic (natural) and human-produced sources contributing to regional ozone formation and the specific contributions of TVA nitrogen oxides emissions to ambient ozone exposures. The North American Research Strategy on Tropospheric Ozone is a national effort to understand why emission control strategies over the past two decades have not been effective in reducing ozone exposures. The Southern Oxidants Study is one component of the larger national program. Results of these studies were not available in time to be evaluated in TVA's analysis of environmental consequences of its future energy supply alternatives.

The Electric Power Research Institute is evaluating risks to human health and the environment due to ozone, fine-particulate, and hazardous air pollutant impacts. The Institute delivers results of its research and risk assessments to the Environmental Protection Agency and regulatory authorities to be considered in developing future emissions regulatory policies. TVA is cooperating with the Electric Power Research Institute, the National Park Service, and several southern utilities to measure visibility and particulate species (i.e. sulfates, nitrates, soil, primary particles, etc.) in the Great Smoky Mountains National Park during summer 1995. Results will not be available in time to be evaluated in TVA's final analysis of environmental consequences of TVA future energy strategies. TVA is also cooperating with the Electric Power Research Institute and the Department of Energy to characterize utility emissions of hazardous air pollutants, the efficiencies of different emissions control strategies, and mercury transport and deposition. The Institute's Air Toxic Risk Assessment will contribute to the Environmental Protection Agency's analysis of utility emissions of mercury and other hazardous air pollutants.

Present Impacts

HEALTH

Introduction

Potential impacts to human health are illustrated in *Figure T1-61*. There are potentially numerous health impacts from environmental air pollutants. Impacts range from temporary eye and lung irritation and headaches to progressive damage to the respiratory, cardiovascular, nervous, and immune systems. United States environmental and health policies are written to protect the general public from the unacceptable risk of adverse effects.

The National Ambient Air Quality Standards for criteria pollutants and the National Emission Standards for Hazardous Air Pollutants are set at levels for ambient outdoor exposure that are intended to protect the public health. These standards are periodically reviewed and revised. Evidence of impacts upon sensitive individuals at ambient levels of ozone and fine particulate matter is being reviewed in 1995 by the Environmental Protection Agency in a draft criteria document.

Health impacts can also occur from air pollutant exposures in indoor environments. Currently, indoor air quality is not regulated by national standards, but several of the same pollutants that occur in the ambient outdoor environment also occur indoors. The Environmental Protection Agency has developed guidelines for levels of other indoor pollutants such as radon.

Risk-Exposure Relationships

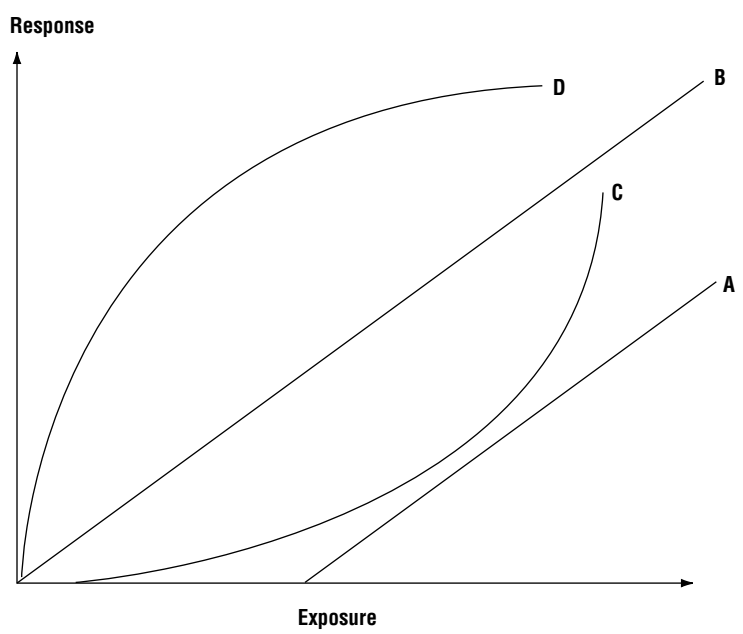
The health risk from exposure to pollutants requires an understanding of the level and duration of exposure. Adverse health effects can come from exposures to high levels for short periods of time and/or prolonged exposures to low levels. The graph in *Figure T1-49* shows examples of theoretical exposure-response relationships. Line A shows a linear relationship with a threshold. For line A, there is no risk for exposures below the threshold. Line B shows a linear relationship without a threshold. For line B, there is some risk at all levels of exposure. Lines C and D are examples of nonlinear relationships. The shape and slope of the exposure-response relationship have substantial implications for assessing the risks from air pollutants and for defining levels sufficient to protect human health. Evaluation of available data has not yielded definitive answers as to which of these curves best fit criteria air pollutants. As a result, the decisions regarding appropriate levels for air quality standards are based in large part on most plausible evaluations and policy goals (Samet et al. 1991). As health effects are better quantified, this evidence is used in reviews and revisions of the National Ambient Air Quality Standards and National Emission Standards for Hazardous Air Pollutants.

Sulfur Dioxide

Depending on concentration, exposure to sulfur dioxide can irritate the eyes, cause respiratory distress, and possibly permanently damage lung tissue. (Durenberger 1991) Under the current ambient standard for the 24-hour average sulfur dioxide concentration, only one group of people might suffer a direct health effect of gaseous sulfur dioxide: People with active asthma who are unmedicated and exercising out of doors might experience an aggravation of asthma symptoms. This occurs infrequently and only in locations near major sulfur dioxide sources (Graham 1990). At locations near major sulfur dioxide sources, short-term sulfur dioxide exposures may be elevated and still meet the 24-hour average standard. These short-term elevated sulfur dioxide exposures may aggravate asthmatics. The Environmental Protection Agency is considering whether a new five-minute sulfur dioxide standard should be set to address this impairment. However, available research indicates that any resulting aggravation is reversible, short-term, and can be avoided with moderation.

Sulfate aerosols that are formed as sulfur dioxide disperses and reacts in the atmosphere also raise concern for human health. The health effects from sulfate aerosols are included in the section that discusses fine-particulate matter. Some epidemiology studies show an association between 24-hour sulfur dioxide concentrations and respiratory illness that may be independent

FIGURE T1-49. **Four Theoretical Exposure-Response Relationships for Health Risks**



Line A = Linear Relationship With a Threshold
Line B = Linear Relationship Without a Threshold
Line C = Non-linear Relationship
Line D = Non-linear Relationships

of particulate concentrations. However, there is uncertainty about whether this is due to sulfur dioxide or the result of another factor correlated with sulfur dioxide (Graham 1990).

Nitrogen Oxides

Depending on its concentration, nitrogen oxides can irritate the eyes, damage the lungs, and lower resistance to respiratory illness and influenza. In its 1994 review of the ambient air quality standard for nitrogen dioxide, the Environmental Protection Agency concluded that the current standard is adequate to protect human health and welfare. The Environmental Protection Agency's annual average standard for nitrogen dioxide is 0.053 parts per million concentration. Current ambient levels of nitrogen dioxide in the Valley are 0.011 parts per million. Evidence from clinical studies suggests that short-term exposures to nitrogen dioxide in the 0.2 to 0.5 parts per million range may cause adverse symptoms for asthmatics. Evidence also suggests that nitrogen oxides from indoor sources such as gas-fired appliances may be associated with greater frequency of respiratory illness in children. This is consistent with some laboratory evidence of reduced resistance to illness. It is difficult at this time to extrapolate health effects from the indoor studies to outdoor levels of nitrogen oxides because the pattern of exposure is quite different. It is uncertain, for example, whether long-term cumulative exposures or peak-level exposures are most important. Some epidemiology studies using measures of outdoor nitrogen oxides have found an association between nitrogen oxides concentrations and acute illness. Other researchers have found no significant relationship (Environmental Protection Agency 1991).

Nitrogen oxides contribute to the formation of two pollutants that are a concern with respect to human health: nitrate aerosols and ozone. Nitrate aerosols are a component of fine-particulate matter and are discussed in that section. Ozone is discussed in the next section.

Ozone

Ozone exposure can cause respiratory tract problems such as difficulty breathing, reduced lung function, asthma, eye irritation, nasal congestion, reduced resistance to infection, and possibly premature aging of lung tissue. (Environmental Protection Agency 1995a.) Ozone levels present in the Tennessee Valley rarely exceed the 1 hour standard of 0.12 parts per million. Epidemiology studies have shown that health effects associated with ozone exposure for the general population include respiratory symptoms, such as acute cough, and minor, restricted activity days. Recent studies in Los Angeles and New York have found small but statistically significant evidence of risk of premature death associated with peak 1-hour ozone exposure at concentrations above 0.20 parts per million (Kinney and Ozkagmak 1990). A study in St. Louis, Missouri, and in Kingston-Harriman, Tennessee, found no increased risk of death at ozone exposure concentrations up to 0.15 parts per million. Extensive evidence exists relating to short term respiratory responses to controlled exposures to ozone in clinical studies. Ozone is also suspected in causing greater susceptibility to chronic respiratory illness, but there is not currently sufficient evidence available to quantify the risk (Krupnik and Kurland 1988; Lippman 1989; U.S. Environmental Protection Agency 1988).

Uncertainty is also associated with the threshold for human health impacts related to ozone. Some evidence indicates effects for certain individuals at levels below the current 1-hour National Ambient Air Quality Standard of 0.12 parts per million. Symptoms have not been observed below 1-hour averages of 0.06 to 0.10 parts per million (Krupnik and Kurland 1988).

Particulate Matter Smaller than 10 Microns

Recent epidemiological studies demonstrate links between particle exposure and respiratory disease in those over age 65 (Fisher et al. 1989). The Environmental Protection Agency standard for particles with diameters of 10 microns or less (PM10), is a concentration of 150 micrograms per cubic meter for 24 hours and 50 micrograms per cubic meter for an annual average. In studies conducted between 1972 and 1980, the Environmental Protection Agency correlated increased death rates with concentrations of PM10 of 100 micrograms per cubic meter. The Agency has also correlated an increase in hospitalizations for respiratory symptoms among people with chronic lung disease with concentrations at this level (Marwick 1991). Some investigators believe the threshold for health effects from particulate matter may be a concentration of 30 micrograms per cubic meter (ORNL 1994).

Some studies have attempted to determine whether the association between particle exposure and respiratory disease is due to sulfates and nitrates associated with fine particles (particles with diameters of 2.5 micron or less), but results have been inconclusive. These smaller particles remain airborne over longer times and distances. It is difficult to separate the potential impacts of sulfate versus acid aerosols because their day-to-day levels tend to be highly correlated. It appears that the association is strongest among the over-65 age group. Those who already suffer from chronic respiratory illness may be at greatest risk (Fisher et al. 1989).

