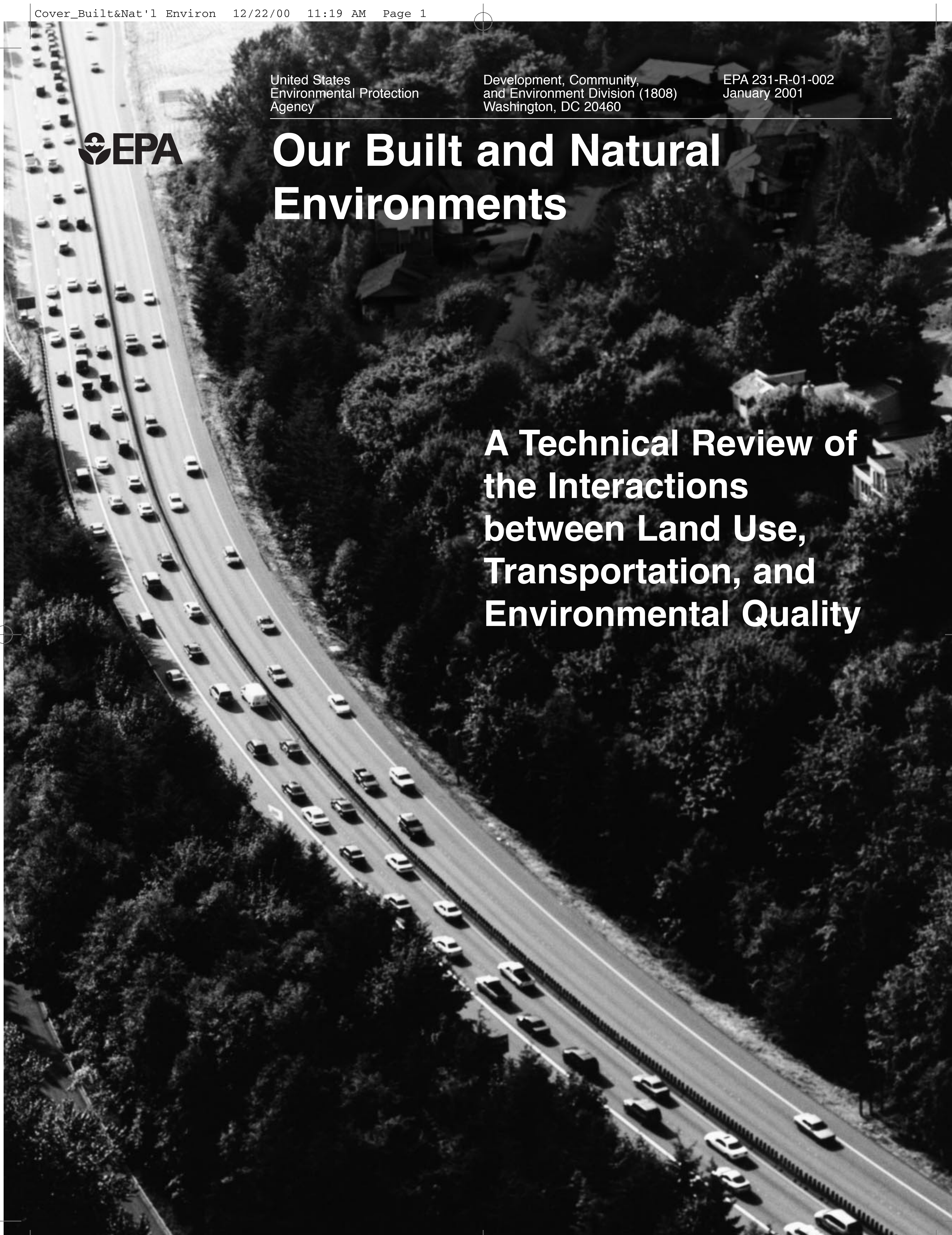
United States
Environmental Protection
Agency

Development, Community,
and Environment Division (1808)
Washington, DC 20460

EPA 231-R-01-002
January 2001

Our Built and Natural Environments

A Technical Review of the Interactions between Land Use, Transportation, and Environmental Quality



Acknowledgements

This document has been peer reviewed. EPA acknowledges the helpful comments of Chester Arnold and James Gibbon, University of Connecticut; Robert Cervero, University of California at Berkeley; Susan Handy, University of Texas; Robert Johnston, University of California at Davis; and Peter Meyer, University of Louisville.

Final document produced under EPA contract 68-W-99-054 for the Development, Community, and Environment Division, US EPA Office of Policy, Economics, and Innovation, by ICF Consulting. EPA staff members Geoffrey Anderson and Mary Kay Santore managed this project.

To request additional copies of this report, call EPA's National Center for Environmental Publications at (513) 891-6561 and ask for publication number EPA 231-R-01-002.

To access this report online, see <http://www.smartgrowth.org/>.

Contents

Executive Summary

In recent years interest has grown in Smart Growth as a mechanism for improving environmental quality. In *Our Built and Natural Environments*, the U.S. Environmental Protection Agency (EPA) summarizes technical research on the relationship between the built and natural environments, as well as current understanding of the role of development patterns, urban design, and transportation in improving environmental quality. *Our Built and Natural Environments* is designed as a technical reference for analysts in state and local governments, academics, and people studying the implications of development on the natural environment.

The built environment has direct and indirect effects on the natural environment. Urban form directly affects habitat, ecosystems, endangered species, and water quality through land consumption, habitat fragmentation, and replacement of natural cover with impervious surfaces. Development patterns and practices also indirectly affect environmental quality since urban form influences the travel decisions that people make. Certain patterns of development encourage increased use of motor vehicles, which is associated with growth in emissions of air pollutants and the greenhouse gases that contribute to global climate change. Air pollution and climate change, in turn, can adversely affect water quality and habitat.

Our Built and Natural Environments first examines trends in land use and their impacts. It then explores how various development patterns and practices can minimize environmental damage.

Land Use: Trends and Environmental Impacts

Trends

Development patterns have changed dramatically over the past century. In the early 1900s, urban areas tended to be compact, with a strong central business district and industrial facilities serving as large employment centers. Communities tended to be walkable and contained a mix of houses and convenience services such as shops. Today's metropolitan areas extend over large areas and employment is frequently widely scattered. People must rely on automobiles for access to jobs and services, as residential and commercial areas are separated, and the pedestrian environment is increasingly inhospitable.

In many regions, urbanized areas have expanded dramatically. Urbanized land area in the United States has quadrupled since 1954. From 1992 to 1997, the national rate of development more than doubled to 3 million acres per year. In most large metropolitan areas, urban land area rose more than twice as fast as population did between 1950 and 1990. The reasons for these dramatic changes in urban form are numerous, including income increases, living style preferences, and public policy on transportation investment, housing, and taxes that have facilitated these trends.

Environmental Impacts

Direct environmental impacts of current development patterns include habitat loss and fragmentation, and degradation of water resources and water quality. Building on undeveloped land destroys and fragments habitat and thus displaces or eliminates wildlife communities. The construction of impervious surfaces such as roads and rooftops leads to the degradation of water quality by increasing runoff volume, altering regular stream flow and watershed hydrology, reducing groundwater recharge, and increasing stream sedimentation and water acidity. A 1-acre parking lot produces a runoff volume almost 16 times as large as the runoff volume produced by an undeveloped meadow. Development claimed more than half of the wetlands in the lower 48 states between the late 1700s and the mid-1980s.

VEHICLE TRAVEL: TRENDS AND ENVIRONMENTAL IMPACTS

Trends

Vehicle travel has increased substantially in recent decades. Between 1980 and 1997, vehicle miles traveled (VMT) in the United States increased 63 percent. This growth rate was almost three times more rapid than population growth during the same period.

Development patterns have contributed to increased vehicle use. Investment in highway capacity encourages more vehicle travel by temporarily reducing travel time and costs. Dispersed, low-density development with significant distances between housing, jobs, schools, and shopping make walking, bicycling, or use of transit difficult for most trips. Urban design that emphasizes the automobile, such as large surface parking lots, wide streets, and a lack of sidewalks, make vehicle use more comfortable and safer than walking or bicycling, even for short trips.

Impacts

The environmental consequences of vehicle travel and dependency include degradation of air quality, greenhouse gas emissions and increased threat of global climate change, and noise.

Emissions from vehicle travel pose serious threats to ecological and human health. In 1991, air pollution from highways is estimated to have caused between 20,000 and 46,000 cases of chronic respiratory illness. Atmospheric deposition of vehicle pollutants into bodies of water also adversely affects water quality. The economic costs of air pollution in terms of health impact, crop damage, and building and materials damage are significant.

Transportation is also a significant source of greenhouse gas emissions. The accumulation of greenhouse gases in the atmosphere is widely associated with changes in global climate that could raise sea level and increase the frequency and severity of extreme weather events worldwide. Although motor vehicle emissions of most air pollutants have declined since 1970 due to improved technologies and cleaner fuels, increasing VMT growth threatens to reverse this trend. Greenhouse gas emissions from motor vehicles have been increasing rapidly, fueled by increased vehicle travel.

DEVELOPMENT PRACTICES TO REDUCE ENVIRONMENTAL IMPACTS

Although the built environment inevitably affects the natural environment, communities can avail themselves of techniques for minimizing the “environmental footprint” of development. Patterns of development and its design greatly affect the level of direct environmental impacts associated with urban form. Environmentally sensitive development patterns minimize habitat and water quality impacts. They also decrease dependence on motor vehicles, reducing air pollution and greenhouse gas emissions. Environmentally sensitive development patterns and practices are summarized below.

Compact Development

Compact development can accommodate growth while minimizing use of undeveloped land. Techniques for encouraging compact development include the following:

- *Infill development*. By accommodating new growth in an already urbanized area rather than using up new land on the periphery of a region, infill development minimizes growth in impervious surface area and thus runoff. Because infill takes place in a developed area, it is often accessible via transit or walking, and requires shorter trip distances than development on the periphery.

- *Brownfield redevelopment*. EPA defines brownfields as “abandoned, idled, or underused industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental consequences.” A special type of infill, brownfields take advantage of the benefits of infill development. Developing brownfields reduces risk to communities by cleaning up contaminated sites.

- *Cluster development*. By reducing lot sizes and employing narrow and shorter road widths and lengths, cluster developments typically have less impervious surfaces than more dispersed development patterns do.

Because compact development uses up less land area, it can reduce habitat disruption and adverse impacts on wildlife, vegetation, and water quality. Regional travel studies have found that most compact development patterns produce less vehicle travel and fewer emissions of air pollutants than dispersed development patterns do. New development in a regionally central infill site can generate significantly less motor vehicle air pollution than the same development on a “greenfield” site.

Reduced Impervious Surfaces and Improved Water Detention

Land use measures can improve water quality by reducing impervious surface area and regulating the flow of stormwater. These measures include:

- Narrowing and shortening streets and minimizing the provision of parking areas

- Using porous surfaces when feasible, such as lattice blocks and bricks set in sand, rather than concrete and asphalt

- Detaining stormwater for short periods in swales and filter strips and for longer periods in ponds and wetlands

- Using special landscaping practices, such as the application of mulch to retain soil moisture and conserve water usage

Safeguarding Environmentally Sensitive Areas

The impacts of development depend not only on how much land is developed but also on the location and type of land. Sensitive natural areas such as streams, wetlands, floodplains, steep slopes, mature forests, swamps, critical habitat areas, and shorelines can be safeguarded through the following measures:

- Minimize impacts. The first approach should always be to avoid disturbing sensitive areas. If impacts are unavoidable, then development should be designed to minimize impacts and limit disturbance to points of least sensitivity.

- Create buffers and greenbelts. A "green corridor" can be preserved along the banks of rivers, streams, or other sensitive environmental habitat to protect these areas from development.

Mixed-Use Developments

In mixed-used developments, complementary functions are located close together. This kind of development has the potential to use parking and transportation infrastructure more efficiently, thus requiring less pavement and reducing runoff. By decreasing travel distances, mixed-use development can reduce average vehicle trip lengths and increase the potential for individuals to use nonautomobile travel modes. Examples of mixed-use development include the following:

- Mixing retail and office uses with residential development

- Mixing uses at employment and commercial centers

- Developing a subregional balance of jobs and housing

Transit Access

Efficient transit networks can serve urban areas effectively, reducing fuel consumption, pollutant emission, and traffic congestion. Compact regions with a limited number of subregional centers linked by transit can support transit ridership and reduce VMT compared with other regional development patterns. Locating high-density commercial and residential development around transit stations improves accessibility to transit since more households are within walking distance of the facilities.

Microscale Urban Design Features

Enhancing the environment for nonmotorized travel such as walking and bicycling can lead to reduced vehicle travel. Microscale urban design features that improve the pedestrian environment include sidewalks, clearly marked crosswalks and walk signals, lighting, and other amenities like shade trees, benches, and streetscapes designed with the pedestrian in mind. Features that improve the bicycling environment include bicycle paths and lanes on streets, bicycle parking, and signage to identify recommended bicycle routes and raise awareness of drivers to bicycle traffic.

SYNERGIES

Many of the land use measures described in *Our Built and Natural Environments* can have positive environmental effects. Their efficacy in particular locations, however, depends on how well they are implemented and how they are combined with each other and with other programs. Communities that offer their residents lasting environmental, economic, and social benefits usually adopt a synergistic method of planning—one that incorporates multiple beneficial aspects of design, according to the particular needs and characteristics of a community.

CONCLUSIONS

Urban form directly and indirectly affects the quality of our nation's air, water, and wildlife habitat. *Our Built and Natural Environments* provides a summary of the current understanding of these effects. The evidence suggests that the way we build our communities is an important concern as the United States attempts to meet its environmental goals.

1. Introduction

1.1 Purpose

Environmental quality and human health are priorities for America. As a nation, the United States has committed to national standards for environmental performance to protect human health and welfare. Congress has set timetables for meeting health and environmental quality goals in every environmental medium, and the U.S. Environmental Protection Agency (EPA) is charged with implementing the federal laws designed to promote public health by protecting the nation's air, water, soil, and climate.

For most of EPA's 30-year history, policy-makers have focused on technological approaches to reducing pollution. These efforts have met with significant success. Emissions from motor vehicles and point sources such as power plants and refineries have been reduced through the use of cleaner fuels and technology, and some of the most visible environmental problems (e.g., lead in gasoline, sulfur dioxide from industry) have been addressed. Despite these successes, technological solutions are unlikely to provide the solution to all of our environmental challenges.

Increasingly, policy-makers are realizing that decisions regarding development patterns and transportation investment have significant impacts on the natural environment. In recent years, cities, states and regions around the nation have begun planning for Smart Growth. Concerns about community livability, loss of open space, traffic congestion, and air and water quality are spurring much of this interest. Recognition is increasing that land use and transportation decisions can either support community goals for livability and environmental protection, or interfere with those goals. Efforts to mitigate growth-related environmental impacts are being promoted by numerous organizations and implemented by communities nationwide.

Our Built and Natural Environments is a technical reference work on the implications of land use and transportation for the environment, written as a resource for technical analysts in state and local governments, academics, and those studying the environmental impacts of urban form. The report:

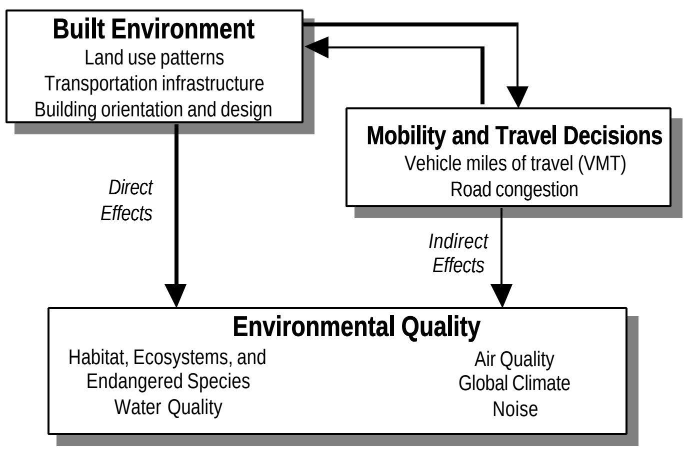
- Articulates current understandings of the relationship between the built environment and the quality of air, water, and habitat.
- Discusses trends in development and transportation and their environmental implications.
- Provides evidence for the view that communities can affect environmental quality positively through Smart Growth land use and transportation development decisions.

The report concludes that together, the built environment and decisions made in response to it dramatically impact environmental health, and ultimately community quality of life. Thus, the form of built environment can help or hinder our nation's ability to meet its environmental goals. As a result, the relationship between the built and natural environments deserves attention from EPA, the agency's colleagues and clients, and communities across America.

1.2 THE EFFECTS OF URBAN FORM ON HUMAN HEALTH AND THE NATURAL ENVIRONMENT

The nation has recognized the environmental implications of industrial discharges for decades. The environmental effects of metropolitan development and transportation investment, however, are more difficult to define. As a result, only recently have they begun to attract widespread attention. As Figure 1-1 illustrates, development decisions have both direct and indirect impacts on the natural and human environments. The built environment directly affects habitat, ecosystems, endangered species, and water quality through consumption, fragmentation, and replacement of natural cover with impervious surfaces. Urban form also affects travel behavior which, in turn, affects air quality (with corresponding impacts on water quality), global climate, and noise.

Figure 1-1: Direct and Indirect Effects of the Built Environment



Direct Effects

Land development affects the environment in two primary ways. First, development uses land and modifies habitats and ecosystems. The extent of land development, the type of development, and the location of infrastructure have direct and long-lasting implications for ecosystems. By interrupting feeding, dispersal, and breeding patterns, even a single roadway that cuts through wilderness can affect the population and diversity of species across a wide area.

Second, development can have significant implications for water quality as buildings, parking lots, roads, and other impervious surfaces alter the natural flow of water within a watershed. The amount of impervious surface as a percentage of land area in a watershed and the location of infrastructure in relation to specific natural resources can be correlated to the health of an area's streams, river, lakes, and estuaries.

These direct effects are relatively well understood and documented, and efforts to preserve wetlands and habitat of endangered species are common. Still, the implications for biodiversity, ecosystems, and water systems are often site-specific and are not universally recognized in community design and planning.

Indirect Effects

Indirect effects of residential and commercial development include the distribution of employment opportunities. In addition, the transportation options available to link residential and commercial locations influence household travel behavior, including trip frequency, trip lengths, and mode of choice. Vehicle travel, in turn, generates air pollutant emissions, greenhouse gas emissions, and noise.

The effects of urban form on travel behavior are less well understood than the direct effects of development, and the magnitude of those impacts is widely debated. Travel behavior is complex, with various factors simultaneously affecting decisions about how much, where, when, and how to travel. Still, significant evidence exists that urban design does affect travel behavior. As a result, there is increasing interest in using land use planning to address transportation, air quality, and greenhouse gas problems.

Our Built and Natural Environments presents findings from researchers, academicians, policy analysts, and others as to how, where, and to what degree development practices and patterns directly and indirectly affect environmental quality.

1.3 Topics of Discussion

Chapter 2 outlines some of the more significant trends in land use and transportation infrastructure development, and their direct environmental consequences. Chapter 3 addresses trends in vehicle travel and environmental effects associated with vehicle use. Both chapters discuss the causes of change over time and suggest that development decisions, public policy, and changing demographics are all important factors in these trends. Chapter 4 provides evidence that different patterns of growth and development can have different impacts on the environment. Patterns and practices that minimize environmental harm include the following:

- Compact development
- Reducing impervious surfaces and improving water retention
- Safeguarding environmentally sensitive areas
- Mixing land uses
- Providing transit accessibility
- Supporting pedestrian and bicycling activity (micro-scale urban design elements)

Chapter 4 also discusses “synergy,” the idea that a combination of strategies together can have greater impact than the sum of individual measures. The chapter illustrates how various planning strategies can work together to improve environmental quality.

The final chapter provides a brief summary and conclusion about the effects of urban form on national environmental goals.

2. Land Use: Recent Trends and Environmental Impacts

2.1 Trends in Land Use

Urban form has changed dramatically over the past century. In the early 1900s, most urban areas were compact and monocentric—that is, most had a strong central business district—and industrial facilities such as ports served as major employment centers. Small neighborhood shops were frequently fixtures in residential areas. Suburbs grew in tandem with extensions of streetcar and railroad lines, and residential developments were clustered along grid street networks. Residential development typically extended only as far from streetcar lines as a person might comfortably walk.

The geographic size and the nature of urban development have undergone tremendous change. Metropolitan areas are polycentric, with multiple clusters of development dispersed over a large area. Increasing numbers of Americans live in suburban communities quite far from the old urban centers.[2] The automobile has become central to mobility, as new subdivisions are constructed in locations separated from commercial services and business parks are built in areas that require vehicle travel not only for access but also for internal circulation. Interstate highways connect geographically dispersed locations, and shopping malls and business parks have become important places for commerce.

One of the most noticeable trends in urban form is the dramatic expansion in the geographic size of metropolitan areas. Virtually every urban area in the United States has expanded substantially in land area in recent decades. Between 1954 and 1997 (the most recent year analyzed in the U.S. Department of Agriculture inventory), urban land area has almost quadrupled, from 18.6 million acres to about 74.0 million acres in the contiguous 48 states.[3] In 1997, developed land totaled about 7 percent of the nation's nonfederal land area—a seemingly small amount. However, from 1992–1997, the national rate of development more than doubled. During this five-year period, more land was developed (nearly 16 million acres) than during 1982–1992 (about 13 million acres). The newly developed land has come mostly from forestland, pasture and range, and cropland.[4] A 1994 study by the American Farmland Trust showed that urban development already has consumed nearly a third of the country's most highly productive farming regions.[5] Developed land

---

[2] From 1950 to 1990, the percentage of the U.S. urban population in the central counties of today's 50 largest metropolitan areas fell from 46.5% to 37.6%. (U.S. Census Bureau).

[3] U.S. Department of Agriculture, Economic Research Service, Natural Resources and Environment Division. *1997 National Resources Inventory.* 1997.

[4] U.S. Department of Agriculture, Economic Research Service, Natural Resources and Environment Division. *Agricultural Resources and Environmental Indicators (AREI) Updates, No. 3.* "Major Land Use Changes in the Contiguous 48 States." June 1997.

[5] American Farmland Trust. *Farming on the Edge: A New Look at the Importance and Vulnerability of Agriculture Near American Cities.* 1994.

area has increased rapidly in many states, particularly in the South and Southwest, as shown in Table 2-1.[6]

Table 2-1: Increase in Developed Land Area for Selected States, 1982-1992

State	Percent increase in developed land, 1982-1992
Arizona	35.1%
California	19.1%
Colorado	22.4%
Florida	34.6%
Georgia	32.8%
Illinois	8.4%
Massachusetts	21.7%
Michigan	14.3%
Nevada	26.3%
New Jersey	23.1%
New York	8.0%
North Carolina	36.2%
Ohio	15.3%
Pennsylvania	14.6%
Texas	20.5%
Tennessee	25.2%
Virginia	25.7%

Source: Noss, R. and R. Peters. *Endangered Ecosystems: A Status Report on America's Vanishing Habitat and Wildlife.* Washington, DC: Defenders of Wildlife, December 1995. Derived from data from the U.S. Bureau of the Census. *Statistical Abstract of the United States, 1994.*

Many urban areas have increased in size by 50% during the past 30 years, with the increase in land development far outstripping population increases. U.S. Census data for the 34 metropolitan areas with populations of more than one million show that urbanized land area has grown on average 2.65 times as fast as population has.[7] In urban areas with relatively slow population growth, the contrast between population growth and urbanized land area growth is especially dramatic. For example, the Census reports that from 1950 to 1990, the Pittsburgh urbanized area grew more than 21 times as fast as its population (from 1.533 million people and 254 square miles

---

[6] Developed areas include urban and built-up areas in units of 10 acres or greater, and rural transportation. Most recent data available are for 1992. An inventory of U.S. land resources by type of use/cover was conducted by the Soil Conservation Service in 1982, 1987, and 1992, and were most recently published in the *1992 National Inventory of Land Resources* (See Statistical Abstract of the United States: 1998. September 1998.)

[7] The Census Bureau delineates urbanized areas to provide a better separation of urban and rural territory in the vicinity of large places. Urbanized area is defined as one or more places ("central place") and the adjacent densely settled surrounding territory ("urban fringe") that together have a minimum of 50,000 persons and a density of least 1,000 persons per square mile. The urban fringe also includes outlying territory of such density if it was connected to the core of the contiguous area by road and is within 1 1/2 road miles of that core, or within 5 road miles of the core but separated by water or other undevelopable territory. Other territory with a population density of fewer than 1,000 people per square mile is included in the urban fringe if it eliminates an enclave or closes an indentation in the boundary of the urbanized area. Metropolitan areas with population over 1 million in any decennial census from 1950 to 1990 were analyzed.

in 1950 to 1.678 million people and 778 square miles in 1990).[8] As Table 2-2 shows, the trend is widespread.

Table 2-2: Growth in Land Consumption Exceeds Population Growth in Metro Areas, 1950-1990

Urbanized Area	Population Growth, 1950-90	Urbanized Area Growth, 1950-90	Ratio of Area Growth to Pop. Growth
Pittsburgh	9.50%	206.30%	21.72
Buffalo	6.60%	132.50%	20.08
Milwaukee	47.90%	402.00%	8.39
Boston	24.30%	158.30%	6.51
Philadelphia	44.50%	273.10%	6.14
St. Louis	39.00%	219.30%	5.62
Cleveland	21.20%	112.00%	5.28
Cincinnati	49.10%	250.70%	5.11
Kansas City	82.70%	411.40%	4.97
Detroit	34.30%	164.50%	4.80
Baltimore	62.70%	290.10%	4.63
New York	30.50%	136.80%	4.49
Norfolk	243.60%	971.00%	3.99
Chicago	38.00%	123.90%	3.26
Minneapolis-St. Paul	110.70%	360.20%	3.25
Atlanta	325.40%	972.60%	2.99
Washington	161.30%	430.90%	2.67
34 Metro Areas with Pop. > 1 million	**92.40%**	**245.20%**	**2.65**

Source: The Public Purpose. "Demographic Briefs and Urban Policy." Calculated based on data from the U.S. Census Bureau.

A 1996 study of traffic congestion trends by the Texas Transportation Institute provides further evidence of the dramatic growth in urbanized area compared to population. Based on data collected from metropolitan planning organizations, the study shows urbanized area continuing to increase faster than population growth in most metropolitan areas, as shown in Table 2-3. Among the areas studied, urbanized area increased on average 43 percent faster than population growth between 1982 and 1996.

Not only have people moved farther from the old city centers, but the nature of development has changed dramatically. Commercial and office developments are surrounded by large parking lots, with few sidewalks or connections to other developments. Hierarchical street patterns channel traffic to a number of large arterials, and wide streets and driveways are common in residential areas. As a result, people are using more land per capita than in the past. According to a report on development in the Chesapeake Bay Watershed,[9] residential and commercial development used 0.65 acre of land per person in 1988 compared with about 0.18 acre in the 1950s. According to the

[8] U.S. Census Bureau.

[9] 2020 Panel. "Population Growth and Development in the Chesapeake Bay Watershed to the Year 2020." Annapolis, MD: 1988.

report, Dorchester County, on Maryland's rural Eastern Shore, actually lost population between 1980 and 1990, yet gained hundreds of new homes. During that time period, less than one-tenth of new population consumed half the newly developed land—due to development on large suburban and rural lots.

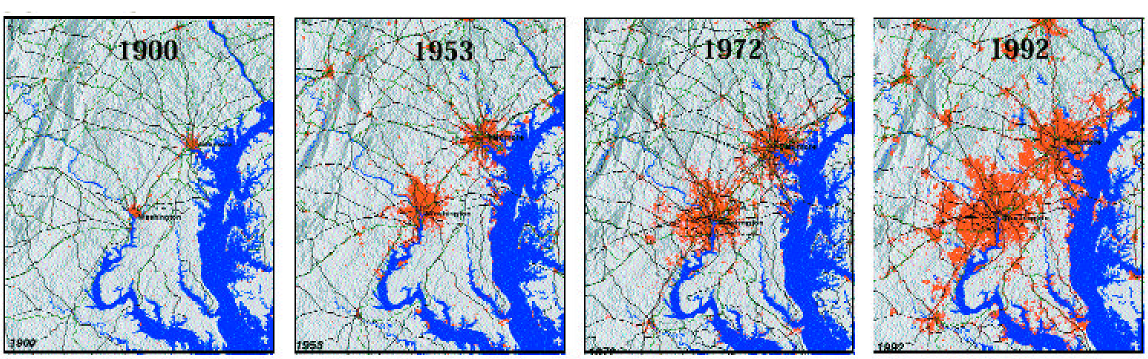
Table 2-3: Growth in Land Consumption Exceeds Population Growth, 1982-1996

Urbanized Area	Population Growth, 1982-96	Urbanized Area Growth, 1982-96	Ratio of Area Growth to Pop. Growth
Detroit, MI	-1.1%	19.6%	–
Rochester, NY	-3.1%	15.5%	–
Buffalo-Niagara Falls, NY	0.0%	52.0%	–
Pittsburgh, PA	6.6%	39.0%	5.9
Harrisburg, PA	14.5%	72.0%	5.0
Boston, MA	5.6%	26.9%	4.8
Chicago-Northwestern IN	10.9%	44.2%	4.1
Cleveland, OH	6.3%	23.8%	3.8
New York-Northeastern NJ	2.9%	10.1%	3.4
St. Louis, MO-IL	9.2%	30.8%	3.3
Baltimore, MD	26.2%	64.4%	2.5
Nashville, TN	25.0%	53.9%	2.2
Tucson, AZ	42.2%	86.7%	2.1
Las Vegas, NV	138.9%	243.8%	1.8
Los Angeles, CA	23.4%	22.7%	1.0
Houston, TX	27.5%	9.8%	0.4
Avg. Of 70 U.S. Metropolitan Regions	**20.2%**	**28.8%**	**1.43**

Source: Calculated based on data from Texas Transportation Institute. Mobility Study (*Urban Roadway Congestion: Annual Report 1998*).

Urban decentralization and growth in transportation infrastructure, mostly in the form of highway construction, have dramatically increased total developed land (and impervious) surface area. Figure 2-1 provides a visual image of growth in urban development for the Baltimore-Washington region, based on a study sponsored by the U.S. Geological Survey.

Figure 2-1: Baltimore-Washington Growth



Temporal databases and mapping document the dramatic increase in urban development following World War II and continuing to the present day in a number of metropolitan areas. Each urban database focuses attention on the forces influencing current spatial patterns and corridors. As seen in the Baltimore-Washington maps, the amount of land area developed has expanded tremendously in the 20th century. In 1900, urban development was located almost exclusively in the cities of Baltimore and Washington, with a vast amount of undeveloped and agricultural land between the two. By 1992, development was so widespread that the two formerly distinct areas shared common suburbs. The U.S. Census Bureau now recognizes the region as one large consolidated metropolitan area.

An analysis of development and transportation clearly demonstrates the influence that transportation infrastructure (roads, railroads, and seaports) exerted on development patterns. Roads alone take up considerable space. Nationwide, roads take up approximately 11.1 million acres of land, or 17,375 square miles, not including road shoulders and medians.[10] This area equals the geographic size of the states of Maryland and Delaware combined. Buildings and parking lots also take up considerable area. According to one estimate, land devoted to parking ranges from 1,910 to 3,035 square miles (or approximately 1.2 to 1.9 million square acres) in the United States.[11]

The exact percentage of land area in U.S. urban areas consumed by streets and parking is unknown.[12] Nonetheless, road and parking areas are known to be increasing. Although the rate of new highway construction has slowed from the growth rates characteristic of the 1950s and 1960s, transportation infrastructure continues to claim new land. A net increase of 91,357 road miles occurred between 1990 and 1997.[13] Each year from 1993 to 1997, an average of 16,389 miles of roadway projects financed with federal aid were underway.

---

[10] Figure is for 1997. U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, *Indicators of the Environmental Impacts of Transportation: Highway, Rail, Aviation, and Maritime Transport.* October 1999, EPA 230-R-99-001.

[11] Delucchi, M.A. “Bundled Private Sector Costs of Motor Vehicle Use.” Report No. 6 in Series: *The Annualized Social Costs of Motor-Vehicle Use in the U.S., Based on 1990-91 Data.* Davis, CA: University of California, Davis, Institute of Transportation Studies. 1995.

[12] There are many problems inherent in calculating this sort of statistic. In particular, some road or parking areas are rarely used by vehicles and may actually function as open space, such as a driveway alongside a house. Many pre-auto cities contained wide streets and boulevards, suggesting that it is inappropriate to consider all roads and parking as associated with automobiles. Still, it is certain that impervious surface area has increased with the development of new roads and parking. There is no data on the share of urban land devoted to parking, and some estimates of land area consumed by roads have been found to be of questionable basis. See Shoup, Donald. “The Pedigree of a Statistic.” *Access.* University of California Transportation Center. Berkeley, CA: Fall 1997, 11: 41.

[13] U.S. Department of Transportation, Federal Highway Administration. *Highway Statistics (1990* and *1997)*. Table HM-12.

2.2 CAUSES OF LAND USE CHANGE

Observed increases in rates of urbanization and population dispersion are enabled and influenced by a variety of factors. New communications and transportation technologies, along with changes in public policy have facilitated increases in the size of metropolitan areas. Reductions in the monetary and time costs of travel play a particularly important role in these trends. The widespread adoption of the automobile as the predominant travel mode and major investments in transportation infrastructure have been important factors in encouraging the dispersal of residential and commercial development within metropolitan areas. However, social and economic dynamics have also played a large role in this shift.

Highway Development and Reduction in Travel Costs

New highways open up land for development by increasing the accessibility of locations that once were remote or difficult to reach.[14] Just as the opening of streetcar lines allowed the development of streetcar suburbs in the early 1900s, the development of interstate highways and other freeways allowed the expansion of residential development into formerly rural areas.

