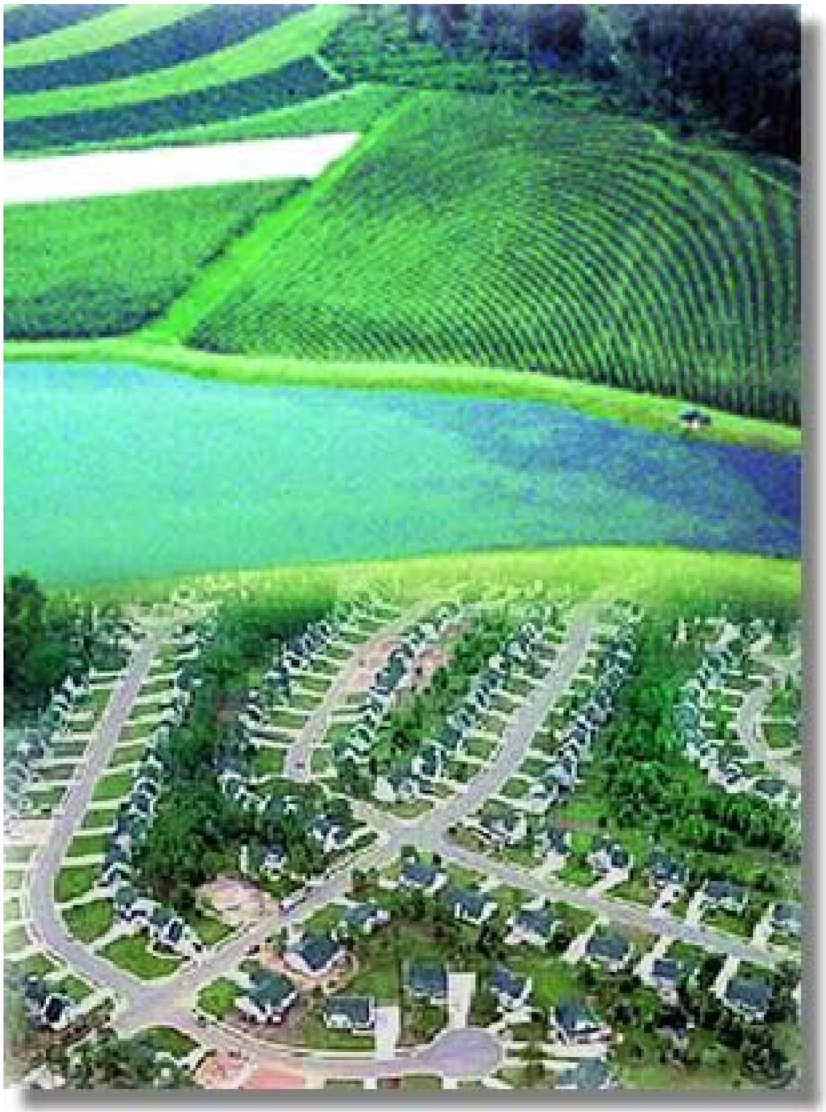
Paving Our Way to Water Shortages:

How Sprawl Aggravates Drought



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ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Over this long, blistering summer, Americans from coast to coast have been suffering through one of the worst droughts in decades. Many blame erratic weather conditions for water shortages, while others point to population growth. But that's not the whole story. Another major contributor to our water problems is the way we develop land. As we pave over more and more wetlands and forests, this new report shows that we are depleting our water supplies. It's not only the arid West that is facing critical shortages. The rapidly suburbanizing Southeast, blessed with a seemingly inexhaustible water supply, is now in serious trouble, as are many other formerly water-rich regions of the country.

Over the last decade, studies have linked suburban sprawl to increased traffic and air pollution as well as the rapid loss of farmland and open space. Sprawl also threatens water quality. Rain that runs off roads and parking lots carries pollutants that poison rivers, lakes, streams, and the ocean. But sprawl not only pollutes our water, it also reduces our supplies. As the impervious surfaces that characterize sprawling development – roads, parking lots, driveways and roofs – replace meadows and forests, rain no longer can seep into the ground to replenish our aquifers. Instead, it is swept away by gutters and sewer systems.