Some studies associate chronic cough and bronchitis symptoms with the level of acidity of aerosols, rather than with sulfate levels or total concentrations of particles. Controlled studies have established a strong relationship between the bronchitis effects on asthmatics and the presence of sulfur dioxide and acidic aerosols at concentrations approaching the ambient standard for

sulfur dioxide (Samet et al.1991). Even so, the evidence to date is inconclusive as to whether acidic aerosols are any more harmful to human health than nonacidic aerosols of similar size (U.S. Environmental Protection Agency 1989).

Epidemiologic studies are limited by the difficulty of measuring exposure and of singling out the effect of acidic aerosols from other factors, particularly for such non-specific health effects as increased symptoms and reduction of lung function. Controlled exposures of volunteer subjects provide information concerning short-term effects. However, this approach cannot fully represent the exposures sustained in a community (Samet et al. 1991).

On a five-year cycle, the Environmental Protection Agency re-evaluates the science on which the National Ambient Air Quality Standards are based. The goal is to either modify or support the current sulfur dioxide and particulate matter standards. The Environmental Protection Agency is currently considering whether standards for acidic aerosols or fine-particulate matter are warranted.

Carbon Monoxide

Carbon monoxide impairs the ability of blood to carry oxygen. Carbon monoxide also affects the cardiovascular, nervous, and pulmonary systems. Carbon monoxide attacks the immune system, especially affecting anyone with heart disease, anemia, and emphysema and other lung diseases. Even at low concentrations, carbon monoxide can affect mental function, vision, and alertness.

Ambient levels of carbon monoxide in the Tennessee Valley are below the level of the National Ambient Air Quality Standards. The Environmental Protection Agency's limit for carbon monoxide is 9 parts per million. At this level, carbon monoxide binds 3 percent of the hemoglobin so that it cannot carry oxygen to body cells and tissues. Toll-booth workers exposed to a 10.8 parts per million level of carbon monoxide had a higher death rate due to heart disease than did toll-booth workers exposed to 6.2 parts per million. There is some question whether a threshold level exists for exposure to carbon monoxide (Marwick 1994). TVA emits less than 1 percent of the regional carbon monoxide emissions.

Air Toxics or Hazardous Air Pollutants

Depending on concentration and duration of exposure, hazardous or toxic air pollutants can increase the risk of cancer. The Environmental Protection Agency has listed 189 chemicals as air toxics. From this list, the air toxics of greatest concern related to coal-fired power plants are arsenic, beryllium, cadmium, chromium, copper, and mercury. Compounds of these toxics are released during combustion of fossil fuels and are ultimately deposited on land and water.

As evidenced in the data outlined in *Figures T1-45* and *T1-46*, the risks to human health appear to be extremely low from air inhalation or water ingestion of arsenic, beryllium, cadmium, chromium, copper, and mercury. Water concentrations of these metals as measured in and around Fort Loudoun, near Knoxville, Tennessee, are compared in *Figure T1-47* with standards set by the U.S. Environmental Protection Agency, the World Health Organization, and other agencies (Joslin 1994). In general, concentrations of these metals would have to increase by at least fiftyfold before established thresholds would be reached. Risk from chromium exposures in the Valley is difficult to evaluate because monitoring data are available only for total levels of chromium while only the hexavalent form of chromium is carcinogenic. Cadmium levels in human diets are considerably below health advisory levels, but levels in human diets have increased (Joslin 1994).

The risk to human health from mercury in the Tennessee Valley is low if one assumes an individual's diet is based on mercury concentrations in local fish and drinking water. High levels of mercury have been reported in fish in Canada, the northern United States, Scandinavia, and Florida. Recent surveys of the Tennessee River system found only one location where mercury in fish was elevated. That location is on the North Fork of the Holston River immediately downstream from Saltville, Virginia. The mercury level, which does not exceed the Environmental Protection Agency guidelines, is from an inactive industrial site unrelated to atmospheric deposition.

Acid Deposition

In addition to those health impacts associated with emissions of sulfur dioxide, nitrogen oxides, acidic aerosols, and fine-particulate matter that have already been discussed, acid deposition can indirectly affect health. Acidic species deposited to surface waters can mobilize metals in the environment. Mercury accumulation in the environment and biological food chains could be increased by acidic deposition under site-specific conditions. These include drinking water systems that use surface ponds or shallow wells and populations that obtain essentially all of their protein in the form of freshwater fish from acidified lakes. Even under these conditions, increased health risk due to increased mercury exposures is low (NAPAP 1991).

Indoor Air Quality

Indoor air quality also raises concern for human health. Exposure to air pollution is determined by the pollutant concentrations and the time that individuals experience those levels. Since Americans spend the majority of their time indoors,

exposures to indoor air pollutant can be a significant component of total personal exposure. Depending on the presence of indoor sources and building ventilation, indoor air pollutant levels can be much higher than outdoor levels. Air pollution advisories, issued when outdoor pollution levels become unhealthy, recommend that sensitive individuals restrict physical activity and time spent outdoors.

There are many kinds and sources of indoor air pollution:

- Combustion gases such as carbon monoxide, carbon dioxide, and nitrogen oxides from indoor combustion sources including wood heaters, unvented kerosene and natural gas space heaters, and other natural gas-fired appliances
- Small particles from smoking, fireplaces, wood heaters, and cooking
- Volatile organic compounds from insecticides, cleaning solvents, stored fuels, paint, vinyl, plastics, adhesives, and furniture and carpet stain repellents
- Biological contaminants such as allergens from pets, insects, and plants; molds and fungi from damp surfaces; and viruses and microorganisms from people and pets
- Radioactive gas (radon) from the earth beneath a structure.

Health complaints associated with poor indoor air quality are varied. They include dizziness, headache, nausea, irritation of the eyes and airways, impaired learning ability, allergies, sleepiness, rashes, abdominal and chest pains, respiratory illness, and cancer. Impacts discussed previously for sulfur dioxide, nitrogen oxides, carbon monoxide, fine-particulate matter, and hazardous air pollutants also apply if these pollutants are elevated in the indoor environment.

Well-designed and maintained heating, ventilating, and air conditioning systems can provide healthy and energy-efficient living spaces. However, indoor air pollution problems can sometimes be aggravated by weatherization or other energy conservation efforts. Reduced ventilation, the existing burden of indoor pollution, and the increased use of alternative heating sources, such as wood heaters and unvented natural gas or kerosene heaters, can lead to elevated indoor air pollutants. Indoor air pollutant levels can exceed regulatory standards for ambient outside air.

Many simple methods may be used to minimize indoor air pollution exposures:

- Use and maintain all appliances according to manufacturers' specifications and recommendations.
- Read the labels on household products such as cleansers, polishes, drain cleaners, and stove cleaners carefully to ensure proper use. Consider switching to "natural" cleaners and polishes.
- Ventilate kitchens and bathrooms during use to remove cooking smoke and excess moisture.
- Store paints, household cleaning products, and fuels in approved containers in well-ventilated areas.
- Avoid smoking indoors.
- In areas with elevated soil radon levels, consider testing to determine levels within the home or office.

Energy Vision 2020 strategies that promote increased conservation and weatherization methods could increase indoor air pollution exposures. It is assumed for this analysis that TVA will continue to provide guidance to minimize indoor pollutant concentrations. Consequently, indoor air quality impacts are not a measure used to differentiate among future TVA strategies.

VISIBILITY IMPAIRMENT

Visibility impairment is of special importance under the Prevention of Significant Deterioration provisions of the 1977 Clean Air Act Amendments. Impacts are discussed in the "Visibility Impairment" section under "Air Quality Concerns Since the 1977 Clean Air Act Amendments" earlier in this section.

CROPS AND FORESTS

Summary

Impacts of gaseous pollutants, including sulfur dioxide, nitrogen oxides, and ozone on crops and forests, have been described in scientific studies and reviewed in numerous reports. The 1990 National Acid Precipitation Assessment Report and the Environmental Protection Agency's Ozone Criteria Document serve as the primary references because they have undergone formal public review. Impacts from primary pollutant emissions (sulfur dioxide, nitrogen oxides, particulate matter) rarely occur at current ambient levels. Historically, acute impacts from gaseous pollutants are most dramatically illustrated by the deforestation and destruction of aquatic and terrestrial ecosystems in the Copper Hill, Tennessee, basin due to emissions from a chemical company. Prior to 1980, incidents of agricultural crop damage have been documented that occurred when TVA coal-fired power plant plumes were intercepted at ground-level (Jones et al. 1988). There was no opportunity for atmospheric mixing to dilute emissions below levels toxic to crops. Impacts of TVA emissions, particularly sulfur dioxide, to crops in the immediate vicinity of TVA power plants were well documented (Jones et al. 1988). Since 1976, TVA sulfur dioxide emissions have been reduced by two-thirds, as shown in the graph in *Figure T1-22*. Direct impacts of sulfur dioxide to crops and forests rarely occur now.

At current ambient exposures, sulfate and nitrate anions in acid deposition and ozone are the pollutants most likely to cause impacts. Such impacts can be cumulative over long-term chronic

(lower level) exposures. Episodes of high ozone exposures can injure foliage of both crops and forest species. Depending on extent and severity, exposure can lead to cumulative impacts to productivity. Impacts from short-term elevated loadings of sulfate and nitrate anions are infrequent but could potentially occur in the undisturbed forests if acid anions in soil solutions mobilized aluminum from soils at levels toxic to plant roots. Forests susceptible to aluminum toxicity are most likely to be in higher elevations of southern Appalachia (Joslin et al. 1992).

Sulfur Dioxide

The effect of sulfur dioxide on crops and other vegetation varies by species and by length and frequency of exposure (Environmental Protection Agency 1982; Shriner et al. 1990). Acute exposures and their associated visual symptoms were once frequently observed in the TVA region. They are very rarely observed today. The current National Ambient Air Quality Standards secondary standard is adequate to protect vegetation from significant negative impacts, based on the literature summarized in the sulfur dioxide criteria document (Environmental Protection Agency 1982) and in the subsequent National Acid Precipitation Assessment Program analysis (Shriner et al. 1990). There may also be a positive contribution of sulfur emissions to the sulfur requirements of agricultural crops (Noggle 1980). Concentrations of sulfur dioxide in most rural areas in the Valley are currently well below the standard and may drop further as the full effects of the 1990 Clean Air Act Amendments are felt.