According to economic theory, accessibility is one factor that affects the desirability and therefore the price of land. All else being equal, reduced travel costs increase the relative value of land at the periphery of a metropolitan area to urban residents and workers. The increased price leads potential residents to outbid farmers for land near the urban region's edge. At the same time, transportation infrastructure enables more land to be available for development. The availability of more land allows people to use more transportation and land resources without an increase in transport cost. However, as a World Bank report emphasizes, "where transport prices do not reflect full social and environmental costs, the land market can generate inefficient land-use patterns."[15]

One of the basic tenets of modern location theory, well articulated since the 1920s, is the influence of transport costs on a company's choice of location. As the relative importance of transportation costs decreased (both due to lower transportation costs and economic shifts from manufacturing to services), transportation's role diminished in location choices, and more locations become viable site alternatives. Reduced transportation costs thus greatly facilitated the dispersal of employment.

For manufacturers, improvements in highway connections simplified the use of trucks for intercity traffic. As manufacturers switched from trains and ships to trucks, they were freed from dependence on railheads and ports, generally located near the city centers, and were able to move manufacturing facilities to sites accessible to interstate highways. The shift from rail and ship to trucks also facilitated the evolution from concentric development around major transport facilities (the port and railyard), to axial and polycentric development patterns.[16]

Finally, changes in commodity flows and the development of modern logistics concepts such as

---

[14] World Bank. *Sustainable Transport: Priorities for Policy Reform.* Washington, D.C.: 1996, p. 59.

[15] *Ibid.* p. 61, citing Egal, Y. 1994. "Des effets positifs de la densité urbaine." *Transports Urbains.* 83 (avril-juin) 27-31.

[16] Button, K.J. *Transport Economics.* Hampshire, England: Gower Publishing Co. Ltd., 1982, p. 261-263.

just-in-time delivery reduced dependence on central locations. The *freight*-generating characteristics of land uses were surpassed in importance by the truck *trip*-generating characteristics, reducing the influence of manufacturing and industrial facilities on land use and development patterns of cities.[17]

Firms with highly skilled work forces have also changed their locational patterns in recent years. Because these firms draw employees from the entire metropolitan area, they need to locate at a point accessible from all points in the area. In the streetcar city, the city center (hub) was the most accessible location. In the modern automobile city, firms may choose to locate in the urban core, but often they are drawn to locations along an urban highway or suburban beltway, since such sites are accessible to a large population via automobile.[18] This change is further reinforced by the tendency for the peripheral suburbs to contain a relatively high proportion of wealthy, well-educated, well-trained workers.[19] In sum, increased highway development loosens ties to the central business district (CBD), allowing the suburbanization of firms. Highway development facilitated similar suburbanization of retailers. If shoppers have access to private vehicles, suburban stores may be more accessible than center city locations. In fact, as residential suburbanization occurred, many retailers followed consumers out to the suburbs to be closer to their markets.

Public Policy

Public policy plays an important role in shaping the built environment. After World War II, federal funding for highway construction opened vast areas of land for development. A survey of experts by the Federal National Mortgage Association ("Fannie Mae") declared "More than any other single measure, the 1956 act created the decentralized, automobile-dependent metropolis we know today."[20]

Efforts to promote homeownership—through the G.I. Bill of Rights and mortgage subsidies, for example—encouraged movement to new subdivisions. In addition, the federal tax deduction of interest paid on home loans provides a subsidy for homeownership. Federal mortgage programs promote housing consumption and increase the relative attractiveness of the suburbs.

[17] Ogden, K.W. *Urban Goods Movement: A Guide to Policy and Planning.* Hampshire, England: Gower House, 1992.

[18] This has been associated with both the growth of new outer rings of land-use development, and subsequently of edge cities. Burchell, R. "Understanding Sprawl." *On the Ground.* Vol. 2, No. 2, 1996.

[19] Largely in consequence to standard rent-bid curves that have been influenced by auto ownership patterns, mortgage subsidies, and rent control and public housing policies, among other factors such as school quality, perceptions of crime, and racial bias.

[20] Robert Fishman, "The American Metropolis at Century's End: Past and Future Influences." Washington, DC: Fannie Mae Foundation, Winter, 1999. Dr. Fishman's survey included a list of 25 possible influences on the American city over the past century and a list of 19 potential future influences. Fishman surveyed 149 urban and regional historians, planners, and practitioners and asked them to rank the 10 most powerful influences--looking at the past 50 years and into the next century.

Government also subsidized suburban development by funding the construction of new water and sewer infrastructure. The effect of subsidizing any kind of infrastructure is to subsidize the type of growth that depends on the infrastructure, which in this case was growth on the urban edge.

Inequitable support for suburban development comes not only from public policies, but sometimes also from private companies. For example, anecdotal and statistical evidence indicates that many insurance companies either resist writing insurance in minority and low-income communities, or only provide over-priced, inferior insurance policies in such areas—a practice commonly referred to as "insurance redlining." Although states are working to eliminate this practice through testing and litigation, redlining still remains a serious deterrent to investment in many areas.

Zoning also has played a large part in the nature of land development. Minimum parking standards, put in place to reduce parking problems, encourage vehicle travel.[21] Similarly, zoning that separates residences from commercial and office development often makes mixed-use communities impossible—the walkable neighborhoods with neighborhood stores that were once common would be illegal to build in most places today. In addition, competition among localities for economic development has led to intra-regional competition for jobs, which has hurt older city centers.

Growing Affluence and Social Change

Changes in the national economy and social attitudes contribute to the dispersal of urban development. Because land is a "normal good" in the parlance of economists, increases in income lead to increases in the demand for land. Historical increases in income led to greater demand for large homes and lot sizes.[22] In turn, single family detached homes on large lots became increasingly associated with monetary success and social prestige. This combination of rising incomes and changing values has encouraged land use patterns marked by low density development, declining urban cores, and a strong reliance on the automobile.

Central city problems, real and perceived, also contribute to movement from city centers. Empirical studies of the suburbanization process provide support for the theory that central city attributes have had some effect on the pace of suburbanization.[23] The appeal of newer and larger

[21] Donald Shoup, "An Opportunity to Reduce Minimum Parking Requirements," *Journal of the American Planning Association*, Winter 1995, pp. 14-28; Willson, Richard W. "Sububan Parking Requirements: A Tacit Policy for Automobile Use and Sprawl." *Journal of the American Planning Association.* Vol. 61, No. 1 Winter 1995. pp. 29-42.

[22] On the other hand, as real income increases, so should the opportunity cost of commuting. As a result, an increase in income should also lead to greater demand for dwellings close to work, all else equal. However, increases in income occurred concurrently with reductions in travel costs associated with highway development. As a result, increased opportunity costs of commuting have been minimized.

[23] See the following: Wasylenko, Michael. "Disamenities, Local Taxation, and the Intrametropolitan Location of Households and Firms." *Research in Urban Economics.* Vol. 4. Ed. Robert Ebel. Greenwich, CN: JAI Press, 1984; Bradbury, Kathernine, Anthony Downs, and Kenneth Small. *Urban Decline and the Future of American Cities.* Washington, DC: Brookings Institution, 1982; Frey, W.H. "Central City White Flight: Racial and Non-Racial Causes." *American Sociological Review.* 44, 1979, pp. 425-88; Grubb, W.N. 1982. "The Flight to the Suburbs of Population and Employment, 1960-1970." *Journal of Urban Economics.* 11: 348-67.

homes and lots in suburban areas, coupled with issues of race, ethnicity, education, and safety, have contributed to considerable out-migration from the urban core. Fiscal problems in the central city, including high taxes and in some cases lower-quality schools and services, also have led many people to leave for the suburbs.[24] A study based on 121 metropolitan areas for the period 1970-75 found that cities experienced relatively rapid suburbanization if their central area had (1) a relatively old housing stock, (2) relatively high taxes, and (3) a relatively large African-American population. In addition, the larger the number of suburban governments to choose from, the more rapid the suburbanization.[25] Another study found that metropolitan areas with high taxes, high crime rates, and low educational expenditures experienced the most rapid suburbanization.[26]

2.3 Environmental Consequences of Land Use Trends

Although changing development patterns provide many social benefits, they also come at a cost to the natural environment and our communities. This section addresses the two major direct environmental impacts of development: (1) habitat loss and fragmentation and (2) the degradation of water resources and water quality.

The effects of land development on the environment are particularly important because development patterns have long-term effects that are not easily reversible. Degradation of water resources can have adverse effects over many generations of wildlife, and habitat and species loss may forever alter ecosystems. As a result, the cumulative effects of development decisions are important when considering the long-term health of the environment and communities.

Habitat Loss and Fragmentation

Habitat loss and fragmentation are two of the most direct impacts of development on previously undeveloped land.[27] According to recent studies, habitat destruction is the main factor threatening

[24] The causality goes both ways: fiscal problems can lead to suburbanization, and suburbanization can contribute to central-city fiscal problems.

[25] Bradbury, Kathernine, Anthony Downs, and Kenneth Small. *Urban Decline and the Future of American Cities.* Washington, DC: Brookings Institution, 1982.

[26] Frey, W.H. “Central City White Flight: Racial and Non-Racial Causes.” *American Sociological Review.* 44: 1979. pp. 425-88.

[27] Habitat impacts from human development have been documented extensively. See: Dobson, A. P., J. P. Rodriguez, W. M. Roberts, D. S. Wilcove. “Geographic Distribution of Endangered Species in the United States,” *Science*, Volume 275, Number 5299. January 24, 1997. pp. 550-553; LaRoe, Edward T., Gaye S. Farris, Catherine E. Puckett. *Our Living Resources - A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems*. U.S. Department of the Interior, National Biological Service, Washington, 1995; Noss, Reed F. and Robert L. Peters. *Endangered Ecosystems: A Status Report on America’s Vanishing Habitat and Wildlife*. Washington, DC: Defenders of Wildlife, December 1995; Peters, Robert L., Evan Frost, and Felice Pace. *Managing for Forest Ecosystem Health: A Reassessment of the ‘Forest Health Crisis*. Washington, DC: Defenders of Wildlife, April 1996; Boucher, Norman, “Species of the Sprawl,” *Wilderness*. Defenders of Wildlife, Washington, DC, Summer 1995. pp. 10-24; Soule, Michael E. “Land Use Planning and Wildlife Maintenance - Guidelines for Conserving Wildlife in an Urban Landscape.” *Journal of the American Planning Association*. Volume 57, Number 3, Summer 1991. pp. 313-323.

80 percent or more of the species listed under the federal Endangered Species Act; more than 95 percent of listed species are endangered to some extent by habitat loss or alteration.[28]

In many metropolitan areas, development has consumed thousands of acres of woodlands, wetlands, and other natural habitats. The Washington, DC, region, for example, lost 211,062 acres of farmland, forest, wetlands, and other open space in the 1980s, according to a study by the National Center for Resource Innovations.[29] The Occoquan Reservoir, which supplies water to much of northern Virginia, is being developed so rapidly that if current trends continue, a full 40 percent of the watershed's open space will be lost by 2020.[30]

And though habitat destruction may be most obvious in cities experiencing explosive growth, such as Phoenix, Las Vegas and Atlanta, it is certainly not limited to these areas. For example, in the lower 10 kilometers of Cape May, New Jersey, 40 percent of the habitat critical to migratory and residential wildlife has been lost to development over the last 20 years[31]. Habitat in even our most protected open spaces is endangered by development. A recent study by the Missouri State Department of Natural Resources indicated that the biological integrity of 27 state parks is currently threatened by increasingly dispersed patterns of development.[32]

Impact of Low Density Development on Wildlife: A Case Study

From 1958 to 1990, low-density development in the Tuckahoe Creek, Virginia watershed dramatically increased, resulting in severe impacts on local warm water fish species. The acreage of low-density development increased from 7% to 8% (seemingly small, but an increase of 300%); the number of houses in the watershed increased from 7,800 to 28,000 (an increase of 250%); road-stream crossings increased from 43 to 85; and road miles increased by 137%, with the area of road pavement increasing by 155%.

Effects on local fish species were startling. Six indigenous fish species became locally extinct, while the population of the remaining fish species declined 80%. Fish species diversity (a measure of resilience or a species' ability to rebound from adverse conditions) declined significantly.

Source: Weaver, L. Alan, and Greg C. Garman. "Urbanization of a Watershed and Historical Changes in a Stream Fish Assemblage." *Transactions of the American Fisheries Society*, Vol. 123, 1994, pp. 162-172.

Another impact—one that frequently follows the destruction and/or degradation of habitat—is the invasion of non-native species. Disturbed habitat is readily invaded by exotic plants. For example, in the Florida Everglades, the Australian melaleuca tree invades after water diversions. In Florida, the non-native melaleuca, Brazilian pepper, and Australian pine now dominate many land areas. In addition, the exotic hydrilla and water hycinth have adversely affected many aquatic communities by outcompeting native species and altering water chemistry. In California, introduced European grasses have altered the structure of fragile coastal dune communities and invaded almost all

[28] Flather, C.H., L.A. Joyce, and C.A. Bloomgarden. 1994. (as cited in: Noss, Reed and Fobert Peters. Endangered Ecosystems: A Status Report on America's Vanishing Habitat and Wildlife. Washington, DC: Defenders of Wildlife, December 1995. p. 46)

[29] *Washington Post*. "As the Economy Grows, the Trees Fall." March 23, 1997. p. A1.

[30] Baley, Janet and Glenn Besa. *Sprawl Costs us All.* Sierra Club, 1997.

[31] Department of Environmental Protection, State of New Jersey. *New Jersey's Environment 1988*.

[32] Etling, Kathy. "Of Owls and Interstates." *Missouri Conservationist*. Volume 54, Number 11, Nov. 1993. pp. 6-9.

remaining valley grasslands. Cases like these are common; more than 50 percent of federally listed species are affected by interactions with non-native species.[33]

Housing developments, roads, and associated infrastructure have the potential to destroy existing forests and vegetation and also cause fragmentation of natural habitats. Road infrastructure in the United States is extensive and growing. In 1997, public roads occupied an estimated 17,345 square miles of land, a 2 percent increase over the road area in 1990.[34] Fragmentation negatively affects wildlife in a number of ways. It interferes with wildlife travel, decreases habitat size, and reduces interaction with other wildlife communities. Fragmentation produces declines in both the number of species (diversity) and populations (abundance).[35] For example, a study of the influence of narrow forest-dividing corridors (small roads and power lines) on forest-nesting birds in southern New Jersey revealed that, although not generally viewed as sources of forest fragmentation, such corridors measurably affect the diversity and abundance of birds in ways that are associated typically with the effects of forest fragmentation.[36]

HABITAT FOCUS: WETLANDS

In recent decades, it has become increasingly clear that wetlands, once viewed as unproductive, perform important ecological functions. Wetlands mitigate flooding and damage from erosion, wind, and waves; they facilitate sediment replenishment; provide habitat for water life, waterfowl, mammals, and reptiles, many of which are economically important; and improve water quality by removing excess nutrients and some chemical contaminants. For this reason, the United States has given particular priority to saving wetlands.[37]

More than half (53 percent) of the wetlands in the lower 48 states were lost between the late 1700s and the mid-1980s.[38] In recent years, urban development and road construction has been a

[33] Flather, C.H., L.A. Joyce and C.A. Bloomgarden; Scemske, D.W., B.C. Husband, M.H. Ruckelshaus, et al. 1994. (As cited in: Noss, Reed and Fobert Peters. *Endangered Ecosystems: A Status Report on America's Vanishing Habitat and Wildlife.* Defenders of Wildlife, December 1995. p. 47.) Also see Bright, C. "Understanding the Threat of Bioinvasions." *State of the World.* Ed., Starke. New York: W.W. Norton & Co., 1996. pp. 95-113; Groves, R.H. and J.J. Burdon, eds. *Ecology of Biological Invasions.* Cambridge, UK: Cambridge University Press, 1986.

[34] Estimate based on data from U.S. Department of Transportation, Federal Highway Administration. "Highway Statistics:" 1990, 1995, 1996, and 1997. Table HM-60.

[35] Tolley, R.S. and B.J. Turton. "Transport Systems, Policy, and Planning: A Geographic Approach." *Longman Scientific and Technical*. 1995. There is a large literature on urban wildlife, critical habitat, and wildlife corridors. See: Beatley, Timothy. *Habitat Conservation Planning and Urban Growth*. Austin, Texas: University of Texas Press, 1994; and Leedy, Daniel and Lowell Adams. "Wildlife in Urban and Developing Areas: An Overview and Historical Perspective." in *Integrating Man and Nature in the Metropolitan Environment: Proceedings of a National Symposium on Urban Wildlife*, 4-7 ed. Adams and Leedy. Columbia, MD: National Institute for Urban Wildlife, November 1986.

[36] Rich *et al*., 1994.

[37] The U.S. Environmental Protection Agency adopted a No Net Loss of Wetlands goal (U.S. Environmental Protection Agency. *EPA Strategic Plan.* Washington, DC: 1997.), and the Federal Highway Administration has adopted a strategic goal of a 50 percent *increase* in net wetland acreage resulting from Federal-aid highway projects in 10 years (U.S. Department of Transportation, Federal Highway Administration. *FHWA National Strategic Plan.* 1997.)

[38] Dahl, T.E. and C.E. Johnson. *Status and Trends of Wetlands in the Conterminous United States*. Washington, DC: U.S. Department of the Interior, U.S. Fish and Wildlife Service, 1991.

major source of wetland loss. Of the 12 states that listed wetland losses, six reported that they suffered significant losses due to highway construction, and 10 reported that they had significant wetland losses due to residential growth and development.[39]

Wetland loss has been significant in many states. Ninety-one percent of California's original 5 million acres of wetlands have been drained or filled, and it is estimated that wetlands in California continue to be lost at a rate of almost 5,000 acres per year.[40]

In a report on the status and trends of wetlands in the United States between 1970 and 1980, the U.S. Department of the Interior concluded: "Road construction in and across wetlands has led to direct and indirect wetland loss through the effects of filling, fragmentation, and alteration of hydrology." Constructed highways also have indirectly led to wetland loss by enabling or inducing secondary development.[41] Another report concludes that "between approximately 310,000 and 570,000 acres of wetlands could potentially have been lost due to the construction of Federal Aid Highway Program roads between 1955 and 1980, at a cost to replace of between $153 million and $6 billion."[42]

Compensatory mitigation efforts attempt to address wetland loss due to highway projects. However, a 1992 Federal Highway Administration study evaluated 23 highway wetland mitigation projects and found that true one-for-one replacements were executed for only a few sites.[43]

Degradation of Water Resources and Water Quality

Many watersheds are rapidly becoming developed. For example, urban land use in the Occoquan watershed in northern Virginia is projected to increase from 7.3 percent in 1977 to 55.7 percent in 2020. Impervious cover—the imprint of land development on the landscape, composed of the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces—in the watershed is expected to grow from 11 percent of the basin in 1995 to 20 percent in 2020.[44] This development has serious environmental consequences. Stormwater runoff has been identified as one of the major contributors to ongoing water quality problems in this country. According to EPA's *National*

---

[39] U.S. Environmental Protection Agency. *National Water Quality Inventory: 1996 Report to Congress*. 1998.

[40] Noss, Reed and Robert Peters. *Endangered Ecosystems: A Status Report on America's Vanishing Habitat and Wildlife.* Washington, DC: Defenders of Wildlife, 1995. p. 28.

[41] LaRoe, Edward T., Gaye S. Farris, Catherine E. Puckett. *Our Living Resources - A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems*. Washington, DC: U.S. Department of the Interior, National Biological Service. 1995.

[42] Apogee Research, Inc. "Quantifying the Impacts of Road Construction on Wetlands Loss - Final Report." Bethesda, MD: September 1997.

[43] U.S. Department of Transportation, Federal Highway Administration. *Evaluation of Wetland Mitigation Measures, Volume I: Final Report.* 1992.

[44] Baley, Janet and Glenn Besa, *Sprawl Costs us All,* Sierra Club, 1997.

Water Quality Inventory: 1996 Report to Congress, impacts of increased imperviousness due to development on rivers include the following:[45]

- 38 percent of assessed estuary miles are impaired, with approximately 46 percent of impairment attributable to urban runoff.
- 36 percent of the total river miles recently assessed by states are still impaired, with urban runoff causing about 12 percent of the problem.
- 39 percent of assessed lake acres are impaired, with urban runoff causing 21 percent of the impairment.
- 13 percent of assessed ocean shorelines are impaired, with approximately 55 percent of impairment due to urban runoff through storm sewers.

Development significantly alters water balance and water quality in a number of ways, including impacts stemming from the following:

- Changes in hydrology (and reduced groundwater recharge)[46]
- Increased water pollution and nutrients
- Increased acidity
- Higher water temperature

These effects are discussed below.

CHANGES IN HYDROLOGY

Development in a watershed changes natural drainage patterns. Increases in impervious areas associated with development increase the volume and the rate of surface water runoff. In a study of 40 runoff monitoring sites across the nation, a 1-acre parking lot was found to produce a runoff volume almost 16 times as large as the runoff volume produced by an undeveloped meadow. Peak discharge, velocity, and time of concentration of storm water runoff were also found to be much greater. Furthermore, transportation-related impervious surfaces seem more often to exhibit a greater runoff volume than disconnected rooftop-related imperviousness of the same surface area.

[45] Note that the percentage of assessed water resources is quite low and differences in the resources being surveyed preclude making historical comparisons based on prior inventory reports. Source: U.S. Environmental Protection Agency, Office of Water. *National Water Quality Inventory: 1996 Report to Congress*. Washington, DC: 1998.

[46] U.S. Environmental Protection Agency. *Environmental Impacts of Storm Water Discharges - A National Profile*. (EPA 841-R-92-001) Washington, DC: June 1992.

Channelization projects, such as concrete retention walls or lining along stream beds, channel realignment, and diversion of streams through culverts, also increase flow velocities.[47]

Increased peak discharges and shorter lag times between storms and the resultant runoff lead to larger and more frequent incidents of local flooding.[48] Because the faster runoff prevents percolation of water that would normally feed regular stream flow, floods are followed by longer periods of below-normal stream levels. Lower flows during periods between storms may affect the aquatic habitat and the ability of a stream to dilute toxic spills.[49] Higher flows often result in stream bank erosion, increased sedimentation in the channel, and decreased stability. Streams may widen to two to four times their predevelopment width if stormwater from developed areas is uncontrolled. Research models suggest that a threshold for urban stream stability exists at about 10 percent site imperviousness.[50]

Sediment pollutant loads created by increased erosion can cause a broad range of impacts in receiving waters, including reduced water storage capacity, impaired dissolved oxygen for aquatic organisms, decreased light penetration, increased need for dredging, increased costs for water treatment, accumulation of pollutants, and adverse effects on fish and shellfish.

When runoff increases in volume and velocity, soils have less opportunity to absorb stormwater. This loss of groundwater recharge can reduce residential and municipal water supplies, decrease base flow into stream channels during dry weather, and threaten the health of local wetlands that rely on groundwater to maintain wet conditions during dry periods of the year.[51]

INCREASED WATER POLLUTION AND NUTRIENTS

Stormwater is often polluted by pesticides and fertilizers from homes, farms, heavy metals, antifreeze, lead and partially oxidized hydrocarbons from gasoline- and diesel-fueled vehicles, oil, urban debris, and spillage from accidents. Pollutants accumulate on impervious surfaces. These pollutants are quickly washed off during storms and delivered through pipes and ditches to

[47] Schueler, Tom. *Environmental Land Planning Series: Site Planning for Urban Stream Protection*. Center for Watershed Protection. Publication No. 95708. Washington, DC: Metropolitan Washington Council of Governments, December 1995. pp. 21-23.

[48] Field, Richard, Hugh Masters, and Melvin Singer. “Porous Pavement: Research, Development, and Demonstration.” *Transportation Engineering Journal of the American Society of Civil Engineers*. Vol. 108, No. TE3, May 1982. pp. 244-258.

[49] *Bellevue NURP Report*. In 1978, the EPA began The National Urban Runoff Program (NURP) to comprehensively study 28 project locations across the county, acquiring data on the receiving water impacts of urban runoff and evaluating management practices. The NURP studies provided the first national assessment of the increased levels of contaminants such as sediment, heavy metals, oil and grease, phosphorus, nitrogen, chemical oxygen demand, bacteria, viruses, and solid wastes in storm water.

[50] Schueler, Tom. *Environmental Land Planning Series: Site Planning for Urban Stream Protection*. Center for Watershed Protection. Publication No. 95708. Washington, DC: Metropolitan Washington Council of Governments, December 1995. pp. 23-24.

[51] Harbor, Jonathon M. “A Practical Method for Estimating the Impact of Land–Use Change on Surface Runoff, Groundwater Recharge, and Wetland Hydrology.” *Journal of the American Planning Association*. Volume 60, Number 1, Winter 1994.

streams, lakes, and estuaries.[52] Monitoring and modeling studies have shown consistently that urban pollutant loads increase with watershed imperviousness.[53]

Natural nutrient cycles may be altered by land use activities within a watershed. Excessive nutrients overstimulate the growth of aquatic plants, which may result in low oxygen levels in water, accelerate eutrophication, cause unsightly conditions, interfere with navigation and treatment processes, and cause unpleasant tastes and odors. Eutrophic conditions are evidenced by surface algal scums, reduced water clarity, odors, and dense algal growth on shallow water substrates.[54] Algal blooms block the light needed by submerged aquatic vegetation, removing habitat for juvenile fish and shellfish. After blooms or at the end of a growing season, the decomposition of dead vegetation may cause reduced oxygen levels. Lower oxygen levels may, in turn, cause the death of fish and mass mortality of benthic organisms.

INCREASED ACIDITY

Nitrogen oxides (NO_x) and sulfur dioxide (SO_2) are the primary air pollutants that result in acid rain and highly acidic stormwater. Acid rain occurs when SO_2, emitted primarily by electric utilities fired by coal, and nitrogen oxides (NO_x), emitted primarily by transportation sources and utilities, are deposited in the form of wet or dry deposition.

Several aspects of urbanization tend to create local conditions that may make receiving waters susceptible to impacts from acidity. High levels of airborne SO_2 and NO_x in large urbanized areas increase the acidity of the rainfall to levels above those typically found in the region. Runoff from paved surfaces and other impervious surfaces may have little or no opportunity to contact soils that could buffer the acidity of the rainfall. In urbanized areas with acidic rain, higher runoff volumes and rates associated with urban development can increase the acidity of receiving streams rapidly and lead to high peak acidity levels.

HIGHER WATER TEMPERATURE

High volumes of runoff from hot paved surfaces and rooftops may cause a rapid increase in surface water temperatures. Discharges from stormwater management devices, which retain collected runoff in unshaded ponds, also may increase stream temperatures.

Increased temperature can harm fish and other aquatic life. Water holds less oxygen as it becomes warmer, which may affect habitat and make the water more susceptible to oxygen-demanding pollutants. Sustained water temperatures in excess of 70°F are considered stressful or lethal to many cold water fish species and stream insects. The availability of food, attendant life cycle chemistry, and water quality changes are all affected by water temperature.

---

[52] Center for Watershed Protection. *Blueprint to Protect Coastal Water Quality*. Land Ethics, Inc. p.3.

[53] Schueler, Tom. *Environmental Land Planning Series: Site Planning for Urban Stream Protection*. Center for Watershed Protection. Publication No. 95708. Washington, DC: Metropolitan Washington Council of Governments, December 1995. p.24.

[54] Schueler, Tom. *A Framework for Evaluating Compliance with the 10% rule in the Chesapeake Bay Critical Area*. Annapolis, MD: Maryland Critical Area Commission, 1987.

2.4 SUMMARY

The size of virtually every metropolitan area in the United States has expanded dramatically in recent decades. As automobile ownership became increasingly common, residential development spread farther from urban centers. Although the sources of development dispersal are numerous and include demographic and socio-economic factors, public policies on highway construction, taxes, and land use also play an important role in shaping urban form.

The direct environmental consequences of dispersed development patterns can be divided into two broad categories: habitat loss and fragmentation, and adverse effects on water resources. Housing developments, roads, and associated infrastructure have destroyed existing forests and vegetation, and displaced or eliminated wildlife populations. Road construction has fragmented natural habitats, causing a decline in the diversity and abundance of populations. In the span of only about three human generations, we have witnessed the extinction of nearly 1 percent of the nation's flowering plants, more than 3 percent of our birds, and about 12 percent of the U.S.'s freshwater mussels.[55] Wetlands, in particular, have been affected substantially. Wetlands trends on nonfederal lands indicate a loss rate of between 70,000 and 90,000 acres annually, most of which is due to increases in development.[56]

Water resources and water quality are also threatened. Increasing acres of impervious surfaces lead to higher runoff volumes, larger and more frequent incidents of local flooding, and longer periods of below-normal stream levels. Development patterns also lead to reduced groundwater recharge and various negative effects like increased sedimentation, increased water acidity, and higher water temperatures. Water quality in many of our nation's rivers, lakes, and estuaries is degraded to a point where those water bodies can no longer support basic uses such as fishing and swimming, and cannot be relied on as sources of clean drinking water. According to EPA's most recent National Water Quality Inventory, approximately 40 percent of surveyed bodies of water in 1996 were too polluted for basic uses.[57]

Clean water and healthy habitat are national priorities, so it is important to understand the impacts that development patterns can have on our natural resources.

[55] Sierra Club. "The State of Disappearing Species and Habitat." (http://www.sierraclub.org/habitat/speciesloss.asp)

[56] U.S. Environmental Protection Agency. Office of Water wetlands webpage: http://www.epa.gov/OWOW/wetlands/vital/status.html.

[57] U.S. Environmental Protection Agency. "National Water Quality Inventory: 1996 Report to Congress." 1996. This report summarizes information submitted by 58 states, American Indian tribes, territories, Interstate Water Commissions, and the District of Columbia in their 1996 Section 305(b) reports.

3. Vehicle Travel: Recent Trends and Environmental Impacts

Vehicle travel has increased substantially in recent decades. Factors contributing to this trend are numerous. Although some new travel can be attributed to shifting demographics and market characteristics, substantial evidence suggests that much of the increase is a direct result of changing development patterns.

As development becomes more dispersed, with increasing numbers of families living on large lots at the urban fringes, and as jobs and housing become increasingly segregated from one another, distances between destinations have increased. Further, people are forced to make more trips by car, since the distances between destinations are often too great to walk or bike.

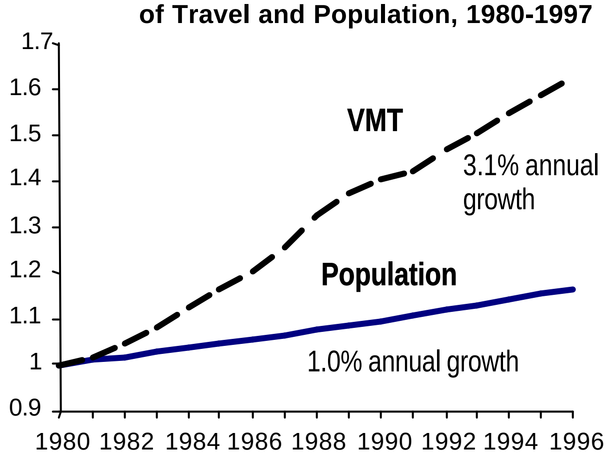
Rapid increases in vehicle travel have negatively affected the environment in numerous ways. The growth in travel degrades air quality, impairs water quality, and increases traffic noise.

3.1 Trends in Vehicle Travel

Vehicle travel increased substantially in recent decades. Total vehicle miles of travel (VMT) in the United States increased 63 percent between 1980 and 1997. VMT has more than doubled since 1970.[57] As shown in Figure 3-1, the rate of growth in VMT has exceeded the rate of population growth significantly over the last decade. VMT growth also outpaced employment growth and economic growth.

VMT is projected to grow considerably into the future. FHWA projects that light-duty VMT will grow at an annual rate of approximately 2.16 percent over the next 20 years, resulting in a 53 percent increase in VMT.[58] (See Figure 3-2.) As a result, FHWA has projected significant increases in annual travel delay times through 2005.

Figure 3-1: Growth in Vehicle Miles of Travel and Population, 1980-1997



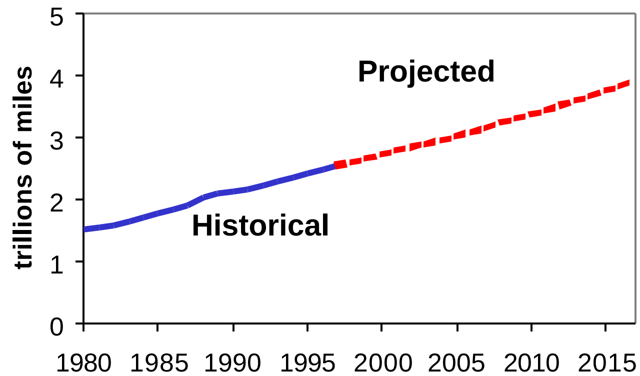
Scale: 1980 value = 1.0

Sources: U.S. Department of Transportation, Federal Highway Administration. *Highway Statistics (Summary to 1995,* and annual editions, *1996* and *1997),* Washington, DC.

[57] U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics (Summary to 1995,* and annual editions, *1996* and *1997.)* Washington, DC.

[58] U.S. Department of Transportation, *1997 Status of the Nation's Surface Transportation System: Condition & Performance Report to Congress,* 1998. p. 60.

Figure 3-2: Projected Growth in VMT



Source: U.S. Department of Transportation. *1995 Status of the Nation's Surface Transportation System: Condition & Performance Report to Congress*, October 1995.

When contrasted against population growth, the VMT increase is particularly high in specific metropolitan areas, as shown in Table 3-1.[59]

Table 3-1: Growth in Daily Vehicle Miles of Travel Exceeds Population Growth, 1982-1996

Urbanized Area	Population Growth, 1982-96	VMT Growth on Freeways and Principal Arterials, 1982-96
Atlanta, GA	53%	119%
Boston, MA	6%	31%
Charlottee, NC	63%	105%
Chicago, IL-IN	11%	79%
Houston, TX	28%	54%
Kansas City, MO-KS	23%	79%
Miami-Hialeah, FL	18%	61%
Nashville, TN	25%	120%
New York, NY-NJ	3%	40%
Pittsburgh, PA	7%	54%
Portland-Vancouver OR-WA	26%	98%
Salt Lake City, UT	32%	129%
San Antonio, TX	29%	77%
Seattle-Everett, WA	35%	59%
Washington, DC-MD-VA	28%	78%

Source: Texas Transportation Institute, *Urban Roadway Congestion, Annual Report 1998.* Tables A-6 and A-7.

[59] U.S. Department of Transportation, Federal Highway Administration, *Highway Statistics*, 1990 and 1997.