The problem has its genesis in the post-World War II push by federal and state governments to promote suburbs at the expense of cities by, among other things, constructing new networks of roads and highways. Suburbs spread decade after decade, and the amount of land eaten up by sprawl jumped 50 percent from the 1980s to the 1990s alone, according to the Department of Agriculture's Natural Resources Inventory. By the 1990s, Americans were developing about 2.1 million acres a year.

The sprawling of America has translated into a significant loss of valuable natural resources. Undeveloped land is valuable not just for recreation and wildlife, but also because of its natural filtering function. Wetlands, for example, act like sponges, absorbing precipitation and runoff and slowly releasing it into the ground. More than one-third of Americans get their drinking water directly from groundwater, and the remaining two-thirds who depend on surface water also are affected, given that about half of a stream's volume comes from groundwater.

This new study by American Rivers, NRDC (Natural Resources Defense Council) and Smart Growth America investigated what happens to water supplies when we replace our natural areas with roads, parking lots and buildings. First, we determined which metropolitan areas have experienced the most development over the last 20 years. We found that 11 of the 20 metro areas with the greatest land conversion rates from 1982 to 1997 are in the Southeast; the other nine are divided evenly among the remaining regions – three each in the Northeast, Midwest and West. And population growth alone does not explain the magnitude of the development. Indeed, in every case but one, developed land growth topped population growth, in many cases by a factor of two to three.

We then developed a "range of imperviousness" for new development in these 20 metro areas. Assuming regional average soil types and accounting for regional rainfall patterns, we calculated the amount of rainwater that runs off the land instead of filtering through and recharging vital groundwater resources. Comparing the level of imperviousness in 1997 to 1982, we found that the potential amount of water lost to infiltration annually ranged from 6.2 billion to 14.4 billion gallons in Dallas to 56.9 billion to 132.8 billion gallons in Atlanta. Atlanta's "losses" in 1997 amounted to enough water to supply the average daily household needs of 1.5 million to 3.6 million people per year. The report found the following groundwater infiltration "losses" in other major sprawl centers:

- Atlanta – 56.9 billion to 132.8 billion gallons;
- Boston – 43.9 billion to 102.5 billion gallons;
- Charlotte – 13.5 billion to 31.5 billion gallons;
- Chicago – 10.2 billion to 23.7 billion gallons;
- Dallas – 6.2 billion to 14.4 billion gallons;
- Detroit – 7.8 billion to 18.2 billion gallons;
- Greensboro, N.C. – 6.7 billion to 15.7 billion gallons;
- Greenville, S.C. – 12.7 billion to 29.5 billion gallons;
- Houston – 12.8 billion to 29.8 billion gallons;
- Minneapolis-St. Paul – 9 billion to 21.1 billion gallons;
- Nashville – 17.3 billion to 40.5 billion gallons;
- Orlando – 9.2 billion to 21.5 billion gallons;
- Philadelphia – 25.3 billion to 59 billion gallons;
- Pittsburgh – 13.5 billion to 31.5 billion gallons;
- Raleigh-Durham-Chapel Hill – 9.4 billion to 21.9 billion gallons;
- Seattle – 10.5 billion to 24.6 billion gallons;
- Tampa – 7.3 billion to 17 billion gallons; and
- Washington, D.C. – 23.8 billion to 55.6 billion gallons

Fortunately there is a way to reverse this growing problem, but it means changing the way we approach development. Using smart growth techniques, we can reduce the impact of development. These approaches protect farms and forests on the metropolitan fringe by encouraging investment in the urban core and older suburbs. By directing growth to communities where people already live and work, we can limit the number of new paved and other impervious surfaces that cover the landscape, make existing communities more attractive, and discourage new infrastructure that alters natural hydrologic functions and increases taxpayer burdens.

Although communities around the country are turning to a range of strategies to cope with water shortages, including conservation, they are overlooking smart growth solutions. There is no one-size-fits-all definition, but smart growth generally entails integrated planning and incentives and infrastructure investments to revitalize existing communities, prevent leapfrogging sprawl, provide more transportation choices, and protect open space. By adopting a regional smart growth approach, metropolitan areas could reduce the spread of impervious surfaces. An analysis completed in 2000, for example, estimated that over the next 25 years smart growth techniques could save more than 1.6 million acres of land in all 20 metropolitan regions in our study. And if these communities focused their efforts on preserving forests, wetlands and other valuable lands, their vital role in recharging groundwater would not be compromised.

