THE U.S. TIMBER RESOURCE SITUATION IN THE 21ST CENTURY:
FINDINGS FROM THE 1989 RPA ASSESSMENT.

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Outlook Overview

- Total demands for hardwoods from domestic timberland are expected to increase 74 percent, and for softwoods, 40 percent by 2040.

- Harvest on forest industry lands is projected to increase 33 percent to 7.2 billion cubic feet by 2040 reflecting the assumption that these lands will be managed intensively in the future.

- Harvest on other private lands is also projected to increase 67 percent to 15.4 billion cubic feet by 2040 as more hardwood is harvested for pulpwood and fuelwood. There is likely to remain significant economic timber investment opportunities on these ownerships.

- For National Forests, harvest levels are assumed to reach the sum of harvests for the final forest plans, and the preferred alternatives where plans are not yet final, by 2000 and to follow these plans after 2000, reaching 2.4 billion cubic feet in 2040 compared with 2.0 billion cubic feet in recent years.

- Supplies will meet demands in the U.S. market, but prices will be higher. For example pine roundwood pine prices are expected to increase 1.7 percent in the South and 1.3 percent annually in Pacific Northwest.

- If global climate or other changes in the natural environment were to cause extensive reductions in timber growth, it would have major impacts on the domestic situation, with the effects building over time.

INTRODUCTION

The Nation's demand timber products has grown steadily over the last couple of decades and the economic and demographic factors that principally determine demand, such as gross national product and population, are also expected to continue increasing in the future. Consequently, it is expected that there will be a continued increases in demands for timber products over the next 50 years, with the rates of increase varying among products.

To make further improvements in the quality of life in the United States, Americans will have to decide how best to manage the Nation's renewable forest resources. On the Nation's 685 million acres of forest land, there are many opportunities to increase and extend supplies. In addition, research can develop new technology that will reduce unit costs, improve quality, and raise
yields. The management of our forests can produce additional timber while providing amenities.

Both private and public actions can be involved in capturing the opportunities to increase the productivity of forest resources and maintain environmental quality. Where institutional structures inhibit improvements in productivity and efficient production, actions can be considered to ameliorate their deterrent influence. Thus, the Nation and its people can be producing more and using more from its forest resource in the future.

BASIC ASSUMPTIONS ABOUT FUTURE DETERMINANTS

In the future, as in the past, demands and supplies of renewable resource products will be determined largely by growth in population and income.

Population

In the past 5 decades, the population of the United States increased by over 100 million people, to some 242 million in 1986, the base year for demand and supply analyses. Projections by the Wharton Econometrics Forecasting Associates using Bureau of the Census assumptions about future population demographics indicate that population will continue to grow, to about 333 million in 2040. The population assumptions are the middle series projections developed by the Bureau of the Census except that net immigration is assumed to be 750,000 people per year rather than the 450,000-person assumption used in the middle series. This adjustment in the immigration assumption is to account for net illegal immigration.

Economic Activity and Income

Economic activity, as measured by the official gross national product in constant dollars (1982 dollars net of inflation and deflation), increased more than five times in the past 5 decades and reached $3.7 trillion in 1986. In this period, there have been major recessions, a world war, and other major shocks to the U.S. economy. In each case, the national economy has recovered, and it is expected to continue to do so in the future. The basic forces for longrun economic growth will continue. Wharton Econometrics projections indicate that the gross national product will reach $15.6 trillion in 2040, over four times its level in 1986. Associated disposable personal income rises to $9.6 trillion, over a threefold increase. Per capita disposable income will increase over 2.5 times, to $28,790.

The assumptions about population, gross national product, and disposable personal income suggest a future with many more people with greater purchasing power—a future with strong growth in demand continuing the historical trend.

THE FOREST BASE--ITS SIZE AND OWNERSHIP

Over 685 million acres is classified as forest land—land that is at least 10 percent stocked with trees, or formerly had such cover, and not developed for other purposes. The two-thirds of the forest land (482 million acres) that can
grow more than 20 cubic feet of industrial wood per acre per year is called
timberland. In 1986, about 90 percent of the timber harvested came from this
area.

Nearly three-quarters of the timberland is in the eastern half of the country.
Most of the timberland in the West is located in the Pacific Coast States and in
Montana, Idaho, and Colorado.