Nitrogen Oxides

Nitrogen oxides refers to a family of atmospheric pollutants consisting of nitrogen oxide, nitrous oxide, nitrogen dioxide, nitric acid vapor, and various forms of nitrates (Shriner et al. 1990). In contrast to sulfur, which has decreased during the past two decades, the family of nitrogen oxides has increased. The most common phytotoxic (poisonous to plants) form of nitrogen is nitrogen dioxide, followed by the less frequent nitric acid vapor (Shriner et al. 1990). Within the Valley region, the potential impacts of nitrogen dioxide are minimal, since its plant-poisoning threshold concentration of 0.5 parts per million is well above current ambient levels. Nitrogen oxides in the atmosphere are currently a greater concern because they can contribute to acidic deposition impacts or can be utilized in the formation of ozone. The lack of nitrogen frequently limits plant growth in both cultivated and native vegetation. Therefore, nitrogen oxides deposition in many forms has the potential to increase plant growth. This contribution is probably of much greater importance in natural systems than in managed ones where fertilizer additions greatly outweigh other nitrogen sources.

Acidic Deposition–Crops

Impacts on crops attributable to acidic deposition were studied extensively during the last decade. Shriner et al. (1990) summarized the results of most of that work. They concluded that acidic deposition does not cause a reduction in crop yields. Potential reductions in fertility or increases in acidity can be offset by normal management practices. As discussed, the deposition of sulfur and nitrogen associated with acidic deposition in agricultural settings can be a potential benefit to most crop species. Atmospheric sulfur inputs can satisfy much of the crop sulfur need, while nitrogen input is a very small portion of total crop requirements.

Acidic Deposition–Forests

The National Acid Precipitation Assessment Program conducted extensive research to determine the possible impacts of acidic deposition on forests in North America. The results of this research are summarized in the State of the Science Reports, SOS/T-16 (Barnard and Lucier 1990) and SOS/T-18 (Shriner et al. 1990), and in the 1990 National Acid Precipitation Assessment Program Integrated Assessment Report (NAPAP 1991). These studies concluded that, in general, the vast majority of forests in eastern North America are not in decline, either from pollution or other sources. However, atmospheric deposition may be implicated in the premature mortality of high elevation red spruce *(Picea ruben sug.)* in the Northeast.

Evidence of red spruce decline and pollution involvement in the southern Appalachians is less substantial. The red spruce-Fraser fir ecosystem occupies approximately 103 square miles (268 square kilometers) in the southern Appalachian mountains of southwestern Virginia, eastern Tennessee, and western North Carolina. The trees are generally confined to mountain peaks above 5,000 feet (1,525 meters) elevation, as shown in the map in *Figure T1-50*. National Acid Precipitation Assessment Program studies in the southern Appalachians have documented extensive mortality of Fraser fir and decreases in crown vigor and annual growth in red spruce. Fraser fir mortality, frequently pictured in popular publications, is the direct result of an insect, the balsam woolly adelgid.

Although it has been suggested that air pollution may have rendered fir more susceptible to the adelgid, supporting evidence is incomplete. In mixed stands with dying fir, spruce decline can be partially explained by increases in wind damage and soil temperatures (Nicholas et al. 1992). Symptoms of decline in spruce-dominated stands, at elevations with a high frequency of cloud interception, have led scientists to consider impacts of atmospheric deposition. Acid deposition components of sulfate, nitrate, and hydrogen ions at high elevations greatly exceed those at lower elevations. This is primarily due to the increased vol-

ume of precipitation and high ion concentrations in cloud water. Exposure to ambient cloud water with concentrated sulfate and nitrate anions (negatively charged ions) has also been shown to accelerate foliar leaching of essential cations (positively charged ions). In field studies, decreases in foliar calcium and magnesium have corresponded to decreases in foliar biomass. Field surveys and fertilization studies indicate that red spruce in the southern Appalachians are experiencing calcium and zinc deficiencies, while those in the Northeast are generally not.

National Acid Precipitation Assessment Program research, (Barnard and Lucier 1990, Shriner et al. 1990) as well as ongoing studies, (Nodvin et al. In Press) have demonstrated that the high elevation forests appear to be nitrogen-saturated. Nitrogen inputs from rain, snow, and cloud water combined with inputs from natural biological process exceed the capacity of soils and vegetation to immobilize nitrogen. The leaching of excess nitrogen depletes essential base cations from the soil and acidifies soil water. In addition, there is evidence that aluminum is being mobilized into soil water at levels that interfere with plant uptake of calcium, magnesium, and zinc. Soils in the southern Appalachians generally have a large capacity to absorb sulfate, but current sulfate loading rates will likely exceed soil sulfate absorption capacity within a few decades (Johnson and Lindberg 1992).

Exposure to ambient cloud water can reduce the cold tolerance of red spruce. Increases in winter damage to red spruce in the Northeast have contributed to crown damage and increased mortality in that region. This impact occurs infrequently in the southern Appalachians, where temperatures seldom approach the cold tolerance limits for red spruce.

National Acid Precipitation Assessment Program studies did not find a regional decline of southern pines (Barnard and Lucier 1990, Shriner et al. 1990). The U.S.D.A. Forest Service had reported widespread reductions in average tree growth rates in natural pine stands in the Southeast. Similar growth rate reductions have not been observed in tree plantations. Reduction in tree growth in natural pine stands is an anticipated consequence of historical land use patterns, increases in stand longevity and competition, and other natural factors. Available information is not adequate to determine whether the magnitude of reported growth reductions is greater or less than would be expected in the absence of acidic deposition and associated pollutants. The magnitude, extent, and timing of soil chemical changes due to acidic deposition and their long-term implications for forest health and productivity are uncertain. Available evidence does not support a hypothesis that acidic deposition has caused aluminum toxicity or nutrient deficiencies in southern pines.

With the possible exception of the spruce-fir forests of southern Appalachia, most Valley forests are receiving acid rain at doses that have not had a serious impact on forest health and productivity. However, the cumulative effects of sulfate and nitrate deposition over several decades could be adverse for some soils. Sulfate and nitrogen oxides deposition increases leaching of nutrient cations from some forest soils and over the long term may reduce the fertility of soils with low buffering capacity or low mineral weathering rate. Nitrogen saturation, a concept currently under discussion in the regulatory arena, could be a long-term impact if nitrogen deposition continues at current rates. Nitrogen saturation is unlikely to occur in Valley forests outside of the high elevation spruce-fir forests or unmanaged old growth wilderness areas.

Impacts to forest soils and nutrient cycling are generally considered to be reversible. Decreases in sulfate deposition would ultimately result in decreases in cation leaching once a new soil equilibrium was established. Decreases in nitrate deposition would probably lead to equivalent decreases in cation leaching in high elevation forests thought to be at or near nitrogen saturation. The Nutrient Cycling Model (Liu et al. 1991) is one method to evaluate the potential benefits to forests that could result from reductions in sulfate and nitrate deposition.

The Nutrient Cycling Model accounts for the exchange of essential nutrients from deposition, vegetation, the forest floor, soils, and soil solutions. The model was applied to project nutrient cycling over a 30-year period in a spruce-fir forest at Noland Divide in the Great Smoky Mountains National Park. Levels of sulfate and nitrate in deposition were varied to simulate alternative reductions in sulfur dioxide and nitrogen dioxide emissions. The initial and no change projections reflect deposition levels monitored at Noland divide for the period 1985 to 1988. Reductions in sulfate and nitrate deposition of 20, 30, 40, or 50 percent compared to the 1980s were projected to represent probable benefits achieved from implementation of the 1990 Clean Air Act Amendments or future emissions reductions.

Calcium is an essential plant nutrient that is susceptible to leaching by acid deposition. Aluminum in soil solutions may be toxic to plant roots and may interfere with plant uptake of calcium. The effects of alternative deposition levels on the distribution of calcium in vegetation, forest floor, and soils and on aluminum and calcium in soil solutions are illustrated in *Figures T1-51* and *T1-52*, respectively (Dale Johnson unpublished data). Calcium is not deficient in this spruce-fir stand, and the model projected very small differences after 30 years in calcium in vegetation and the forest floor as a function of deposition levels. Calcium in the exchangeable soil pool is projected to be greater at lower levels of sulfate and nitrate deposition. Calcium and aluminum in soil solutions (an indication of nutrients lost from the ecosystem) are projected to be lower at lower levels of sulfate

FIGURE T1-50. **The Energy Vision 2020 Study Area Includes the Southern Appalachian Spruce-Fir, a Threatened Ecosystem**