3.2 SOURCES OF VMT GROWTH

VMT growth can be attributed to a variety of factors, including the following:

- Demographic and market changes that allow more families to own multiple cars and lead more individuals to drive on a regular basis
- Development patterns that lead to increases in the number and average distance of trips
- The ability of increased road capacity to encourage additional travel—"induced travel"

Demographic and Market Changes

VMT growth has occurred in response to a number of factors, including recent changes in the profile of the workforce and in general demographics. As the baby boom generation came of age, large numbers of people were thrown into the driving population at one time, causing VMT numbers to escalate. Female participation in the labor force has increased dramatically in recent decades, putting more drivers on the road in general, and during peak commute times in particular. According to the Nationwide Personal Transportation Survey (NPTS), women workers as a percentage of women aged 16 or older grew from 37 percent to 59 percent between 1969 and 1995. By 1995, women were driving approximately 60-70 percent as many miles as men do. This gap continues to close as women's participation in the workforce increases.[60]

A combination of rising incomes and falling fuel prices also affected VMT. As household incomes increased and fuel prices fell over the past several decades, families became better able to afford one or more cars. In 1969, 48 percent of all households owned one vehicle. By 1995, the figure dropped to 32 percent, while the proportion of households with two and three cars increased.[61]

Development Patterns

Observed VMT growth can be only partially attributed to demographic factors; changing development and commuting patterns also play a significant role. The 1990 NPTS found that between 1983 and 1990, only 36 percent of VMT growth was associated with demographic change. The remainder can be attributed to changes in land use patterns that have led to increases in average trip distances (38 percent) and in the number of trips made (25 percent). [62]

As discussed in Chapter 4 of this report, numerous studies have found a direct relationship between development patterns and the amount of driving done. On a national level, from 1983 to 1995, the average length of work trips increased by 36 percent (from 8.5 to 11.6 miles), reflecting the fact that jobs and housing have become increasingly segregated from one another in recent years.[63]

---

[60] U.S Department of Transportation, Federal Highway Administration. "1995 Nationwide Personal Transportation Survey." September, 1997.

[61] *Ibid*.

[62] U.S. Department of Transportation, Federal Highway Administration, "1990 Nationwide Personal Transportation Survey".

[63] United States Department of Transportation, Federal Highway Administration. *Our Nation's Travel: 1995 NPTS Early Results Report*, 1997. Note that some of the increase in work trip lengths could be associated with trip chaining or other methodological issues associated with measuring trip lengths.

Induced Traffic and VMT Growth

"Induced traffic" is a term for traffic growth produced by the addition of highway capacity. The theory behind induced travel is that of supply and demand. Adding highway capacity (supply) reduces the cost of vehicle travel, particularly the costs associated with travel time. Demand is inversely related to cost. When cost goes down, demand goes up. As travel time and monetary costs fall, people travel more.

Expansion in road capacity can have multiple effects on behavior. An increase in capacity may result in changes in travel route, timing, vehicle occupancy, or mode choice for any given trip. It may also result in changes in trip frequency and switches to alternative destinations. Of these effects, increases in trip making and mode switches clearly contribute to induced travel. Other effects, such as switching routes or changing travel times, may occur as well. Although these effects may reduce some of the expected improvement in traffic flow and savings in travel time associated with the road project, they do not constitute new vehicle travel.

Different types of induced traffic are believed to occur in the short term and long term. In the short term, people may make more trips or switch from transit or carpools to driving alone because of improved traffic conditions. In the long term, reduced travel costs encourage more dispersed land use patterns that, in turn, can increase trip lengths and vehicle dependency.[64]

A Regression Analysis on Impacts of New Lane-Miles

Probably the best-known quantification of induced travel using U.S. data is a study by a University of California-Berkeley team led by Mark Hansen. Using time-series data and multiple regression, Hansen *et al.* estimated the auto traffic effects of changes in road capacity. Hansen studied relatively long-run time-series data—up to 16 years—and cross-sectional data to overcome difficulties in other studies that used only cross-sectional data and limited time periods.[65] The peer-reviewed results are statistically robust and quite clear: induced travel can occur and can absorb all new capacity.[66]

According to the study, vehicle miles traveled on state highways increase, on average, by 0.6 to 0.7 percent at the county level for each 1 percent increase in highway miles, and by 0.9 percent at

[64] See discussion in section 2.2 of this paper. Also refer to: Litman, Todd. "Incorporating Generated Travel in Transportation Economic Analysis." Paper presented at the 75th Annual Meeting of the Transportation Research Board. Washington, DC: January 1996; Cohen, H., "Review of Empirical Studies of Induced Traffic." *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use.* Transportation Research Board Special Report 245, Washington, DC: National Academy Press, 1995.

[65] Hansen *et al.*'s 1993 study has been widely cited. He and his team have since improved on it, and we present here the updated results from Mark Hansen and Yuanlin Huang, "Road Supply and Traffic in California Urban Areas," *Transportation Research-A*, 31:3 (1997), pp. 205-218. The Hansen team used data from 30 California urban counties. "The populations of the regions ranged over two orders of magnitude, from 150,000 to 15 million." Because of the wide variety of urban sizes and types included in the sample, the findings are applicable beyond California. Because the 1997 journal article was much shorter than the 1993 report, the article did not go into as much detail about the mechanisms of induced travel. In some cases we have quoted and cited the 1993 report to fill in detail.

[66] The explanatory power of the models is quite high, at $R^2 = .92 - .99$. Unless noted otherwise, we report here only statistically significant results.

the metropolitan level. The full increase in VMT materializes within five years of the change in road supply. [67]

New road capacity does not simply affect travel on the new road or new lanes. It may also affect traffic outside its own corridor. People might use the new road rather than an older, more congested route. People may choose new destinations. A decision to use the new road probably means a decision to use a road connecting to it. Thus, capacity increase can lead to travel growth on other roads as well as on new roads highway lanes.

Hansen found that:

> …adding lane miles in a given county increases VMT throughout the wider region. This will occur if, for example, increasing the capacity of a highway in a given county induces commuting to or through that county from other counties in the region. [68]

Hansen found that capacity additions have different impacts in different metropolitan areas. An additional lane mile in San Francisco, Los Angeles, or San Diego metro areas produces roughly 12,000 additional daily VMT. In smaller Stockton, just over 8,000 additional daily VMT are produced per new lane mile. In much smaller Redding, roughly 3,000 additional VMT occur per new lane mile. "Greater quantities of induced traffic are predicted for larger urban regions because such regions have higher ratios of VMT to state highway lane miles."[69]

Hansen does acknowledge that other factors (specifically, population growth, income level, and gasoline prices) also affect VMT. However, his findings call into question whether communities can relieve congestion through new road construction. Transportation decisions can produce travel changes over a wide area, and local capacity additions can increase VMT system-wide.

LITERATURE REVIEW AND SYNTHESIS OF EVIDENCE ON INDUCED TRAFFIC

Goodwin's paper, "Empirical Evidence on Induced Traffic: A Review and Synthesis," is useful in surveying additional evidence for induced traffic. Where Hansen used a traditional multiple regression approach in his study, Goodwin assembled evidence for induced travel from studies in several fields.[70]

Goodwin drew the evidence from studies on several subjects: the cost of car use, travel time budgets, the value of time, and other multiple regression studies. Together, those studies supported "an elasticity of traffic volume with respect to travel speed of about –0.5 in the short term and up to –1.0 in the long term." That is, in the short term, a 1 percent decrease in travel time will result in a 0.5 percent increase in vehicle travel. Over the long term, a 1 percent improvement in travel time will cause a 1 percent increase in VMT.

---

[67] Hansen investigates whether and how the effect grows over time, using lagged and unlagged models. He finds that the effect does grow. For further discussion, see both the 1993 report and the 1997 article.

[68] Hansen, Mark and Yuanlin Huang. "Road Supply and Traffic in California Urban Areas," *Transportation Research*, Volume 31, Number 3. Great Britain: Elsevier Science Ltd, 1997. p. 213.

[69] Hansen, Mark and Yuanlin Huang. "Road Supply and Traffic in California Urban Areas," *Transportation Research*, Volume 31, Number 3. Great Britain: Elsevier Science Ltd, 1997. p. 217.

[70] "The approach taken is that inferences are to be judged on the basis of 'the balance of probability' rather than conclusive rejection of a formal hypothesis." Goodwin 1996.

Goodwin's review led in part to a significant change in British national policy on the evaluation of road projects. The British government announced in December 1994 that "there is likely to be a significant proportion of schemes where there is a real possibility of extra traffic," and ordered re-review of construction proposals to take into account the induced travel.

OTHER STUDIES OF INDUCED TRAVEL

Hansen and the U.S. Transportation Research Board (TRB), a unit of the National Academy of Sciences, have, like Goodwin, reviewed various empirical studies of induced travel. *Our Built and Natural Environments* does not analyze the empirical studies in the level of detail that Goodwin did, but our review of the studies found estimated elasticities of VMT with respect to road supply ranging from 0.1 to 0.8. Most of the U.S. studies collected were older than those reviewed by Goodwin. Nonetheless, the two reviews are fundamentally in agreement in finding consistent evidence for induced travel in response to road improvements.

Transportation demand forecasting models that estimate the likelihood of choosing a specific mode for a trip, such as transit or motor vehicle, typically use a measure of travel cost as a determinant of mode choice. The statistical significance of travel cost in these models suggests that changes in travel costs associated with highway development typically will result in mode shifts from transit to personal vehicle use. There is a wide literature on travel price elasticities.[71] Stated preference surveys also have found that people plan to make more auto trips in response to added capacity.[72]

A recent statistical study analyzing the issue of how additions of highway lane miles can increase vehicle miles of travel found elasticities within the ranges of previous research, with short-run elasticities of about 0.5 and long-run elasticities of about 0.8.[73]

The 1995 TRB Report, *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*, stated:

> The evidence from the studies reviewed here supports the view that highway capacity additions can induce new trips, longer trips, and diversions from transit.[74]

The study suggests that land use and pricing policies may be more effective than efforts to restrain the growth in highway capacity to achieve long-run improvements in air quality.

---

[71] Many of these studies estimate elasticities based on fuel prices. See: Dahl C., and T. Sterner. "Analyzing Gasoline Demand Elasticities: A Survey." *Energy Economics* 13, 1991, No. 3:203-210. Dahl, C.A. 1986. "Gasoline Demand Survey." *The Energy Journal* 7, no. 1:67-82. Gately, D. 1990. "The U.S. Demand for Highway Travel and Motor Fuel." *The Energy Journal* 11, no 3:59-73. Greene, D.L. "Vehicle Use and Fuel Economy: How Big is the Rebound Effect?" *The Energy Journal* 13, 1992, No. 1:117-143. Southworth, F. "VMT Forecasting for National Highway Planning: A Review of Existing Approaches." Oak Ridge, TN: Center for Transportation Analysis, Oak Ridge National Laboratory, 1986.

[72] Dowling, Richard G. and Steven Colman. "Effects of Increased Highway Capacity: Results of a Household Travel Behavior Survey." Transportation Research Board paper No. 95-0409, presented at the 74th Annual TRB meeting, January 22-28, 1995.

[73] Noland, Robert. "Relationships between Highway Capacity and Induced Vehicle Travel." Paper presented at the 78th Annual Meeting of the Transportation Research Board, January 1999.

[74] Transportation Research Board, *Expanding Metropolitan Highways: Implications for Air Quality and Energy Use*, TRB Special Report 245, Washington, DC: National Academy Press, 1995, p. 162.

Trends in Vehicle Travel – Conclusion

Literature on trends in vehicle travel indicate that numerous factors including demographic and market shifts, contributed to recent increases in VMT. Studies also show that increases in VMT cannot be entirely explained by those factors and that changes in development patterns have had a particularly significant impact on VMT growth. Furthermore, because additional road capacity can be absorbed quickly by induced traffic, adding capacity alone is not likely to solve the problem of rapidly rising VMT.

Section 3.3 discusses how these increases in vehicle travel affect our natural environment.

3.3 Environmental Consequences of Vehicle Travel

Although vehicle travel produces benefits in terms of mobility, convenience, and flexibility, it also creates unintended environmental consequences. Outcomes include:

- Degradation of air quality
- Impairment of water quality associated with deposition of air pollutants
- Greenhouse gas emissions and global climate change
- Increased traffic noise
- Upstream impacts from activities associated with vehicle use, such as oil spills and water quality impacts from road de-icing.

Many of these consequences have severe effects on environmental quality. [75] The following subsections review these problems.

Degradation of Air Quality

Motor vehicles emit pollution through fuel combustion (exhaust) during operation and fuel evaporation during and between periods of operation. EPA established National Ambient Air Quality Standards (NAAQS) to protect public health, including the health of sensitive populations such as children and the elderly, from adverse effects of poor air quality. Pollutants covered by NAAQS (so-called "criteria pollutants") include carbon monoxide (CO), nitrogen dioxide (NO_2), ozone (O_3), sulfur dioxide (SO_2), particulate matter less than or equal to 10 micrometers in diameter (PM_{10}), particulate matter less than or equal to 2.5 micrometers in diameter ($PM_{2.5}$), and lead (Pb). Volatile organic compounds (VOC) and oxides of nitrogen (NO_X) are precursors to the formation of ozone. Motor vehicles emit each of these pollutants, and contribute a large portion of CO and ozone precursors in particular. Vehicle travel also kicks up large quantities of particulate matter from roads (especially on unpaved roads in rural areas). Table 3-2 presents emissions from motor vehicles in 1997, and Figure 3-3 shows the share of air pollutants emitted by motor vehicles.

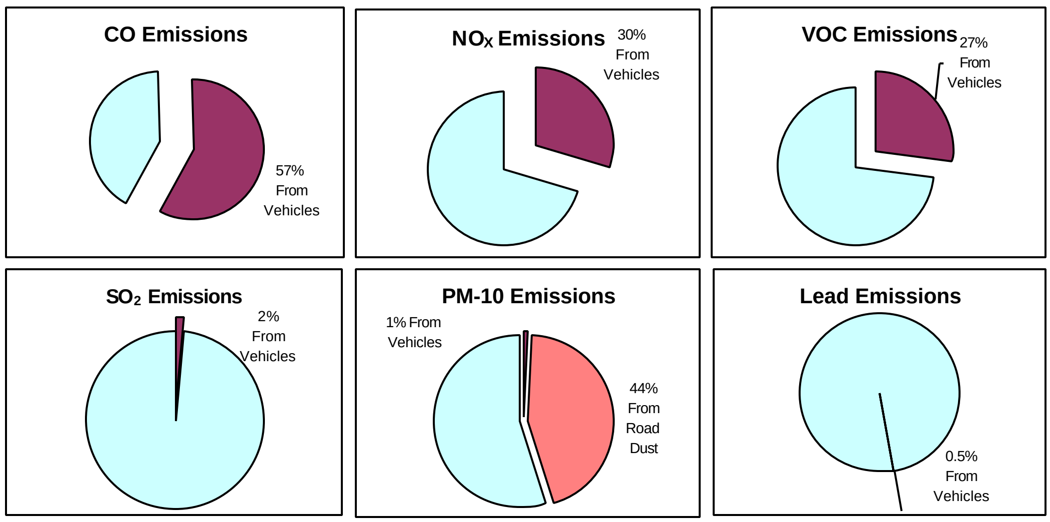
[75] For complete data on transportation's impacts on the environment, see: U.S. Environmental Protection Agency, Office of Policy. *Indicators of the Environmental Impacts of Transportation: Highway, Rail, Aviation, and Maritime Transport.* October, 1999, EPA 230-R-99-001.

Table 3-2: Motor Vehicle Emissions, 1997

Pollutant	Quantity Emitted (thousand short tons)
Carbon monoxide (CO)	50,257
Nitrogen oxides (NO_X)	7,035
Volatile organic compounds (VOC)	5,230
Sulfur dioxide (SO_2)	320
Particulate matter (PM_{10}):	
From exhaust	268
From road dust	14,820
Lead (Pb)	0.019

Source: U.S. Environmental Protection Agency. *National Air Pollutant Emissions Trends, 1900-1997*. 1999.

Figure 3-3: Highway Share of Air Pollutants Emitted, 1997



Note: percentages are based on anthropogenic emissions, except for PM-10, which includes natural emissions.
Source: U.S. Environmental Protection Agency. *National Air Pollutant Emissions Trends, 1900-1997*. 1999.

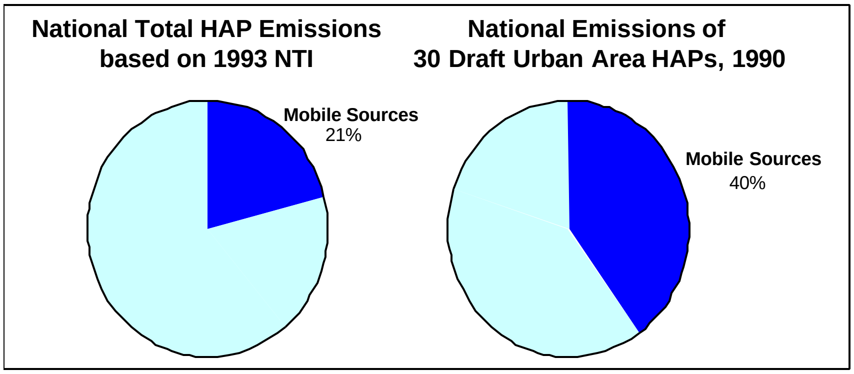
Since 1970, per mile motor vehicle emissions have been decreasing as a result of vehicle emissions control systems and cleaner fuels. However, increasing VMT threatens to reverse this trend in the near future for carbon monoxide, sulfur dioxide, and particulate matter (PM_{10}). The share of total emissions attributable to on-road mobile sources varies greatly by location. The share of NO_x can range from 20 to 60 percent of total emissions (including biogenic) in most ozone nonattainment areas, and on-road VOC emissions can range from 10 to 40 percent of the total.[76]

Motor vehicles also emit hazardous air pollutants (HAPs), sometimes referred to as air toxics. HAPs are pollutants known or suspected to cause cancer or other serious human health effects or ecosystem damage. Persistent air toxics are of particular concern in aquatic ecosystems, as toxic levels can magnify up the food chain. Compared with the criteria pollutants, less information is available concerning the health and environmental impacts of individual HAPs. According to EPA's 1993 National Toxics Inventory (NTI), mobile sources released about 21 percent of the

[76] Apogee Research, Inc. and Sierra Research. "Strategic Analysis of Mobile Source Options for Air Quality: Regional Differences and Implications for Ozone Policy." Prepared for the Federal Highway Administration. August 1996.

8.1 million tons of air toxics released nationwide.[77] EPA also compiled an interim 1990 emissions inventory of 30 proposed urban HAPs that pose the greatest threat to public health in urban areas. Of these, about 40 percent of emissions come from mobile sources, as shown in Figure 3-4.

Figure 3-4: Mobile Source Contribution to HAPs, 1993



Source: U.S. Environmental Protection Agency. *National Air Quality and Emissions Trends Report, 1997,* December 1998.

Table 3-3 shows the quantity and share of individual toxic emissions that were emitted by motor vehicles in 1993.

Table 3-3: Toxic Emissions Due to Highway Vehicle Operations, 1993

Pollutant	Quantity Emitted (1993, metric tons)	Percent of Total Emission
Benzene	158,149	60%
1,3 Butadiene	27,972	56%
Formaldehyde	73,874	33%

Source: U.S. Environmental Protection Agency. *Motor Vehicle-Related Air Toxics Study,* April 1993.

IMPACT: HEALTH PROBLEMS

In 1997, approximately 113 million people lived in counties that had failed to attain the NAAQS for at least one criteria pollutant.[78] As shown in Table 3-4, these pollutants are associated with numerous public health problems.

[77] EPA National Toxics Inventory. 1993.

[78] U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. *National Air Quality and Emission Trends Report, 1997.* Research Triangle Park, NC, December 1998.

Table 3-4: Health Impacts of Criteria Pollutants

Pollutant	Health Impacts
CO	Interferes with the absorption of oxygen by hemoglobin in the blood. Lack of oxygen impairs the cardiovascular and nervous system, with symptoms including chest pain, headaches, dizziness, nausea, fatigue, and slower reflexes. In addition, impairs visual perception, work capacity, manual dexterity, learning ability and performance of complex tasks. Affects fetal growth and tissue development. Results in mortality at extremely high concentrations.
Ozone	May cause temporary lung irritation, minor eye irritation, coughing, pain upon inhalation with short-term exposure. Heavy exercise becomes difficult. Long-term exposure to ambient ozone may cause structural lung damage leading to chronic lung disease, lung cancer, and increased susceptibility to respiratory infections, such as bronchitis and pneumonia. May interfere w/ the immune system. May be agent for infectious disease since produces more receptors for viruses. Exacerbates allergies.
Particulate Matter	May cause coughing, lung tissue damage, alteration in immune system, and respiratory and cardiovascular diseases. Effects on breathing and respiratory symptoms, aggravation of existing respiratory and cardiovascular disease, alterations in the body's defense systems, damage to lung tissue, carcinogenesis. Raises risk of cancer (since particulates adhere to carcinogens).
SO_2	Constricts bronchial passages and alters the lungs' defenses, with symptoms including effects on breathing, asthma, and respiratory illness. People with pre-existing chronic lung and heart diseases are at increased risk of acute illness or premature death during episodes of combination of SO_2 and particulate matter. Also important since it contributes to particulate formation by reacting in the atmosphere to form sulfates, which are believed to be a significant portion of PM-10 in terms of both volume and effect on humans.
Lead	May cause increased blood pressure and heart disease. Impairment of children's mental functioning. Neurological impairments, such as seizures, mental retardation, and/or behavioral disorders.

Source: Apogee Research, Inc. *Incorporating Additional Effects into the HERS Model for National Highway Investment Analysis.* Prepared for the Federal Highway Administration. January 1996. Based on reviews from various health studies.

There is strong evidence that air pollution from highways causes a significant number of public health problems. A detailed analysis of the costs of motor vehicle travel concluded that in 1991 motor vehicle pollution was responsible for the following health problems:[79]

- Roughly 50-70 million respiratory-related restricted activity days, of which approximately 43-60 million can be attributed to particulate matter alone
- About 852 million headaches from CO
- Approximately 20,000-46,000 cases of chronic respiratory illness (chronic cough, phlegm, wheezing, chest illness, and bronchitis)
- An estimated 530 cases of cancer from air toxins (estimates of cancer risk, however, are highly uncertain)
- An estimated 40,000 premature deaths in the United States.

[79] McCubbin, D. and M. Delucchi. *Health Effects of Motor Vehicle Air Pollution.* 1995.

IMPACT: IMPAIRMENT OF WATER QUALITY FROM AIR POLLUTANTS

Air pollution can significantly affect water quality, as illustrated by the following statistics:[80]

- Estimates of atmospheric nitrogen input to water bodies such as the Chesapeake Bay and other major East Coast estuaries range from 5 percent to 50 percent of the controllable load of nitrogen (most estimates are in the range of 30 percent). The error in such estimates, however, is cited as at least plus or minus 20 percent and up to a factor of two or three, depending on location and pollutant considered.

- Atmospheric loadings of metals to water bodies such as the Chesapeake Bay may range from more than 95 percent of total loadings in the case of lead to about 10 percent in the case of cadmium.

- Annual fluxes from wet deposition reported at various coastal locations range from under 5 mg per square meter for copper, nickel, and lead to 15-30 mg per square meter for iron and zinc.

- Wet deposition of various polycyclic aromatic hydrocarbons such as benzo[ghi]perylene (including some carcinogenic products of incomplete combustion) is in the range of 1-10 micrograms per square meter per year.

EPA and others are in the process of modeling the source contribution of each pollutant for the Chesapeake Bay and the Great Lakes.

IMPACT: ECONOMIC COSTS

In addition to causing health problems, air pollution causes damage to building materials, agriculture, and visibility. These impacts have large costs to society. A comprehensive study of air pollution from motor vehicles estimated annual costs of $28.7 to $531 billion in health damage, $2.5 to $4.6 billion in crop damage, and $6.0 to $43.54 billion in damage to visibility.[81] Another study estimated $36.6 billion (1990 dollars converted to 1999 dollars) in annual air pollution health and property costs due to roadway transportation.[82] A 1993 study calculated air pollution health costs as ranging from $146 to $271.6 billion (1990 dollars converted to 1999 dollars) and building damage to cost another $365.6 million (1990 dollars converted to 1999 dollars).[83]

Greenhouse Gas Emissions and Global Climate Change

Greenhouse gases from human sources threaten to alter Earth's atmosphere, since the planet's ecosystems cannot absorb such elevated levels of these gases. Carbon dioxide (CO_2) is one of the primary greenhouse gases emitted by humans.

---

[80] Air deposition data from AQCG/STAC 1994/95, and Valigura *et al*., 1994/1995.

[81] Delucchi, M. et al. *The Annualized Social Cost of Motor-Vehicle Use in the U.S., based on 1990-1991 Data, June 1997.* Converted into 1999 dollars. (UCD-ITS-RR-96-3).

[82] Ketcham, B. and C. Komanoff. Win-Win Transportation: A No-Losers Approach to Financing Transport in New York City and the Region. 1992.

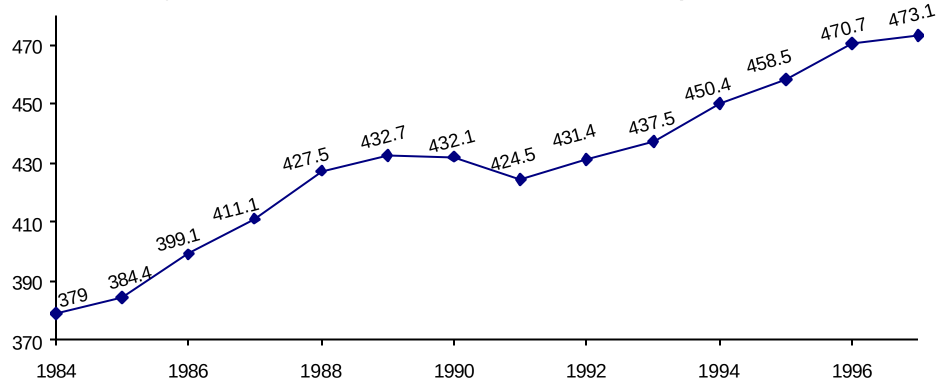
[83] Miller, P. and J. Moffet. *The Price of Mobility: Uncovering the Hidden Costs of Transportation.* Natural Resources Defense Council, 1993.

The accumulation of greenhouse gases in the atmosphere can lead to global climate change (also called "global warming," since one outcome is an increase in the *average* atmospheric temperature). The results of global climate change are potentially dramatic. Increases in atmospheric and oceanic temperatures might raise sea levels and alter associated weather patterns, which in turn could increase the frequency and severity of extreme weather events worldwide. Such changes might alter current patterns of land use and human activity, as well as ecosystems and natural habitats.[84]

Even an increase of a few degrees can lead to dramatic changes in climate. The total global warming since the peak of the last ice age—18,000 years ago—was only about 5°C. In 1990 EPA estimated that a doubling of atmospheric levels of CO_2 would lead to an increase in average temperatures of anywhere from 1.5 to 5.5°C.[85] The Intergovernmental Panel on Climate Change (IPCC) in 1995 predicted an increase of about 2 to 3.5°C between 1990 and 2100.[86]

Transportation is a significant source of greenhouse gas emissions. In 1997, for example, the transportation sector emitted 32 percent of U.S. CO_2 emissions from fossil fuels, or 473.1 million metric tons of carbon. As indicated by Figure 3-5, carbon emissions from transportation have increased significantly over time.[87]

Figure 3-5: US Carbon Dioxide Emissions from Transportation



The transportation sector is projected to be the fastest growing contributor to carbon emissions in the next 20 years. Carbon emissions from transportation are projected to grow by 47.5 percent over the period 1996-2020. Projected carbon emissions from transportation (based on modeling by the U.S. Department of Energy) are shown in Table 3-5.

[84] U.S. Congress Office of Technology Assessment. *Preparing for an Uncertain Climate.* Washington, DC, 1993.

[85] U.S. Environmental Protection Agency. *Policy Options for Stabilizing Global Climate: Report to Congress*. Washington, DC, December, 1990.

[86] Intergovernmental Panel on Climate Change. *Second Scientific Assessment of Climate Change, Summary and Report.* World Meteorological Organization/U.N. Environment Program. Cambridge, MA: Cambridge University Press, 1995.

[87] U.S. Department of Energy, Energy Information Administration. *Emissions of Greenhouse Gases in the United States, 1997.* October 1998.

Table 3-5: Projected Carbon Emissions from Transportation

Year	Million metric tons per year
1996 est.	472.8
1997 est.	475.3
2000	515.8
2005	572.8
2010	626.3
2015	662.3
2020	697.3

Source: U.S. Department of Energy, Energy Information Administration. *Annual Energy Outlook 1999: With Projections to 2020.* DOE/EIA-0383(98), December 1998, Table A-19. Reference Case Forecast.

In addition to carbon emissions, vehicle travel contributes to emissions of two other greenhouse gases, methane and nitrous oxide. Emissions for these gases for 1997 are tabulated in Table 3-6:

Table 3-6: Greenhouse Gas Emissions Due to Highway Vehicle Travel

Pollutant	Quantity Emitted (1997, thousand metric tons)
Methane (CH_4)	213
Nitrous Oxide (N_2O)	205

Source: U.S. Department of Energy. *Emissions of Greenhouse Gas in the US 1997,* October 1998, Table 26.

Global climate change may have severe consequences for ecosystems and economies around the globe. IPCC models predict a rise in sea level over the next 100 years of 20 to 86 centimeters, with the most likely case of a rise of 50 centimeters.[88] EPA predicts a median estimate of 45 centimeters. Such a rise would inundate wetlands and lowlands, accelerate coastal erosion, worsen coastal flooding, threaten coastal structures, raise water tables, and increase salinity of rivers, bays, and aquifers.[89] Low-lying coastal areas would be the hardest hit, since a small sea level rise could put large areas under water. EPA estimated that a 50-centimeter sea level rise would inundate 5,000 square miles of dry land and 4,000 square miles of wetlands in the United States.[90] Total monetary losses caused by a 1-meter rise are estimated to be between $270 and $475 billion, not including future development.[91]

The rises in global average temperature predicted by EPA, the IPCC, and the U.S. Congress Office of Technology Assessment could increase average global precipitation by as much as 7 to 15 percent. Predictions suggest that precipitation would increase at high latitudes and decrease at low to middle latitudes, increasing the potential for more severe and longer-lasting droughts.[92]

---

[88] Intergovernmental Panel on Climate Change, *Second Scientific Assessment of Climate Change, Summary and Report*. World Meteorological Organization/UN Environment Program. Cambridge, UK: Cambridge University Press, 1995.

[89] Titus, J. and V. Narayanan. “Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea,” *Coastal Management*. Volume 19, 1991.

[90] Gardiner, David. “Global Climate Change Negotiations.” Testimony before the House Commerce Committee, Subcommittee on Energy and Power. June, 1996.

[91] Titus, J. and V. Narayanan. “Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea,” *Coastal Management*. Volume 19, 1991.

[92] U.S. Office of Technology Assessment. *Preparing for an Uncertain Climate Volume 1*. Washington, DC: U.S. Government Printing Office, 1993.

Human health also could be significantly affected by global climate change, due to extended heat waves and a marked increase in vector-borne diseases such as malaria (due to the extension of the hospitable geographical range and seasons for these organisms).[93] Although costs of mitigating these problems are uncertain, they may be in the billions of dollars per year. Two 1992 studies estimated the annual social costs of greenhouse gas emissions to the United States to be $25 billion (1990 dollars) to $27 billion (1989 dollars).[94]

Noise

Automobile travel creates noise from engine operations, pavement-wheel contact, and wind noise. As a result, increased vehicle travel is likely to cause increased noise disturbances to communities. Because noise diminishes with distance from its source, the most serious transportation noise problems are experienced along major transportation corridors. The passage of the federal Noise Control Act of 1972 marked the recognition of noise as a major problem in urban living. As shown in Table 3-7, an estimate for 1980 indicated that 37 percent of the U.S. population was exposed to noise from road use great enough to cause annoyance—defined at Leq greater than 55 dB (A).[95]

Table 3-7: Percent of U.S. Population Exposed to Road Transportation Noise

(Outdoor Sound Level in Leq [dB(A)])

>55 dB(A) Annoyance	>60 dB(A) Normal Speech Level	>65 dB(A) Communication Interference	>70 dB(A) Muscle/Gland Reaction	>75 dB(A) Changed Motor Coordination
37.0%	18.0%	7.0%	2.0%	0.4%

Source: Organization for Economic Cooperation and Development. *Indicators for the Integration of EnvironmentalConcerns into Transport Policies,* OECD Publications, 1993.

Numerous research projects for Organization for Economic Cooperation and Development (OECD) countries on the effects of noise and its wider repercussions indicate that an outdoor sound level of 65 dB(A) is "unacceptable," and an outdoor level of less than 55 dB(A) is desirable.[96] Studies have estimated the annual social costs of vehicle-related noise to be anywhere from $2.7 to $9 billion.[97]

Other Environmental Impacts of Motor Vehicle Use

Activities associated with the use of motor vehicles can create pollution that affects water quality and damages ecosystems. Upstream impacts associated with fuel production and distribution, in particular, are associated with adverse impacts to the environment, such as oil spills. About 1.6

---

[93] McMichael, Antony. "Global Health Watch: Monitoring Impacts of Environmental Change," *The Lancet*. Volume 342, December, 1993.

[94] Lower estimate from Ketcham and Komanoff (*Win-Win Transportation: A No-Losers Approach to Financing Transport in New York City and the Region*. 1992). Upper estimate from MacKenzie, et al. (*The Going Rate: What it Really Costs to Drive.* Washington, DC: World Resources Institute, 1992).

[95] Leq stands for Equivalent Sound Level and is a measure of a steady sound that has the same sound energy as an amplitude-varying sound of the same duration. Sound pressure levels are expressed in decibels (dB).

[96] Organization for Economic Cooperation and Development. *Indicators for the Integration of Environmental Concerns into Transport Policies.* OECD Publications. 1993.