A little less than 30 percent of the Nation's forest land is in Federal
ownership. These lands are concentrated in the Rocky Mountains and Pacific
Coast States. Their wood volume is mostly timber that has never been harvested,
and they contain a large part of the Nation's softwood timber inventory. Some
of the high-elevation forests also have great scenic beauty and contribute in
important ways to meeting the demand for outdoor recreation.

About three-fourths of the Nation's privately owned forest land is in the
eastern part of the country and the Pacific Northwest. Much of this area has
good soils and other conditions favorable for growing trees and is close to the
largest markets for timber products. These private forests are likewise closest
to the most highly populated areas of the country and provide opportunities for
many kinds of outdoor recreation.

In recent years, the area of forest land has been declining as these lands have
been converted to other uses. This trend in forest land area decline will be
influenced somewhat by the Food Security Act of 1985, which established the
Conservation Reserve Program and offered incentives for landowners to enroll
acreages of highly erodible cropland for conversion to grass or forest land.
The law intends that landowners enroll not less than 40 million nor more than 45
million acres in the program. To the extent practicable, not less than
one-eighth of the acreage placed in the conservation reserve shall be devoted to
trees.

Although the Conservation Reserve Program should add three to six million acres
to the forest land base, an even larger area of existing forest land is expected
to be converted to other uses. The net loss is expected to be about 21 million
acres by 2040, mainly in the South and Pacific coast regions. Much of the loss
in forest land is due to conversions associated with roads and urban space
utilized by a growing population.

TIMBER SUPPLIES

The Nation's timberlands contain some 830 billion cubic feet of roundwood; 91
percent of this is in growing stock (live, sound trees suited for roundwood
products) and the remaining 9 percent is in rotten, cull, and salvageable dead
trees. Some of the latter may be suitable for lumber and veneer, but most of it
is usable only for pulp, fuel, and other products where there are no significant
log quality requirements.

Timber inventories rise when net annual growth (total growth less mortality) is
greater than the volumes removed by timber harvesting, clearing, or changing
land use (timber removals). The growth-removals balance for the United States
is positive for all species (1.31), for softwoods (1.07), and for hardwoods
(1.86). The ratios in the North are very high, indicating continued substantial
increases in growing stock volume. The softwood ratio for the South is declining and approaching 1.00. The growth-removals ratio in the Rocky Mountains exceeds 2.00, and for the Pacific coast, it is .91. Such growth-removal balances and inventory declines on the Pacific coast result from harvesting the mature and unmanaged stands in the region. Net annual growth in such stands is low because mortality tends to offset growth. Once harvested and regenerated, however, the lands in the Douglas-fir subregion of Oregon and Washington and those in coastal Alaska have the capacity to grow large volumes of timber.

The Rocky Mountain region has had a growth-removal balance greater than 1.00 for a long time, but inventories have increased slowly because many of the stands are old, mortality is high, and thus net annual growth is low.

**TIMBER DEMAND--SUPPLY--THE OUTLOOK**

The current growth-removal balances for timber show that the hardwood forests and eastern softwood forests can support additional harvests. However, these balances will change, and future harvests, particularly in the decades beyond 2000, could vary over a wide range. Nonetheless, assuming that timberland owners continue to respond as they have in the past to price and inventory changes and manage their timber stands as projected, timber harvests will be increased substantially in most regions. Total projected softwood roundwood harvests rise from 11.5 billion cubic feet in 1987 to 16.0 billion cubic feet in 2040, an increase of 36 percent. Projected hardwood harvests increase by 80 percent, rising from 6.5 billion cubic feet in 1987 to 11.3 billion in 2040. The largest increases will be in the South.

Assumptions about future management intensities vary by ownership. Forest industry lands in the South and western Washington and Oregon are assumed to be managed intensively to the point where most economic opportunities for management are captured. The projection of intensified management of forest industry lands has important implications for expectations of future harvests on private lands in western Oregon and Washington and the South. In western Oregon and Washington, previous projections of harvests using assumptions of lower management intensity on the industry portion of private lands indicated that current harvest levels could not be maintained for the private ownership category. If industry-owned lands are managed intensively in the future, current total private harvest of about 1.5 billion cubic feet could be maintained and possibly increase as second-growth timber reaches merchantable size. Research is currently underway to assess the potential of this second growth to be the base for expanded timber harvests in the future. In part because of unexplained growth declines on natural pine stands in the South, harvest volumes are near or exceed net annual growth in some areas. After the turn of the century, timber from intensively managed plantations forms the basis for expansion of harvests from current levels of some 5 billion cubic feet to over 6.5 billion cubic feet.