American Rivers, NRDC and Smart Growth America urge policymakers to embrace smart-growth policies to address water shortage issues. Specifically, the groups recommend that state and local authorities:

- allocate more resources to identify and protect open space and critical aquatic areas;

- practice sound growth management by passing stronger, more comprehensive legislation that includes incentives for smart growth and designated growth areas;
- integrate water supply into planning efforts by coordinating road-building and other construction projects with water resource management activities;
- invest in existing communities by rehabilitating infrastructure before building anew – a "fix it first" strategy of development;
- encourage compact development that mixes retail, commercial and residential development;
- manage stormwater using natural systems by replacing concrete sewer and tunnel infrastructure, which conveys stormwater too swiftly into our waterways, with low-impact development techniques that foster local infiltration of stormwater to replenish groundwater;
- devote more money and time to research and analysis of the impact of development on water resources, and make this information accessible.

These are efficient, cost-effective and proven approaches. They would provide multiple benefits for communities that not only want to conserve water, but also to find relief from endless commutes, air and water pollution, and disappearing open spaces. All we need is the political will to adopt them.

INTRODUCTION

The drought and its attendant water shortages have been making headlines nationwide since last summer, and the experts say there is no end in sight. Over half the nation is gripped by drought and many states are suffering an "exceptional" drought, the worst level measured.[1] Restrictions on water use are growing. Parts of Pennsylvania, New Jersey and Maryland are under drought emergencies that limit car washing, lawn watering and the filling of pools. The drought in Georgia is in its fourth year, and the last 12 months were the driest in more than 100 years.[2] In early August 2002, officials in Monticello, Georgia, south of Atlanta, banned all outside watering, saying creek levels were so low that the area could run out of water in 30 to 45 days.[3] And in Union County, North Carolina, restrictions carry severe consequences for scofflaws: a fine of up to $500 or 20 days in jail and disconnection of water services.[4]

But is it just the weather that is causing water shortages, or does the way we develop our land have an effect on water supplies? In this report, we explain how sprawl affects the natural supply of freshwater available to us, and we estimate how much water we may be losing from sprawling development. We speak primarily to the rain rich regions of the United States – the East, Southeast, Midwest, and Northwest – because those areas are particularly reliant on rain as a source of groundwater recharge and flow to rivers and lakes from which we draw our water.

Sprawl is development marked by automobile-dependent, spread-out suburbs, where the activities of daily life – home, school, shopping and work – are separated by long distances linked only by pavement. It results in the excessive transformation of natural areas to hard surfaces, such as ever-widening roads, parking lots, and roofs. These "impervious surfaces" significantly change natural patterns of water movement, affecting river flows and the recharge of underground water supplies. Quite simply, rainfall cannot soak into the ground through hard surfaces and consequently does not replenish water supplies.

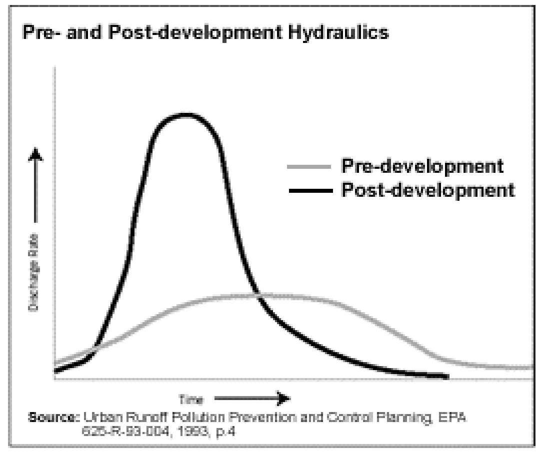
How we *use* our water supply – whether efficiently or wastefully – is not what this report is about, although it is a subject of great import.[5] Here we discuss what to most people is a hidden water supply issue. The ways in which we urbanize and grow affect the water available for us to use – wisely or not – and thus not only the quality of our lives, but the possibilities for our children and grandchildren as well.