[97] Lower estimate from Miller and Moffet. *The Price of Mobility: Uncovering the Hidden Costs of Transportation.* Natural Resources Defense Council, 1993. Upper estimate from MacKenzie, et al. (*The Going Rate: What it Really Costs to Drive.* Washington, DC: World Resources Institute, 1992).

million gallons of oil were spilled in U.S. navigable waters from vessel incidents during 1996.[98] One study estimates that large oil spills from vehicles transporting fuel cause water pollution that costs society $2.36 to $5.9 billion annually.[99] Leaking underground storage tanks at gas stations and other facilities can cause groundwater contamination with associated environmental and health costs estimated at $0.12 to 0.59 billion annually.[100]

Motor vehicle manufacture is associated with environmental impacts including air pollutant emissions, toxic releases, and the generation of various solid and liquid wastes. Highway maintenance to support vehicle travel also involves activities that can adversely affect the environment, such as road salting, use of solvents, and pesticides. Highway de-icing can adversely affect roadside vegetation, soil structure, drinking water supplies, and aquatic life. Highway de-icing is estimated to cost society $0.826 to $2 billion annually.[101]

3.4 SUMMARY

Over the past several decades, improvements in automobile-related infrastructure (highways, roads, parking lots), greater separation between jobs and housing, greater distances between destinations, and induced traffic (or additional travel prompted by road capacity expansions) have led to increases in vehicle travel.

The environmental consequences of vehicle travel and vehicle dependency pose a potential threat to long-term community and environmental health. Highway emissions cause chronic health problems, affect water quality, and impose economic costs stemming from crop damage, building and property damage, and damage to visibility. Transportation is also a generator of noise and a major contributor to global climate change.

Communities are also realizing that adding new road capacity no longer generates the same economic benefits it may have at one time. Studies have indicated that new highway development, which was often viewed as necessary to economic development in the past, offers increasingly fewer economic benefits at the state and national levels. As the national road network nears completion, the benefits of additional network construction decrease drastically. New roads may offer fewer benefits on the local level, too; although they may appear to spur growth, they often simply shift economic activity away from other areas.[102]

Communities across the country realize that adding new road capacity is not by itself a viable long-term solution to traffic congestion problems. As they also realize that adding new capacity offers fewer economic benefits than previously assumed, they are beginning to examine the relationship between development patterns, travel patterns, and their environmental consequences. Communities

[98] U.S. Department of Transportation, Bureau of Transportation Statistics. *National Transportation Statistics 1998.* Table 4-42.

[99] Delucchi, M. et al. *The Annualized Social Cost of Motor-Vehicle Use in the U.S., based on 1990-1991 Data, June 1997.* Converted into 1999 dollars. (UCD-ITS-RR-96-3). Converted to 1999 dollars.

[100] Delucchi, M. et al. *The Annualized Social Cost of Motor-Vehicle Use in the U.S., based on 1990-1991 Data, June 1997.* Converted into 1999 dollars. (UCD-ITS-RR-96-3). Converted to 1999 dollars.

[101] Delucchi, M. et al. *The Annualized Social Cost of Motor-Vehicle Use in the U.S., based on 1990-1991 Data, June 1997.* Converted into 1999 dollars. (UCD-ITS-RR-96-3). Converted to 1999 dollars.

[102] Boarnet, Marlon G. "Highways and Economic Productivity: Interpreting Recent Evidence." *Journal of Planning Literature.* Vol. 11, No. 4. May, 1997.

are recognizing that in order to meet federal air quality standards and protect other aspects of environment and community, they must turn toward more land use-based solutions to transportation challenges. We examine those solutions in Chapter 4.

4. Effects of Different Development Types on the Environment

Problems with air quality, water quality, and biodiversity are serious enough that Congress has passed national legislation setting timetables for improvement. The best known of these timetables is the Clean Air Act, which sets deadlines for states to clean their air to levels that protect vulnerable populations.

In order to establish a framework for future actions, EPA recently developed a strategic plan that identifies the agency's goals for implementing its mission "to protect human health and to safeguard the natural environment." Five strategic goals with strong connections to aspects of the built environment are listed in Table 4-1, along with a description of how urban form affects the attainment of each goal.[103]

Table 4-1: EPA Strategic Goals with Built Environment Linkages

Health or Environmental Goal	Is attainment of these goals affected by current land-use trends and increased VMT?
1. Clean Air	Yes, from tailpipe and evaporative emissions
2. Clean and Safe Waters	Yes, from road and pavement runoff, and from deposition of airborne emissions
3. Preventing Pollution and Reducing Risk in Communities, Homes, Workplaces, and Ecosystems	Yes, from habitat and ecosystem fragmentation and destruction
4. Better Waste Management, Restoration of Contaminated Waste Sites, and Emergency Response	Yes, to the extent that communities abandon or fail to redevelop brownfields
5. Reduction of Global and Cross-Border Environmental Risks	Yes, from greenhouse gas emissions from motor vehicles

Although land use and transportation development affect EPA's environmental goals, historically national efforts have relied principally on tailpipe or smokestack solutions. As Congress passed legislation to address environmental and human health threats, EPA responded with regulations aimed largely at controlling the most obvious risks, such as pollution from large industries. Although the logic and efficiency of managing risks in this manner are well recognized, it has become increasingly clear that there are limitations to this approach and that these strategies alone will not achieve our national goals. In particular, changes in the built environment threaten various environmental goals and may require new approaches.

Not all development affects the environment in the same ways. As communities examine how to grow, they are looking for strategies that will protect the environment while accommodating new growth. This section examines how various types of development patterns and practices affect the environment.

---

[103] EPA's strategic plan was completed in September 1997 and addresses the Government Performance and Results Act's direction for each executive department and agency to develop a strategic plan that outlines the goals that will provide the framework for planning and resource allocation. EPA's strategic plan includes 10 goals. The other five are: 6) Safe Food; 7) Expansion of Americans' Right to Know about their Environment; 8) Sound Science, Improved Understanding of Environment Risk, and Greater Innovation to Address Environmental Problems; 9) A Credible Deterrent to Pollution and Greater Compliance with the Law; and 10) Effective Management.

Although the evidence is ample that different types of development patterns can affect the environment in different ways, the understanding of these effects is not yet complete. The direct effects in terms of habitat consumption and disruption are well documented and widely accepted. By contrast, the effects of highway investment on vehicle travel and the effects of specific development patterns on travel and emissions are somewhat less well understood, and the exact magnitude of these effects is subject to some debate. This section of *Our Built and Natural Environments* synthesizes findings from several researchers, noting where greater or less certainty exists about linkages between causes and effects and the relative magnitude of effects. Where previous sections described broad land use and transportation trends and impacts, this section focuses on impacts of current development versus more environmentally sensitive development.

Certain characteristics of the built environment are associated with beneficial environmental results. This chapter discusses six of these features:

1) Compact development
2) Reduced impervious surfaces and improved water detention
3) Safeguarding of environmentally sensitive areas
4) Mixed land uses
5) Transit accessibility
6) Support for pedestrian and bicycle activity and other micro-scale urban design factors

These elements are not entirely separable from each other. For example, encouraging compactness through infill or brownfields redevelopment often facilitates mixed-use development and provides support for transit use, and walking and cycling. Safeguarding environmentally sensitive areas often involves developing more compact or clustered development. In similar ways, other elements listed above may work most effectively in combination with each other rather than individually.

Incorporating one beneficial element without others could have minimal effects or possibly prove detrimental to environmental goals. For example, increasing density without taking care to safeguard environmentally sensitive areas or to improve transit access could result in increased water quality impacts, traffic congestion, or air quality problems. The enhanced benefit of incorporating multiple aspects of design into communities is often referred to as “synergy.” Synergy is discussed in Section 4.7.

Because most practices work synergistically with one another isolating the effects of one from another can be difficult. In general, the studies presented in the first six sections of this chapter were chosen because they attempt to isolate the effects of particular strategies. However, studying one technique in isolation is often nearly impossible, and the utility of doing so is somewhat limited, as most practices are used in combination with others. Nonetheless, although findings may differ on the magnitude of the effects of different practices, the evidence is overwhelming that some developments yield better environmental results than others.[104]

[104] For evidence of consensus on the view that some development practices yield better environmental results than others, see Burchell, Robert W. et al. *The Costs of Sprawl – Revisited.* Transit Cooperative Research Program (TCRP) Report 39. Washington, DC: National Academy Press, Transportation Research Board, 1998. Burchell *et al* provide a synthesis and critical assessment of the literature on sprawl.

4.1 COMPACT DEVELOPMENT

Compact metropolitan development generally means that the space needs of a population can be satisfied with less land area. Compact development can take various forms. From a regional perspective, metropolitan areas may limit the extent of development so that it does not extend too far into rural areas. New development can be targeted to specific areas, such as redevelopable areas within established communities.

Compact Development in Practice

Some metropolitan areas have decided to preserve the scenic open space that attracted their residents in the first place, as a means of preserving the continuing desirability of their communities. A number of communities have chosen to target development and place limits on the geographic extent of regional development. In particular, Portland, Oregon, chose to implement an urban growth boundary as a means of preserving open space. Montgomery County, Maryland, established an agricultural reserve in the western half of the county. Other areas have elected to preserve greenway corridors, establish state or city parks, and purchase easements on land as ways of preserving open space. Portland plans to accommodate all market-demanded housing types within its urban growth boundary, which is periodically adjusted to ensure a 20-year supply of developable land.

Types of Compact Development

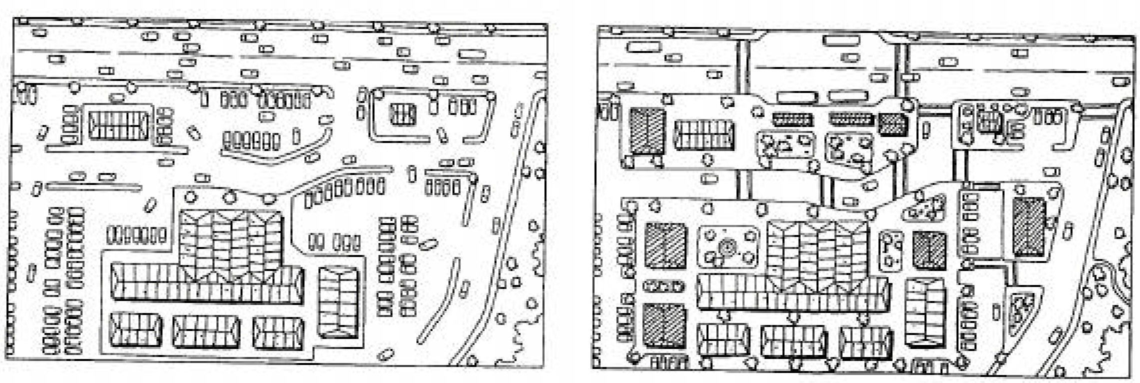
Communities can develop more compactly by using three techniques:

- Infill development
- Brownfields redevelopment
- Cluster development

INFILL DEVELOPMENT

Infill development occurs in locations where some development has already taken place and infrastructure is already in place. In urban areas, infill development is typically executed by converting old buildings and facilities into new uses (redevelopment) or by filling undeveloped space within these areas. Figure 4-1 shows an example of infill development in an urban area, where parking lots are replaced by buildings, parks, and/or garages.

Figure 4-1: Infill Development in an Urban Area



Infill development is a way to accommodate regional growth using relatively less suburban and rural greenspace. The potential for infill is considerable. In 1994, researchers at the University of California at Berkeley's Institute of Urban and Regional Development surveyed planning directors in 1,200 political jurisdictions nationally and concluded that "existing urban areas have substantial capacity for new residential development." This conclusion was reached based on a conservative estimate: The survey asked only about currently undeveloped land, not about underutilized properties that are important land resources in most older urban areas.[105]

BROWNFIELDS REDEVELOPMENT

As a particular kind of underdeveloped land, brownfields have received significant attention as both a problem and a potential source of multiple urban benefits. Brownfields are "abandoned, idled, or underused industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental consequences."[106] Brownfields redevelopment has potentially strong repercussions for environmental quality and community life since undeveloped brownfield sites may be a health threat or a discouragement to further investment in established urban areas.

The General Accounting Office estimates that the nation has between 13,000 and 450,000 brownfields.[107] Brownfields, like infill sites, have the potential to absorb significant amounts of development. A 1982 study of three urban areas found that vacant land within developed areas could accommodate from two-thirds to 100 percent of the projected 10-year housing need.[108] That capacity has apparently not diminished significantly in the past 15 years. A 1996 study found that brownfields in Detroit, Chicago, Milwaukee, and Cleveland could absorb 1 to 5 years of residential development, 10 to 20 years of industrial development, or 200 to 400 years of office space.[109] These estimates are conservative because, due to cost constraints, only a subset of existing known brownfields was examined. Significant amounts of vacant land in each of these metropolitan areas have not been inventoried.

Brownfield sites are different from other urban infill sites because of uncertainties about environmental liability and clean-up costs. Site owners, developers, and lenders often avoid investing in brownfields because of fear of contamination and the costs associated with it. Clean-up costs of brownfields vary widely depending on site size, the intensity and type of contamination, and the nature of the remediation required. Rather than developing brownfields, firms and investors instead turn to surrounding areas and undeveloped greenfields or relatively untouched and uncontaminated land.[110]

---

[105] Pendall, Rolf. "Land Availability and Zoning: Indications from a National Survey." On the Ground. Fall, 1994. pp. 19-20.

[106] U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. Brownfields Initiative. (Quick Reference Fact Sheet) April, 1996.

[107] U.S. General Accounting Office. Community Development: Reuse of Urban Industrial Sites. (GAO/RCED-95-172) Washington, DC: US Government Printing Office, June 1995.

[108] Real Estate Research Corporation. Infill Development Strategies. Washington, D.C.: ULI-the Urban Land Institute and American Planning Association, 1982.

[109] Simons, Robert, Planning and Development, Cleveland State University. Brownfields Supply and Demand Analysis for Selected Great Lakes Cities. Prepared for EPA, 1996.

[110] "What is a Brownfield?" http://www.brownfield.org/#Brownfield.

Local government officials frequently cite brownfields as one of their biggest environmental problems.[111] Based on a national survey of communities, the U.S. Conference of Mayors reports that "brownfields are a major problem for cities large and small and the lack of funds to clean up these sites was the most frequently identified obstacle in recycling these lands."[112] Consequently, local, state, and federal agencies are targeting attention and resources to brownfields.

Redevelopment also can help assure that no stigma (of either perceived or real contamination) impedes investment in the community. As a result, clean-up and redevelopment of brownfield sites may encourage additional redevelopment in surrounding areas.

Despite the numerous barriers associated with brownfield redevelopment, productive reuse is becoming increasingly feasible and common.

CLUSTER DEVELOPMENT

In newly developed areas, clustering development into concentrated areas can protect natural habitat. Cluster developments are built at gross densities comparable to conventional developments but leave more open space by reducing lot sizes.[113] Square footage of buildings and residential and commercial capacity may remain the same, but compact clusters reduce the dimensions and geometry of individual lots and shorten road lengths, as shown in Figure 4-2. In the large-lot development, private lots take up the entire area of the subdivision, while in the compact development, private lots take up only a portion of the total land area, allowing more than half the land area to remain in its natural state.

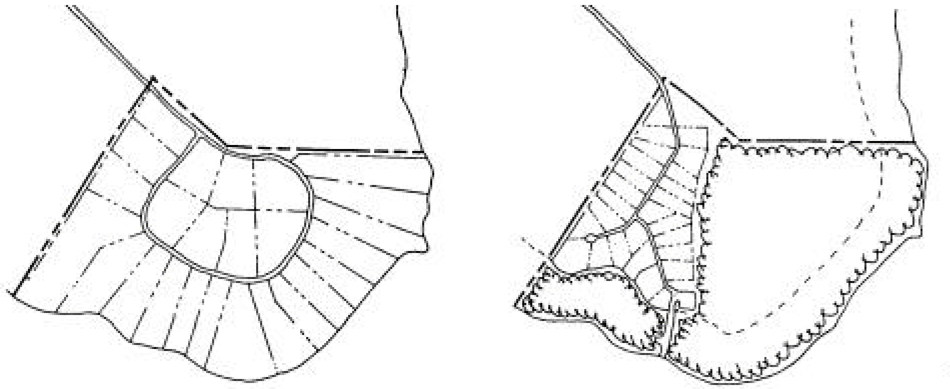
Clustering has a number of advantages in addition to the environmental benefits discussed below. One of the main advantages of cluster development as a conservation tool is that it does not take development potential away from developers, since it changes the arrangement but not the number of units permitted on a property. It also can reduce costs for developers—by requiring fewer miles of roads and, if applicable, water and sewer lines. Furthermore, cluster development does not require large public expenditures to purchase development rights.

[111] Snyder, Robin, EZ/EC EPA Programmatic Contact – Personal communication, 1997

[112] U.S. Conference of Mayors. "Recycling America's Land: A National Report on Brownfields Redevelopment, Volume II." April 1999.

[113] Measures of density depend on the geographic area being examined. Perceptions of density are influenced by many factors, including the design of buildings, site layout, and mix of buildings and green space. Cluster developments are not necessarily perceived as denser than "large lot" developments, especially since they often contain larger tracts of continuous green space.

Figure 4-2: Large-Lot Development Versus Compact Development



Direct Environmental Effects of Compact Development

Compact development has some clear effects on the environment that are a direct result of reduced use of land and the nature of development or redevelopment:

- Reduced disruption and fragmentation of habitat
- Reduced impervious surfaces, resulting in improved water quality
- Clean-up of contaminated waste through brownfield redevelopment, which can reduce water pollution and community environmental risks

REDUCED DISRUPTION AND FRAGMENTATION OF HABITAT

Compact development minimizes land conversion to urban use, and maximizes retained natural habitat. Infill development of all kinds, including brownfields redevelopment, reduces development in more pristine areas since an acre built in town is often at least an acre less that is developed on a greenfield. In addition, the acre developed in an existing urban area usually requires less supporting space, especially roads and parking lots, because it can take advantage of urban transit and existing streets and parking facilities. When existing infrastructure is renovated, infill development can spare natural resources such as the wood and metal that would be needed for the construction of new facilities.

Several studies document losses of fragile lands due to development. Numerous growth management plans also have evaluated how alternative development patterns would affect fragile lands. For example, a study comparing managed growth to a continuation of past trends in Orlando, Florida, projected that managed growth would result in a loss of 20 percent fewer acres of wetlands and floodplains.[114] Studies of alternative development patterns have found that infill and compact

[114] Orlando, Florida. *Urban Area Growth Management Plan.* 1991.

development maximize bird species abundance and diversity compared with a lower-density development of the same number of units spread over the same area.[115]

Several analyses of development impacts on fragile lands have been conducted by Burchell *et al.* for New Jersey; Lexington, Kentucky; the Delaware Estuary; and Michigan.[116] These studies generally find that planned versus trend development would reduce consumption of fragile environmental lands by almost one-fifth. The range of savings varied from 12 to 27 percent, depending on the starting level and location. Similar studies conducted in the San Francisco Bay area by Landis found even larger land savings under a compact growth scenario.[117]

Large-tract, low-density development is usually characterized by plantings of lawns, flowers, shrubs and trees, some of which may offer habitat for certain songbirds and other human-tolerant creatures. But the diversity of native species can be reduced significantly. Large tracts of continuous development associated with cluster development allow preservation of more natural wildlife habitats, less affected by human disturbance.

Compact development allows preservation of open space, including wetlands, farmland, and forests. Maintaining the integrity of wetlands is beneficial to water quality in many ways. (See Chapter 2.) Open space—farmlands and forests—all contribute to the economic, recreational, and ecological value of a community.

REDUCED IMPERVIOUS SURFACES

Infill development accommodates new growth with significantly less impervious surfaces per unit of development than development on undeveloped land does. As shown earlier in Figure 4-1, infill development may result in minimal changes in impervious surfaces by redeveloping parking lots or sites with abandoned buildings into new buildings. The infill site has roughly the same amount of impervious surface area (since parking lots or old rooftops are now new rooftops or other structures) before and after development and little net loss of vegetative cover occurs. Since locating the buildings on undeveloped land would result in new impervious surface cover (i.e. new roads and parking facilities), development at the infill site—that uses existing infrastructure—reduces overall impervious cover. Particularly in comparison to the alternative of building on a greenfield site—undeveloped land at the urban periphery—infill development can reduce impervious surfaces by decreasing the need for new roads and parking lots. Infill also can promote mixed-use development and help support transit usage, discussed below in Sections 4.4 and 4.5.

---

[115] Landis and Pendall, pp. 14-15. Also see: Johnston, Robert and Tomas de la Barra. Comprehensive Regional Modeling for Long-Range Planning: Linking Integrated Urban Models to Geographic Information Systems. Resubmitted to *Transportation Research: A*, 1998.

[116] Burchell, Robert and David Listokin. *Fiscal Studies.* Report to the Governor's Commission on Growth in the Chesapeake Bay Region. Annapolis, MD: 2020 Commission, 1990; Burchell, Robert *et al. Impact Assessment of the New Jersey Interim State Development and Redevelopment Plan.* Trenton, NJ: New Jersey Office of State Planning. 1992.; Burchell, Robert and David Listokin. *The Economic Impacts of Trend versus Vision Growth in the Lexington(Kentucky) Metropolitan Area.* Report prepared for Bluegrass Tomorrow, Lexington, KY: January 1995; Bruchell, Robert and Harvey Moskowitz. *Impact Assessment of DELEP CCMP versus Status Quo on Twelve Municipalities in the DELEP Region.* Report prepared for the Local Governments Committee of the Delaware Estuary Program. Philadelphia, PA: August 1995; Burchell, Robert *et al. Fiscal Impacts of Alternative Land Development Patterns in Michigan: The Costs of Current Development Versus Compact Growth.* Southeast Michigan Regional Council of Governments. 1997.

[117] Landis, John. "Improving Land Use Futures: Applying the California Urban Futures Model." *Journal of the American Planning Association.* 61, 4 (Autumn), 1995. pp. 438-457.

By reducing the need for impervious surfaces, compact development significantly reduces runoff and water pollution. The Center for Urban Policy Research's New Jersey Impact Assessment concluded that the state's compact development plan would produce 40 percent less water pollution than more dispersed development patterns would. The smaller impervious areas would produce 30 percent less runoff, and concentrating this development in areas served by sewers would reduce its impact on the environment by another 10 percent.[118]

In the Chesapeake Bay watershed, a study compared compact and dispersed developments on tracts of land of the same size. Compact development consumed one-third as much land as a dispersed development consumed and included about half as much impervious surface. As a result, the compact development pattern resulted in 43 percent less runoff than the more dispersed development.[119]

Studies show that the impervious surface area of a clustered development site is often 10 to 15 percent less than that of more dispersed development, depending on the size and configuration of each individual project and the original lot size and road network. The greatest reduction in impervious surface area is found when cluster development is applied on large lots. Reductions in impervious surface area are primarily due to the shorter length of road network needed to serve lots.[120] With impervious surfaces, the transportation component—roads, sidewalks, and parking lots—usually constitutes a larger share of impervious cover than rooftops do, both in residential and commercial areas.[121]

Although individual lots in low-density developments are generally more permeable (e.g., lawns, gardens) than higher density developments, the greater total amount of land affected by low-density development (its "footprint"), plus the greater amount of land devoted to roads and parking lots, often results in greater water quality impacts.[122] In addition, low-density residential developments that are served by septic systems, rather than by sewers, can cause nitrogen and pathogen contamination of groundwater and surface waters if they are not properly sited, designed, installed, and maintained.[123]

In addition, less stormwater runoff and pollutant loads are found in cluster developments, due to reductions of impervious cover. By clustering development, 30 to 80 percent of the entire site may be left undisturbed, without reducing the number of lots on a site.[124] Cluster zoning seems to be an effective method of preserving a site's existing landscape character, forested areas, aquatic and terrestrial habitat, and watershed resources, and protecting these sensitive areas from the secondary impacts typically associated with new development.

---

[118] CUPR, and Landis and Pendall. The Real Estate Research Corporation in its 1974 report *The Cost of Sprawl* also found less runoff from compact communities.

[119] Chesapeake Bay Foundation. *A Better Way to Grow*. 1996. p.7.

[120] Schueler, Tom. Environmental Land Planning Series: Site Planning for Urban Stream Protection. Center for Watershed Protection. Publication No. 95708. Washington, DC: Metropolitan Washington Council of Governments, Dec. 1995. p. 61.

[121] Schueler, Tom. Environmental Land Planning Series: Site Planning for Urban Stream Protection. p. 19

[122] Arnold, Chester L. Jr., C. James Gibbons. "Impervious Surface Coverage - The Emergence of a Key Environmental Indicator." *Journal of the American Planning Association*. Volume 62, Number 2, Spring 1996. pp. 243-258.

[123] U.S. Environmental Protection Agency. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*. Chapter 4, Section VII: Onsite Sewage Disposal Systems. 1991.

[124] Schueler, Tom. *Environmental Land Planning Series: Site Planning for Urban Stream Protection*. pp. 63-4.

Conventional urban fringe and suburban development—with large lot sizes, wide streets, and substantial parking—can produce storm runoff almost 50 percent greater than more compact development.[125] Watersheds containing less than 10 percent impervious surface maintain healthy streams, thus providing habitat for sensitive species. At more than 10 percent imperviousness, most watersheds show signs of impairment, and watersheds with more than 30 percent imperviousness are seriously degraded.[126]

A case study of Remlick Hall Farm, a planned subdivision outside Washington, DC, illustrates the importance of development patterns for the watershed.[127] The conventional plan contains a total of 84 residential lots spread out fairly evenly over the site. Assuming a 20-foot road width, approximately 20,250 linear feet of roadway are required to serve the development pattern. Road and driveways alone, under this scenario, comprise about 10.8 acres of new impervious surface area. Including rooftops and other hard surfaces, the total impervious surface cover reaches 26.3 acres. It should be noted that this estimate is quite conservative, considering that conventional road width for suburban developments is actually approximately 32 feet, with 50 feet not uncommon in many new suburban developments.

In contrast, an alternative clustered subdivision plan clusters 52 individual residential sites to preserve farmland, shoreline areas, and forests. Roads are narrowed from 20 to 18 feet in width, while a 53 percent reduction in road length is achieved under the cluster plan. Total impervious surface cover comes to 15.37 acres. Reductions in road infrastructure lead to an estimated $525,000 savings in development costs, as well as major savings in polluted stormwater runoff. Runoff in the conventional subdivision was estimated at 79 acre feet per year, while for the cluster development estimated runoff amounted to only 46 acre feet per year.

Clean-up of Contamination through Brownfields Redevelopment

Past industrial activity bequeathed a legacy of soil and water pollution at formerly industrialized sites. Thousands of these brownfields are located in densely populated, urban areas where residents tend to congregate and children play. Many of these sites are located near rivers and streams, which once served as valuable transportation corridors. The juxtaposition of toxic chemicals, human activity, and sensitive environmental habitats can lead to a range of problems, including compromised human and environmental health.

Even in areas where individual properties are not highly contaminated, the collective effect of a number of mildly contaminated properties in one area can be significant. The clean-up and redevelopment of these sites can lead to substantial environmental and human health benefits. The benefits of brownfields clean-up are dependent on several factors, including the type and severity of contamination; the geographic distribution of the contamination and its proximity to communities, water resources, and biologically sensitive areas; and the clean-up standard employed.

Potential public health benefits of brownfields clean-up include reduced blood lead levels, decreased risk of cancer, and minimized respiratory problems. The encapsulation ("capping") of contamination on brownfields can reduce runoff of toxics into nearby bodies of water. This reduced runoff can lead to improvements in overall water quality and, consequently, improvements in habitat.

[125] Schueler, Tom. *Site Planning for Urban Stream Protection*. Center for Watershed Protection, Silver Spring, Maryland: 1995.

[126] Arnold, Chester L. Jr., C. James Gibbons. "Impervious Surface Coverage - The Emergence of a Key Environmental Indicator." *Journal of the American Planning Association*. Volume 62, Number 2, Spring 1996. p. 246.

[127] Chesapeake Bay Foundation. *A Better Way to Grow*. 1996. pp. 28-31.

Brownfields redevelopment also benefits the environment; removing toxics from the site can result in cleaner soil and improved water quality. In addition, many brownfields are located in urban areas that are already served by existing sewer lines, roads, and other infrastructure. Redeveloping these properties can consequently minimize greenfield development.

> **Efficient Use of Infrastructure**
>
> Existing public infrastructure often is inadequate for serving new low-density development. Frequently, jurisdictions or developers are forced to build new infrastructure, even while existing capacity is underutilized. For example, in metropolitan Minneapolis-St. Paul, school enrollment fell by 81,000 between 1970 and 1990 as the growth in the baby boom population ended. Approximately 130 schools were closed in the central city and immediate suburbs, yet 50 new schools were opened on the metropolitan fringe.[128] Some school closings were probably justified in terms of physical obsolescence. However, many schools were still adequate, meaning that the investment in suburban schools was inefficient.
>
> One advantage of compact development is that it makes more efficient use of infrastructure. Development on infill sites can usually tap into existing infrastructure, including roads, water lines, sewer systems, and schools. Even when new infrastructure is necessary, compact development is still less costly because the community can be adequately served by fewer schools, fewer miles of roads, and fewer new water pipes than a low-density community might require.

Indirect Environmental Effects of Compact Development: Reduced VMT and Emissions

In addition to direct effects on habitat, water quality, and brownfields, compactness in a metropolitan area also affects travel activity. Increased compactness is viewed as a means to reduce vehicle travel because it affects travel demand in the following ways:

- *Trip lengths* – Compactness increases the number of activities accessible within a given area. By locating activities closer together, compact development can reduce travel distances.

- *Mode choice* – Locating activities closer together allows trips to be made by walking and bicycling rather than motor vehicle. In addition, density provides the "mass" needed for mass transit and carpooling. Compactness reduces the costs of providing transit services since shorter trips and trip times allow transit operators to provide the same frequency of service with fewer vehicles and fewer driver hours.[128] As a result, dense areas tend to have greater access to transit, which reduces the relative costs of using transit, and creates greater opportunities for shared rides during commuting.

- *Vehicle ownership* – Dense areas reduce the need for vehicle travel for personal mobility, so people are less likely to own as many vehicles. Dense areas also tend to be associated with limited parking availability and higher cost, as well as increased transit accessibility, all of which are associated with reduced vehicle ownership.

Evidence from Simulation Models

Several regional models of development patterns and transportation investments find that more compact development results in less vehicle travel and fewer emissions of air pollutants than

[128] Parsons Brinckerhoff Quade and Douglass, Inc. *Transit and Urban Form.* "Part I: Transit, Urban Form, and the Built Environment: A Summary of Knowledge." Transit Cooperative Research Program Report 16. Washington, DC: Transportation Research Board, 1996.

dispersed development patterns do.[129] It should be noted that simulation models typically have a margin of error of 5-10 percent and that their results may not be exact in terms of the magnitude of VMT reductions. Taken together, however, these models clearly indicate that compact development does have an effect on VMT, even if consensus on the magnitude of that effect has not been reached.[130]

An analysis of changing allocations of new employment and residential growth over the period 1990 to 2020 in the Puget Sound, Washington, region found that patterns of compact development reduced VMT compared with more dispersed patterns. The regional metropolitan planning organization (MPO) examined three alternative land-use patterns. In the "Major Centers" alternative, new employment growth was concentrated in a few major centers, higher density residential development within walking distance of major transit access points was encouraged, and transit investments were emphasized. The "Multiple Centers" alternative concentrated new employment and housing growth in a relatively large number of centers, with a balance of jobs and housing within each center's area of influence, with high transit emphasis. Finally, the "Dispersed Growth" alternative dispersed employment and housing growth into newly developing areas. The modeling suggested that the Major Centers alternative would reduce VMT by 4 percent from the baseline, and the Multiple Centers alternative would reduce VMT by 1 percent from the baseline. The Dispersed alternative meanwhile was projected to increase VMT 3 percent above the baseline level. [131]

The estimate from the Puget Sound model may understate the benefits of planning that increases regional concentrations of development. Travel impacts were estimated using traditional four-step Urban Transportation Planning System-based models. These traditional models are not sensitive to land use characteristics when predicting vehicle ownership, mode choice, or trip frequency. In addition, these models do not account for non-motorized trips and so fail to account for trips that may be diverted to walking and bicycling in dense urban areas.

The Region 2040 process in Portland, Oregon, employed more sophisticated travel demand models that included sensitivity to land uses. Portland used the models to examine land-use scenarios. In the base case, the urban area expanded by more than half its current size. In the Growing Up alternative, urban growth was maintained inside the current urban growth boundary. The simulations suggest that

---

[129] Four regional simulation studies sponsored by the Federal Highway Administration are profiled in: DeCorla-Souza, Patrick. *The Impacts of Alternative Urban Development Patterns on Highway System Performance.* Presentation to ITE Conference on Transportation Engineering in a New Era. 1992. Although these models predict the future, they are based on the observed behavior of people reacting to real choices. Other simulations that demonstrate a relationship between the compactness of development and travel behavior include: Rodier, Caroline A. and Robert A. Johnston. "Travel, Emissions and Welfare Effects of Travel Demand Management Measures." *Transportation Research*. Record 1598. 1997; Johnston, R.A., and R. Ceerla. "Land Use and Transportation Alternatives," in D. Sperling and S. Shaheen (eds.), *Transportation and Energy*, ICEEE, 1995.

[130] Some researchers have suggested that vehicle hours traveled (VHT) have greater impact on air quality than vehicle miles traveled (VMT) do—a view implying that investments that ease congestion and increase vehicle speed may be more effective in reducing pollution than policies that aim to change land use patterns. Even if the relationship between VHT and air quality is a strong one, research on the relationship between development patterns, vehicle travel, and air quality indicates a direct relationship between VMT and air quality, suggesting that reductions in VMT will lead to improved air quality. In any case, reductions in VMT from additional capacity are likely to be short-term as induced demand returns congestion to its original levels. See Chapter 3.

[131] The Multiple Centers alternative was expected to reduce delay and congestion more than any of the other alternatives, presumably because reduced VMT would more than offset potential increases in local congestion around the activity centers.

the Growing Up scenario would double the regional transit mode split to 6 percent from 3 percent in the base case and would reduce regional VMT by 16.7 percent compared with the base scenario.[132]

REGIONAL LOCATION OF DEVELOPMENT

Recent research indicates that location of development within a metropolitan region is a significant factor in determining the vehicle travel and emissions generated by the development. One recent simulation study compared alternative locations for a proposed development located in the San Diego, CA; Montgomery County, MD; and West Palm Beach, FL, metropolitan areas.[133] Using four-step transportation models and a geographic information system-based analysis tool, the travel and emissions impacts of location in a central infill site in each case versus location at the regional periphery (a greenfield site) were compared.