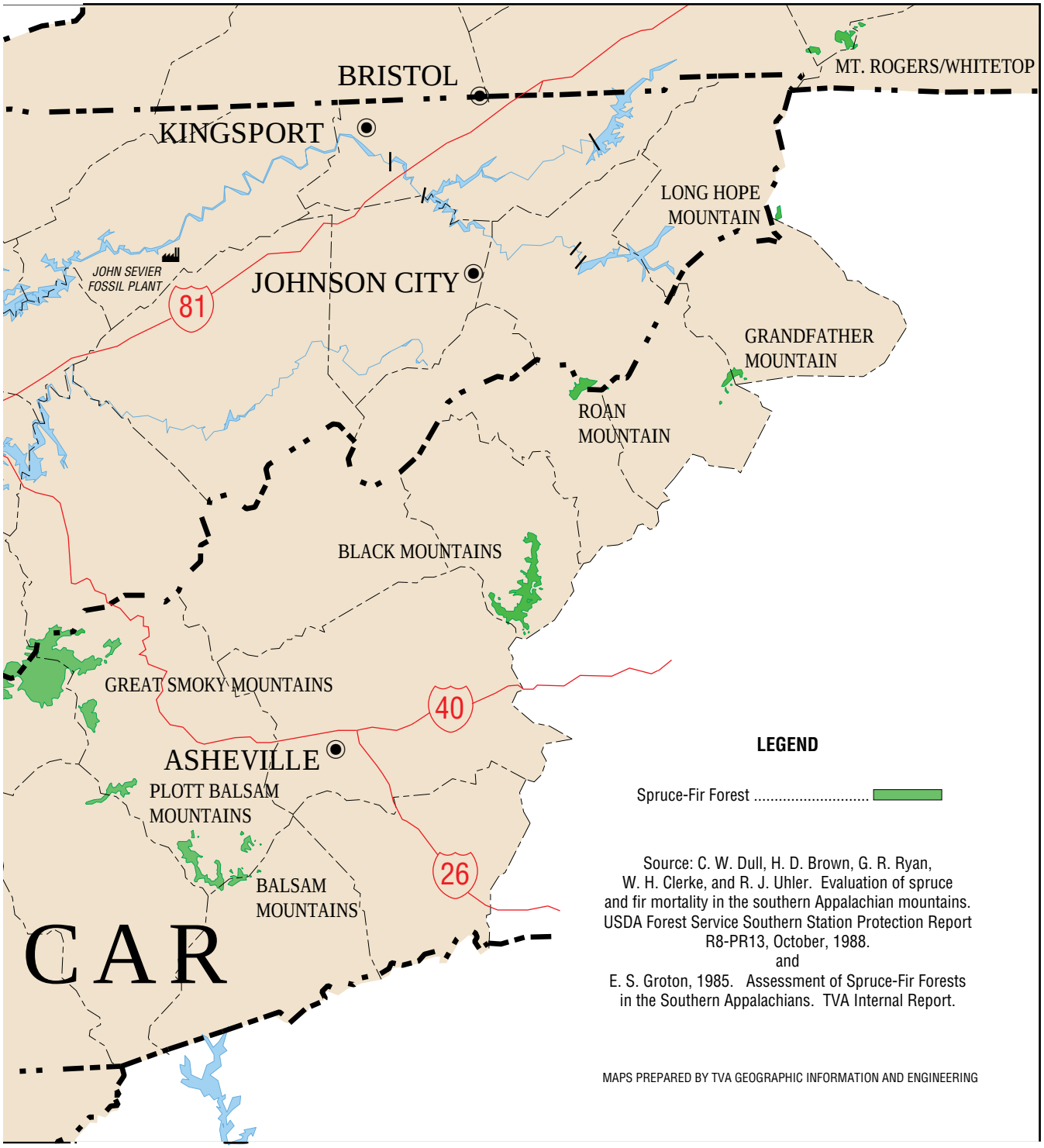
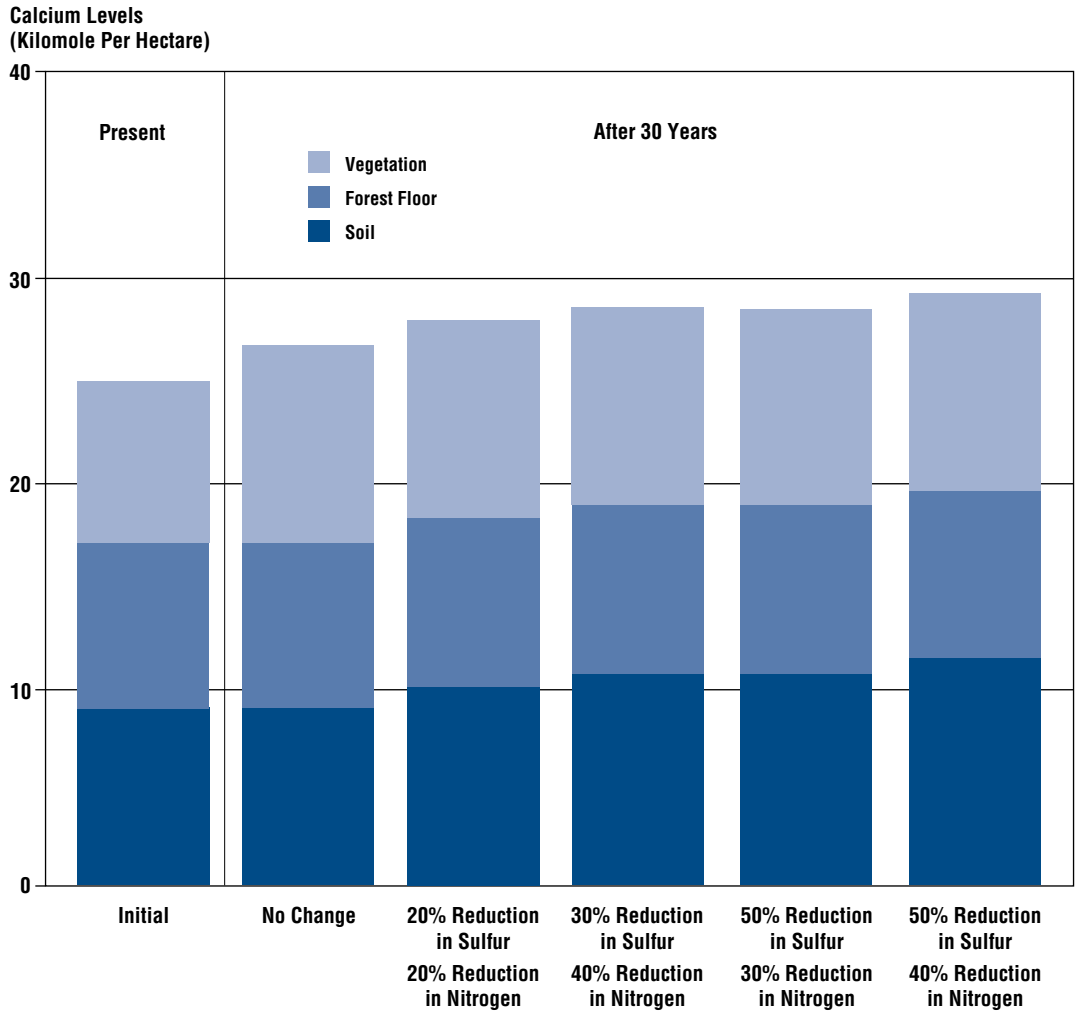

BRISTOL
KINGSPORT
MT. ROGERS/WHITETOP
LONG HOPE MOUNTAIN
JOHN SEVIER FOSSIL PLANT
JOHNSON CITY
81
GRANDFATHER MOUNTAIN
ROAN MOUNTAIN
BLACK MOUNTAINS
GREAT SMOKY MOUNTAINS
40
ASHEVILLE
PLOTT BALSAM MOUNTAINS
26
BALSAM MOUNTAINS
CAR
LEGEND
Spruce-Fir Forest
Source: C. W. Dull, H. D. Brown, G. R. Ryan, W. H. Clerke, and R. J. Uhler. Evaluation of spruce and fir mortality in the southern Appalachian mountains. USDA Forest Service Southern Station Protection Report R8-PR13, October, 1988.
and
E. S. Groton, 1985. Assessment of Spruce-Fir Forests in the Southern Appalachians. TVA Internal Report.
MAPS PREPARED BY TVA GEOGRAPHIC INFORMATION AND ENGINEERING

FIGURE T1-51. **Changes in Calcium Levels in Vegetation, Forest Floor, and Soil Exchangeable Pools in a Spruce-Fir Forest at Noland Divide in the Great Smoky Mountains National Park Based on a 30-Year Simulation Using the Nutrient Cycling Model**



and nitrate. The greatest improvements are projected for the case representing implementation of the 1990 Clean Air Act Amendments compared to the no change (pre-1990 Clean Air Act Amendments) conditions. *Figure T1-52* illustrates that the ratio of aluminum to calcium would improve with reduced deposition levels, particularly during periods of high runoff.

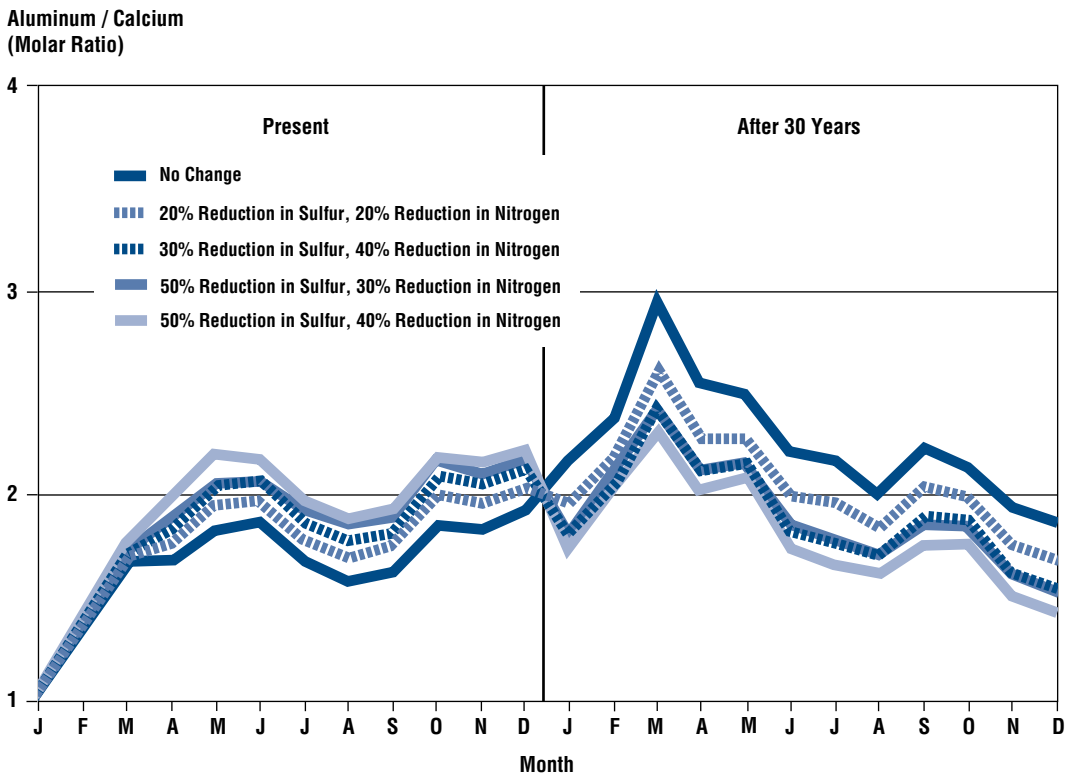
This model application illustrates a potential method to evaluate forest response to reduce deposition levels. Assessments under the Southern appalachian Mountain Initiative will further address methods to evaluate benefits of emissions reductions.

Ozone–Crops

Impacts of ozone are a function of concentration and duration of exposure (external to plants) and plant uptake (internal dose). Ozone is currently the most pervasive air pollutant in rural areas and the pollutant most likely to impact agricultural crops negatively. Impacts to crop productivity, physiology, reproduction, and economic yields have been well documented (Environmental Protection Agency 1995).