Management on private lands other than industry-owned lands is assumed to continue at recent levels in all regions. These management levels reflect the influence of federal and state programs and result in increased harvests in the future for nonindustrial private lands.
Harvests from national forest lands are assumed to gradually change over time and equal the sum of preferred alternatives in Forest plans by 2000. Beyond 2000, harvests are assumed to follow the Forest plans. Harvest on other public lands is assumed to remain constant at recent levels.

The level of timber management activities depicted will be needed to meet the anticipated increases in timber product demands. Between 1950 and 1980, there was a slight upward trend in lumber consumption, punctuated by well-defined short-term fluctuations. Demand for lumber follows cycles in new housing starts and other general measures of the economy. For example, the severe recession of the early 1980's caused a decline in housing that forced a drop in lumber demand. This was followed in the mid-1980's by record consumption brought on by reduced interest rates that stimulated both new housing and repair and remodeling of existing structures. Demand for softwood plywood rose rapidly through the decades of the 1950's and 1960's, reaching a peak in the early 1970's. Much of this growth was due to the substitution of plywood for lumber in many end uses. By the 1970's, opportunities for this substitution had largely been captured and demand for plywood began to follow housing cycles, much as for lumber.

The late 1970's and 1980's were years of major changes in the plywood and structural panel industries. Fiber-based structural panels began to make significant inroads into markets for solid softwood plywood. These fiber-based panels have now been accepted in the marketplace and should have major influences on the species and quality of roundwood needed in the structural panel industry. The new panels can be made from almost any species of wood with the preference being soft hardwoods such as aspen. After the recession of the early 1980's, consumption of structural panels reached record levels in response to the strong markets of the mid-1980's. Future growth in demand for structural panels is expected to be strongest for the new fiber-based panels until 2010 when consumption of softwood plywood also begins to rise.

Consumption of wood in the manufacture of pulp, paper, and paperboard grew rapidly in the decades following World War II in response to rapid growth in the economy, which stimulated consumption of packaging and other pulp-based products. Much of the increase in consumption of wood fiber during the 1960's and 1970's came from the byproducts of lumber and plywood manufacture. In recent years, the use of hardwood roundwood has increased, and this is expected to continue in the future. In the 1970's, demand for pulp, paper, and paperboard demand became more susceptible to economic cycles. By the mid-1980's, however, consumption was again at record levels.

The oil-price shocks of the 1970's caused many structural shifts in the U.S. economy. The major impact on timber demand in the United States was the reversal of a long decline in the use of fuelwood. Rising costs for oil and natural gas stimulated both commercial and noncommercial demand for wood as fuel. These structural shifts involved new investments in technology and equipment that are not easily reversed. As a result, consumption of fuelwood continued to increase in the 1980's despite sharp declines in crude oil prices. Although there has been a respite in energy price rises in the 1980's, there is a consensus that these prices will increase significantly after the turn of the century, with the result that fuelwood demand is expected to continue to grow over the long term. Demand may be dampened by concerns over the effect of wood
burning on air quality and by the increasing cost of insurance for homes burning
wood.

The longrun demands for all major timber products are projected to go up over
the next five decades. The projection methodology used takes account of the
effects of supplies of products and projects market equilibrium measures of
demand and supply. Consumption levels for pulpwood and fuelwood rise faster
than for lumber and plywood. The product mix of future demands will influence
the way the Nation's forests are managed in the coming decades. Consumption
levels have been presented in the standard measurement units for the various
products--board feet for lumber, square feet for plywood, and cords for pulpwood
and fuelwood. These are then converted to cubic feet roundwood equivalent--the
volume of roundwood needed from the Nation's forests to produce the various
products.