Four-step transportation models use regional data, including data on local and regional transportation patterns, transportation behavior of residents, and roadway and transit networks, to estimate the number of trips by purpose, mode, and travel times. The first step, trip generation, estimates the total number of trips produced by households and total trips attracted by employment centers, recreational facilities, etc. In the second step, trip distribution, the model allocates trips generated in the first step to specific origin-destination movements. The third step, mode split, determines the share of trips made by mode of travel (driving, transit, walking, etc.). Traffic assignment, the final step, estimates traffic volumes by mode for each link in the transportation system.

In each of the cases modeled, the infill site generated less VMT per capita and reduced emissions of most air pollutants and greenhouse gases, as shown in Table 4-2.

Table 4-2: Travel and Emission Indicators for Infill Site versus Greenfield Site

Case Study	Per capita daily VMT, infill as percentage of greenfield	Emissions, infill as percentage of greenfield
San Diego, CA	52%	CO: 88% NO_X: 58% SO_X: 51% PM: 58% CO_2: 55%
Montgomery County, MD	42%	CO: 52% NO_X: 69% SO_X: 110% PM: 50% CO_2: 54%
West Palm Beach, FL	39%	CO: 75% NO_X: 72% SO_X: 94% PM: 47% CO_2: 50%

Source: Allen, E, Anderson, G, and Schroeer, W, “The Impacts of Infill vs. Greenfield Development: A Comparative Case Study Analysis,” U.S. Environmental Protection Agency, Office of Policy, EPA publication #231-R-99-005, September 2, 1999.

[132] Metro. *Metro 2040 Growth Concept.* Portland, OR: December 8, 1994.

[133] Allen, E, Anderson, G, and Schroeer, W, “The Impacts of Infill vs. Greenfield Development: A Comparative Case Study Analysis,” U.S. Environmental Protection Agency, Office of Policy, EPA publication #231-R-99-005, September 2, 1999.

The sources of the projected emissions reductions differed among the sites. In West Palm Beach, the estimated travel reduction was projected to come from reductions in average trip length, with minimal changes in mode share, due to the relative auto-dependence of the region. In contrast, in Montgomery County, outside Washington, DC, more significant changes in mode share were projected to occur. In this case, the infill site was located near a major transit center, well-served by buses and heavy rail. Although projected road congestion results varied across the case studies, in general the shorter trip distances made up for slower in-town travel speeds and total vehicle trip times were lower for the infill sites.

Despite some potential increases in localized congestion, the three site comparisons suggest that infill development would reduce motor vehicle emissions compared with a greenfield site. Even when infill development cannot take advantage of regional transit, infill tends to reduce air pollution because regionally accessible, centrally located sites require shorter average trip distances than do sites along the regional periphery.

A follow-up study in Atlanta, GA, examined the transportation and emissions impacts of locating a large new development at an infill site formerly occupied by the former Atlantic Steel mill, compared to suburban alternatives.[134] Results suggest that vehicle miles of travel associated with a suburban site could run as much as 52 percent higher, while NO_X emissions could be 81 percent higher than would result from placing the same amount of development at the Atlantic Steel site.

VMT at Infill versus Suburban Development Sites: The Atlantic Steel Case

EPA recently conducted an analysis to determine the transportation and emissions impacts of locating a new development at an infill site (formerly used by Atlantic Steel) compared with several suburban sites. EPA used Atlanta's regional travel model and EPA's MOBILE 5 emissions model to analyze the likely effects of developing each site with the same amount and mix of development. The study concluded that, depending on which suburban site is considered, development on the infill site would result in the following savings:

- VMT savings of 15-52 percent
- NO_X emissions savings of 37-81 percent
- VOC emissions savings of 293-316 percent

Transit share of work trips were projected to be significantly higher at the Atlantic Steel site: 27 percent of work trips made by transit compared with the regional average of approximately 8 percent and the 0-13 percent transit share that would result from development at the suburban alternatives.

Source: U.S. Environmental Protection Agency. November 1, 1999. "Transportation and Environmental Analysis of the Atlantic Steel Development Project." Prepared by Hagler Bailly.

EVIDENCE FROM EMPIRICAL STUDIES

Increasing regional compactness generally involves increasing density in specific targeted areas of the region. A large number of empirical studies (based on comparisons of actual communities) have found that population density is associated with reduced vehicle travel.[135]

[134] U.S. Environmental Protection Agency. "Transportation and Environmental Analysis of the Atlantic Steel Development Project." Prepared by Hagler Bailly, November 1, 1999.

[135] Boyce, D.E., M.C. Romanos, B.N. Janson, P. Prastacos, M. Ferris, and R.W. Eash. *Urban Transportation Energy Accounts.* September 1981.; University of Toronto/York University Joint Program in Transportation, Data Management Group. *The Transportation Tomorrow Survey: Travel Survey Summary for the Greater Toronto Area.* June 1989; Harvey, G. *Relation of Residential Density to VMT per Resident: Oakland.* Metropolitan Transportation Commission. 1990. As cited by Holtzclaw, John. "Explaining Urban Density and Transit Impacts on Auto Use." Presented to State of California Energy Resources Conservation and Development Commission, January 1991.

One well known study by Holtzclaw found that a doubling of residential densities is associated with a decrease of 20 to 30 percent in VMT per capita.[136] His analysis, which used odometer readings from 27 California communities, suggested that residential density and access to public transportation were the two urban form factors that most reliably predict household auto travel behavior. Communities with higher residential density and transit service had the lowest rates of auto ownership and vehicle mileage per capita. Hotzclaw concludes that if a region's population doubles wholly by infill, its vehicle miles of travel will likely increase by only 40 to 60 percent, rather than the 100 percent if the population grew at its present density. Doubling population at low density (as is common in many new suburbs) would likely increase average auto mileage by 150 to 186 percent.

An earlier study, based on data for 105 U.S. metropolitan areas, including the New York City region, also found a correlation between density and mode share, and reported threshold densities at which transit use increases.[137] According to the study, at densities between 1 and 7 dwellings per acre, transit use is minimal, while at densities above 60 dwellings per acre, more than half the trips tend to be made by public transportation. The authors conclude that a minimum density of 7 dwellings per acre appears to be a threshold above which transit use increases sharply.

The highest density areas (e.g., Manhattan) tend to have the most transit service and the tightest parking supply. Recent evidence suggests that the effects of density on household travel behavior are complex and may be more related to characteristics typically associated with dense development than to population density itself. High-density areas tend to be associated with higher parking costs, limited parking, increased transit service, and a mix of land uses. Dense areas also tend to be located toward the center of a metropolitan region rather than on the periphery, and as a result are more accessible. Separating these effects is difficult, so the statistical significance of density in studies that fail to account for other urban form factors may be due in part to the strength of density as a proxy for other difficult-to-observe variables that affect travel behavior.[138]

Population density also tends to be correlated with income, a primary source of differences in travel behavior. A number of studies have attempted to control for income and other household characteristics to identify the independent effects of urban form on travel behavior. These studies generally find that urban form factors do have a discernible effect on travel behavior, even after accounting for household characteristics. For example, a study using data from the 1985 American Housing Survey performed a regression analysis to simultaneously test the effects of various factors on components of travel demand. The study found that vehicle ownership and vehicle mode share decline with neighborhood density. The study, which controlled for household income, household size, adequacy of public transit service, and location within a central city, found that households in an area of high-rise apartments were likely to own 0.42 fewer vehicles than households in a nearby

[136] Holtzclaw, John. "Explaining Urban Density and Transit Impacts on Auto Use." Presented to State of California Energy Resources Conservation and Development Commission, January 1991.

[137] Pushkarev, B. and J. Zupan. *Public Transportation and Land Use Policy.* Bloomington, IN: Indiana University Press, 1977.

[138] For example, a study by Kockelman, K. ("Travel Behavior as a Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from the San Francisco Bay Area." Submission to the 76th Annual Meeting of the Transportation Research Board, January 1997), on the effect of urban form on VMT, automobile ownership, and mode choice found that under all but the vehicle ownership model, the effect of population density was minor after controlling for accessibility. Work by Cambridge Systematics et al.(*Making the Land Use Transportation Air Quality Connection: Model Modifications.* Vol. 4. Prepared for Thousand Friends of Oregon, May 1996) on the Portland regions' travel models also found that residential density was not statistically significant in explaining vehicle ownership; rather, a measure of land use mix, transit accessibility to jobs, and the pedestrian environment were statistically significant in predicting vehicle ownership levels.

neighborhood with single-family detached units. Holding transit service and number of vehicles constant, the probability of automobile commuting was greater in a neighborhood of single-family units or low-rise apartments than in a neighborhood with mid- or high-rise buildings. For example, the probability that a person in a one-car household commutes by transit was almost 30 percent if that household lived in a mid- to high-rise multifamily neighborhood in the central city but was less than 10 percent if that person lived in a mostly single-family neighborhood in the city. [139]

A multivariate regression analysis of mode choice based on travel data from the Puget Sound region found that employment density at trip origins and destinations was significant in predicting the percentage of travel by each mode—more significant, in fact, than population density, after accounting for various control variables such as household type, proportion with a driver's license, and vehicle availability. Modal shifts from single occupant vehicles (SOV) to transit and walking occurred between 20 and 75 employees per acre (causing SOV percentage to drop from about 90 percent to 60 percent), and again with more than 125 employees per acre.[140]

4.2 Design for Reduced Impervious Surfaces and Improved Water Detention

As described in Chapter 2, impervious surfaces have substantial environmental impacts. Impervious surfaces increase peak discharges, pollutant loads, and volumes and velocity of runoff. In areas with large paved surfaces (such as parking lots), high volumes of storm runoff are carried out through storm drains into watercourses, starting soon after the storm begins and continuing during the duration of heavy rainfall. During periods of heavy rainfall, widespread coverage by impervious surfaces can increase the likelihood of serious flash flooding. Absorbing runoff where it originates helps reduce flooding and maintain the water table, wells, and creeks.[141]

Techniques for Reducing Impervious Surfaces and Improving Water Detention

Compact development often minimizes or reduces impervious land area, as described in Section 4.1. Compact development devotes less land area to roads and may also devote fewer acres to buildings if residential or commercial space is built up vertically rather than out horizontally. In addition to compact or cluster development, other variations in built environment designs can reduce impervious cover and improve stormwater infiltration and detention. This section describes those designs.

Techniques for reducing impervious surfaces and improving water detention include:

- Modification of street standards and parking requirements

---

[139] Cervero, Robert. "Mixed Land Uses and Commuting: Evidence from the American Housing Survey." *Transportation Research.* Vol. 30, No. 5, 1996. pp. 361-377.

[140] Frank, L. and G. Pivo. "Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit, and Walking." *Transportation Research Record* 1466, 1994, pp. 44-52.

[141] Thelen, Edmund, and L. Fielding Howe. *Porous Pavement*. The Franklin Institute Press. 1978.

- Use of porous surfaces rather than concrete and asphalt
- Use of open and natural drainage systems
- Landscaping that helps retain soil moisture and conserve water usage

MODIFYING STREET STANDARDS AND PARKING REQUIREMENTS

Surfaces used for transportation infrastructure account for much of the imperviousness at a development site and in urban areas. In areas with dispersed development patterns, for example, roads and parking lots account for as much as 70 percent of the total impervious surface.[142] Impervious areas may be reduced in size, while retaining their utility.

Reduced street widths (to widths typical in many existing communities) have been found to handle traffic and emergency response equipment adequately while significantly reducing the impervious surface area.[143] Reducing street widths provides benefits beyond reduced imperviousness: Less clearing and grading is required, neighborhood traffic is slowed (traffic calming), and construction and maintenance savings accrue.[144] In fact, livability issues, pedestrian-friendliness, and traffic calming are major reasons reduced street widths have been proposed. Portland, Oregon, for example, implemented its Skinny Streets Program in 1991 to reduce street widths and calm traffic. Reducing street widths has helped to preserve livability in communities, lessen stormwater runoff, reduce construction costs of new streets, and limit the impact of grading on slopes.[145]

Existing roads also can be retrofitted to reduce impervious surface area. For example, cul-de-sacs may be retrofitted with vegetated islands designed to retain and infiltrate stormwater, and vegetated grass swales may be used in place of concrete curbing to capture and infiltrate runoff from paved streets.[146] Median islands can be added with grass, flowers, or other vegetation.

Another way to reduce impervious cover is modifying or downsizing parking areas. Studies suggest that parking is greatly oversupplied in both residential and commercial areas. Zoning codes typically require between three and five spaces per 1,000 gross square feet of office building area, with four spaces per 1,000 square feet often used as a rule of thumb.[147] Parking utilization surveys, however, typically show peak demand levels of between two and three spaces per 1,000 square feet.[148] A case

[142] Chesapeake Bay Foundation. *A Better Way to Grow.* 1996. p.6.

[143] Federal Highway Administration. *Flexibility in Highway Design.* 1998; Institute of Transportation Engineers. *Traffic Calming in Practice*. Landor Publishing. 1994.

[144] Schueler, Tom. *Environmental Land Planning Series: Site Planning for Urban Stream Protection*. p.148.

[145] Southworth, Michael, and Eran Ben-Josaph. *Streets and the Shaping of Towns and Cities*. McGraw Hill, 1997. p.34.

[146] See Institute of Transportation Engineers (ITE). *Traditional Neighborhood Development Street Design Guidelines.* (Pub. No. RP-027). 1997. for more information about street designs.

[147] Bergman, David. "Off-Street Parking Requirements." *APA Planning Advisory Service Report 432.* Chicago: American Planning Association. 1991; Gruen Gruen + Associates. *Employment and Parking is Suburban Business Parks: A Pilot Study.* Washington, DC: Urban Land Institute, 1986; Shoup, Donald. "Cashing Out Employer-Paid Parking." FTA-CA-11-0035-92-1. Washington, DC: U.S. Department of Transportation. 1993.

[148] Cervero, Robert. *America's Suburban Centers: The Land Use Transportation Link.* Winchester, MA: Unwin Hyman, 1989; Gruen Gruen + Associates. *Employment and Parking is Suburban Business Parks: A Pilot Study.* Washington, DC: Urban Land Institute, 1986.

study of suburban office buildings in southern California found that parking was oversupplied by a factor of almost two in the typical sites studied—the amount of parking supplied averaged 3.8 spaces per 1,000 square feet, while only 2.1 spaces were used during peak times.[149] Similarly, a recent survey of parking demand at neighborhood commercial lots in Iowa City, Iowa, during the 10-day period before Christmas found that the highest parking occupancy rate was 74 percent; over the count period and all sites, the average occupancy rate was 36 percent. The parking supply at the sites closely matched parking required in the city zoning ordinance. Based on these data, Iowa City reduced its parking requirements for neighborhood commercial lots by 33 percent.[150]

Conventional design standards for parking areas may be revised to reduce the total parking area by several means. Parking standards can be developed for average parking needs rather than for those of a single peak day, such as holiday shopping periods. Research shows that a 10 to 15 percent reduction in total impervious cover can be achieved through either: (a) substituting parking stalls designed for compact cars for 30 percent of all spaces, (b) sharing parking arrangements (in which two businesses agree to share parking spaces, enabled by different peak times for parking demand), and (c) using the smallest allowable dimensions for regular parking stalls. If all three measures are used in combination, a 30 percent reduction in total impervious cover could be attained.[151]

USE OF POROUS SURFACES

Porous surfaces allow the soil to absorb precipitation, reducing runoff and replenishing the water table compared with impervious surfaces. Two types of paved surfaces allow soil to absorb water:

- *Surfaces that allow some precipitation to seep into the soil, such as lattice blocks, bricks set in sand, stones bonded with epoxy, perforated cast concrete slabs, steel grids, and wood slabs or logs (corduroy)* — Surfaces such as lattice blocks and bricks set in sand can be used in place of concrete and asphalt for certain purposes such as sidewalks, walkways, driveways, parking areas, and low-volume roads. They usually do not lend themselves to projects requiring large pavement areas or heavy traffic volumes.[152]

- *A porous pavement, which involves a porous asphalt layer and underground stone reservoir.*[153] — Precipitation passes through the pavement and is collected and stored in stone voids beneath the top surface. The stored water then gradually infiltrates into the subsoil. To the extent that stormwater can be absorbed using porous pavement, stormwater collector systems and treatment plants can be minimized. Pervious pavement may be designed to retain rainfall completely with no runoff or to retain enough precipitation so that runoff flow is delayed and

---

[149] Willson, Richard W. "Sububan Parking Requirements: A Tacit Policy for Automobile Use and Sprawl." *Journal of the American Planning Association.* Vol. 61, No. 1 Winter 1995. pp. 29-42.

[150] Shaw, John. "Minimum Parking Requirements in Midwestern Zoning Ordinances." Paper presented at 76th Annual Meeting of the Transportation Research Board. January 1997.

[151] Schueler, Tom. *Environmental Land Planning Series: Site Planning for Urban Stream Protection*. p.168.

[152] Thelen, E., and L. F. Howe. *Porous Pavement*. The Franklin Institute Press, 1978.

[153] See: Schueler, Thomas, Peter Kumble, and Maureen Heraty, Anacostia Restoration Team, Metropolitan Washington Council of Governments. "A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone." Prepared for U.S. Environmental Protection Agency. March 1992. Field, R., H. Masters, and M. Singer. "Porous Pavement: Research; Development; and Demonstration," *Transportation Engineering Journal of the American Society of Civil Engineers*. Volume 108, Number TE3, May 1982. pp. 244-258.

peak demand on storm sewers is reduced.[154] The use of porous pavement is highly constrained, requiring deep and permeable soils, limited traffic, and suitable adjacent land uses.

Since porous pavements can replicate natural drainage patterns, they are useful for pavement in areas where the natural character of the land should be preserved and in areas where surfacing will be only temporary. If removed later, the land is returned to its natural state.[155]

Over time, porous pavement sites have a high failure rate due to partial or total clogging of the facility that occurs when porous asphalt is clogged by sediment and oil.[156] In addition, porous surfaces should not be exposed to spillage of toxic chemicals and intermediates and so should not be used for highways and heavy-duty streets.[157]

OPEN AND NATURAL DRAINAGE SYSTEMS

In a traditional closed drainage system, stormwater is removed as fast as possible with curbs and gutters, catch basins, underground pipers, culverts, and/or lined channels. An open drainage system, in contrast, detains stormwater for short periods in swales and filter strips, and for longer periods in ponds and wetlands..[158] Extended detention lowers peak discharge rates and gives physical, chemical, and biological processes time to work on pollutants.

Figure 4-3 demonstrates how the inclusion of a detention pond in a new development can spread the discharge period out over time. After development, because of impervious surfaces, the total volume and peak flow of stormwater is much greater than before urbanization. A detention pond does not reduce the amount of runoff but spreads the flow to minimize erosion and the potential for flash flooding. Stormwater is detained in the basin and released at a constant rate.

Open drainage systems can be more cost-effective than storm sewer systems. In addition, wetlands and wet ponds have amenity value that can be captured in the price of adjacent lands.[159]

---

[154] Thelen, E. and L. F. Howe. *Porous Pavement*. The Franklin Institute Press, 1978.

[155] U.S. Environmental Protection Agency, Office of Research and Monitoring. *Investigation of Porous Pavements for Urban Runoff Control.* March, 1972.

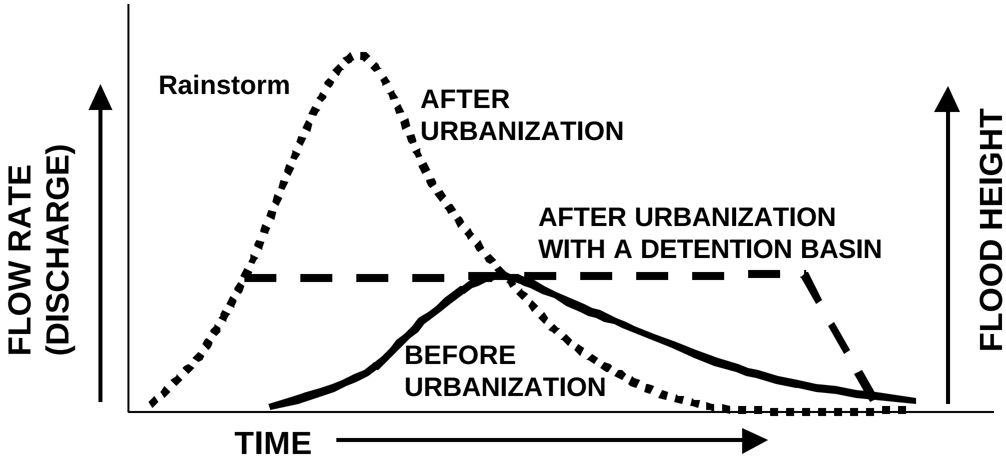
[156] Ways to improve longevity include routine vacuum sweeping, restriction of use to low-intensity parking areas, restrictions on access by heavy trucks, and restrictions of use of de-icing chemicals. Source: Schueler, Thomas, Peter Kumble, and Maureen Heraty, Anacostia Restoration Team, Metropolitan Washington Council of Governments. “A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.” Prepared for U.S. Environmental Protection Agency. March 1992.

[157] Thelen, E. and L. F. Howe. *Porous Pavement*. The Franklin Institute Press, 1978.

[158] Field, R., H. Masters, and M. Singer. “Porous Pavement: Research; Development; and Demonstration.” p.244-258.

[159] Ewing, R. *Best Development Practices.* Joint Center for Environmental and Urban Problems. Florida Atlantic University/Florida International University. May 1995. p.106.

Figure 4-3: Impact of Urbanization and Mitigation on Runoff Rates



Source: Adapted from Harbor, J. "A Practical Method for Estimating the Impact of Land Use Change on Surface Runoff, Groundwater Recharge and Wetland Hydrology. *Journal of the American Planning Association.* 60: 1, Winter 1994. pp. 95-108.

LANDSCAPING

Effective landscaping can retain soil moisture and conserve water usage in any developed area. Natural vegetation can reduce runoff, provide habitat for birds and other native wildlife, and reduce water consumption. Trees, shrubs, and other plants can help reduce runoff by absorbing precipitation. Locally adapted plants with large leaf surfaces and deep fibrous root systems absorb the most water.[160]

Conversely, conversion of woodlands and undisturbed land affects storm runoff and groundwater discharge. An 11 to 100 percent loss of natural groundwater recharge, along with an 11- to 19-fold increase in stormwater, occurred at one site when its woodlands were converted to residential and commercial land use.[161]

Landscaping in suburban areas can reduce water usage itself. All development requires water, but low-density development tends to require more water for lawns and gardens. Adequate water supply is an important issue in some regions of the country. Development in several states—most notably six of the eight mountain states—is leading to net water supply depletion.[162] A water-conserving landscaping scheme applies mulches instead of turf to retain soil moisture. Vegetation species used in xeriscaping typically require minimal irrigation and less maintenance. Less maintenance implies fewer air emissions from lawn and garden equipment.

---

[160] Ewing, R. *Best Development Practices.* p.114.

[161] Harbor, J. M. "A Practical Method for Estimating the Impact of Land Use Change on Surface Runoff, Groundwater Recharge, and Wetland Hydrology." *Journal of the American Planning Association.* Vol. 60, 1994. p. 95-108.

[162] U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation. *Natural Resources for the 21st Century: An Evaluation of the Effects of Land Use on Environmental Quality*. Washington, DC: June, 1989. p. 61.

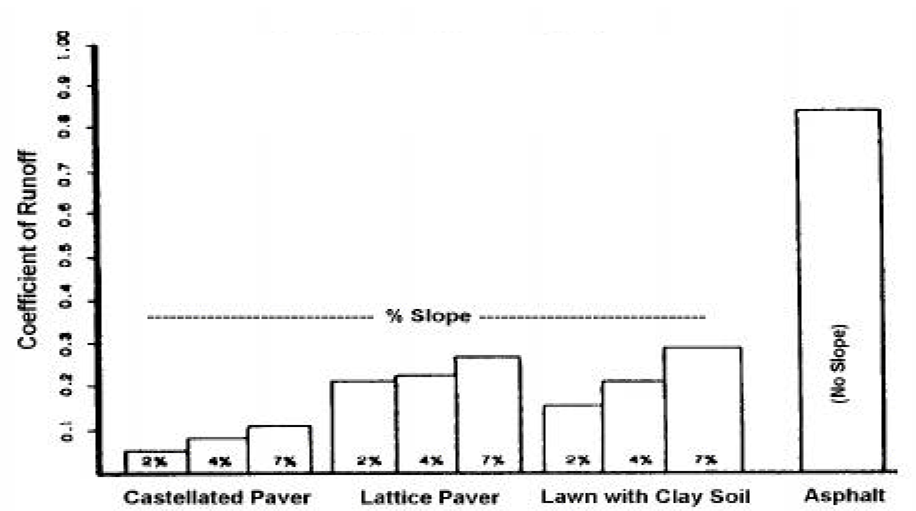
Direct Environmental Effects of Reducing Impervious Surfaces and Improving Water Detention

Reducing impervious surfaces and improving water detention can have positive effects on hydrology and water quality, plus vegetation and wildlife.

Large parking lots are major contributors to runoff. A 1-acre parking lot produces 16 times as much runoff as does a 1-acre meadow.[163] Parking lot runoff usually has a more detrimental effect on water quality than runoff from most other impervious cover because parking lots tend to be heavily polluted by leaks and drips from vehicles. Because smaller parking lots also decrease vehicle travel, decreasing the size of parking lots can reduce both runoff and associated pollutant loads.[164]

Using porous surfaces is another strategy for reducing runoff and increasing groundwater recharge. In Figure 4-4, runoff from three types of pervious pavement are compared with an asphalt surface. All three pervious surfaces are shown to exhibit much lower coefficients of runoff than asphalt.[165]

Figure 4-4: Comparison of Runoff from Various Surfaces



Source: Adapted from Day, G.E. "Investigation of Concrete Grid Pavements." In Downing, W.L. *Proceedings of the National Conference on Urban Erosion and Sediment Control: Institutions and Technology.* Great Lakes National Program Office, U.S. Environmental Protection Agency. Chicago. 1980, pp. 127-136. As presented in Ewing, R. *Best Development Practices: Doing the Right Thing and Making Money at the Same Time.* Prepared for the Florida Department of Community Affairs. May 1995.

---

[163] Chesapeake Bay Foundation. *A Better Way to Grow.* 1996. p.4.

[164] Higgins, Thomas, K.T. Analytics, Inc. "Parking Management and Traffic Mitigation in Six Cities: Implications for Local Policy." Paper presented to Transportation Research Board, January 1989. U.S. Department of Transportation. *Implementing Effective Travel Demand Management Measures: Inventory of Measures and Synthesis of Experience.* September 1993. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. *Transportation Control Measure Information Documents.* March 1992.

[165] Ewing, R. *Best Development Practices.* p.104.

Porous pavement systems also have been shown to have high removal rates for sediment, nutrients, organic matter, and trace metals. The majority of the removal occurs as the result of the exfiltration of runoff into the subsoil and subsequent absorption or straining of pollutants within the subsoil.[166]

Open and natural drainage systems also can serve as effective pollutant removers. At one site near Orlando, Florida, an alternative stormwater treatment system of catch basins, wet ponds, and marsh areas was established. During larger storm events for 1993-94, pollutant levels were measured for stormwater flowing into, through, and out of the system. Table 4-3 shows average reductions in pollutant concentrations found with the natural drainage system:[167]

Table 4-3: Pollutant Removal Efficiencies, Lake Greenwood Stormwater Treatment System, Florida

Pollutant	Removal Efficiency
Total Solids	91%
Total Lead	81%
Total Zinc	59%
Total Phosphorous	85%
Total Nitrogen	64%

Source: McCann, K. and L. Olson. Greenwood Urban Wetland Treatment Effectiveness. Florida Department of Environmental Protection. Tallahassee, FL, 1994, pp. 17 and 28. Cited in Ewing, Reid. *Best Development Practices: Doing the Right Thing and Making Money at the Same Time*. Prepared for the Florida Department of Community Affairs. May 1995.

The natural drainage system proved effective in significantly reducing pollutant loads in runoff, with reductions of 59 to 91 percent in pollutant levels.

When properly designed, open and natural drainage systems also can provide valuable habitat areas. The more natural the drainage system, the more valuable it will be for wildlife and water quality. Vegetated swales, stormwater ponds, marshes, and wetlands can serve as habitat for many creatures, including wetland birds and other waterfowl.[168]

Porous pavement can be beneficial to native vegetation and wildlife as well, by allowing roadside vegetation to receive the water it needs to survive and grow. Porous pavement is particularly beneficial to water-starved street trees in urban areas.[169]

---

[166] Schueler, Thomas, Peter Kumble, and Maureen Heraty, Anacostia Restoration Team, Metropolitan Washington Council of Governments. “A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone.” Prepared for U.S. Environmental Protection Agency. March 1992.

[167] Ewing, R. *Best Development Practices.* p.105.

[168] Franklin, T.M. “Use of Urban Stormwater Control Impoundments by Wetland Birds.” *Wilson Bulletin.* Vol. 97, 1985, pp. 120-122; Adams, L.W. *et al.* “Design Considerations for Wildlife in Urban Stormwater Management.” *Transactions of the 51st North American Wildlife and Natural Resources Conference,* 1986, pp. 249-259.

[169] U.S. Environmental Protection Agency, Office of Research and Monitoring. *Investigation of Porous Pavements for Urban Runoff Control.* March, 1972.

4.3 DESIGN FOR SAFEGUARDING SENSITIVE AREAS

Minimizing environmental impacts not only involves decisions about how much to build, but also where to build. Some locations lessen direct effects on habitat and water resources. Minimizing harmful environmental impacts may mean forestalling development in sensitive natural areas such as streams, wetlands, floodplains, steep slopes, mature forests, swamps, critical habitat areas, and shorelines.

Environmentally sensitive areas have benefits beyond scenic value. Riparian buffers along rivers and streams, for example, are often critical habitats. One study indicates that nearly 70 percent of all vertebrate species use riparian areas in some significant way during their life cycles.[170]

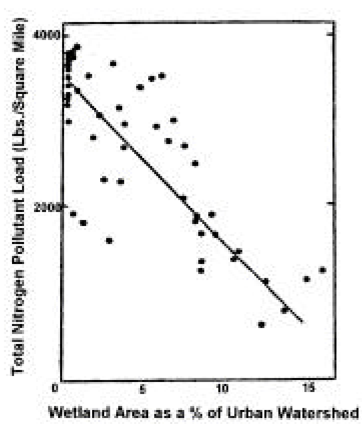
Techniques for Safeguarding Environmentally Sensitive Areas

Different communities have different types of environmental assets that they want to protect, so techniques for safeguarding environmentally sensitive areas vary across communities. Three of the most commonly used techniques are wetlands protection, establishing riparian buffers, and use of greenbelts.

WETLANDS PROTECTION

Wetlands are an especially valuable resource. Reductions in wetland area as a percentage of an urban watershed are associated with increases in water pollutant loads, as shown in Figure 4-5. Each point on the graph represents a watershed, showing the pollutant load in relation to wetland area as a percentage of the watershed. Total nitrogen pollutant loads increase as the percentage of wetlands decreases.

Figure 4-5: Increase In Pollutant Load with Loss of Wetland Area



Source: Adapted from Oberts, G.L. "Impacts of Wetlands on Watershed Water Quality." In B. Richardson (ed.), *Selected Proceedings of the Midwest Conference on Wetland Values and Management.* Freshwater Society, Navarre, MD: 1981, pp. 213-226. Cited in Ewing, R. *Best Development Practices: Doing the Right Thing and Making Money at the Same Time.* Prepared for the Florida Department of Community Affairs. May 1995, p. 96.

Although development of undisturbed areas inevitably will persist to some degree, well-designed communities and infrastructure can protect the most sensitive natural areas and minimize adverse

[170] Ewing, R. *Best Development Practices.* p.95.

impacts. The best means of safeguarding sensitive areas is simple avoidance. Given the same site and development program, new development can stand back from wetlands or encroach into them. When encroachment on wetlands is unavoidable, cautious planning can minimize negative impacts.

RIPARIAN BUFFERS

Protection of sensitive areas can be improved by establishing buffers. Riparian buffers between land and water along shorelines, around wetlands, and adjacent to tidal guts, creeks, and streams may be applied systematically to create a "green corridor" along the banks of rivers or streams. Three primary aquatic areas qualify for buffers: the shoreline of a lake or estuary, a delineated wetland, or a stream channel.

Buffer systems are typically inexpensive and simple to implement. Often a prescribed distance, usually between 25 and 100 feet from a water's edge or mean high tide mark, is adopted by a local jurisdiction as the setback standard for a protected buffer area. Typically, construction, grading, dredging, and any other form of environmental disturbance are prohibited or severely restricted within the buffer area.[171] Usually only low-intensity uses such as recreation are allowed. Natural and cultural characteristics of the river basin determine correct buffer width. Relevant natural factors include seasonal water levels, the nature and extent of adjacent wetlands and floodplains, the steepness of adjacent topography, the nature of riparian vegetation, and the wildlife values of adjacent lands. Relevant cultural factors include riverfront parcel size and depth, traditional use patterns of the river and its adjacent lands, and existing development along the river.

[171] Mantell, M. A., S. F. Harper, and L. Propst. *Creating Successful Communities: A Guidebook to Growth Management Strategies.* The Conservation Foundation. Island Press, 1990.

Multiple Species Conservation Plan, County of San Diego, California: A Case Study

On March 18, 1998, the San Diego City Council approved a Multiple Species Conservation Plan (MSCP), a subregional development and conservation plan under California's Natural Communities Conservation Program. The MSCP covers approximately 900 square miles in San Diego County and includes goals and criteria to conserve the habitats of more than 85 species in the area. The regional plan designates those areas that may be developed and those that must be conserved. To the greatest extent possible, the plan tries to use public lands to satisfy required conservation levels.

Before the development of the MSCP, non-federal property owners wishing to build on or alter their land in ways that might result in the incidental "take," or harm, of a listed species had to obtain an Incidental Take Permit (ITP) from the U.S. Fish and Wildlife Service. In order to obtain an ITP, the property owner had to develop a Habitat Conservation Plan (HCP) outlining ways in which the negative effects on the listed species would be offset.