Ozone enters plants through the leaf stomates and may disrupt cellular function. High short-term exposures can injure or lead to death of cells in the vicinity of the stomates. The degree of impact increases with the ozone dose received. Visible dis-

FIGURE T1-52. **Changes in Aluminum to Calcium Soil Solution Molar Ratio in a Spruce-Fir Forest at Noland Divide in the Great Smoky Mountains National Park Based on a 30-year Simulation Using the Nutrient Cycling Model**



coloration of foliage may be a result of high short-term exposure to ozone or of the cumulative longer term ozone dose received over the growing season. At frequent, low-level exposures, ozone may inhibit photosynthetic function and reduce plant carbon reserves. Under ozone stress, a greater portion of the carbon fixed through photosynthesis must be used to repair injury to cells rather than contribute to growth. Allocation of carbon from leaves and stems to the root system, which stores carbon for future growth, is frequently limited by chronic ozone exposure. Thus, impacts from ozone can accumulate over the duration of exposure, which can last seasons or years.

At current ambient levels of ozone in the eastern United States, average reductions in crop yield are likely on the order of 10 to 15 percent (Environmental Protection Agency 1995). Some crops, such as tobacco, spinach, and grapes, are very sensitive to ozone and could experience greater than 15 percent reductions in annual yields at current ambient levels. Economic analyses (Kopp et al. 1985; Adams et al. 1989) have considered the economic impacts of yield reductions for major commodity crops such as wheat, corn, soybeans, and cotton. Studies summarized by the Environmental Protection Agency (1995) estimated that net economic losses attributable nationally to current levels of ozone are in the range of 1 to 2 billion dollars per year.

The effects of plant exposure to ozone accumulate over the growing season. Exposures above a threshold value cause greater impacts than lower exposures. Consequently, a cumulative index that sums the hours above a threshold is proposed in the Environmental Protection Agency's 1995 draft ozone criteria document. The Environmental Protection Agency suggests that the sum of hours exceeding a concentration of 0.06 parts per million (SUM06) for the maximum 3-month period between April and October should not exceed 26.4 parts per million-hour. This value was derived from the results of the National Crop Loss Assessment Network (Heck et al. 1990) and is intended to protect 50 percent of crops from 10 percent yield reduction.

Response to ozone can be highly modified by the plant's nutrient and water status. Environmental conditions that limit the extent that leaf stomates are open limit the uptake of ozone.

Consequently, ozone impact is less severe for crops exposed to ozone under low moisture or fertility conditions compared to crops with the same exposure under high moisture and fertility conditions. The table in *Figure T1-53* summarizes the range in ozone exposure at which 10 percent yield reductions were observed for several common crop species in controlled exposure field studies conducted under the National Crop Loss Assessment Network (Heck et al. 1990). Exposure is expressed as the maximum 3-month sum of hours exceeding 0.06 parts per million (SUM06). Plants in these studies were well-watered and fertilized. Yield reductions in unwatered fields may be less than estimated in these studies. In 1992, the maximum 3-month sum of hours greater than 0.06 parts per million exceeded 26.4 parts per million-hour over large areas of the TVA region *(Figure T1-53)*.

FIGURE T1-53. **Crop Response to Ozone Projected by the National Crop Loss Assessment Network Using Controlled Exposure Field Studies**

Crop Species	Maximum 3-Month Sum of Hours Above a Concentration of 0.06 Parts per Million-Hour to Cause a 10% Yield Loss
Corn (2 cultivars)	42-56
Cotton (4 cultivars)	14-95
Kidney Bean (1 cultivar)	15-19
Lettuce (1 cultivar)	37
Peanut (1 cultivar)	36
Potato (1 cultivar)	10-20
Sorghum (1 cultivar)	68
Soybean (7 cultivars)	8-90
Tobacco (1 cultivar)	26
Turnip (4 cultivars)	6-10
Wheat (4 cultivars)	3-35

Source: Environmental Protection Agency 1995 Draft Ozone Criteria Document

Ozone–Forests

Impacts of ozone to forests and natural systems are less well understood than impacts to crops. The bulk of information on ozone impacts to unmanaged vegetation (mainly forest species) has been summarized recently by Barnard and Lucier (1990), Kiester (1990), Shriner et al. (1990), and Environmental Protection Agency (1995). Based on these summaries and other information, it appears that forests in the eastern United States are not in a general state of decline as a consequence of ozone or any other air pollutant. However, ozone has been implicated as the key air pollutant responsible for decreases in productivity in the mountains of southern California and for foliar injury to several forest tree species in the eastern United States. Based on controlled exposure studies with tree seedlings, the table in *Figure T1-54*, summarized from the 1995 draft ozone criteria document, identifies the ozone exposure at which 10 percent losses in biomass are projected for several tree species.

Ozone sensitivity increases in the following order: high elevation conifers, southern pines, late successional hardwoods such as oak, early successional hardwoods such as tulip poplar, black cherry and ash, lichens, and herbaceous forest species (Chappelka et al. 1993; Thornton et al. 1994; Kelly et al. 1993; Samuelson and Edwards 1993; and Samuelson 1994). Species sensitivity to ambient ozone exposures is greatly influenced by site environmental conditions. Species that occur in communities associated with moist sites are generally more sensitive than those species in communities associated with dry sites. While certain varieties of loblolly pine may be negatively impacted by ozone at current ambient levels, the Environmental Protection Agency (1995) concluded that there was no evidence to indicate a general decline in loblolly pine due to ozone in the region.

The National Park Service has documented foliar injury to several sensitive species based both on field surveys in natural forest stands and on controlled chamber exposure studies. (Neufeld and Renfro 1993; Shaver et al. 1994). In natural stands the extent of foliar injury is less than reported from controlled studies. Black cherry is particularly prone to foliar injury. While foliar injury does not necessarily indicate that plant growth has been reduced, it is an indicator of plant sensitivity. Reductions in photosynthesis and growth were documented in the controlled chamber exposures for several of the species sensitive to foliar injury. Results for black cherry and tulip poplar in *Figure T1-54* are from controlled exposure studies in the Great Smoky Mountains National Park (Neufeld and Renfro 1993). Current ambient levels of ozone in the Valley *(Figure T1-37)* exceed levels at which these species experienced biomass losses in controlled chamber studies. Cumulative ozone exposures in the Great Smoky Mountains can actually be greater than in other parts of the Valley because ozone levels in the mountains do not decline as quickly in the late afternoon and evening hours as generally occurs at lower elevations *(Figure T1-35)*. Thus, greater injury to forest species may be occurring in the Great Smoky Mountains than in other areas of the Valley.

Predictions of ozone impacts on forests are still subject to significant scientific uncertainty. The actual ozone dose (uptake) received by a plant is not always a linear function of the ambient exposure because interactions with moisture and fertility can limit stomatal function and ozone uptake. Ozone uptake and plant response to ozone exposures occurring in late afternoon and evening is not well understood. Also, the great bulk of information on tree response to ozone is based on con-

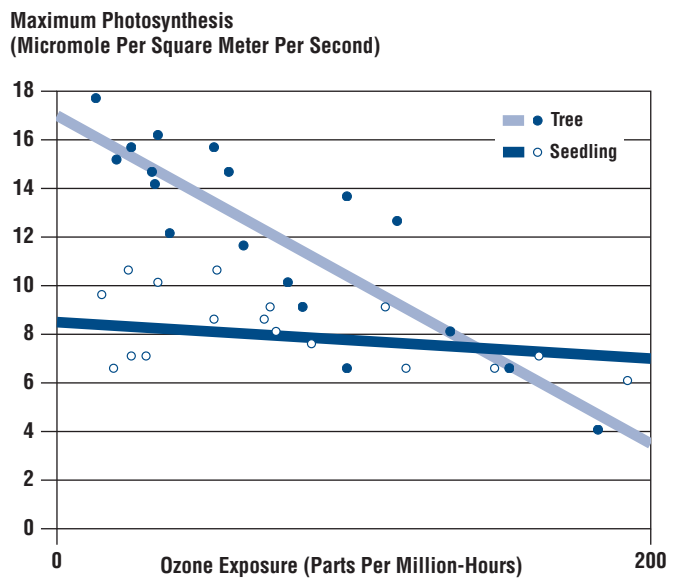
FIGURE T1-54. **Ozone Sensitivity for Several Tree Species Measured as 10 Percent Loss in Seedling Biomass in Controlled Exposure Field Studies**

Tree Species	Maximum 3-Month Sum of Hours Above a Concentration of 0.06 Parts per Million-Hour to Cause 10% Loss in Biomass[1]
Aspen (6 studies)	9-65
Black Cherry (2 studies)	13-17
Tulip Poplar (2 studies)	17-35
Ponderosa Pine (5 studies)	14-65
Red Alder (4 studies)	22-250
Eastern White Pine (1 study)	39-41
Sugar Maple (1 study)	39-105
Red Maple (1 study)	150
Douglas Fir (2 studies)	73-250
Loblolly Pine (1 study)	77-229
Virginia Pine (1 study)	250

[1] Actual ozone exposure in controlled field studies was weighted by duration of exposure to derive maximum 3-month sum of hours greater than 0.06 parts per million-hour. Weighted sum of hours above a concentration of 0.06 parts per million-hour allows sensitivity of tree seedlings to be compared to agricultural crops.

Source: Environmental Protection Agency 1995 Draft Ozone Criteria Document

FIGURE T1-55. **Maximum Photosynthesis of Seedling and Mature Red Oak Under Controlled Ozone Exposures in Chambers in Norris, Tennessee**



trolled exposures of seedlings. Recently completed work has indicated that, at least for northern red oak, mature trees may be more vulnerable to ozone than seedlings (Samuelson and Edwards 1993). *Figure T1-55* indicates that photosynthetical function in mature red oak trees is more sensitive than in seedlings and that ozone impacts increase over that of increased cumulative exposure. Field measures of incremental changes in diameter growth of mature loblolly pines growing on moist and dry sites indicate that ambient levels of ozone may reduce growth of loblolly pine. Site conditions, air temperature, and soil moisture levels were interactive with ambient ozone to affect growth (McLaughlin and Downing, in press).

The Environmental Protection Agency has proposed a new secondary standard that would provide additional protection for crops and forests. This reflects both the possible importance of exposure peaks and the cumulative nature of ozone impacts. The proposed secondary standard suggests a maximum 3-month sum of hours greater than 0.06 parts per million not to exceed 26.4 parts per million-hour. The proposal is based on evidence from agricultural crops, for which there is currently a more complete understanding of plant response to ozone. Because trees are exposed to ozone over several growing seasons, a standard lower than that recommended for annual crops may be necessary to protect sensitive tree species from injury. The next iteration of the ozone criteria document will more fully consider impacts to forests as current studies on mature tree responses provide better scientific evidence to define levels necessary to protect forest species. *(See Figure T1-55.)*

Hazardous Air Pollutants

Terrestrial Impacts

TVA's emissions of hazardous air pollutants primarily involve metals. At current ambient exposures, these metals are not likely to degrade crop and forest productivity. In fact, some vegetation species are very effective at removing metals from the soil and have been used as a biological remediation method to reclaim contaminated sites. The terrestrial ecosystem is a repository for metals deposited from the atmosphere. Soil and vegetation components influence the accumulation or the transport of metals to aquatic ecosystems. Concentrations of metals in tree wood and in lichens have been used as indicators of historical deposition patterns for metals because many of the metals accumulate in vegetation.