Table 1--Roundwood supplies (consumption) from U.S. timber resources, softwoods
and hardwoods, 1952-87 and projections

<table>
<thead>
<tr>
<th>Year</th>
<th>Softwoods</th>
<th>Hardwoods</th>
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<tr>
<td></td>
<td>(Billion cubic feet, roundwood equivalent)</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1952</td>
<td>6.9</td>
<td>2.6</td>
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<tr>
<td>1962</td>
<td>7.1</td>
<td>2.5</td>
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<td>1970</td>
<td>8.7</td>
<td>2.8</td>
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<tr>
<td>1976</td>
<td>9.5</td>
<td>3.0</td>
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<tr>
<td>1987</td>
<td>11.7</td>
<td>6.3</td>
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<tr>
<td>2000</td>
<td>12.5</td>
<td>8.3</td>
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<tr>
<td>2010</td>
<td>13.9</td>
<td>10.4</td>
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<tr>
<td>2020</td>
<td>15.1</td>
<td>11.0</td>
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<tr>
<td>2030</td>
<td>15.7</td>
<td>11.2</td>
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<tr>
<td>2040</td>
<td>16.1</td>
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Consumption of softwoods continues to grow through the projection period,
reflecting a growing economy and repair and remodeling of an aging housing
inventory. Also, experts believe that, over time, new houses will be bigger,
consuming more lumber and structural panels than today's new homes. By 2010,
softwood timber consumption will be about 1.2 times consumption in 1987 and in
2040, 1.4 times.

Projected consumption of hardwood timber in 2010 will be some 1.4 times
consumption in 1984 and in 2040, 1.5 times, largely due to the rising demands of
a growing economy and energy demands. Demands for pulpwood, fuelwood, and
pallets in particular are expected to increase.
Imports of timber products have been rising and have supplied important parts of the Nation's woodpulp, newsprint, and softwood lumber. However, net imports (imports minus exports) are expected to decrease 0.8 billion cubic feet from current levels of about 2.4 billion cubic feet. Most imports originate from Canada. The 1980's were characterized by several trade disputes with Canada centered on softwood lumber, western redcedar shakes and shingles, and softwood plywood. Similar disagreements have characterized this bilateral trade relationship in earlier decades of the 20th century. It is assumed that the current issues will be resolved over time and that future imports from Canada will be determined largely by U.S. demand and the extent and to 2040 competitiveness of Canada's timber resource. Canada's longrun supply potential is currently unknown, but there appears to be a growing consensus that historical rates of harvest volume cannot continue in the future.

Exports of timber products have also been going up. The outlook for exports varies by product, however. Because of assumed offsetting trends among various products, annual export volumes are projected to increase from 2.0 billion cubic feet currently to 2.5 billion cubic feet by 2010 and stay at this level through the projection period.

The volume of imports of logs into the United States has generally been small over the years and has not been a major trade or domestic issue. Beginning in the 1960's and continuing today, however, exporting softwood logs has at various times been a national issue. These exports originate mainly in Washington and Oregon and affect roundwood prices and the structure of the timber industries in that part of the country. The existing prohibition on roundwood exports from Federal lands in the West has been in effect since 1974 and is assumed to continue. Currently, there are no restrictions on exports from State and private lands, and none are assumed in the future. If restrictions were to be placed on State lands in the West, there would be major effects in local roundwood markets but not much effect on the overall demand-supply situation. The volumes of log exports from State lands are relatively small compared with total U.S. log supply.

Given the above trends, net imports--total imports less total exports--will amount to some 1.6 billion cubic feet in 2040. This will satisfy only a small part of the 29.0 billion cubic feet demands projected by 2040. Domestic forest lands must supply most of the demands.

The projected demand-supply situation implies rising prices for timber. In the U.S. economy, demand and supply for market commodities are equated through price adjustments and the workings of the market. When demand increases faster than supply, price brings the two together by reducing demand and inducing supply increases. This type of situation has existed for lumber at least since the early 1800's. Although there have been periods as long as a decade or more when the price of lumber did not increase relative to the general price level, the trend over the long term has continued upward.

In general, it is expected that the price of softwood roundwood will follow the historic trend and continue to increase throughout the projection period, an indicator that demand pressures are rising faster than supply responses. For example, in the South, the real price for pine roundwood measured net of inflation or deflation is expected to go up an average rate of 1.7 percent a year during the coming decades. In the Douglas-fir subregion of the Pacific
Northwest, real softwood prices are projected to rise at an average rate of about 1.3 percent annually.