Because the new MSCP functions as a Habitat Conservation Plan for the region, it allows issuance of all ITPs for covered species. Political jurisdictions develop their own plans consistent with the MSCP, then obtain ITPs for the plan area. The jurisdictional possession of ITPs for the entire sub-area eliminates the need for private citizens to develop HCPs for activities that are already taken into consideration under the MSCP and, in most cases, the Environmental Impact Report for the entire MSCP will satisfy the requirements for project-specific Environmental Impact Reports.

A regional conservation plan such as the MSCP is advantageous to all involved: Critical species and habitats are protected, and private landowners benefit from a simplified development process.

Sources: Merrick, J. (1998). The San Diego Multiple Species Conservation Plan. In *Improving Integrated Natural Resource Planning: Habitat Conservation Plans*, [Web page]. National Center for Environmental Decision-making Research. Available: http://www.ncedr.org/casestudies/hcp/sandiego.htm [1998, October 14].; County of San Diego, Department of Land Use and Planning. http://www.co.san-diego.ca.us/cnty/cntydepts/landuse/planning/mscp/ ; US Fish and Wildlife Service [Web page] http://endangered.fws.gov/hcp/index.html

GREENBELTS

Greenbelts are areas of preserved open space, or areas of significantly reduced development, designed as buffers to protect areas of land or water resources from development impacts. The preservation of patches of high-quality habitat, connected by wildlife corridors, can preserve wildlife and ecosystems even in areas with significant adjoining development. Wildlife corridors can serve as "land bridges" between "habitat islands" and as dwelling habitats in their own right.[172]

Greenbelts also may be used to preserve agricultural land, recreational areas, and natural resources in close proximity to a town or city. Greenbelts are achieved through zoning, creative development planning, or land acquisition, or a combination of these approaches. Since greenbelts are usually considered amenities, they have the potential to increase property values of adjacent land.

Direct Environmental Effects of Protecting Environmentally Sensitive Areas

Buffers, greenbelts, and other preservation tools have numerous environmental benefits. They can protect watersheds, guard animal habitats, and preserve existing vegetation. For example, buffers may reduce watershed imperviousness (by preventing development on land along the streambed), provide effective flood insurance (by keeping structures away from floodplains), protect stream temperatures

[172] Ewing, R. *Best Development Practices.* p. 95.

(with their canopies), stabilize streambanks, and protect against streambed erosion (since trees and vegetation are more resistant to bank erosion than grass is). Buffers can protect sensitive areas from physical encroachment and scenic degradation, and preserve wildlife habitat for terrestrial and aquatic animals.[173]

Since buffers are able to intercept and absorb runoff before it reaches the water resource, they have the potential to improve water quality by reducing runoff volume. Buffers act as a sort of natural scrubber, preventing excess nutrients and pollutants from entering waterways and wetland areas.[174] A buffer's ability to reduce pollutant loads depends on runoff velocity and site conditions such as soil, vegetation, buffer size, and slope.[175]

4.4 MIXED LAND USES

Standard zoning separates uses into distinct zones for residential, commercial, or industrial uses. In contrast, mixed-use development locates land uses with complementary functions close together. Complementary uses may include housing, shopping, offices, restaurants, and movie theaters—any destinations that people travel to on a regular basis.

Techniques for/ Types of Mixed Use Development

Mixed-use development can occur on a number of levels: site-specific, neighborhood, or subregional. On a site-specific basis, individual buildings or complexes can be designed to incorporate a variety of uses. For example, a single building might include apartments, offices, and retail. At the neighborhood level, mixed-use development refers to the arrangement of different uses across several blocks or acres of land so that they are not physically isolated from one another. Finally, at the subregional level, mixed-use often aims to balance jobs and housing so that people have the opportunity to live closer to their places of employment.

Direct Environmental Effects of Mixed-Use Development: Habitat and Water Quality

Mixing land uses can have direct effects on habitat loss and runoff since mixed-use developments have the potential to use surface parking lots and transportation infrastructure more efficiently, requiring less pavement. When office buildings also contain retail shops and restaurants, the infrastructure that supports the building—the roads and parking lots—is in use for more of the day. Office traffic arrives during rush hour and uses the parking lot during the day. That parking can be used in the evenings for restaurant and theater traffic. The alternative is two sets of roads and parking lots—one set serving office buildings and another that serves retail and entertainment areas.

---

[173] Schueler, Tom. *Environmental Land Planning Series: Site Planning for Urban Stream Protection*. Center for Watershed Protection. Publication No. 95708. Washington, DC: Metropolitan Washington Council of Governments, December 1995. p. 90.

[174] Center for Watershed Protection. *Blueprint to Protect Coastal Water Quality*. Land Ethics, Inc. Section 4-3.

[175] Jones, H., L..M. Maureen Heraty, and B. Jordan. *Environmental Land Planning Series: Riparian Buffer Strategies for Urban Watersheds.* Urban Watershed Planning Section. Washington, DC: Department of Environmental Programs. Metropolitan Washington Council of Governments. December, 1995. p.3.

Indirect Environmental Effects of Mixed-Use Development: Reductions in Vehicle Travel

At any level—building, neighborhood, or regional—the travel-related environmental effect of mixing uses is similar. By encouraging people to walk, bike, and use transit rather than drive, mixed-use development patterns reduce VMT. Reductions in VMT lead to decreases in automobile emissions, thereby improving regional air quality.

Mixing land uses can reduce VMT in several ways:

- *Trip lengths* – By locating activities closer together, a mix of land uses can minimize travel distances and improve access to employment, services, or recreational opportunities.

- *Mode choice* – Locating activities closer together allows trips to be made by walking and bicycling rather than by driving motor vehicles and increases the opportunity for non-auto trip chaining. Individuals can drive to one destination, for example, and then walk to others once they have parked their car.

- *Vehicle ownership* – Access to employment and shopping by walking and bicycing reduces the need to own a motor vehicle for personal mobility.

Land use mixing may influence travel demand in a number of ways, but its greatest impact is thought to be on mode choice.[176] Mixed land use areas influence mode choice by enhancing the relative convenience of non-auto modes. For example, mixing employment and residential uses may reduce commute distances, thus making walking, bicycling, and transit more competitive with auto travel in terms of time. Alternatively, mixing employment or residential centers with retail and commercial establishments may increase the attractiveness of alternatives to single occupant vehicle driving by reducing the need for a vehicle to accomplish mid-day tasks or errands typically completed on the way to or from work.

Evidence of the effects of land use mixing on travel patterns is organized around three geographic levels of mixing:

- Mix (or balance) of jobs and housing within subregions

- Mix of uses within neighborhoods or communities

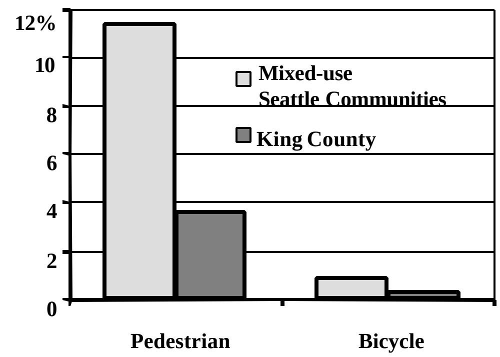
- Mix of uses at employment centers.

[176] Cervero, R. “Mixed Land Uses and Commuting: Evidence from the American Housing Survey.” *Transportation Research.* Volume 30, Number 5. 1996. p. 363.

MIXING USES WITHIN RESIDENTIAL NEIGHBORHOODS

Several empirical studies have found that places with a mix of land uses and retail services located within walking distance of residences have higher levels of pedestrian travel and fewer vehicle trips compared with solely residential neighborhoods. For example, a comparison of travel diaries of residents in three Seattle mixed-use neighborhoods with those of residents of suburban, single-use neighborhoods in surrounding King County found that the average trip length was significantly lower in the mixed-use neighborhoods. In most cases, the average distance per trip driven by residents of mixed-use neighborhoods was half that of those living in the single-use neighborhood. For work trips, nonmotorized mode share was significantly higher in mixed-use communities—12.2 percent of trips in mixed-use Seattle neighborhoods compared with 3.9 percent of trips in the comparison communities, as Figure 4-7 shows.[177] The higher numbers of auto trips lead to increased emissions. In the most compact mixed-use communities, the share of weekday trips by walking was as high as 18.1 percent.

Figure 4-7: Mode Share for Work Trips in Seattle Mixed-Use Communities and King County



These findings reflect the fact that in mixed-use communities, more destinations are located near each other. In the survey, respondents of mixed-use Seattle communities reported making more than three times as many weekday trips to destinations within a mile of home as King County residents did. The results are summarized in Table 4-4.

Table 4-4: Percent of Weekday Trip Stops by Distance from Household

Location	Distance of Stops from Household Location		
	1.0 miles	1.5 miles	2.0 miles
Mixed Use	17.4%	25.4%	38.7%
King County	4.5%	11.6%	18.2%

An analysis of American Housing Survey data demonstrates that locating retail activities within a short walk of homes is associated with increased levels of commuting by mass transit, walking, and bicycling. Households with grocery stores and other consumer services within 300 feet—generally a one- or two-block distance—of one's residence were less likely to commute by automobile,

[177] Rutherford, G.S., E. McCormack, and M. Wilkinson. "Travel Impacts of Urban Form: Implications from an Analysis of Two Seattle Area Travel Diaries." TMIP Conference on Urban Design, Telecommuting, and Travel Behavior. October 27-30, 1996. The counter to this argument is that people self-select into areas that support their preferred behaviors. Those who prefer to avoid driving choose homes where they do not have to drive. Those who like driving choose suburbs. The implication that the latter group would drive at the rates they do now, even if for some reason they lived in dense, mixed-use, transit-served communities.

controlling for such other factors as land density, number of automobiles per household, and adequacy of public transit services.[178]

Travel model improvements undertaken in the Portland region found that one measure of land-use mix—the number of retail jobs in a transportation analysis zone—was statistically significant in explaining residential automobile ownership and the choice between motorized and nonmotorized modes. The addition of a measure of employment density into the auto-ownership and mode choice models improved the fit of the models to actual survey data.[179]

Locating parks and recreational facilities, small shops or grocery stores, schools, and religious institutions within residential neighborhoods also has been found to reduce VMT (and, therefore, emissions), even in places that are automobile-oriented. A comparison of work and nonwork travel among residents of six communities in Palm Beach County, Florida, found that the presence of shopping, recreation, and school facilities within communities can lower vehicle hours traveled per capita significantly even when transit is not widely available.[180] This study suggests that locating facilities and services *in* communities reduces vehicle travel even in locations where the automobile for all intents is the only primary mode of transportation. Increased accessibility within the region also was associated with reduced vehicle hours of travel. Given that the presence of additional uses in a neighborhood cannot directly increase speeds, the decrease in VHT must be a function of shorter trips, which would, in turn, lead to decreased emissions.[181]

MIXING USES AT EMPLOYMENT AND COMMERCIAL CENTERS

Just as improving the mix of uses in residential communities has been shown to reduce vehicle travel, mixing uses within commercial and employment areas also has been identified as a way to increase transit share and reduce vehicle use. Locating stores close to workplaces makes stores accessible by foot during the workday and allows efficient linking of trips even if the stores are distant from the employees' homes. As a result, employees may substitute mid-day pedestrian errands for after-work, vehicle-based trips. The presence of restaurants, shops, and consumer services at or near employment sites encourages transit use and ridesharing since many workers no longer need to have a car available for mid-day or after-work trips.

Pedestrian connections are an important component in mixing land uses. Many larger commercial developments contain both office space and commercial development but still require a car to get around. These developments do not function as a mixed-use area, because most of the commercial

[178] Cervero, R. "Mixed Land Uses and Commuting: Evidence from the American Housing Survey." *Transportation Research.* Vol. 30, No. 5, 1996. pp. 361-377. Cervero controlled for such factors as residential densities and vehicle ownership levels. His analysis also found that having retail shops beyond 300 feet yet within 1 mile of residences tended to encourage auto-commuting, perhaps because of the ability to link work and shop trips efficiently by car. In any case, the mixed-use neighborhoods were associated with shorter commuting distances.

[179] Cambridge Systematics *et al. Making the Land Use Transportation Air Quality Connection: Model Modifications.* Vol. 4. Prepared for Thousand Friends of Oregon. May 1996.

[180] VMT could not be easily derived from the travel survey data files. However, differences in VMT are almost certainly even more pronounced than differences in VHT are since vehicle travel speeds are highest in areas of high VHT. Ewing, R., P. Haliyur, and G. W. Page. "Getting Around a Traditional City, a Suburban Planned Unit Development, and Everything in Between." *Transportation Research Record 1466.* 1994. pp. 53-62.

[181] Again, lower VHT is sometimes the product of higher vehicle speeds, which, if high enough, can increase emissions. But the decrease in VHT in this study must be from decreased trip lengths.

development is in large malls and shopping centers separated from office developments by wide highways lacking sidewalks.

Several studies have demonstrated that developing a mix of uses at employment and commercial centers reduces the portion of trips made by personal vehicles and increases rates of transit use. In particular, several studies of suburban activity centers have found that office developments that have a mix of uses, even those in auto-oriented locations, have lower vehicle trip rates. A study of 57 large U.S. office developments found that each 10 percent increase in floor space devoted to retail-commercial uses was associated with a 3 percent increase in the share of transit and ridesharing commutes.[182] A follow-up survey of commuting to six large suburban activity centers, including Perimeter Center north of Atlanta and Tyson's Corner in the Washington, DC, area, found the existence of a retail component within a suburban office building was associated with an 8 percent reduction in vehicle-trip rates per employee. Buildings with mixed uses averaged 3 percent more commutes by transit than buildings containing only offices.[183] Enabling workers to switch from automobile to transit commutes decreases VMT and associated emissions.

A study of suburban centers in southern California suggested that at sites with travel demand management (TDM) incentives, areas with a substantially mixed land use had more than double the transit mode share of other site—6.4 percent share in centers with a substantial mix compared with 2.9 percent in those with a limited mix. [184] In locations without demand management, the presence of mixed land uses increased commute trips by transit from 3.6 to 5.5 percent. People also bicycled and walked more in areas with a substantial mix of uses.[185]

The same study also found that having convenience-oriented services, such as restaurants, banks, child care centers, dry cleaners, drugstores, and post offices, located near work sites significantly increased the portion of commuters using transit. Among sites using financial incentives, locations with convenience services had more than double the transit share of sites with limited services nearby—7.1 percent in sites with convenience services compared with 3.4 percent in areas without convenience services. Employment sites with a substantial level of nearby convenience services also had higher rates of bicycling and walking than other sites did.

In a study of mixed-use sites in Colorado, the Colorado/Wyoming Section Technical Committee of the Institute of Transportation Engineers (ITE) found that average trip rates for individual shops in retail plazas and other mixed commercial settings were below the mean rates for freestanding stores published in ITE's Trip Generation (1991) manual.[186] The committee recommended adjusting trip rates downward by 2.5 percent to reflect the higher likelihood of linked walk trips, instead of separate vehicle trips

---

[182] Cervero, R. "Land Use Mixing and Suburban Mobility." *Transportation Quarterly.* Volume 42, 1988. p. 429-446.

[183] Cervero, R. "Land Uses and Travel at Suburban Activity Centers." *Transportation Quarterly.* Volume 45, 1988. p. 479-491.

[184] U.S. Department of Transportation, Travel Model Improvement Program. "The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior." Prepared by Cambridge Systematics, November, 1994.

[185] The study also found that in locations with a substantial mix of uses, transit use increases with the introduction of financial incentives for transportation demand management. On the other hand, in areas with a limited land use mix, transportation demand management incentives appeared to shift trips from transit to rideshare, resulting in a lower transit mode share than if no incentives were offered.

[186] Colorado/Wyoming Section Technical Committee, Institute of Transportation Engineers. "Trip Generation for Mixed Use Developments." *ITE Journal*, Volume 57, 1987. p. 27-29.

between establishments in mixed-use settings. Replacing short car trips with walk trips would decrease the total number of auto trips, and thus the emissions levels, generated at these settings.

SUBREGIONAL BALANCE OF JOBS AND HOUSING

On a larger scale, promoting a "balance" of employment and housing at the subregional level has been identified as a way to reduce commute distances. The idea is that if people could live closer to their employment sites, they would do so to reduce commute time and costs. Balanced communities offer affordable, high-quality housing that is close enough to employment sites that residents can avoid commuting long distances on congested highways to get to work.

Measuring the jobs-housing balance is somewhat difficult since there is no nonarbitrary geographic scale at which to assess the match or mismatch. Regions as a whole are by definition "balanced," while individual blocks or neighborhoods almost never are. Considerable debate continues over the effectiveness of the jobs and housing balance as a measure for reducing congestion or improving air quality. On the one hand, increasing the availability of housing near employment centers provides individuals with the option to live closer to work. On the other hand, some researchers have found little evidence suggesting that the balance or mismatch of jobs and housing alone has had a significant effect on commuting patterns.[187]

Those promoting a jobs-housing balance suggest that increasing the housing opportunities near major employment centers allows workers to locate closer to their jobs and may reduce traffic. A number of studies suggest that this effect may occur. For example, an analysis in Toronto suggested that the effect of substantial new office construction between 1975 and 1988 on peak-hour work trips was offset by increased housing occupied by people working in the central city. [188] Another study based on 1980-1990 U.S. journey-to-work data showed that "balanced" cities averaged 12 to 15 percent less work-trip VMT per employed residents than did "job-surplus" cities.[189]

A simulation of regional development patterns in the Washington, DC area found that an alternative that promoted a closer balance between employment and housing growth within the region resulted in greater transit use and shorter average trip lengths due to greater proximity of housing to jobs. Vehicle trips per household were reduced by 5.0 percent. When combined with a 4.5 percent reduction in average trip length, the balanced alternative resulted in 9.2 percent less VMT per household.[190] Reducing vehicle trips and VMT can lead to similar reductions in vehicle emissions.

A number of studies have found that accessibility to jobs is one of a number of determinants of vehicle ownership. An analysis of travel in the San Francisco region found that controlling for other

[187] From the analysis of the location of jobs and housing in a number of regions, Giuliano, G. and K. Small ("Is the Journey to Work Explained by Urban Structure?" University of California Transportation Center. Working Paper, No. 107, June 1992) and Genevieve Giuliano and Kenneth Small ("Subcenters in the Los Angels Region." *Journal of Regional Science and Urban Economics.* Vol. 21, pp. 163-182) concluded that a jobs-housing balance has a statistically significant but not very large influence on actual commuting times and therefore that policies attempting to alter the jobs-housing balance alone are likely to have little impact on commute patterns.

[188] Nowlan and Stewart. "Downtown Population Growth and Commuting Trips." *Journal of the American Planning Association.* Vol. 57(2), 1991. pp. 165-182.

[189] Cervero, Robert. "Jobs-Housing Revisited." *Journal of American Planning Association*. 1996.

[190] Metropolitan Washington Council of Governments. "Transportation Demand Impacts of Alternative Land Use Scenarios." May 31, 1991.

land use and household factors, a doubling in accessibility results in a 7.5 percent decrease in the number of vehicles owned.[191] Efforts to incorporate land use factors into the vehicle ownership model of Portland, Oregon, also suggest that the number of retail jobs in a transportation analysis zone is statistically significant in helping to explain residential automobile ownership.[192] As the number of retail jobs in a zone increases, vehicle ownership per household decreases, holding other factors like household income and size constant. The possibility of using transit to get to work is also found to reduce vehicle ownership rates, while residential density does not prove to be important on its own.

By definition, "accessible" areas require shorter travel distances than "nonaccessible" areas. However, a strategy for improving the balance of housing and jobs reduces commute trip distances only if jobs-housing imbalances are a major source of long commute lengths and if people make location decisions at least in part on the basis of commute distances. Some researchers argue that a jobs-housing imbalance has little to do with long commutes.[193] There are many reasons why the journey to work might play only a limited role in residential location decisions. Rapid job turnover and high moving costs may cause households to seek accessibility to an array of future jobs, two-worker households may be unable to find jobs close together, and the importance of nonwork trips may reduce the importance of travel time to work. In addition, other neighborhood characteristics, such as crime, school quality, and taxes, might overshadow time and travel costs.

The degree to which different factors affect location decisions is widely debated and may vary in different circumstances. An analysis of travel and housing location in the Minneapolis region found that if one is considering communities representing commute differences of only 5 minutes, local service attributes and housing characteristics dominate residential choice. However, within an entire 60-minute commute shed, commute time was found to be overwhelmingly the best explanatory variable of household location choice.[194] The analysis suggested that jobs-housing balances and imbalances were particularly significant influences on residential location decisions for low- to moderate-income single worker households. A recent poll of San Francisco Bay area residents found that given a choice between houses that cost the same, 60 percent would opt for a smaller home closer to where they work rather than a larger one farther away.[195]

Although various factors might prevent households from locating close to their places of work, a jobs-housing balance provides more opportunities for living closer to work than a land-use pattern in which employment and residential areas are widely separated. As a result, communities that provide that balance are likely to require shorter commutes, which generate fewer VMT and associated emissions.

---

[191] Kockelman, K. "Travel Behavior as a Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from the San Francisco Bay Area." Submission to the 76th Annual Meeting of the Transportation Research Board. January 1997.

[192] Cambridge Systematics *et al. Making the Land Use Transportation Air Quality Connection: Model Modifications.* Vol. 4. Prepared for Thousand Friends of Oregon. May 1996.

[193] See Giuliano, G. "Is Jobs-Housing Balancing a Transportation Issue?" *Transportation Research Record* 1305, 1991, pp. 305-312; Giuliano, G. and K. Small. "Is the Journey to Work Explained by Urban Spatial Structure?" *Urban Studies* 30:9, 1993. p. 1485-1500.

[194] Levine, J. (University of Michigan) "Land Use Solutions to Transportation Problems? Rethinking Accessibility and Jobs-Housing Balancing." Paper submitted to the 75th Annual Meeting of the Transportation Research Board. 1996.

[195] *San Francisco Chronicle*. "Long Haul to American Dream." March 18, 1997. p. A-1.

4.5 TRANSIT ACCESS

Transit systems that are well designed and operated can reduce vehicle travel, resulting in reduced criteria pollutant and greenhouse gas emissions. A transit bus carrying 40 passengers requires only about one-sixth the energy consumption it takes to transport each person in a private vehicle.[196] Transit also helps to reduce traffic congestion. One full 40-foot bus is equivalent to a line of moving automobiles stretching six city blocks, and one full six-car heavy rail train is equivalent to a line of moving automobiles stretching 95 city blocks (assuming traffic operates at 25 mph).[197] Transit provides mobility to individuals of all ages, income levels, and abilities. With an aging population and increased attention being paid to linking low-income families to jobs, improved accessibility and mobility are particularly important.

Techniques for Improving Transit Access

Shifting location of employment and housing centers within a region can render once-useful transit service obsolete. These changes have encouraged many cities across the country to rethink and improve transit access. Two general ways in which transit access can be improved are by expanding transit supply through construction or service improvements, and focusing development around existing transit (transit-oriented development).

EXPANDING TRANSIT SUPPLY THROUGH CONSTRUCTION OR SERVICE IMPROVEMENTS

Cities can expand transit supply through the construction of new transit systems or the expansion of existing facilities. Constructing new systems or expanding existing ones are capital projects with a significant price tag. Cities across the country, however, are determining that an increase in transit access is worth the investment.

Salt Lake City, for example, is currently constructing new light rail and commuter rail systems. Other cities have chosen to expand or alter the mix of transit options provided to residents. The Chicago metropolitan area has proposed extending commuter rail lines to serve the suburbs on the far northern, southern, and western edges of the city. This expansion of service would remove cars and the associated emissions from the roadways and reduce congestion on the area’s roads.

Cities can improve transit access by making existing transit services more responsive to the needs of the population they serve. Extending service hours, for example, could capture ridership from individuals who need to travel later or earlier than the existing service allows. Regions have found that reducing wait times at stations (by adding trains or buses to existing lines) and improving transit-related signage (by making bus stops more obvious and posting schedules and route maps at each stop) can encourage transit use.

---

[196] Average U.S. energy consumption per vehicle mile for an automobile = 5,748 Btu; for a transit bus = 39,081 Btu. US Department of Energy. *Transportation Energy Data Book.* 15th Edition, Table 2.15, p. 2-25.

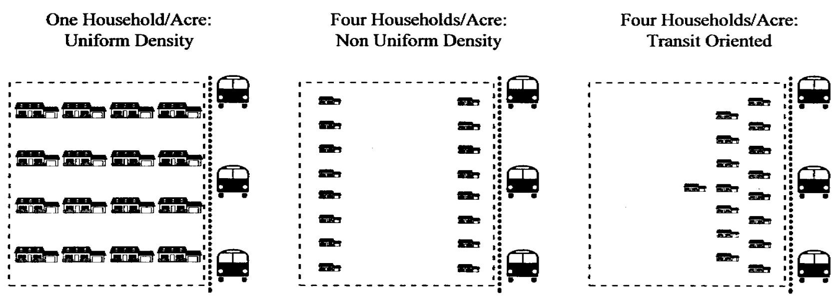
[197] A full 40-foot bus holds about 70 people including standees. At an estimated national average of 1.2 persons per automobile, one bus is equivalent to 58 automobiles. A full heavy rail car accommodates about 180 people; a train of six cars carries 1,080 people, replacing 900 automobiles. Ten city blocks per mile, an average auto length of 16 feet, and a one-car-length-per-each-10-mile-per-hour following length is assumed. (American Public Transit Association. *1994-1995 Transit Fact Book*.)

FOCUSING DEVELOPMENT AROUND EXISTING TRANSIT STATIONS (TRANSIT-ORIENTED DEVELOPMENT)

For some areas, the most cost-effective way to improve transit access may be to increase development around existing stations, rather than extend transit service. This type of development is typically referred to as transit-oriented development (TOD). The premise of transit-oriented development is that locating residential development and employment near transit stations increases the market for transit services and yields greater ridership than is achieved at stations (or bus stops) surrounded by low-density development.

Figure 4-8 shows three different development patterns with varying levels of transit access for 640 households in a 1 square mile zone. The first development alternative features a perfectly uniform density of households to 1-acre parcels. The second alternative increases the density of households to four per acre and locates them on the east and west sides of the zone, as if oriented to north-south arterial streets. The last alternative also has density of four households per acre, but the households are oriented to the side of the zone where transit service is available. Although the three alternatives have equal overall density, they feature very different levels of transit accessibility.[198]

Figure 4-8: Transit Access Distance and Local Land Use Organization



Households	640	640	640
Area/Household	One Acre	Quarter-Acre	Quarter-Acre
Average Transit Access Distance	0.63 miles	0.63 miles	0.24 miles
Households < 0.5 Miles From Transit	220	320	640

Diagram excerpted from: Eash, R. "Incorporating Urban Design Variables in Metropolitan Planning Organizations' Travel Demand Models." Prepared for Conference on Urban Design, Telecommuting, and Travel Behavior, Travel Model Improvement Program. October 1996.

As discussed below, results from a number of empirical studies and regional simulations indicate that increasing transit accessibility through transit-oriented development has the potential to increase the share of trips made by transit.

[198] Locating higher density development near transit does not necessarily mean increasing an area's average density. Rather, it could simply rearrange land uses and densities so that more people are close to the transit lines.

Indirect Environmental Impacts from Improving Transit Access

Effective transit systems require supportive land use patterns. Locating high-density commercial and residential development around transit stations is expected to reduce vehicle travel for two reasons:

- *Mode Choice* – Providing increased transit access increases the likelihood that the average trip will be made by transit, irrespective of vehicle ownership rates.
- *Vehicle Ownership* – Transit provides a potential substitute for vehicle travel and is expected to reduce the need to own personal vehicles for mobility.

EVIDENCE FROM REGIONAL SIMULATIONS

A number of metropolitan areas including Orange County (CA), Los Angeles, San Francisco, Boston, Seattle, Baltimore, Washington (DC), Dallas, and Denver have conducted simulations using regional travel demand forecasting models to identify the types of urban form that best support transit use and reduce dependence on vehicle travel. These analyses generally find that compact regions with a limited number of subregional centers linked by transit can support transit ridership and reduce VMT compared with other regional development patterns.[199]

An analysis of alternative land-use/transportation plans in the Chicago region, using a sketch-planning network of the northeastern Illinois region, indicated that compact patterns of residential and employment development would reduce vehicle travel. In particular, focusing development on regional corridors was projected to yield an increase in transit use and a decrease in average trip length due to an improvement in the jobs-housing balance. Dense regional centers were projected to produce less VMT due to increased transit use, and produce even less VMT when transit service improvements are added. In addition, this development pattern was projected to reduce auto trip lengths due to the more compact nature of the region.[200]

Montgomery County, Maryland, performed a similar analysis, using computerized transportation models to examine alternative long-range development scenarios and their impact on VMT and traffic congestion. The study found that by clustering most new development near an expanded rail and bus-way system, making improvements to pedestrian and bicycle conditions, and equalizing commuter subsidies, the county could accommodate a doubling of households and employment over 30 years with acceptable levels of traffic congestion. The strategy could result in countywide VMT and traffic congestion levels comparable to those of the existing 2010 forecast, while accommodating 62 percent more houses and 29 percent more jobs in the county than the current forecast does.[201]

---

[199] Parsons Brinckerhoff Quade and Douglass, Inc. “Part I: Transit, Urban Form, and the Built Environment: A Summary of Knowledge.” Transit Cooperative Research Program Report 16. *Transit and Urban Form.* Washington, DC: Transportation Research Board, 1996. p.5.

[200] The sketch/aggregated planning approach did not include a trip-generation step, so auto ownership and auto occupancy were fixed parameters. These aspects suggest that the magnitude of effects may have been underestimated (Lupa, Mary, et. al., “Transportation Sketch Planning with Land Use Inputs.” *Transportation Research Record 1499.* 1995. p. 83-94.)

[201] Replogle, Michael. “Land Use/Transportation Scenario Testing: A Tool for the 1990s.” Silver Spring, MD: Montgomery County Planning Department. 1993. (Prepared for Presentation at Transportation Research Board 1993 Annual Meeting.)

EVIDENCE FROM EMPIRICAL STUDIES

A number of empirical studies also show a relationship between transit accessibility and factors that affect air quality, such as mode choice or car ownership. Several studies, including some international case studies, describe how regional transit systems have promoted development around stations, helping to improve accessibility and reduce regional congestion.[202] Locating high-density commercial and residential development around transit stations improves accessibility to transit since more households are within walking distance of transit facilities.

Several studies show that increased density around transit stations is associated with increased transit use.[203] Light rail stations in higher density residential settings have higher ridership than those in lower density settings, holding constant other factors that influence ridership such as the distance between stations, the availability of feeder bus service, and the distance of the station from the Central Business District.[204] Increasing densities depend on adequate transit service to provide access without excessive congestion. San Francisco's higher density and better transit service shorten trip lengths sufficiently to allow 1 mile on transit to replace 8 miles of driving compared with trips in suburban Danville-San Ramon.[205] Compared with households in Danville-San Ramon, the average household in Nob Hill spent nearly $14,000 less on autos, the average resident burnt 339 gallons less gasoline, and emitted 14 kg less hydrocarbons, 12 kg less nitrogen oxides, and 98 kg less CO per year.

Increasing accessibility of housing to transit increases transit mode shares. For the Washington, DC Metrorail (heavy rail) system, for example, a 1987 survey of residential buildings within one-third mile of a suburban station found rail transit capture rates for work trips in the range of 18 to 63 percent, which is significantly higher than the regional work-trip average. Ridership was highest for projects closest to Metrorail stations and among station-area residents headed to central Washington, DC.[206]

A more recent study of travel to regional shopping centers in California found that travel mode shares were best explained by the amount and regional coverage of public transit services and the density and proximity of the surrounding land uses. One shopping center in a suburban, low-density area with limited transit service had a 95 percent auto share, while the shopping center in an urban, high-density

---

[202] Parsons Brinckerhoff Quade and Douglass, Inc. "Part IV: Public Policy and Transit-Oriented Development: Six International Case Studies." Transit Cooperative Research Program Report 16. *Transit and Urban Form.* Washington, DC: Transportation Research Board, 1996. pp. 37-70.

[203] High densities around transit stations may reflect high land values associated with desirable, accessible locations.

[204] For example, a study of 19 light-rail lines in 11 regions found that a 10 percent increase in residential density yields on average 5.9 percent more riders per station. Further, a 10 percent increase in CBD employment density increases light rail boardings at stations outside the CBD by about 4 percent holding other factors constant (Parsons Brinckerhoff Quade & Douglas, Inc. "Transit and Urban Form." Transit Cooperative Research Program. Washington, DC: National Academy Press, 1996). The most useful studies for examining environmental implications focus on *mode shares*, since transit ridership does not provide information on vehicle travel reduction. It is possible that dense areas yield increased transit ridership but also yield increased driving because more trips are made than in low-density areas.

[205] The savings result from the increased convenience of higher density mixed-use areas. Holtzclaw, J. "Explaining Urban Density and Transit Impacts on Auto Use." Presented to State of California Energy Resources Conservation and Development Commission. January 15, 1991.

[206] Station location also was found to play a role in transit ridership. Downtown offices averaged transit work trip modal shares of about 50 percent, compared with less than 20 percent for suburban office projects near rail stations. These differences may reflect differences in parking availability and price, pedestrian friendliness, or transit time compared to driving time. JHK and Associates. *Development-Related Ridership Survey I.* Washington, DC: Washington Metropolitan Area Transit Authority, 1987.

area with high transit service had the highest use of transit and walking—roughly 60 percent for the two modes combined. Modal share trends were consistent within demographic categories (e.g., age, income, household size), suggesting that site characteristics were an important factor in mode share.[207]

A study of transit-oriented development in California found that developments near transit have significantly higher shares of trips made by transit than the regional average.[208] For the 27 surveyed residential developments near transit, rail was used for 19 percent of work trips. For developments near Bay Area Rapid Transit (BART), rail was used for 33 percent of work trips, significantly higher than the 5 percent 1990 average for the three BART-served counties. In each Bay Area city served by BART, residents living near rail stations are about five times as likely to commute by rail as is the average resident-worker in the same city. Rail's mode share falls linearly with distance from the station for the surveyed housing projects—on average, by about 0.85 of a percentage point for every 100-foot increase in walking distance.