Aquatic Impacts

Impacts of metals in aquatic ecosystems are of concern for sensitive invertebrate and vertebrate species. Impacts of regional atmospheric deposition of metals are considered to be minor in

the Tennessee Valley *(Figure T1-47)*. Metals such as mercury or lead are more readily mobilized into soil solutions and transported by acid anions including sulfates, nitrates, and organics. In ecosystems sensitive to acidification, these metals may occur at elevated concentrations. However, the Tennessee Valley watersheds are generally well buffered against acidification, have a high land-to-surface water ratio, and have comparatively lower loadings of dissolved organic carbon than other regions of the country experiencing impacts (Joslin 1994). *Figure T1-48* indicates that levels of mercury in air precipitation, lake water and fish at Fort Loudoun reservoir on the Tennessee River are lower than levels in Wisconsin.

MATERIALS DAMAGE

Sulfur Dioxide

Exposure to gaseous sulfur dioxide at sufficient concentration causes corrosion of the protective zinc coating on galvanized steel and contributes to the erosion and pitting of other metals such as copper and aluminum. Sulfur dioxide forms white deposits called gypsum as it reacts with marble and limestone. It degrades protective paint coatings on steels and exterior wood surfaces and speeds the degradation of wood (Sherwood 1990, Sherwood and Lipfert 1990, Boedecker et al. 1990, Brown and Callaway 1990). Sulfur dioxide is also the major component of acid deposition, which is discussed below. Frequent cleaning reduces the impact of sulfur dioxide on materials. Repainting exposed surfaces as needed can largely mitigate the effects of sulfur dioxide.

Nitrogen Oxides

Exposure to gaseous nitrogen oxides at sufficient concentration causes corrosion of metals and other materials similar to the gaseous sulfur dioxide process described above. The effect is about 75 percent less than that for the same weight concentration of sulfur dioxide (ORNL 1994). The corrosion products are generally soluble, so there are no deposit buildups such as the gypsum associated with corrosion from sulfur dioxide. Nitrogen oxides are a significant component of acid deposition, which is discussed below.

Ozone

Ozone is a strong oxidant that can damage rubber and other elastic substances, textile fibers and dyes, paints, and other materials, including plastics and asphalt. Anti-ozonants and anti-oxidants have been incorporated in paints and other elastic substances to mitigate the effects of ozone. The damage to textile fibers and certain dyes tend to be of secondary effect over product lifetimes when compared with other factors such as abrasion, biological degradation, soiling, and changes in fashion. The studies of dose response are largely empirical, and the Environmental Protection Agency cautions that that they are not reliable (Environmental Protection Agency 1986).

Particulate Matter Smaller than 10 Microns

All exterior surfaces are subject to soiling from particulate matter 10 microns or less in size. Ventilated interior surfaces are also subject to soiling and require more frequent cleaning. Some materials, such as selected fabrics, can be permanently stained. Particulate matter can interact with acid deposits to accelerate the effect from acid deposition.

Acidic Deposition

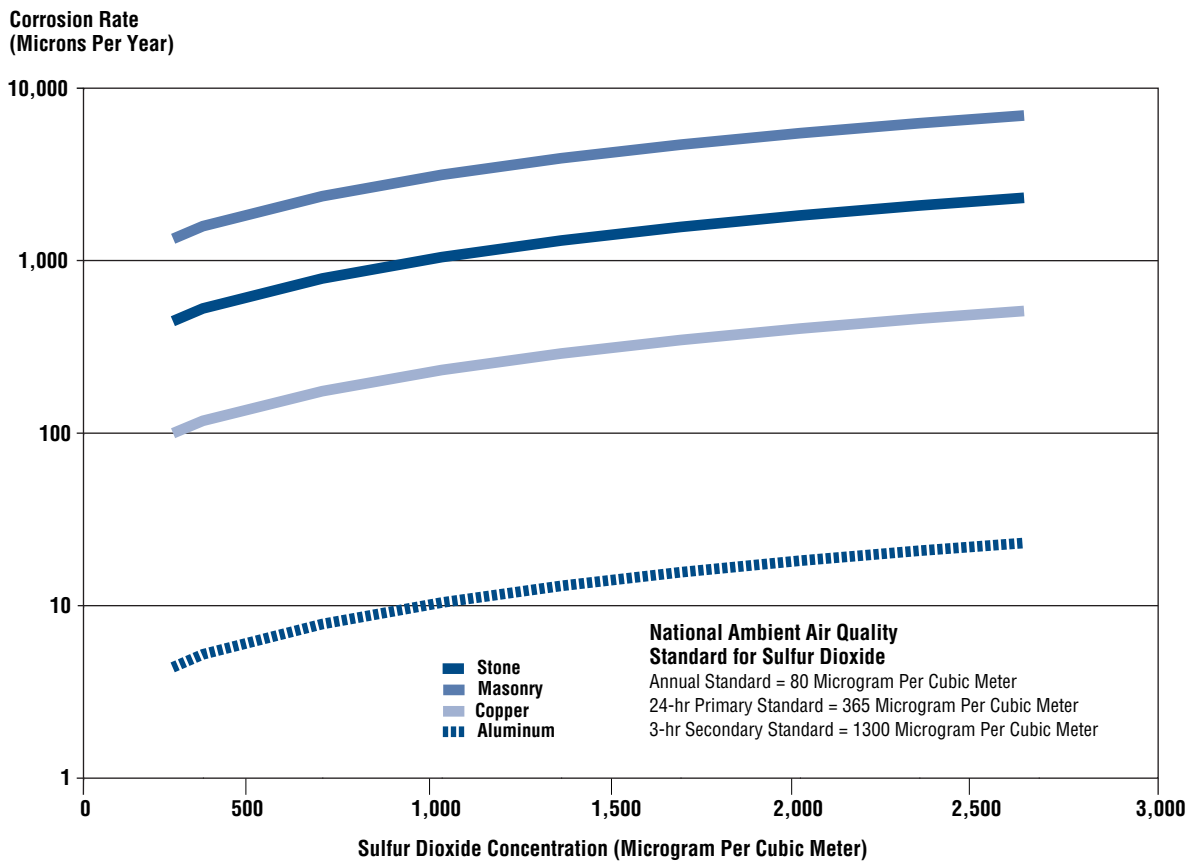
The National Acid Precipitation Assessment Program conducted extensive studies on the effects of acidic deposition on materials (Brown and Callaway 1990). Emissions of sulfur dioxide and nitrogen oxides from power plants are major contributors to acidic deposition. The chemistry of acid deposition involves the oxidation of both sulfur dioxide and nitrogen oxides to form strong acids, sulfuric acid, and nitric acid. These are deposited both directly by dry deposition and by wet deposition with rain, snow, and fog.

Materials that can be damaged from acid deposition include galvanized steel and other metals, painted steel (including automobiles), painted wood, mortar, and carbonate masonry (marble and limestone). Galvanized steel depends on zinc oxides for protection. Over time, these zinc oxides are slowly worn away by clean rain accelerated by acid deposition. Acid deposition corrodes the zinc oxide coating so that it is easily eroded by rain, thus exposing the substrate to corrosion. Copper and bronze develop a natural protective oxide patina that is attacked by acid deposition. As this natural patina is removed, a more porous sulfate patina develops. On copper this sulfate patina has a green color. Painted metals and wood can also be affected by acid deposition. The paints can be damaged, discolored, or spotted. Also, some paints are porous, allowing penetration to the substrate (Brown and Callaway 1990).

Exposures to ambient concentrations of sulfur dioxide can cause marble surfaces to lose 15 to 30 micrometers per year and limestone surfaces, 25 to 45 micrometers per year. Reactions to acidic deposition tend to accumulate as gypsum on the sheltered surfaces of carbonate stone buildings and monuments. Even small material losses can cause significant loss of artistic detail in statues and cultural or historic structures (Brown and Callaway 1990).

National Acid Precipitation Assessment Program corrosion studies in the 1980s have correlated decreased corrosion rates in the eastern United States with diminished sulfur dioxide concentrations. The graphs in *Figure T1-56* shows the

FIGURE T1-56. **Dose-Response Functions for Materials Exposed to Acidic Deposition**



dose-response relationship between sulfur dioxide levels and the corrosion rate on common materials (ORNL 1994).

While a correlation exists, caution should be taken in assuming a cause-and-effect relationship. The level of nitrogen oxides, ozone, acid deposition, and particulates also tended to track with sulfur dioxide, so the investigators could not isolate effects of individual pollutants. Therefore, this table is best viewed as showing the composite effect of acid deposition with sulfur dioxide acting as the marker.

The effects of acidic depositions can be reduced by frequent cleaning and repainting as needed. Paints and protective coatings that are more resistant to attack from acidic deposition need to be developed.

Air Indices and Rationale for Weightings

TVA's existing energy resources and many of the resource options considered for Energy Vision 2020 can affect air quality in different ways. Several air quality issues were identified as concerns in the scoping phase of the Energy Vision 2020 process. Air indices were developed to help characterize how TVA power system operations and alternative energy strategies might affect air quality impact areas. *Figure T1-57* contains the weightings used in Energy Vision 2020 for air emissions. The values in the index are weighted by the relative importance among TVA emissions in contributing to pollutant loadings that could affect human health and the environment. The index allows the emissions of greater concern for impacts to be given greater emphasis in multi-attribute analysis of alternative energy strategies.

To understand how the index translates to differences in impacts, it is necessary to understand how TVA emissions contribute to pollutant exposures and how changes in expo-

FIGURE T1-57. **Weighting Factors for Air Quality Evaluation Measures Used in Four Impact Area Indices**

	IMPACT AREAS			
Measure	**Health-Inhalation**	**Visibility Impairment**	**Forest and Crop Productivity**	**Materials Damage**
Sulfur Dioxide Emission	0.40	0.70	0.25	0.60
Nitrogen Oxides Emission	0.50	0.25	0.75	0.40
Total Suspended Particulate Emission	0.05	0.05		
Mercury Emission	0.05			

sures result in changes in impacts. Uncertainty in scientific understanding limits the ability to quantify the relationships among emissions, exposures, and impacts. In applying this index to multi-attribute analysis, percentile differences in the weights among strategies can be interpreted as differences in TVA contributions to the air pollutant loadings that cause impacts. The air index, as presented, does not provide a weighting of TVA's contribution to the total pollutant loading in the area of concern.