The price outlook for the bulk of the hardwood timber—the smaller sized timber of common species—is for lower prices than for softwood timber. However, after 2000, as hardwood inventories begin to show substantial declines in response to increased removals, stumpage prices are expected to rise.

During recent decades, there have been demand pressures on high-quality preferred hardwood species such as select white and red oak, walnut, hard maple, and black cherry. The resulting stumpage price increases led to the development of substitutes such as plastic overlays for furniture. Although analyses of the past decade have been mixed as to continuation of price rises, it is assumed that prices for preferred species will rise in the future because of strong demands for these species.

Rising stumpage prices will be reflected in prices of timber products. For example, softwood lumber prices measured in real terms increase at annual rates of about 1 percent over the projection period.

ENCOURAGING RENEWABLE RESOURCE MANAGEMENT IN A MARKET ECONOMY

Just as there are many kinds of management and research opportunities to increase and extend the supplies and to increase the qualities of nearly all renewable resource products, there are also important obstacles to realization of these opportunities. Some are economic, some relate to lack of information, and some are based on existing policies and legislation. These obstacles must be recognized and managed if a greater proportion of the full potential of the forest and rangelands and inland waters resources is to be realized.

To bring about changes in the supplies of goods and services the U.S. economy relies largely on a system of markets and prices. For example, we expect that the market system will bring forth adjustments in management of industry-owned timberland and private rangeland. Also, privateland owners may respond to market signals by creating opportunities for some forms of recreation. For some uses of renewable resources, however, the key to increasing supplies sufficiently and maintaining the quality of resource outputs is to facilitate improvements in the workings of markets or to have public market intervention in situations where the market does not work well, as in the case of market externalities such as water pollution.

There are four major reasons why supplies of some resources are not fully responsive to market forces: (1) management philosophies and priorities for public lands, (2) the broad societal nature of some resource-program outputs, (3) the lack of market prices for some resource products and uses, and (4) inadequate knowledge of resource-production opportunities.

The fish and wildlife resource is an example of why markets and current institutional arrangements do not respond well to changes in demands and supplies. Here as in many other countries, wildlife and fish are considered public property even though it is difficult or impossible to control their movement across property and jurisdictional lines, including international
boundaries. Most changes in supplies of fish and wildlife depend upon publicly financed programs. Thus, supplies are based upon political rather than market-driven decisions.

The lack of market prices for fish and wildlife, water, wilderness, and many forms of outdoor recreation results from the broad societal nature of the benefits. It is also due in part to the mobile nature and public ownership of the resource. Thus far, despite considerable research, it has been difficult to develop market prices for scenic beauty, water quality, songbirds, or the enjoyment associated with nature walks.

Most tangible products of forest lands, especially timber products, do have established markets and prices. But the market response for these goods (particularly timber) is affected by inadequate knowledge about the resource-management opportunities and the failure of capital markets to recognize fully the present net value of future resource outputs. Private owners, who control nearly three-quarters of the timberland are greatly affected by these markets.

Various studies have shown that the millions of America's private owners of timberland have widely diverse ownership objectives and attitudes, limited knowledge of existing management opportunities, and varying willingness and capacity to make investments that could increase timber growth. Ownership tenures are typically short, and most owners are in the older age groups. Thus, for timber, where the time between investments and harvest is long, there is the likelihood that direct benefits, such as income from timber sales, will not accrue to many current owners. There is also substantial public ownership of forest and rangeland, and management decisions made by public institutions are only indirectly related to changes in market prices.

The same kinds of considerations--different owner characteristics, objectives, and attitudes; lack of knowledge of existing technology; lack of capital; and varying willingness to make changes--also constrain improvements in utilizing timber and timber products.

The factors that affect investments in management and utilization programs also affect investments in research on forest resources. The broad societal nature of the benefits, the lack of conventional markets and market prices for research knowledge, and the large numbers and characteristics of the owners of forest lands effectively cause research in the private sector to be limited to that of a few large industrial ownerships. Even this private-sector investment has declined in recent years. Thus, most of the research on renewable resources is now, as in the past, carried on by public research agencies and publicly supported educational institutions.