In the same study, surveys of 18 office sites near rail found that the average rail modal split for work trips was nearly 9 percent. For worksites near BART, rail share was 17 percent, well above the Bay Area's rail work trip share of 5 percent. For offices, the ridership gradient follows an exponential decay function. For non-BART sites, only offices within 500 feet of a station have as much as 15 percent of their workers commuting by rail; beyond 500 feet, no more than 10 percent of workers take rail to work.

Proximity to transit is one of the most important factors in encouraging transit mode share. An analysis of transit-oriented developments in California concluded that barring serious problems like urban blight or high crime rates, the characteristics of the immediate surroundings (e.g., mix of land uses and pedestrian quality) were of minor importance once people were near stations. As long as development was geographically close and oriented toward a rail station, reasonable percentages of residents and workers traveled by rail. When both trip ends were clustered around a transit station, the odds of traveling by rail transit increased dramatically. [209]

Other analyses have found that distance to transit is the most significant factor in the decision whether to reach transit by foot. An analysis of pedestrian access to transit using a 1992 survey of BART riders found that distance to the transit station was the most significant factor in deciding whether to walk to the station, drive, or take a bus.[210] Generally, individuals will walk up to about a half mile.[211]

---

[207] The suburban low-density, low-transit service sites consistently had higher shares of personal vehicle use than the urban high-density, high-transit service sites for shoppers within all income categories. JHK & Associates and K.T. Analytics. *Analysis of Indirect Source Trip Activity: Regional Shopping Centers.* Prepared for California Environmental Protection Agency, Air Resources Board. November 1993.

[208] Cervero, R. "Ridership Impacts of Transit-Focused Development in California." University of California Transportation Center, Working Paper No. 176. 1993.

[209] Cervero, R. "Ridership Impacts of Transit-Focused Development in California."

[210] This study found that walk trips accounted for the highest proportion of home-based access trips at stations located in dense, mixed-use areas of San Francisco—74.2 percent of trips at the 16th and Mission station and 67.2 percent of trips at the 24th and Mission station. At the opposite end of the spectrum, the Fremont station had a 3.9 percent pedestrian share and the Orinda station had a 2.8 percent pedestrian share. These stations are surrounded by large parking lots and low-density development. When individual characteristics, such as gender, age, and income, were taken into account, population density provided to be insignificant in the decision of whether to walk or take another mode to the transit station. Rather, the distance to the transit station was the most significant factor in mode choice (Loutzenheiser, David. "Pedestrian Access to Transit: A Model of Walk Trips and their Design and Urban Form Determinants Around BART Stations." Presentation to 76th Annual Meeting of Transportation Research Board, 1997.)

Transit-oriented communities often include mixed-use clusters of housing, office, and retail. By bringing these activities closer together, these developments also reduce the need to own a private vehicle. In the Portland, Oregon region, Metro incorporated a measure of transit accessibility–the number of employees within 30 minutes travel time by transit—into its vehicle ownership model. Based on statistical analysis in which the utility of owning zero, one, two, or three cars depends on a variety of factors, vehicle ownership drops as transit accessibility increases, independent of income and other household demographic factors.

4.6 Support for Pedestrian and Bicycling Activity/ Microscale Urban Design Factors

Currently we don't build either land use or transportation systems for pedestrians and bikes, creating barriers that are dangerous, inconvenient, and aesthetically displeasing.

Aspects of the built environment such as building orientation, street connectivity and design, and building design all contribute to the relative friendliness of that area to pedestrians and bicyclists, and to the general aesthetic appeal of an area. Together, these are often referred to as "microscale" urban design factors—small-scale elements that affect the safety, convenience, and desirability of living and working in areas of higher density and of using transit and nonmotorized modes of transportation.

These design factors affect travel mode choice. In areas that do not include adequate bicycle and pedestrian facilities (sidewalks, bike lanes, and crosswalks), people are more hesitant to travel by foot or bike. More than 6,000 pedestrians die in collisions with cars each year, and 110,000 are injured. , According to federal statistics, pedestrians and bicyclists account for 15 percent of all "highway" fatalities.[212] The risks fall disproportionately on senior citizens, who make up 13 percent of the population but account for 23 percent of pedestrian fatalities. "Long crosswalk distances and traffic signals timed for young adults present added difficulties, even life-threatening hazards, for older persons at intersections," according to the American Association of Retired Persons.[213]

Children face similar challenges; only 13% of trips to school are made by walking,[214] a figure down from what some experts believe was more than 50% in the 1960s.[215]

---

[211] Data from the National Personal Transportation Study suggest that 70 percent of Americans walk 500 feet (one-tenth of a mile) for normal daily trips, 40 percent walk 1,000 feet (one-fifth of a mile) and 10 percent walk up to a half mile (Unterman, D. "Accommodating the Pedestrian: Adapting Towns and Neighborhoods for Walking and Bicycling." *Personal Travel in the U.S., Vol. II, A Report of the Findings from 1983-1984 NPTS, Source Control Programs.* U.S. Department of Transportation. 1990). A study in Montgomery County, MD, found that residents will walk one-quarter of a mile median distance to a bus and one-half of a mile to a rail stop (Replogle, M. *Bicycles and Public Transportation.* 1984. Cited by Holtzclaw, J. "Using Residential Patterns and Transit to Decrease Auto Dependence and Costs." Natural Resources Defense Council. June 1994).

[212] In 1996, of 41,907 traffic fatalities, 5,412 were pedestrians and 761 were bicyclists. Source: U.S. Department of Transportation, Bureau of Transportation Statistics. *National Transportation Statistics 1998.* Table 3-19.

[213] Quote is from Jo Reed, of the American Association of Retired Persons. Figures were taken from: Witham, Drake and Bill Salisbury. "The Walking Wounded." *St. Paul Pioneer Press*. April 14, 1997, B2.

[214] Calculations from 1995 National Personal Transportation Survey.

[215] Ulman, Marian, "A Healthy Start: Aiming to Revive the Walk to School." *Philadelphia Inquirer*, March 28, 2000.

By increasing the relative desirability of walking compared with driving, urban design factors can encourage more walking or bicycling trips. Reductions in vehicle travel and emissions can occur if walking and bicycling trips replace vehicle trips.

Techniques for Enhancing Micro-Design Features

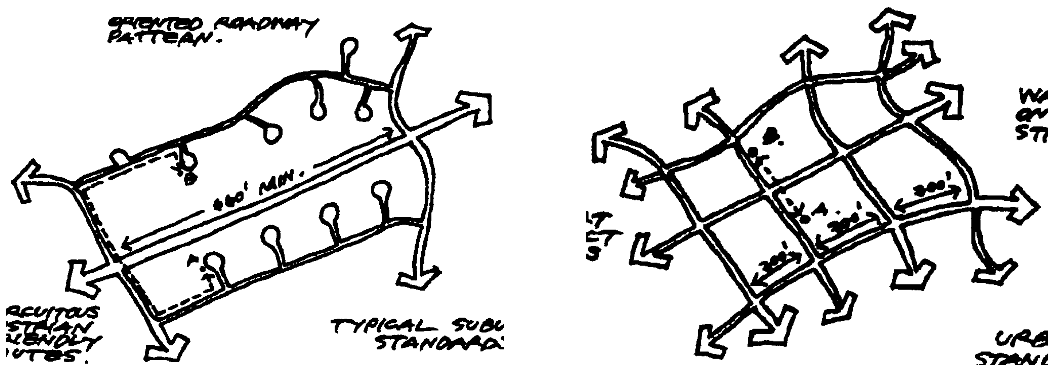
A community's micro-design may be improved through pedestrian and bicycle facilities and street connectivity, as well as design and architecture.

Pedestrian and Bicycle Facilities and Street Connectivity: Typical modern communities often contain a hierarchy of dead-end or cul-de-sac local streets that lead to collector streets and then to major arterials that connect communities to others via freeways. (See Figure 4-9.)

Figure 4-9: Street Network Design

Disconnected, Hierarchical Street Network

Pedestrian-oriented Grid Street Network



Many communities are bounded by walls, lakes, or other physical barriers, and often do not have sidewalks. This pattern makes pedestrian and bicycle travel difficult since circuitous routes and limited access increase the length of trips. Collector and arterial streets tend to be wide to allow vehicles to move faster and to handle the large traffic volumes that are channeled onto a few high-traffic routes. Wide streets are difficult and often dangerous for pedestrians and bicyclists to cross or to share with vehicles, especially if they lack facilities such as sidewalks and crosswalks. Such poor pedestrian environments encourage people to drive, even for short trips.

Aside from well-connected street networks, features that improve the pedestrian environment include sidewalks, clearly marked crosswalks and walk signals, lighting, and other amenities, such as shade trees, benches, and streetscapes designed with the pedestrian in mind. Features that improve the bicycling environment include bicycle paths and lanes on streets, bicycle parking, clear signs, and facility design that improves accessibility.

Design and Architecture: Just as street connectivity and bike and pedestrian facilities are important, the design and placement of buildings and the aesthetics of streetscapes also shape people's attitudes toward travel. In residential areas, design for pedestrians includes making the street environment more attractive by placing porches and home entrances in the foreground, and garages and driveways more in the background. In commercial areas, pedestrian design means orienting stores to the street with window displays and pedestrian entrances, rather than entrances through parking lots and garages. Narrow streets, shade trees, well-maintained sidewalks and traffic slowed through traffic calming measures (such as speed bumps, raised crosswalks, traffic circles, and median barriers) also improve the pedestrian environment. In less pedestrian friendly environments, structures are located without reference to neighboring buildings or properties. Some office parks lack provision for foot traffic, so that a walk from an off-site bus stop to an office might involve walking through large parking lots.

Indirect Environmental Effects of Microscale Urban Design and Pedestrian and Bicycle Support: Travel Mode Choice

The most significant benefit of good urban design is that it reduces auto travel by enabling other travel choices.

EFFECT OF DESIGN FOR PEDESTRIANS AND BICYCLISTS

Several studies have found that higher levels of pedestrian and bicycling activity occur in areas with street connectivity and pedestrian amenities than in those without those features. For example, a recent study compared two Puget Sound area neighborhoods that are similar in terms of gross residential density and intensity of commercial development: Wallingford in Seattle and Crossroads in Bellevue. The analysis found that Wallingford—the neighborhood with a high level of pedestrian network connectivity—had almost three times as much pedestrian activity as did Crossroads, which had a low level of pedestrian connectivity. [216]

An analysis conducted in Portland, Oregon (using data from a home interview survey, results from regional travel forecasting models, and land use information) found that the pedestrian environment is a significant factor in mode choice decisions and vehicle miles traveled. In particular, the analysis found that improving the quality of the pedestrian environment to a level comparable to that of Portland's most pedestrian-oriented zones would result in a 10 percent reduction in VMT.[217] A similar analysis by the Maryland National Capital Parks and Planning Commission, using its regional travel models, found that pedestrian and bicycle friendliness is quantifiable and is a significant predictor of work trip mode choice.[218]

Neither the Portland nor the Maryland studies explicitly included safety in their analyses. Not surprisingly however, pedestrian safety is a factor that people typically consider when deciding whether to walk in an area. An analysis of employment sites in southern California, for example,

---

[216] This study, however, did not address effects on vehicle travel. Moudon, *et al.* "Effects of Site Design on Pedestrian Travel in Mixed Use, Medium Density Environments." Submission to 76th Annual Meeting of the Transportation Research Board, 1997.

[217] A pedestrian environment factor (PEF), measured on a scale of 4 to 16, was developed based on street connectivity, sidewalk connectivity, ease of street crossing, and topography. A value was assessed for each zone in the travel demand forecasting model. The model found household vehicle trips and vehicle miles of travel declined with increases in the PEF. Multiple regression analysis suggested that each unit increase in the zonal PEF would reduce daily VMT per household by 2.5 percent, or 0.7 miles. Cambridge Systematics *et al. Making the Land Use Transportation Air Quality Connection: Analysis of Alternatives. Model Modifications.* Vol. 4. Prepared for Thousand Friends of Oregon. May 1996.

[218] Replogle, M. *Integrating Pedestrian and Bicycle Factors into Regional Transportation Planning Models: Summary of State-of-the-Art and Suggested Steps Forward.* Environmental Defense Fund. July 20, 1995.

found that areas characterized as "safe" had higher levels of transit use and bicycling and walking than those that were characterized as "unsafe."[219]

A number of studies contrasting bicycling in European cities with biking in U.S. communities note that bicycling is thriving in those metropolitan areas that have adopted policies to make bike travel faster, safer, and more convenient. In Munich, Germany, for example, bicycle use has almost tripled since 1976, with modal split rising from 6 percent to 15 percent. The increase is due in part to the fact that the length of the bikeway network was more than doubled during that period, all residential neighborhoods in the city have been traffic calmed, and bicycle parking facilities have been expanded.[220]

The pedestrian environment also has been found to influence decisions about vehicle ownership. In the Portland, Oregon regional travel models, data on the pedestrian environment were found to improve the predictive ability to estimate the number of vehicles owned per household.[221] Similarly, in a logit model for vehicle ownership developed by the Chicago Area Transportation Study, the pedestrian environment and auto work trip mode share were found to be statistically significant in predicting vehicle ownership rates. Less than 40 percent of these households in urban areas have two or more vehicles, while more than 90 percent in suburban areas have two or more vehicles.[222] As these studies indicate, a pedestrian-friendly environment allows walking trips to substitute for vehicle trips and, as a result, reduces the need to own as many vehicles.

A number of studies suggest that grid street patterns can reduce vehicle trip lengths. For example, a simulation study found that traditional grid circulation patterns reduce VMT by 57 percent compared with VMT in more conventional networks.[223] A modeling analysis of two simple, hypothetical street patterns estimated that total morning peak hour vehicle travel would fall more than 10 percent when a conventional suburban street pattern is replaced by a grid network.[224] The full VMT implications are unclear, however, since the simulations assume that trip frequencies are unaffected by the street patterns. Some researchers argue that increased accessibility associated with grid street patterns can

---

[219] In this study, sites were considered to have a higher level of safety if they were characterized by sidewalks, street lighting, pedestrian activity, and the absence of vacant lots. In locations that offered TDM incentives, the share of transit was 5.4 percent in safe areas compared with 3.6 percent in less safe areas. The share of bicycling and walking was 3.2 percent in safe areas compared with 1.7 percent in less safe areas. U.S. Department of Transportation, Travel Model Improvement Program. "The Effects of Land Use and Travel Demand Management Strategies on Commuting Behavior." Prepared by Cambridge Systematics. November 1994. p. 3-18.

[220] Pucher, John. "Bicycling Boom in Germany: A Revival Engineered by Public Policy." *Transportation Quarterly*, Vol. 51, No. 4. Fall, 1997. P. 41.

[221] Cambridge Systematics *et al. Making the Land Use Transportation Air Quality Connection: Analysis of Alternatives. Model Modifications.* Vol. 4. Prepared for Thousand Friends of Oregon. May 1996.

[222] Eash, R. "Incorporating Urban Design Variables in Metropolitan Planning Organizations' Travel Demand Models." Conference on Urban Design, Telecommuting, and Travel Behavior. Williamsburg, VA, October 1996.

[223] Kulash, Anglin, and Marks "Traditional Neighborhood Development: Will the Traffic Work?" *Development,* Vol. 21, July/August 1990, pp. 21-24.

[224] McNally and Ryan. "A Comparative Assessment of Travel Characteristics for Neotraditional Developments." University of California Transportation Center. University of California at Berkeley. Working Paper No. 142. August 1992.

induce additional travel. The degree to which this travel occurs by walking or driving is unclear and may differ depending on specific circumstances.[225]

EFFECT OF BUILDING DESIGN AND ARCHITECTURE

A preponderance of research finds that urban design can affect mode choices. However, identifying discernible travel effects from individual design features has proven difficult. For example, a study of 12 census tracts in the San Francisco Bay area found that most individual neighborhood urban design features alone were not useful for explaining mode choice. However, when considered as a bundle of attributes, the influence of urban design was apparent. Pedestrian design was found to increase the probability that a nonmotorized mode would be used for nonwork trips by about 10 percent.[226] A separate analysis of four neighborhoods in the San Francisco area also found no evidence that individual residential design elements has an effect on travel. However, the research suggested that neighborhood design as a whole is an important determinant of whether residents perceive walking as an option and affects pedestrian activity in a community.[227] Although certain specific design treatments, such as building orientation, might appear trivial, their collective influences may be important.[228]

4.7 SYNERGIES: COMBINING TECHNIQUES

Many of the above patterns and practices—compact development, mixing of land uses, higher density development oriented around transit, and pedestrian and bicycle facilities—have demonstrated positive environmental implications—reducing infrastructure requirements, reducing vehicle travel, reducing land and habitat consumption, and reducing water consumption and pollution.

The efficacy of these practices depends on how well they are implemented, and how they are combined with other programs. Some of the benefits of mixed-use development, for example, require

[225] Crane, R. "Cars and Drivers in the New Suburbs." *Journal of the American Planning Association* 62: 1, Winter 1996. pp. 51-65. A 1992 study of travel in four San Francisco neighborhoods found that residents of older, compact neighborhoods made 2.75 to 5.5 times as many shopping trips by walking as residents of more auto-oriented neighborhoods, but that residents of both types of neighborhoods made about the same number of auto trips to regional shopping centers. Handy, S. *Regional Versus Local Accessibility: Implications for Non-Work Travel.* Doctoral Dissertation, University of California, Davis. Institute of Transportation Studies. 1992.

[226] Transit Cooperative Research Program (TCRP). *Influence of Land Use Mix and Neighborhood Design on Transit Demand.* TCRP Project H-1. March 1996.

[227] Handy, Susan. "Understanding the Link between Urban Form and Travel Behavior." Paper presented at the 74th Annual Meeting of the Transportation Research Board, January 1995. In different areas, different types of design elements may be appropriate or fit into the neighborhood environment differently. A specific element such as the absence or availability of trees and shrubs at sidewalks may not be effective in the absence of other important pedestrian enhancements. This analysis suggests the importance of comprehensive design rather than identifying a specific design element that works in all places. The overall pedestrian environment is the prime concern.

[228] Cervero, Robert. *Suburban Gridlock.* New Brunswick, NJ: Rutgers University Press, 1986. p. 61. A study conducted by Susan Handy in Austin, Texas, confirms this finding. In the study, Handy surveyed residents from six Austin neighborhoods that are similar in socio-economic profile but different in design characteristics. Handy found that respondents from Clarksville—the neighborhood in which the quality of the pedestrian environment is high and many households are within walking distance of commercial areas—walked to a store about six times per month, as compared with residents of the other neighborhoods, who walked to a store between 0.72 and 2.06 times per month. Handy, Susan. "Urban Form and Pedestrian Choices: Study of Austin Neighborhoods." *Transportation Research Record 1552*. p. 142.

pedestrian amenities. The reverse is also true. Adding pedestrian facilities, such as sidewalks and crosswalks, may be most effective in reducing vehicle travel when a variety of shops and services are within a short walk. Provided together, land use characteristics produce synergy—enhanced benefits due to incorporating multiple beneficial aspects of design into communities.[229]

Measuring the Effects of Combined Policies

The previous sections examined the impacts of individual actions. It is nonetheless difficult to isolate the effects of specific aspects of urban form on travel. Certain land use attributes, such as high density, a mix of land uses, and a pedestrian-friendly environment tend to occur together.[230] This section therefore reviews studies that look at the combined effects of density, transit, etc.

In practice, isolating the effects of individual land use characteristics on travel behavior may not be extremely important. The evidence indicates that the location of development in a region is important in affecting trip distances and that a *combination* of urban design factors is important in influencing mode choice. There appear to be synergies that come from combining beneficial aspects of land use and thresholds in the travel effects of individual land use factors. Thresholds occur when the travel effects of changing one land use factor are limited unless other land factors also are altered.

Several studies have found that changes in individual microscale aspects of urban form, such as adding sidewalks and street benches, may not be sufficient to achieve changes in vehicle ownership or mode choice if the region as a whole is oriented toward vehicle travel. For example, an analysis of travel in Palm Beach County, Florida, found that transit mode share was minimal in all communities examined despite differences in design, presumably because the entire region is relatively auto-dependent, with limited transit service. Similarly, other studies have found that in a low-density area characterized by a wide separation of distinct land uses, sidewalks and attractive landscaping are unlikely to prompt residents to walk to shops and stores.[231] Some newly built neotraditional communities may not significantly reduce vehicle travel if they are not regionally accessible or transit-accessible.[232]

---

[229] A community that contains a mix of land uses but that does not provide a pedestrian-friendly environment would be unlikely to achieve the full benefits associated with a mix of uses, such as reduced vehicle trip-making. People may drive even short distances between employment, retail, and restaurants if the pedestrian environment is poor. Locating higher density development near transit and employment provides the mass necessary for local stores that rely on foot traffic to locate there. Although not all compact urban environments have a mix of uses or transit-supportive urban design, few low-density environments have meaningful land use mix or transit-oriented amenities (Parsons Brinckerhoff Quade & Douglass. “Transit, Urban Form, and the Built Environment: A Summary of Knowledge.” Transit Cooperative Research Program. Washington, DC: 1996. p. 25.)

[230] A number of researchers have found correlations between these variables. See: Dunphy, R. and K. Fisher. *Transportation, Congestion and Density: New Insights.* Urban Land Institute, August 1993. Holtzclaw, John. “Using Residential Patterns and Transit to Decrease Auto Dependence and Costs.” Natural Resources Defense Council. June 1994. Loutzenheiser, David. “Pedestrian Access to Transit: A Model of Walk Trips and their Design and Urban Form Determinants around BART Stations.” Submission to the 76th Annual Meeting of the Transportation Research Board. January 1997. Cambridge Systematics, Inc.; Parsons, Brinckerhoff, Quade & Douglas; S.H. Putman Associates, Inc. *Making the Land Use Transportation Air Quality Connection: Model Modifications.* Vol. 4. Prepared for Thousand Friends of Oregon. May 1996.

[231] Cervero, R. and K. Kockelman. “Travel Demand and the Three Ds: Density, Diversity, and Design.” Institute of Urban and Regional Development, University of California at Berkeley. July 1996.

[232] The Kentlands community in suburban Washington, DC, is a well-known example of a new neotraditional development. Although Kentlands has been cited for its character and quality of life, the community is not located in an inner suburb or along the region’s transit rail system. As a result, one would not expect significant differences in transit share or vehicle travel between Kentlands and other nearby suburban communities.

When travel options are available, however, urban form and design characteristics can affect travel behavior to a greater degree, particularly in terms of mode choices. Increases in the mix of land uses, improved transit access to employment, and enhancements to the pedestrian environment together can alter the relative utilities of different choices, under the right conditions. Density is generally viewed as important because without compactness, urban design and mix are often not sufficient to ensure a built environment in which transit, bicycle, and pedestrian travel can play an important role. More compact neighborhoods support a diversity of land uses since they require commercial activities, which may be located close enough to a large population to facilitate nonmotorized trips. Researchers have concluded that higher *densities*, *diverse* land uses, and pedestrian-friendly *designs* (the three Ds) must co-exist to a certain degree if meaningful transportation benefits are to accrue.[233]

Evidence from Comparisons of Communities

Household characteristics like income, household size, and employment characteristics affect travel behavior. Several studies that control for these factors suggest that urban design and land use patterns have an important effect on travel behavior regardless of demographics. In the San Francisco area, a comparison of two neighborhoods with similar socio-economic characteristics found that residents of the compact neighborhood were more likely to walk or bicycle than residents of the auto-oriented community. When income and auto-ownership were taken into account, households with one or more cars in the "traditional" Rockridge neighborhood were about twice as likely to use a nonautomotive mode for nonwork trips as households in the "suburban" Lafayette neighborhood. A member of a two-car household in Rockridge had a 19 percent probability of walking, bicycling, or riding transit for a nonwork trip compared with a 9 percent probability for a similar resident of Lafayette.[234]

The San Francisco Bay area has been the subject of considerable study due to its wide variation in land use types and neighborhoods. An analysis of trip data from a 1980 regional travel survey of San Francisco Bay area households found that those in newer suburban communities have substantially higher vehicle trip generation rates, a higher proportion of drive-alone trips, and a lower percentage of public transportation trips than households in communities that have high-density, mixed land use, and interconnected street networks.[235] For all trips, the rate of travel by transit in compact communities was more than double the rate in suburban communities (7 percent compared with 3 percent) and the share of trips made by walking was 50 percent greater (12 percent compared with 8

[233] Cervero, R. and K. Kockelman. "Travel Demand and the Three Ds: Density, Diversity, and Design." Institute of Urban and Regional Development, University of California at Berkeley. July 1996; Cervero, R. "Mixed Land Uses and Commuting: Evidence from the American Housing Survey." *Transportation Research.* Vol. 30, No. 5: 361-377. 1996.

[234] Transit Cooperative Research Program (TCRP). *An Evaluation of the Relationship between Transit and Urban Form.* Research Results Digest, No. 7. June 1995.

[235] This analysis was based on data from a 1980 regional travel survey of San Francisco Bay area households. Communities were defined as suburban if they were developed since the early 1950s with segregated land uses, have a well-defined hierarchy of roads, concentrate site access at a few key points via arterial roadways, and have relatively little transit service. Survey zones were labeled traditional if they were mostly developed before World War II, have a mixed-use downtown with significant on-street parking, and have an interconnecting street grid and mixed land uses. (Friedman, Bruce, Stephen Gordon, and John Peers. "Effect of Neotraditional Neighborhood Design on Travel Characteristics." *Transportation Research Record 1466.* p. 63-70.)

percent). Auto use per household was about 32 percent higher in the suburban areas (7.1 trips per day) than in the compact areas (5.3 trips per day).[236]

Another study in the San Francisco Bay area found results similar to those cited above for nonwork trips: residents of older, compact neighborhoods make more trips by nonmotorized modes than residents of suburban neighborhoods do. [237] Neighborhood design may provide the most potential for reducing nonwork VMT, since shopping and recreational activities are accessible by walking and bicycling. Residents of older, compact neighborhoods made 2.75 to 5.5 times as many shopping trips by walking as residents of more auto-oriented neighborhoods do. A set of neighborhood case studies suggests that urban form is an important determinant of whether residents perceive walking as an option. Short distances, commercial areas designed for pedestrian access, and certain types of destinations (such as restaurants) are particularly conducive to pedestrians.[238]

On the East Coast, trip data compiled for two older, compact neighborhoods in Portsmouth, New Hampshire, showed that trip rates in these neighborhoods, which have moderate residential densities, gridded street patterns, and local shops and services, were about 50 percent lower than those predicted by the ITE Trip Generation manual.[239]

Finally, a study recently conducted for a proposed suburban “village center-style” development in the San Joaquin Valley, California, estimated that the project would produce about one-third less vehicle travel per household on average than a typical single-use, low-density suburban housing tract would. The study also projected that such suburban villages could reduce the number of automobile trips by about 13 percent per household when compared with the typical suburban development pattern.[240]

An Evaluation of Synergistic Policies

Like the strategies, individual policies may be effective but they are most valuable when pursued comprehensively.

Portland, Oregon, recently adopted a regional Vision 2040 and now evaluates transportation and development projects according to how well they move the region toward that vision. The region expects to grow 60 percent by 2040, and its citizens are deciding how to meet today’s needs while not

[236] The analysis suggests that community design and urban form have a sign\ificant relationship to travel behavior. The researchers eliminated from analysis those in the lowest and highest income categories; however, differences in income, demographics, and other factors may explain some of the travel differences.

[237] Handy, Susan. “How Land Use Patterns Affect Travel Patterns: A Bibliography.” *Built Environment.* Winter/Spring 1992.

[238] The researchers noted that given an opportunity to walk, it is likely that more residents will choose to walk. However, not all of these trips will be in place of driving; many of them will be in addition to driving trips. This increased accessibility enhances quality of life even when it does not reduce vehicle travel. The travel impact depends on what other choices are available and thus will be different in various contexts. (Handy, Susan. “Understanding the Link between Urban Form and Travel Behavior.” Paper presented at the 74th Annual Meeting of the Transportation Research Board. January 1995.)

[239] White Mountain Survey Company. “City of Portsmouth Traffic/Trip Generation Study.” Ossippee, New Hampshire: White Mountain Survey Company, 1991 (unpublished), cited by Robert Cervero (“Mixed Land Uses and Commuting: Evidence from the American Housing Survey.” 1996. p. 362).

[240] Fehr and Peers. “Effect of Stockton’s Proposed Suburban Village Center Development.” January 1992. As cited by Parker, Terry. California Air Resources Board. *The Land Use-Air Quality Linkage: How Land Use and Transportation Affect Air Quality.* 1994. p. 10.

damaging the city's ability to meet the needs of citizens in 2040. The region has decided to accommodate growth on its West Side by targeting development in transit-oriented developments. The proposed Land Use, Transportation, Air Quality Connection (LUTRAQ) alternative includes transit-oriented development, mixed-use centers, transit system improvements, and market strategies (a daily parking charge for commuters who drive alone and free transit passes, at least partially funded by parking revenues).

State-of-the-art analysis showed that the LUTRAQ alternative is superior to the more auto-oriented alternative on many fronts not just on many of the criteria discussed above related to sustainability, but also on those often used to judge standard highway projects:[241]

- 22.5 percent fewer work trips made in single-occupant vehicles, saving congestion, fuel, emissions, and money
- 27 percent more trips made on transit and by walking and biking
- 18 percent less highway congestion with 10.7 percent fewer hours of vehicle travel during the afternoon rush hour
- 21 percent greater access to jobs in the region, as measured by the percentage of the area within 30 minutes travel of 500,000 jobs
- Reduced air pollution: hydrocarbons, -6 percent; NO_x, -8.7 percent; and CO, -6 percent.
- Reduced emissions of the greenhouse gas CO_2: -7.9 percent, and 7.9 percent less fuel used.

The projected benefits stem from the combination of land use measures and market-based mechanisms. These benefits are for the entire West Side. Benefits will be even larger for homes and businesses in the new transit-oriented developments. The new developments avoid wetlands and other sensitive areas, maximizing biodiversity and recreational opportunities. The plan also reduces paved areas and interferes with the hydrologic cycle as little as possible.

4. 8 SUMMARY

Research has shown that development decisions have both direct and indirect effects on the environment and that growth can be accommodated in ways that minimize negative impacts on human and natural environments and in some cases even improve environmental quality. Strategies that minimize negative environmental impacts include compact development, reduced impervious surfaces and improved water detention, safeguarding of environmentally sensitive areas, mixed land uses, transit accessibility, and support for pedestrian and bicycle activity.

Used in combination, these practices can significantly reduce impacts to habitat, ecosystems and watersheds, and can reduce vehicle travel, which in turn reduces emissions of local, regional, and global concern.

[241] 1000 Friends of Oregon, "Making the Connections: A Summary of the LUTRAQ Project." February 1997.

5. Conclusion

Across the country, communities are concerned about the built environment not just for community and economic reasons, but also because of the effect that development has on human health, environmental resources, and natural habitats. *Our Built and Natural Environments* has reviewed evidence demonstrating that the built environment can significantly affect ecological and human health. As citizens and public officials have come to understand the relationships among land use, transportation, and the environment, they have begun to seek new ways to grow—ways that capture the benefits of protecting the environment, and the jobs, economic development, health, and quality of life that depend on the protection of air and water quality.

Urban form affects attainment of national environmental goals in each of the following areas:

- ***Habitat and Ecosystems***—Development uses land space and modifies habitats and ecosystems. Land consumption rates in the United States are high and are rapidly increasing. More land was developed during the five-year period from 1992–1997 than during the 10-year period that preceded it. Over those five years, the national rate of development more than doubled to 3 million acres per year. Not only does development directly destroy areas of natural habitat, it can fragment habitat and lead to invasion of non-native species that severely alter ecosystem function and reduce biodiversity. Adverse impacts can be reduced by clustering development to preserve large areas of continuous natural habitat. Development that avoids sensitive and critical habitats, such as wetlands, greenways, and buffer zones around sensitive habitat, can preserve ecosystem integrity and can create amenities for adjacent neighborhoods.

- ***Water Quality—***Urban development affects water quality through alterations to the natural flow of water within a watershed, particularly by increasing impervious surfaces and channeling stormwater runoff. EPA estimates that 36 percent of the nation's lakes, rivers, and estuaries are impaired by pollution, and approximately 21 percent of the lakes, 12 percent of the rivers, and 46 percent of the estuaries are impaired due to urban runoff. As communities nationwide strive to comply with the Clean Water Act and Safe Drinking Water Act, which protect water resources both as natural habitat areas and as sources of clean drinking water, understanding the impact of development on water quality becomes increasing important. Development results in increased runoff volumes and peak period discharges, which in turn increase sedimentation and pollutant levels, increase water temperature, and reduce stream stability. Water quality is adversely affected by increased pollutant loads that are washed from surfaces in paved areas and deposited from air pollution. Water quality can be improved by minimizing impervious surfaces through more compact, mixed-use development, minimization of parking areas and street widths, use of porous or pervious pavements, and landscaping.

- ***Air Quality—***As regions seek to reach air quality attainment goals outlined in the Clean Air Act, the need to improve understanding of the relationship between air quality and development and transportation patterns becomes clear. Motor vehicles emissions currently account for a significant portion of many air pollutant emissions, contributing 57 percent of all CO emissions, 30 percent of NO_X emissions, 44 percent of PM-10 emissions, and 27 percent of VOC emission. Per mile motor vehicle emissions have decreased since about 1970 as a result of vehicle emissions control systems and cleaner fuels, but increasing VMT threatens to reverse this trend in the future.

Air quality is indirectly affected by urban form to the degree that development patterns affect travel behavior. There is significant evidence that compact, mixed-use development focused around transit can reduce vehicle travel and air pollution from motor vehicles. Infill development (including redevelopment of brownfields) generally means greater accessibility to existing transit services, which should reduce vehicle travel compared with development on the urban periphery. Enhancement of the pedestrian environment also can encourage people to walk rather than drive for short distances. In addition, pricing roads and parking so that drivers recognize the full costs of their behavior can work in tandem with changes in urban form to encourage use of transit, carpooling, walking, and bicycling.