RELATIONSHIPS

Energy Vision 2020 defines TVA's future energy options as alternative energy supply strategies and does not define specific sites where TVA air emissions might increase. To understand impacts of specific TVA sources to specific receptors of concern, it is necessary to use atmospheric models to project the transformation and delivery of emissions under specific meteorologic conditions. This analysis does not attempt to model delivery of emissions from specific TVA sites to specific receptors. In TVA siting decisions for future energy supply, atmospheric modeling can be used to better project site-specific impacts from TVA emissions.

General relationships between pollutant loadings and impacts are illustrated in *Figures T1-58* through *T1-60* for acid deposition, ozone, and visibility. In these diagrams, factors that can be controlled, e.g. emissions management decisions, are illustrated in a box. Arrows illustrate dependencies between variables and end results. Impacts to human health, crop and forest productivity, materials, and visibility are the end results of decisions on levels of emissions from human activity and the many environmental variables that influence pollutant formation, transport, and exposure. The variables in these diagrams must be considered to evaluate what changes in impacts will occur as a result of changes in emissions under different TVA energy supply strategies. As can be seen from these figures, utility emissions are just one category of emissions that contribute to air pollution impacts.

TVA's contribution to total pollutant loadings can be estimated by using predominant wind speeds and directions for seasonal or annual time periods to define the general source area for the Tennessee Valley. (See discussions under ozone, acid deposition, and visibility impairment sections.) TVA's emissions within the source area are projected from 1996 to 2020, and changes in impacts are considered as a function of changes in loadings. Analyses assume that emissions from non-TVA sources will remain level over this period, and any changes in loadings will be a function only of changes in TVA's contribution.

Potential changes in impacts have been considered for the region and for sensitive receptors. For human health impacts, any reduction in loadings will have positive benefit. Environmental and material damages can be episodic (hours or days) or cumulative (seasonal, annual, or over decades) and can vary as a function of the site conditions. Reductions in pollutant loadings below a threshold level may be required before benefits are measurable.

WEIGHTINGS ASSIGNED TO EMISSIONS IN AIR INDICES

Weightings of key pollutants in the indices are given in *Figure T1-57*.

Human Health–Inhalation

Figure T1-61 contains a summary of possible health effects associated with various types of pollutants. Any TVA contributions to health impacts associated with inhalation of pollutants are primarily related to ozone and fine-particulate matter on respiratory functions of sensitive individuals. Ambient levels of sulfur dioxide associated with TVA's emissions are below levels that impact lung function directly. However, sulfur dioxide can be converted to sulfate particles that are of the size most irritating to lung function (particles less than 2.5 microns). Increased health risk has also been associated with elevated levels of the fine particles.

TVA's nitrogen oxides emissions contribute to ozone formation. Ambient levels of ozone are estimated to have slightly greater risks of respiratory impacts than fine particles. Because of the importance of ozone, nitrogen oxides were weighted slightly more than sulfur dioxide (0.5 versus 0.4).

TVA's emissions of hazardous air pollutants are estimated to have less risk than the Environmental Protection Agency's one-in-one million health risk threshold. Therefore, a low weighting of 0.05 was applied. TVA mercury emissions are tracked in the air index as a surrogate for other metals emitted in trace quantities from coal combustion because more quantitative data is available for mercury emissions than for other hazardous air pol-

FIGURE T1-58. **Acid Deposition: Relationships Among Emissions, Exposures, and Impacts**