Over time, markets change and have the effect of redefining opportunities. For example, higher prices will signal private landowners to invest more in forest resources. To be effective, public and private activities that attempt to influence markets in order to capture opportunities will have to be sensitive to changes in markets.
IMPLICATIONS FOR TIMBER MANAGEMENT

The numerous opportunities to expand timber resource supplies have implications for both public and private programs and activities that affect forest resource management. Forest resources can be managed in any number of ways so as to change the demand-supply outlook in ways that benefit society. Some management practices yield quick results, and some take years or even decades to achieve the desired change in the outlook. The reason that the projections are long term--50 years--is to determine the circumstances for market equilibriums likely to evolve from a continuation of trends in forest resource management and use.

As in the past, demands will equal supplies in the future. This implies that for situations where demands are projected to exceed supplies, mechanisms will develop for equilibrating demands and supplies. For example, in the case of timber production, it will mean higher prices; for air quality, it may mean changes in land use; and for recreation, it may mean higher access fees or lower quality recreational experiences if preferred opportunities are not available or affordable. Through appropriate public and private actions, the Nation can make choices about the costs and associated benefits of opportunities to adjust the supplies of resource outputs to meet projected demands at levels desired by society.

A wide variety options are available. For instance, timber management and utilization decisions can influence the rate of increase in timber prices. One option to keep future timber prices down is to increase timber supplies. This could be achieved by accelerating harvests of softwoods on the national forests in Washington, Oregon, northern California, northern Idaho, and western Montana. Both softwood and hardwood timber supplies can be expanded by increasing harvests on the private timberlands in the South and North, and by improving the utilization of timber and wood resources.

Acceleration of harvests on the national forests would require (1) building roads into old-growth timberlands; (2) protecting the environment and mitigating unacceptable adverse effects on wildlife, outdoor recreation, and other uses of the managed timberlands; and (3) establishing and caring for replacement stands.

Sustained higher harvest levels on private timberlands in the South and North would also benefit from technical assistance and financial incentives to nonindustrial private landowners to assure that productive stands are regenerated and maintained. The improved management would include appropriate control of forest insects and diseases as well.

While improved utilization provides some options, especially in the short run, increased net annual growth offers the only practical means of meeting the longrun projected demands for softwoods and hardwoods at lower prices.

Research can lead to the extending of timber supplies. It can generate major improvements in utilization, primarily by reducing the costs and increasing the efficiency of utilizing currently unused wood materials, of construction and manufacturing, and of the design and maintenance of products and structures.

As they did in the past, forest-products markets will continue to change in the future. Therefore, research emphases will evolve over time. For example, much
of the growth in roundwood consumption in the future will be for pulp and other fiber-based products. Research can develop technologies that will enable pulp manufacturers to use all species in the existing timber inventory for pulp manufacture. There are associated implications for the changes in the direction of forest management research as well.

It must be pointed out, however, the United States contains only a small part of the world's forest resources. It depends upon other countries for a share of its timber supplies. At the same time, other countries depend upon the United States for supplies of their timber products. Similarly opportunities and global environment are shared by everyone, and everyone loses or gains as these resources and the environment change. For example, global climate change would affect all people. As a partner in these shared resources, the United States should consider ways to support improved management and use of all forest renewable resources and protection for the natural environment. Such support would facilitate sustainable development and trade in renewable resources based on environmentally sound conservation policy.

There is a growing awareness that global climate change could significantly affect the forest resources of the United States. The Department of Agriculture and the Forest Service are closely monitoring the reports of the carefully documented increase in levels of the so-called "greenhouse" gases - chlorofluorocarbons, carbon dioxide, methane, nitrous oxide and others in the atmosphere. Good theory recognizes the selective adsorption of long wave radiation by these gases and that the cumulative adsorption by these gases can contribute to climatic change. Man's activities contribute to greater levels of these gases in the atmosphere as well as natural sources. Management such as energy efficiency, emission control, irrigation water conservation, reforestation, protection of forests from fire, and management of national forests for vigorous growth of young forests and other activities can and are contributing to the reduction or amelioration of the rate of accumulation of these gases in the atmosphere.

The United States is faced with assessing the potential impact of possible future climate changes and differentiating them from the separate impact of local air pollution. Further, since existing forests were produced under different environmental conditions than we have today, even without any future climate change, tomorrow's forests could be quite different. Thus, the Forest Service is faced with great complexity and the challenge of developing appropriate databases and models that will provide a reliable basis for decisions about what to do in many different forest ecosystems and locations and under various conditions which involve a wide range of external variables in addition to the greenhouse gases.