- ***Global Climate—***Like air quality, global climate is indirectly affected by urban form to the degree that development patterns affect travel behavior. Combustion of motor vehicle fuel emits carbon dioxide, a greenhouse gas that helps trap heat within the atmosphere. Emissions of carbon dioxide from motor vehicles have been increasing over time, and transportation is projected to be the fastest growing source of carbon dioxide emissions of any sector. In 1997, the transportation sector emitted 32 percent of U.S. carbon dioxide emissions from fossil fuels, and carbon emissions from transportation are projected to grow by approximately 48 percent over the 1996-2020 period. Many communities have agreed that global warming is an issue of serious concern and are attempting to encourage practices that reduce greenhouse gas emissions. Examples include providing more transportation choices, reducing vehicle travel, and improving vehicle fuel economy through decreases in traffic congestion.

- ***Contamination and Risk in Communities***—Old abandoned industrial facilities in urbanized areas, potentially contaminated with hazardous or toxic waste, pose risks to communities. Redevelopment of brownfields provides the opportunity to clean up contaminated sites, reducing threats to water quality and human health. Brownfields redevelopment has numerous other benefits. It allows more efficient use of existing infrastructure, saving the money and time needed to construct new infrastructure such as schools, roads, and water systems, and it protects a community's open space by placing new development in previously developed areas, rather than on greenspace.

The extent to which some development practices can reduce the direct impacts of development on habitat and hydrology is relatively clear. The magnitude of the impact of land use practices that reduce indirect effects of urban form on air quality can be more ambiguous, due to uncertainties regarding travel behavior. Nonetheless, an overwhelming number of studies on this topic agree that urban form has undeniable implications for environmental goals.

The information reviewed in *Our Built and Natural Environments* provides evidence that:

- U.S. urban form, including its land use and transportation components, has changed significantly in recent decades.

- These changes affect environmental quality over the short and the long run, and interfere with the ability of the United States to meet its health and environmental goals.

- Current development patterns are not simply due to population growth and therefore are not inevitable.

- Communities have choices in their development decisions.

- Communities can exercise that choice by developing the built environment in ways that contribute toward the attainment of health and environmental goals.

There is ample evidence that the built environment matters to communities—not just for social and economic reasons, but also for environmental reasons of national concern. Issues related to our built environment are growing in importance and, if left unaddressed, will make it difficult to meet our nation's environmental goals. Fortunately, communities, regions, and states are starting to find ways to expand that achieve better economic, community, and environmental outcomes. The U.S. Environmental Protection Agency plans to continue building knowledge about the relationships between land use, transportation, and the environment as it supports our nation in meeting its environmental and human health goals.

6. Bibliography

2020 Panel. "Population Growth and Development in the Chesapeake Bay Watershed to the Year 2020." Annapolis, MD: 1988.

Adams, L.W. et al. "Design Considerations for Wildlife in Urban Stormwater Management." *Transactions of the 51st North American Wildlife and Natural Resources Conference,* 1986, p. 249-259.

Allen, E, Anderson, G, and Schroeer, W, "The Impacts of Infill vs. Greenfield Development: A Comparative Case Study Analysis," U.S. Environmental Protection Agency, Office of Policy, EPA publication #231-R-99-005, September 2, 1999.

American Farmland Trust . *Farming on the Edge: A New Look at the Importance and Vulnerability of Agriculture Near American Cities.* 1994.

American Public Transit Association. *1994-1995 Transit Fact Book.* 1995.

Apogee Research, Inc. "Quantifying the Impacts of Road Construction on Wetlands Loss - Final Report." Bethesda, MD: September, 1997.

Apogee Research, Inc. "Review of Transportation and Land Use Literature." Prepared for U.S. Environmental Protection Agency: 1997.

Arendt, Randall. "Open Space Zoning: What It Is and Why it Works." *Planning Commissioners Journal*. Issue 5, 1992.

Arnold, Chester L. Jr., C. James Gibbons, "Impervious Surface Coverage - The Emergence of a Key Environmental Indicator." *Journal of the American Planning Association*. Vol. 62, No. 2, Spring 1996, p. 243-258.

Baley, Janet and Glenn Besa. *Sprawl Costs us All.* Sierra Club. 1997.

Baltimore Regional Council of Governments. *Impact of Land Use Alternatives on Transportation Demand*. January 22, 1992.

Bank of America, California Resources Agency, Greenbelt Alliance, and Low Income Housing Fund. *Beyond Sprawl: New Patterns of Growth to Fit the New California* . San Francisco: February 1995.

Beatley, Timothy. *Habitat Conservation Planning and Urban Growth*. Austin: University of Texas Press, 1994.

Benfield, F. Kaid, Matthew Raimi, Donald Chen. *Once There Were Greenfields: How Urban Sprawl is Undermining America's Environment, Economy and Social Fabric.* Natural Resources Defense Council, 1999.

Bergman, David. "Off-Street Parking Requirements." *APA Planning Advisory Service Report 432.* Chicago: American Planning Association, 1991.

Boucher, Norman. "Species of the Sprawl." *Wilderness*. Washington, DC: Defenders of Wildlife, Summer 1995.

Boyce, D.E., M.C. Romanos, B.N. Janson, P. Prastacos, M. Ferris, and R.W. Eash. *Urban Transportation Energy Accounts.* September 1981.

Bradbury, Kathernine, Anthony Downs, and Kenneth Small. *Urban Decline and the Future of American Cities*. Washington, DC: Brookings Institution, 1982.

Bright, C. "Understanding the Threat of Bioinvasions." *State of the World.* Ed. Starke. New York: W.W. Norton & Co., 1996, p. 95-113.

Brown et al. "SW Phase II Report to Congress." 1985.

Burchell, Robert W. et al. *The Costs of Sprawl – Revisited.* Transit Cooperative Research Program (TCRP) Report 39. Washington, DC: National Academy Press, Transportation Research Board, 1998.

Novotny, V. And G. Chesters. *Handbook of Nonpoint Pollution Sources and Management.* New York: Von Nostrand Reinhold Environmental Engineering Series, 1981.

Burchell, R. "Understanding Sprawl." *On the Ground.* Vol. 2, No. 2, 1996.

Burchell, Robert and David Listokin. "Fiscal Studies." Report to the Governor's Commission on Growth in the Chesapeake Bay Region. Annapolis, MD: 2020 Commission, 1990.

Burchell, Robert and David Listokin. "The Economic Impacts of Trend versus Vision Growth in the Lexington (Kentucky) Metropolitan Area." Report prepared for Bluegrass Tomorrow. Lexington, KY: January 1995.

Burchell, Robert and Harvey Moskowitz. "Impact Assessment of DELEP CCMP versus Status Quo on Twelve Municipalities in the DELEP Region." Report prepared for the Local Governments Committee of the Delaware Estuary Program. Philadelphia, PA: August 1995.

Burchell, Robert et al. *Fiscal Impacts of Alternative Land Development Patterns in Michigan: The Costs of Current Development Versus Compact Growth.* Southeast Michigan Regional Council of Governments, 1997.

Burchell, Robert et al. *Impact Assessment of the New Jersey Interim State Development and Redevelopment Plan.* Trenton, NJ: New Jersey Office of State Planning, 1992.

Button, K.J. *Transport Economics.* Hampshire, England: Gower Publishing Co. Ltd., 1982, p. 33.

Cambridge Systematics et al. *Making the Land Use Transportation Air Quality Connection: Model Modifications*. Prepared for Thousand Friends of Oregon. Vol. 4, May 1996.

Center for Watershed Protection. *Blueprint to Protect Coastal Water Quality.* Land Ethics, Inc.

Cervero, Robert and Kara Kockelman. "Travel Demand and the Three Ds: Density, Diversity, and Design." Berkeley, CA: University of California Institute of Urban and Regional Development, 1996.

Cervero, Robert. "Land Use Mixing and Suburban Mobility." *Transportation Quarterly.* Vol. 42, 1988. p. 429-446.

Cervero, Robert. "Land Uses and Travel at Suburban Activity Centers." *Transportation Quarterly.* Vol. 45, 1988. p. 479-491.

Cervero, Robert. "Mixed Land Uses and Commuting: Evidence from the American Housing Survey." *Transportation Research.* Vol. 30, No. 5, 1996. p. 363.

Cervero, Robert. "Ridership Impacts of Transit-Focused Development in California." University of California Transportation Center, Working Paper No. 176, 1993.

Cervero, Robert. *America's Suburban Centers: The Land Use Transportation Link.* Winchester, MA: Unwin Hyman, 1989.

Cervero, Robert. *Suburban Gridlock*. New Brunswick, NJ: Rutgers University Press, 1986.

Chesapeake Bay Foundation. *A Better Way to Grow*. 1996.

Colorado/Wyoming Section Technical Committee, Institute of Transportation Engineers. "Trip Generation for Mixed Use Developments." *ITE Journal*, Volume 57, 1987. p. 27-29.

Crane, R. "Cars and Drivers in the New Suburbs." *Journal of the American Planning Association* 62: 1, Winter 1996. p. 51-65.

Dahl, T.E. and C.E. Johnson. *Status and Trends of Wetlands in the Conterminous United States, Mid-1970's to Mid-1980's*. Washington, D.C.: US Department of Interior, Fish and Wildlife Service, 1991.

DeCorla-Souza, Patrick. *The Impacts of Alternative Urban Development Patterns on Highway System Performance*. Presentation to ITE Conference on Transportation Engineering in a New Era. 1992.

Delucchi, M.A. "Bundled Private Sector Costs of Motor Vehicle Use." Report No. 6 in Series: The Annualized Social Costs of Motor-Vehicle Use in the U.S., Based on 1990-91 Data. Davis, CA: University of California, Davis, Institute of Transportation Studies, 1997.

Dobson, A. P., J. P. Rodriguez, W. M. Roberts, D. S. Wilcove. "Geographic Distribution of Endangered Species in the United States," *Science*. Volume 275, Number 5299, January 24, 1997.

Dowling , Richard G. and Steven Colman, "Effects of Increased Highway Capacity: Results of a Household Travel Behavior Survey," Transportation Research Board paper No. 95-0409, presented at the 74th Annual TRB meeting, January 22-28, 1995.

Duany, Andres, and Elizabeth Plater-Zyberk. "The Second Coming of the American Small Town." *The Wilson Quarterly*. 16,1, 1992. p. 19-48.

Dunphy, Robert and Kimberly Fisher. *Transportation, Congestion, and Density: New Insights*. Urban Land Institute, January 1994.

Eash, R. "Incorporating Urban Design Variables in Metropolitan Planning Organizations' Travel Demand Models." Williamsburg, VA: Conference on Urban Design, Telecommuting, and Travel Behavior, October 1996.

Etling, Kathy. "Of Owls and Interstates," *Missouri Conservationist*. Volume 54, Number 11, November 1993.

Ewing, R. *Best Development Practices*. Florida Atlantic University/Florida International University, Joint Center for Environmental and Urban Problems, May 1995.

Ewing, Reid, Padma Haliyur, and G. William Page. "Getting Around a Traditional City, a Suburban Planned Unit Development, and Everything in Between," *Transportation Research Record 1466*. 1994. p. 53-62.

Ewing, Reid. "Is Los Angeles-Style Sprawl Desirable?" *Journal of the American Planning Association*. Volume 63, Number 1, Winter 1997.

Fehr and Peers. "Effect of Stockton's Proposed Suburban Village Center Development." January 1992.

Field, R., H. Masters, and M. Singer. "Porous Pavement: Research; Development; and Demonstration." *Transportation Engineering Journal of the American Society of Civil Engineers*. Volume 108, Number TE3, May 1982.

Flather, C.H., L.A. Joyce, and C.A. Bloomgarden. 1994. (as cited in: Noss, Reed and Fobert Peters. *Endangered Ecosystems: A Status Report on America's Vanishing Habitat and Wildlife*. Defenders of Wildlife, December 1995. p. 46.)

Frank, L. and G. Pivo. "Impacts of Mixed Use and Density on Utilization of Three Modes of Travel: Single-Occupant Vehicle, Transit, and Walking." *Transportation Research Record* 1466, 1994. p. 44-52.

Franklin, T.M. "Use of Urban Stormwater Control Impoundments by Wetland Birds." *Wilson Bulletin.* Vol. 97, 1985. p. 120-122.

Frey, W.H. "Central City White Flight: Racial and Non-Racial Causes." *American Sociological Review*. Vol. 44, 1979. p. 425-88.

Friedman, Bruce, Stephen Gordon, and John Peers. "Effect of Neotraditional Neighborhood Design on Travel Characteristics." *Transportation Research Record* 1466, 1994. p. 63-70.

Friend, Milton. *Increased Avian Diseases With Habitat Change.* Madison, WI: National Biological Service.

Gardiner, David. "Global Climate Change Negotiations." Testimony before the House Commerce Committee, Subcommittee on Energy and Power. June, 1996.

Giuliano, Genevieve and Kenneth Small. "Is the Journey to Work Explained by Urban Spatial Structure?" *Urban Studies* 30:9, 1993. p. 1485-1500.

Giuliano, Genevieve and Kenneth Small. "Is the Journey to Work Explained by Urban Structure?" University of California Transportation Center. Working Paper No. 107, June 1992.

Giuliano, Genevieve and Kenneth Small. "Subcenters in the Los Angeles Region." *Journal of Regional Science and Urban Economics*. Vol. 21, p. 163-182.

Giuliano, Genevieve. "Is Jobs-Housing Balancing a Transportation Issue?" *Transportation Research Record* 1305, 1991, p. 305-312.

Groves, R.H. and J.J. Burdon, eds. *Ecology of Biological Invasions.* Cambridge, UK: Cambridge University Press, 1986.

Grubb, W.N. "The Flight to the Suburbs of Population and Employment, 1960-1970." *Journal of Urban Economics.* Vol. 11, 1982. p. 348-67.

Gruen Gruen & Associates. *Employment and Parking in Suburban Business Parks: A Pilot Study.* Washington, DC: Urban Land Institute. 1986.

Hagler Bailly and Criterion. "The Transportation and Environmental Impact of Infill versus Greenfield Development: A Comparative Case Study Analysis." Prepared for U.S. Environmental Protection Agency, 1998.

Handy, Susan. "How Land Use Patterns Affect Travel Patterns: A Bibliography." *Built Environment.* University of California at Berkeley, Winter-Spring 1992.

Handy, Susan. *Regional Versus Local Accessibility: Implications for Non-Work Travel.* Doctoral Dissertation. Davis, CA: University of California, Davis, Institute of Transportation Studies. 1992.

Handy, Susan. "Understanding the Link between Urban Form and Travel Behavior." Paper presented at the 74th Annual Meeting of the Transportation Research Board. January 1995.

Handy, Susan. "Urban Form and Pedestrian Choices: Study of Austin Neighborhoods." *Transportation Research Record* 1552. p. 142.

Hansen, Mark and Yuanlin Huang. "Road Supply and Traffic in California Urban Areas." *Transportation Research*, Volume 31, Number 3. Great Britain: Elsevier Science Ltd, 1997.

Harbor, Jonathon M. "A Practical Method for Estimating the Impact of Land –Use Change on Surface Runoff, Groundwater Recharge, and Wetland Hydrology." *Journal of the American Planning Association*. Volume 60, Number 1, Winter 1994. p. 95-108.

Harvey, G. *Relation of Residential Density to VMT per Resident: Oakland.* Metropolitan Transportation Commission, 1990.

Herson-Jones, Lorraine M. Maureen Heraty, and Brian Jordan. *Environmental Land Planning Series: Riparian Buffer Strategies for Urban Watersheds.* Urban Watershed Planning Section. Washington, DC: Department of Environmental Programs, Metropolitan Washington Council of Governments, December 1995.

Higgins, Thomas, K.T. Analytics, Inc. "Parking Management and Traffic Mitigation in Six Cities: Implications for Local Policy." Paper presented to Transportation Research Board, January 1989.

"Highway Capacity Expansion and Induced Travel: Evidence and Implications." *Transportation Research Circular*, Number 481. Transportation Research Board, 1998.

Holtzclaw, John. "Using Residential Patterns and Transit to Decrease Auto Dependence and Costs." Natural Resources Defense Council, June 1994.

Holtzclaw, John. "Explaining Urban Density and Transit Impacts on Auto Use." Presented to State of California Energy Resources Conservation and Development Commission, January 1991.

Institute of Transportation Engineers (ITE). *Traditional Neighborhood Development Street Design Guidelines*. Pub. No. RP-027.

Institute of Transportation Engineers. *Traffic Calming in Practice*. Landor Publishing, 1994.

Intergovernmental Panel on Climate Change (IPCC). *Second Scientific Assessment of Climate Change, Summary and Report.* World Meteorological Organization / U.N. Environment Program. Cambridge, MA: Cambridge University Press, 1995.

JHK & Associates and K.T. Analytics. *Analysis of Indirect Source Trip Activity: Regional Shopping Centers.* Final Report. Prepared for California Environmental Protection Agency, Air Resources Board, November 1993.

JHK & Associates. *Development-Related Ridership Survey I.* Washington, DC: Washington Metropolitan Area Transit Authority, 1987.

Johnston, R.A., and R. Ceerla. "Land Use and Transportation Alternatives" In D. Sperling and S. Shaheen (eds.), *Transportation and Energy*, ICEEE, 1995.

Johnston, Robert and Tomas de la Barra. "Comprehensive Regional Modeling for Long-Range Planning: Linking Integrated Urban Models to Geographic Information Systems." Resubmitted to *Transportation Research: A*, 1998.

Jones, H., L.M. Maureen Heraty, and B. Jordan. *Environmental Land Planning Series: Riparian Buffer Strategies for Urban Watersheds.* Urban Watershed Planning Section. Washington, DC: Department of Environmental Programs, Metropolitan Washington Council of Governments, December 1995.

Ketcham, B. and C. Komanoff. *Win-Win Transportation: A No-Losers Approach to Financing Transport in New York City and the Region*. 1992.

Kockelman, Kara. "Travel Behavior as a Function of Accessibility, Land Use Mixing, and Land Use Balance: Evidence from the San Francisco Bay Area." Submission to 76th Annual Meeting of the Transportation Research Board, 1997.

Kulash, Anglin, and Marks. "Traditional Neighborhood Development: Will the Traffic Work?" *Development,* Vol. 21, July/August 1990. p. 21-24.

Landis, John. "Improving Land Use Futures: Applying the California Urban Futures Model." *Journal of the American Planning Association* 61, 4 (Autumn), 1995. p. 438-457.

LaRoe, Edward T., Gaye S. Farris, Catherine E. Puckett. *Our Living Resources - A Report to the Nation on the Distribution, Abundance, and Health of US Plants, Animals, and Ecosystems*. Washington, DC: U.S. Department of the Interior, National Biological Service, 1995.

Leedy, Daniel and Lowell Adams, "Wildlife in Urban and Developing Areas: An Overview and Historical Perspective," in *Integrating Man and Nature in the Metropolitan Environment: Proceedings of a National Symposium on Urban Wildlife*, 4-7, ed. Adams and Leedy. Columbia, MD: National Institute for Urban Wildlife, November 1986.

Levine, Jonathon. "Land Use Solutions to Transportation Problems? Rethinking Accessibility and Jobs-Housing Balancing." Paper submitted to the 75th Annual Meeting of the Transportation Research Board, 1996.

Levinson, D.M. and A. Kumar. "Is Residential Density a Transportation Issue?" Submitted to *Urban Studies.* Unpublished. 1993.

Loutzenheiser, David. "Pedestrian Access to Transit: A Model of Walk Trips and their Design and Urban Form Determinants Around BART Stations." Presentation to 76th Annual Meeting of Transportation Research Board, 1997.

Luce, Thomas F., Barbara Lukerman, and Herbert Mohring. "Regional Sewer System Rate Structure Study." Minneapolis: Hubert H. Humphrey Institute of Public Affairs, University of Minnesota, December 7, 1992.

Lupa, Mary, et al. "Transportation Sketch Planning with Land Use Inputs." *Transportation Research Record 1499,* 1995. p. 83-94.

MacKenzie, et al. *The Going Rate: What it Really Costs to Drive.* Washington, DC: World Resources Institute, 1992.

Mantell, Michael A., Stephen F. Harper, and Luther Propst. *Creating Successful Communities: A Guidebook to Growth Management Strategies.* The Conservation Foundation. Island Press, 1990.

McCubbin, D. and M. Delucchi. *Health Effects of Motor Vehicle Air Pollution.* 1995

McMichael, Antony. "Global Health Watch: Monitoring Impacts of Environmental Change." *The Lancet.* Volume 342, December 1993.

McNally and Ryan. "A Comparative Assessment of Travel Characteristics for Neotraditional Developments." University of California Transportation Center. University of California at Berkeley. Working Paper No. 142. August 1992

Metro 2040 Growth Concept. Portland, OR: December 8, 1994.

Metropolitan Washington Council of Governments. "Transportation Demand Impacts of Alternative Land Use Scenarios." May 31, 1991.

Miller, P. and J. Moffet. *The Price of Mobility: Uncovering the Hidden Costs of Transportation.* Natural Resources Defense Council, 1993.

Miramontes, Ellen Marie. University of California at Berkeley. "The Bay Area's Love-Hate Relationship With The Motorcar." San Francisco *Examiner,* October 20, 1997.

Moudon, et al. "Effects of Site Design on Pedestrian Travel in Mixed Use, Medium Density Environments." Submission to 76th Annual Meeting of the Transportation Research Board, 1997.

National Urban Runoff Program. *Bellevue NURP Report.*

Nelessen, Anton C. "Visions for a New American Dream." Chicago, IL: American Planning Association, 1994.

Noss, Reed F. and Robert L. Peters. *Endangered Ecosystems: A Status Report on America's Vanishing Habitat and Wildlife*. Washington, DC: Defenders of Wildlife, December 1995.

Novotny, V. and G. Chesters. *Handbook of Nonpoint Pollution Sources and Management*. New York: Von Nostrand Reinhold Environmental Engineering Series, 1981.

Nowlan and Stewart. "Downtown Population Growth and Commuting Trips." *Journal of the American Planning Association.* Vol. 57(2), 1991. p. 165-182.

Ogden, K.W. *Urban Goods Movement: A Guide to Policy and Planning.* Hampshire, England: Gower House, 1992.

Orfield, Myron. *Metropolitics.* Washington, DC: Brookings Institution, 1997. p. 53.

Organization for Economic Cooperation and Development. *Indicators for the Integration of Environmental Concerns into Transport Policies.* OECD Publications. 1993.

Orlando, Florida. *Urban Area Growth Management Plan.* 1991.

Parker, Terry. California Air Resources Board. *The Land Use-Air Quality Linkage: How Land Use and Transportation Affect Air Quality*. 1994.

Parsons Brinckerhoff Quade and Douglas *et al*. *Making the Land Use Transportation Air Quality Connection: Building Orientation.Vol. 4B*. Prepared for Thousand Friends of Oregon. Portland, OR: May 1994.

Parsons Brinckerhoff Quade and Douglass, Inc. "Part I: Transit, Urban Form, and the Built Environment: A Summary of Knowledge." Transit Cooperative Research Program Report 16. *Transit and Urban Form*. Washington, DC: Transportation Research Board, 1996.

Parsons Brinckerhoff Quade and Douglass, Inc. "Part IV: Public Policy and Transit-Oriented Development: Six International Case Studies." Transit Cooperative Research Program Report 16. *Transit and Urban Form*. Washington, DC: Transportation Research Board, 1996.

Pendall, Rolf. "Land Availability and Zoning: Indications from a National Survey." *On the Ground*. Fall, 1994. p. 19-20.

Pepper, Edith M. *Lessons from the Field.* Washington, DC: Northeast-Midwest Institute, 1997.

Peters, Robert L., Evan Frost, and Felice Pace. *Managing for Forest Ecosystem Health: A Reassessment of the 'Forest Health Crisis*. Washington, DC: Defenders of Wildlife, April 1996.

Pucher, John. "Bicycling Boom in Germany: A Revival Engineered by Public Policy." *Transportation Quarterly*. Vol. 51, No. 4. Fall, 1997.

Pushkarev, B. and J. Zupan. *Public Transportation and Land Use Policy*. Bloomington, IN: Indiana University Press, 1977.

Real Estate Research Corporation. *Infill Development Strategies*. Washington, DC: The Urban Land Institute and the American Planning Association, 1982.

Real Estate Research Corporation. *The Cost of Sprawl.* 1974.

Replogle, Michael. *Bicycles and Public Transportation.* 1984.

Replogle, Michael. *Integrating Pedestrian and Bicycle Factors into Regional Transportation Planning Models: Summary of State-of-the-Art and Suggested Steps Forward*. Environmental Defense Fund, July 20, 1995.

Replogle, Michael. "Land Use/Transportation Scenario Testing: A Tool for the 1990s." Silver Spring, Maryland: Montgomery County Planning Department, 1993. (Prepared for Presentation at Transportation Research Board 1993 Annual Meeting.)

Rivlin, Alice. "Budgeting for Performance." *Intergovernmental Perspective*. Fall 1993-Winter 1994.

Rodier, Caroline A. and Robert A. Johnston. "Travel, Emissions and Welfare Effects of Travel Demand Management Measures." *Transportation Research Record* 1598. 1997.

Rutherford, G.S., E. McCormack, and M. Wilkinson. "Travel Impacts of Urban Form: Implications from an Analysis of Two Seattle Area Travel Diaries." TMIP Conference on Urban Design, Telecommuting, and Travel Behavior, October 27-30, 1996.

"Long Haul to American Dream." *San Francisco Chronicle*. March 18, 1997.

Schueler, Thomas, Peter Kumble, and Maureen Heraty, Anacostia Restoration Team, Metropolitan Washington Council of Governments. "A Current Assessment of Urban Best Management Practices: Techniques for Reducing Non-Point Source Pollution in the Coastal Zone." Prepared for U.S. Environmental Protection Agency, March 1992.

Schueler, Tom. *Environmental Land Planning Series: Site Planning for Urban Stream Protection*. Center for Watershed Protection. Publication No. 95708. Washington, DC: Metropolitan Washington Council of Governments, December 1995.

Schueler, Tom. *A Framework for Evaluating Compliance with the 10% rule in the Chesapeake Bay Critical Area*. Annapolis, MD: Maryland Critical Area Commission, 1987.

Shaw, John. "Minimum Parking Requirements in Midwestern Zoning Ordinances." Paper presented at 76th Annual Meeting of the Transportation Research Board, January 1997.

Shoup, Donald. "Cashing Out Employer-Paid Parking." FTA-CA-11-0035-92-1. Washington, DC: U.S. Department of Transportation, 1993.

Shoup, Donald. "The Pedigree of a Statistic." *Access*. Vol. 11, Berkeley, CA: University of California Transportation Center, Fall 1997, 41.

Simons, Robert. *Brownfields Supply and Demand Analysis for Selected Great Lakes Cities.* Cleveland State University, Department of Planning and Development. Prepared for EPA, 1996.

Snyder, Robin, EZ/EC EPA Programmatic Contact- Personal communication, 1997.

Soule, Michael E. "Land Use Planning and Wildlife Maintenance - Guidelines for Conserving Wildlife in an Urban Landscape." *Journal of the American Planning Association.* Volume 57, Number 3, Summer 1991.

Southworth, Michael, and Eran Ben-Josaph. *Streets and the Shaping of Towns and Cities.* McGraw Hill, 1997.

State of New Jersey, Department of Environmental Protection. *New Jersey's Environment 1988.*

SW Phase II Report To Congress Brown et al., 1985; Novotny and Chesters, 1981

Texas Transportation Institute. *Urban Roadway Congestion, Annual Report 1998*. 1998.

The Public Purpose. "Demographic Briefs and Urban Policy." See web site: http://www.publicpurpose.com/dm-uad.htm

Thelen, Edmund, and L. Fielding Howe. *Porous Pavement*. Philadelphia, PA: The Franklin Institute Press, 1978.

Thousand Friends of Oregon. “Making the Connections: A Summary of the LUTRAQ Project.” February 1997.

Titus, J. and V. Narayanan. “Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea.” *Coastal Management*. Volume 19, 1991.

Tolley, R.S. and B.J. Turton, “Transport Systems, Policy, and Planning: A Geographic Approach.” *Longman Scientific and Technical*. 1995.

Tourbier, J. Toby. *Water Resources Protection Technology : A Handbook of Measures to Protect Water Resources in Land Development*. Washington, DC: Urban Land Institute, 1981.

Transit Cooperative Research Program (TCRP). “An Evaluation of the Relationship between Transit and Urban Form.” *Research Results Digest*. No. 7, June 1995.

Transit Cooperative Research Program (TCRP). “Influence of Land Use Mix and Neighborhood Design on Transit Demand.” TCRP Project H-1, March 1996.

U.S. Congress, Office of Technology Assessment. *Preparing for an Uncertain Climate Volume 1, II.* Washington, DC: U.S. Government Printing Office, 1993.

U.S. Department of Agriculture, Economic Research Service, Natural Resources and Environment Division. *Agricultural Resources and Environmental Indicators: 1996-97.* July 1997.

U.S. Department of Agriculture, Economic Research Service, Natural Resources and Environment Division. . “Major Land Use Changes in the Contiguous 48 States.” *Agricultural Resources and Environmental Indicators (AREI) Updates, No. 3.* June 1997.

U.S. Department of Commerce, *Statistical Abstract of the United States: 1998*. September 1998.

U.S. Department of Energy, Energy Information Administration. *Annual Energy Outlook 1999 with Projections to 2020.* October 1998.

U.S. Department of Energy, Energy Information Administration. *Emissions of Greenhouse Gases in the United States, 1997.* October 1998.

U.S. Department of Energy. *Transportation Energy Data Book.* Annual Editions.

U.S. Department of Transportation, Bureau of Transportation Statistics. *National Transportation Statistics 1998.* 1998.

U.S. Department of Transportation, Federal Highway Administration. *Evaluation of Wetland Mitigation Measures. Volume I: Final Report.* 1992.

U.S. Department of Transportation, Federal Highway Administration. *FHWA National Strategic Plan.* 1997.

U.S. Department of Transportation, Federal Highway Administration. *Flexibility in Highway Design.* 1998.

U.S. Department of Transportation, Federal Highway Administration. *Highway Statistics.* Washington, DC: Annual Editions.

U.S. Department of Transportation, Federal Highway Administration. *Nationwide Personal Transportation Survey 1990.*

U.S. Department of Transportation, Federal Highway Administration. *Nationwide Personal Transportation Survey 1995.*

U.S. Department of Transportation, Federal Highway Administration. *Our Nation’s Highways: Selected Facts and Figures*. Annual Editions.

U.S. Department of Transportation, Federal Highway Administration. *Our Nation's Travel: 1995 NPTS Early Results Report.* 1997.

U.S. Department of Transportation. *1997 Status of the Nation's Surface Transportation System: Condition & Performance Report.* Report to Congress. 1998.

U.S. Department of Transportation. *Implementing Effective Travel Demand Management Measures: Inventory of Measures and Synthesis of Experience.* September 1993.

U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. *National Air Pollutant Emissions Trends, 1900-1997*. 1998.

U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards. *National Air Quality and Emission Trends Report, 1997.* Research Triangle Park, NC: December 1998.

U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation. *Natural Resources for the 21st Century: An Evaluation of the Effects of Land Use on Environmental Quality*. Washington, DC: June 1989. p. 61.

U.S. Environmental Protection Agency, Office of Policy, Planning, and Evaluation, *Indicators of the Environmental Impacts of Transportation: Highway, Rail, Aviation, and Maritime Transport.* Prepared by Hagler Bailly, 1999.

U.S. Environmental Protection Agency, Office of Research and Monitoring. *Investigation of Porous Pavements for Urban Runoff Control.* March 1972.

U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response. *Brownfields Initiative* (Quick Reference Fact Sheet) April 1996.

U.S. Environmental Protection Agency, Office of Water. *National Water Quality Inventory: 1996 Report to Congress*. Washington, DC: 1998.

U.S. Environmental Protection Agency. *Environmental Impacts of Storm Water Discharges - A National Profile*. Washington, D.C., June 1992. (EPA 841-R-92-001)

U.S. Environmental Protection Agency. *EPA Strategic Plan.* Washington, DC, 1997.

U.S. Environmental Protection Agency. *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters.* Chapter 4, Section VII: Onsite Sewage Disposal Systems, 1991.

U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation. *Natural Resources for the 21st Century: An Evaluation of the Effects of Land Use on Environmental Quality*. Washington, DC: June 1989.

U.S. Environmental Protection Agency. *Policy Options for Stabilizing Global Climate: Report to Congress.* Washington, DC: December 1990.

U.S. Environmental Protection Agency. November 1, 1999. "Transportation and Environmental Analysis of the Atlantic Steel Development Project." Prepared by Hagler Bailly

U.S. General Accounting Office. *Community Development: Reuse of Urban Industrial Sites*. (GAO/RCED-95-172) Washington, DC: U.S. Government Printing Office, June 1995.

University of Toronto/York University Joint Program in Transportation, Data Management Group. *The Transportation Tomorrow Survey: Travel Survey Summary for the Greater Toronto Area.* June 1989.

Unterman, D. "Accommodating the Pedestrian: Adapting Towns and Neighborhoods for Walking and Bicycling." *Personal Travel in the U.S., Vol. II, A Report of the Findings from 1983-1984 NPTS, Source Control Programs.* U.S. Department of Transportation. 1990.

Washington Post. "As the Economy Grows, the Trees Fall," March 23, 1997.

Wasylenko, Michael. "Disamenities, Local Taxation, and the Intrametropolitan Location of Households and Firms." *Research in Urban Economics*. Vol. 4. Ed. Robert Ebel. Greenwich, CN: JAI Press, 1984.

Weaver, L. Alan, and Greg C. Garman. "Urbanization of a Watershed and Historical Changes in a Stream Fish Assemblage." *Transactions of the American Fisheries Society*. Volume 123, 1994.

White Mountain Survey Company. "City of Portsmouth Traffic/Trip Generation Study." Ossippee, New Hampshire: White Mountain Survey Company, 1991 (unpublished).

Willson, Richard W. "Suburban Parking Requirements: A Tacit Policy for Automobile Use and Sprawl." *Journal of the American Planning Association*. Vol. 61, No. 1, Winter 1995. p. 29-42.

Witham, Drake and Bill Salisbury. "The Walking Wounded." *St. Paul Pioneer Press*. April 14, 1997, B2.

World Bank. *Sustainable Transport: Priorities for Policy Reform*. Washington, DC: 1996, p. 59.