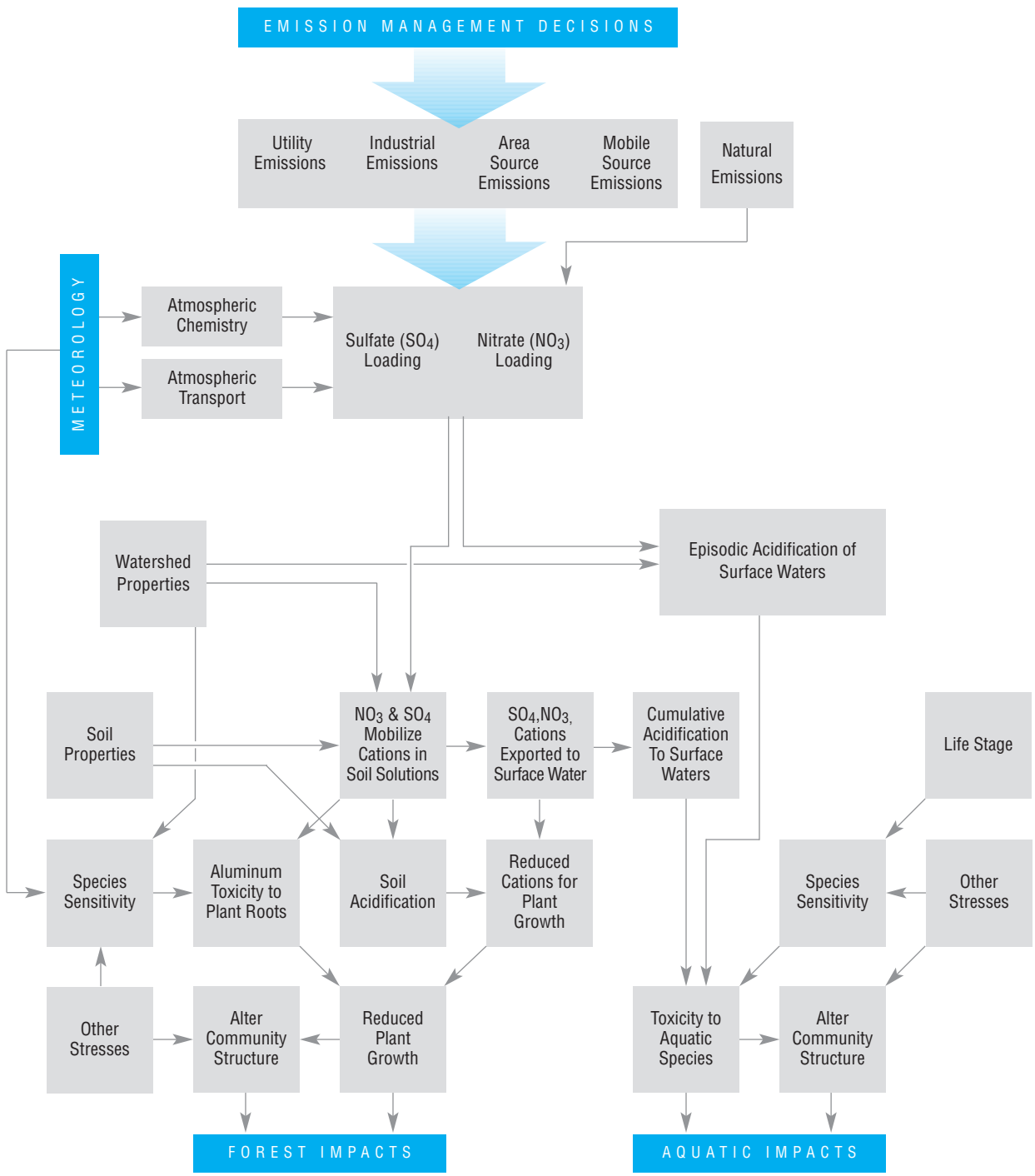


FIGURE T1-59. **Ozone: Relationships Among Emissions, Exposures, and Impacts**

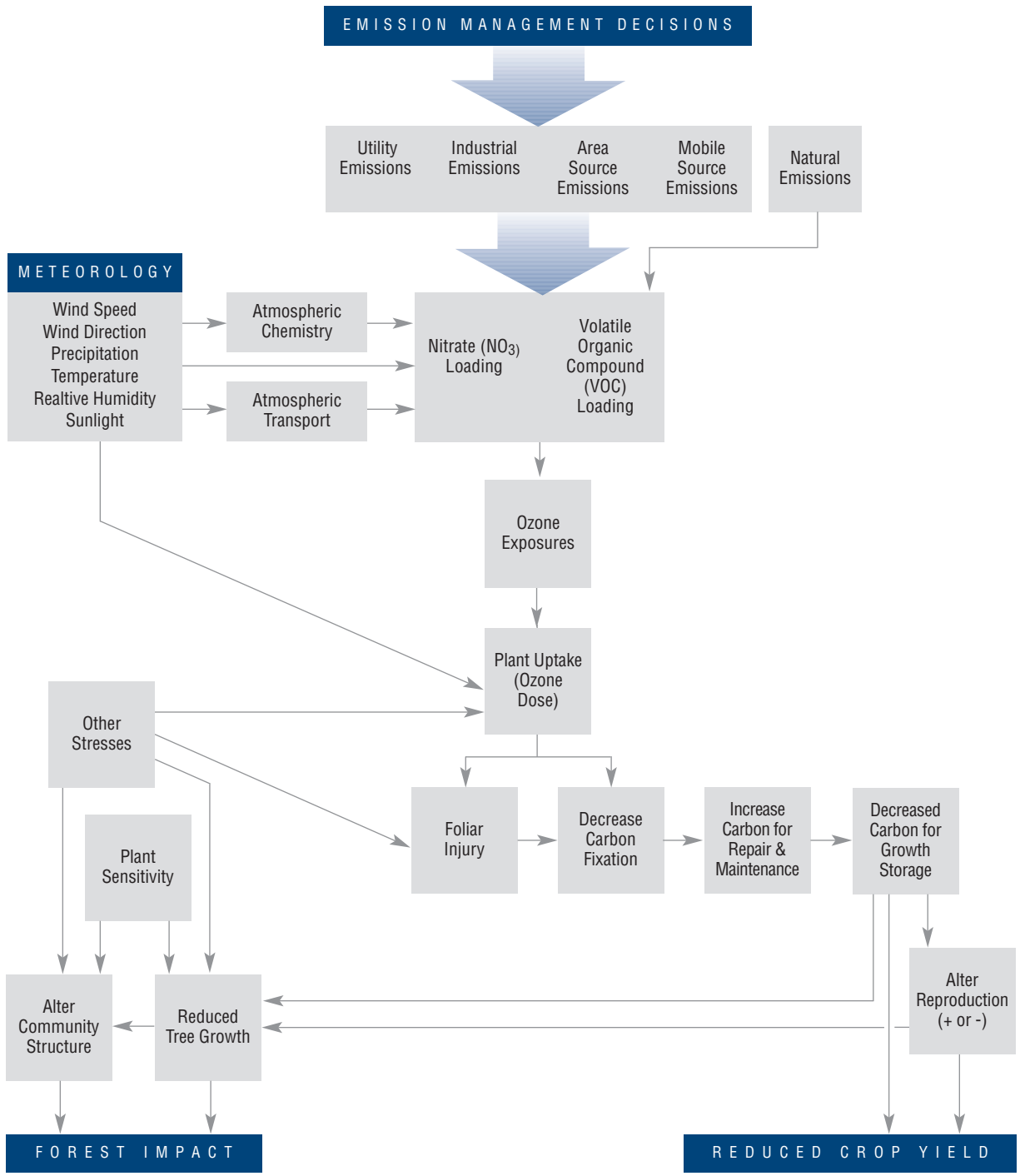
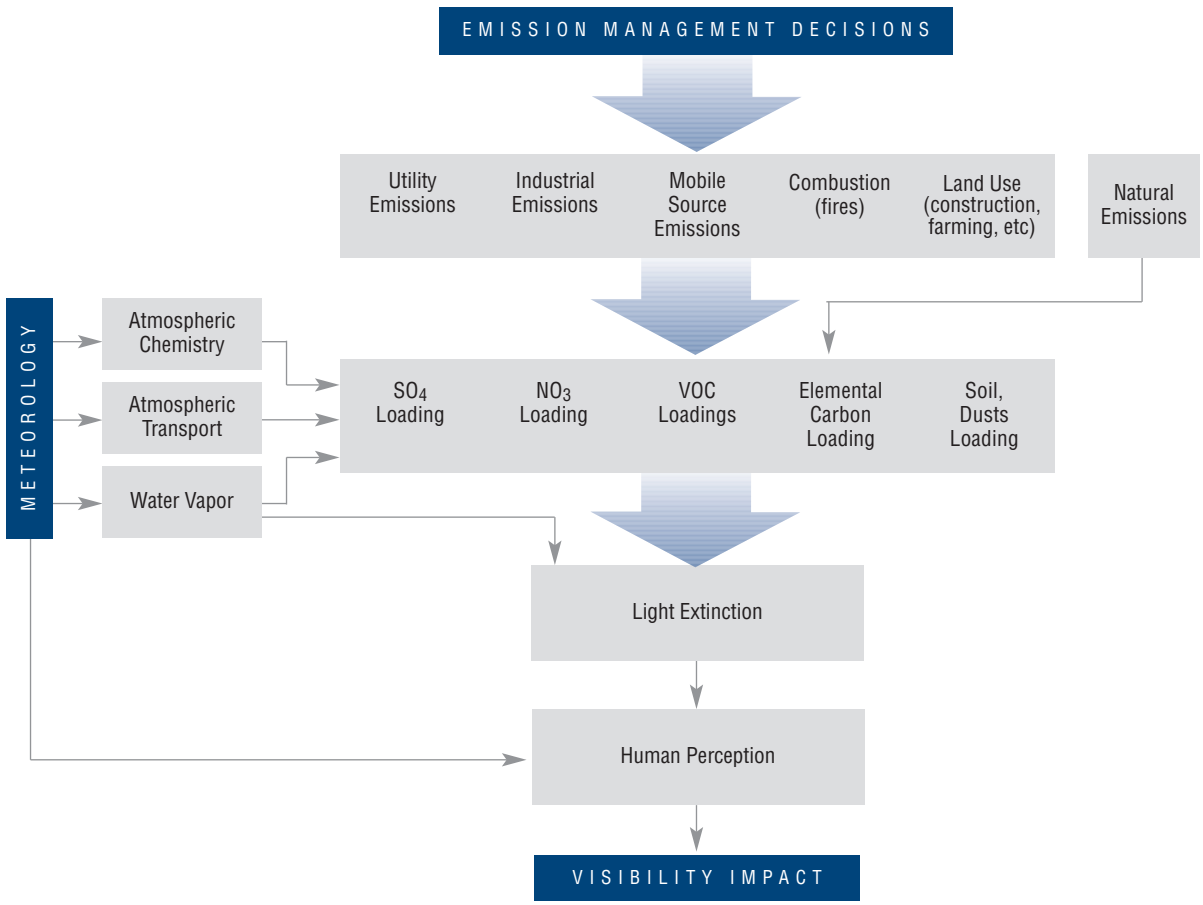


FIGURE T1-60. **Visibility: Relationships Among Emissions of Particulate Matter, Gaseous Pollutants, and Visibility Impairment**



lutants. Mercury effects are discussed in the water resources section of this section.

TVA's emissions of primary particulates are a minor component of the fine-particulate size contributing to health risk. For this reason, total suspended particulates received a weight of only 0.05.

Any reduction in emissions is assumed to have positive benefits for human health.

Visibility Impairment

TVA's contribution to regional visibility impairment is primarily associated with fine sulfate particles. Because sulfate production from sulfur dioxide in the atmosphere is slow, TVA sulfur dioxide emissions contribute very little to visibility impairment in the Great Smoky Mountains National Park.

TVA's nitrogen oxides emissions contribute only indirectly to visibility impairment through their role in ozone formation and the conversion of sulfate particles to organic aerosols. As a result, sulfur dioxide was weighted as almost three times more significant than nitrogen oxides (0.70 versus 0.25).

TVA's emissions of primary particles are a minor component of the fine-particulate size most responsible for scattering light in the atmosphere and thus impairing visibility. Because of this minor role, total suspended particulates received a weight of only 0.05.

Forests and Crops

Any TVA contributions to crop and forest impacts are primarily associated with ozone and with nitrate and sulfate in acid deposition. TVA's sulfur dioxide emissions contribute to sulfate in acid deposition, and nitrogen oxides emissions contribute to both ozone and nitrate in acid deposition. At ambient ozone levels, several crop and forest species in the Tennessee Valley are sensitive and exhibit foliar injury and reduced productivity. Sulfate in acid deposition is not thought to have adverse impacts to vegetation and

may have slight positive benefits as a plant nutrient where soils are low in native sulfur. For crops and many forests growing on nitrogen-deficient soils, nitrate in deposition has positive benefits. However, loadings of sulfate and nitrate from wet, dry, and cloud deposition are greatest at high elevation, and high-elevation spruce and fir forests in the southern Appalachians are sensitive to acidification.

Nitrate in deposition has greater impact than sulfate for high elevation forests because soils in the southern Appalachians generally are able to absorb sulfate. Biological processes that use nitrogen are slower at high elevation. When nitrogen deposition exceeds the biological demand for nitrogen, nitrates in soil water can combine with and remove nutrients such as calcium and magnesium that are essential for plant growth. Nitrate can acidify soil waters, leading to aluminum toxicity for sensitive plants. Due to its contributions to ozone and nitrate in acid deposition, nitrogen oxides emissions have been weighted three times greater for their impact to crop and forest productivity than sulfur dioxide emissions (0.75 versus 0.25).

Materials (Structural and Cultural)

Any TVA contribution to damage of materials is associated with both acid deposition and ozone. Acid deposition can erode surfaces of paint, limestone, and metals. Ozone can oxidize some materials such as rubber. Sulfate is considered more corrosive than nitrate in acid deposition, and acid deposition can damage a greater variety of surfaces than ozone, including cultural resources such as historic buildings and tombstones. Therefore, sulfur dioxide emissions are weighted as more significant than nitrogen oxides emissions for material damage (0.60 versus 0.40). Material damage is cumulative, so any reductions in current ambient exposures will likely reduce the rate of material degradation.

Greenhouse Gases

A separate measure was also developed to sum the net greenhouse gas emissions for alternative future energy supply strategies. The measure is expressed in equivalent tons of carbon dioxide, the most common greenhouse gas. Other greenhouse gases, principally methane, are converted to equivalent carbon dioxide by multiplying emissions by the radiative forcing potential. *(See Figure T1-62.)* The radiative forcing potential for any greenhouse gas is an indication of the relative effect of the gas on the global warming potential compared to carbon dioxide, which has a radiative forcing potential of one. For example, methane has a radiate forcing potential of 21, which means its effect on global warming is 21 times greater than that of an equivalent weight of carbon dioxide.

An explanation of the process used to develop measures for environmental evaluation criteria and the calculations for indices can be found in Volume 1, Chapter 5, Evaluation Criteria, and Volume 2, Technical Document 4, Evaluation Criteria.

FIGURE T1-61. **Summary of Possible Health Effects Associated with Certain Types of Pollutants**

Emission	Pollutant	Health Effect	Air Quality Index [1] Weighting Factor
Sulfur Dioxide	Sulfur Dioxide Sulfate Aerosols Sulfate Fine Particulate (PM10)	Eye Irritation Respiratory Distress Lung Damage	0.40
Nitrogen Oxides	Nitrogen Oxides Nitrate Aerosols Nitrate Fine Particulate (PM10) Ozone	Respiratory Distress Lung Damage Eye Irritation	0.50
Carbon Monoxide	Carbon Monoxide	Headaches Reduced Mental Alertness Heart Damage	0.00
Primary Particulates	PM10	Respiratory Distress Lung Damage Eye Irritation	0.05
Mercury	Mercury	Neurotoxin Brain Damage	0.05

[1] Weighting of the relative importance among TVA air emissions is qualitative, based on estimated magnitude of health impact in the Tennessee Valley and TVA's relative contribution to loadings in that pollutant category. Weightings do not attempt to estimate TVA contribution to health impacts outside the Tennessee Valley.

FIGURE T1-62. **Weighting Factors for Greenhouse Gases**

Environmental Measure	Units [1]	Total Equivalent Carbon Dioxide (Millions of Tons)
Carbon Dioxide Emissions	Annual Average Thousands of Tons	1
Coalbed Methane Emissions Avoided	Annual Average Tons	-21
Nat. Gas Methane Emissions	Annual Average Tons	21
Landfill Methane Recovered	Annual Average Tons	-21
Wood Waste Methane Avoided	Annual Average Tons	-21
Wood Waste Carbon Dioxide Avoided	Annual Average Tons	-1
Short Rotation Woody Crops Carbon Dioxide Avoided	Annual Average Thousands of Tons	-1

[1] Annual Average Equivalent TVA Carbon Dioxide Emissions