SPRAWL WASTES WATER

It has been evident for some time that suburban development causes serious water pollution problems. Rain and snowmelt move across roads, parking lots and yards, sweeping a multitude of urban pollutants into our storm drains and on to our rivers and lakes. Sewer systems are often overwhelmed by the rapid runoff of stormwater from impervious surfaces, resulting in the discharge of raw sewage into our streams, lakes and coastal areas.[6] These effects alone warrant our attention. But we are now realizing that sprawling development affects *supplies* as well.

When we sprawl, we threaten our freshwater resources at the very time our demand for them is increasing. The large number of hard surfaces created by traditional suburban development fundamentally alters the local movement and availability of water. Suburban sprawl and its associated loss of forests, small streams, meadows, and wetlands, and the road-building and other hardening of natural areas that goes with it, prevent rain and snowmelt from soaking into the ground. Under natural conditions, rainwater filters into the ground, feeding rivers through springs and seepage during dry periods, and recharging underground aquifers.

Figure 1



But suburban sprawl has changed this relationship (See Figure 1). Instead, precipitation runs off of impervious surfaces much more rapidly and in much greater volume than under natural conditions. The result is a decrease in groundwater flows into streams, less recharge into aquifers, an increase in the magnitude and frequency of severe floods, and high stream velocities that cause severe erosion and mobilize large quantities of sediment, damaging water quality, aquatic habitat, and infrastructure, such as roads, bridges, and water and sewer lines.[7]

Low-density, automobile-dependent development is a leading cause of imperviousness. Transportation-related hard surfaces account for over 60% of the total imperviousness in suburban

The Problem with Lawns

Suburban sprawl also contributes to water scarcity because it promotes more lawn areas, and larger lots planted with turf grass. A study in the Seattle metropolitan area found significant differences in water use among suburban housing patterns. As might be expected, large suburban "estate" properties consumed as much as 16 times more water than homes on a more traditional urban grid, with smaller lots. According to the EPA, 32 percent of residential water use on average is for outdoor purposes. Per capita use of public water is about 50 percent higher in the West than the East, however, mostly due to the amount of landscape irrigation in the West. Some communities, particularly in the arid West, are responding to the drain on water supplies from outdoor water use by requiring reductions in turf grass area. Moreover, soils beneath our developed turf sites are often as impervious as roads and parking lots. Development involves wholesale grading of the site, removal of topsoil, severe erosion during construction, compaction by heavy equipment and filling of depressions. Indeed, some studies have shown that with these practices, the infiltration rate of urban soils actually approaches those of impervious surfaces.

Sources: EPA, *Clean Water Through Conservation*, EPA 841-B-95-002 (April 1995); Sakrison, R., *Water Use in Compact Communities: The Effect of New Urbanism, Growth Management and Conservation Measures on Residential Water Demands* (University of Washington, 1997); Schueler, T., *The Peculiarities of Perviousness*, Watershed Protection Techniques, Vol. 2, Issue 1, 1995.

areas.[8] Indeed, the city of Olympia, Washington found that transportation imperviousness constituted approximately two-thirds of total imperviousness in several residential and commercial areas.[9] Commercial parking lots are one of the biggest offenders because they are typically constructed with much greater parking capacity than needed. Vacancy rates are frequently as high as 60 to 70 percent; it is standard practice to provide four spaces per 1,000 sq. ft. of retail space and some big-box retailers supply five or more.[10] And a one-acre parking lot produces *16 times more runoff* than an undeveloped meadow.[11] Wide streets and excessive parking around single-family homes in sprawling developments also contribute to runoff.

Many jurisdictions are taking water out of underground aquifers faster than the natural replacement rate as it is. The problem is exacerbated when the water's return through infiltration is slowed even further by increases in hard surfaces that accompany land development. This raises the costs of pumping groundwater, and has been known to cause serious water quality degradation (such as seawater intrusion), and slumping and collapsing of the land (subsidence), and can eventually cause loss of the resource.[12]

Two-thirds of Americans obtain their drinking water from a water system that uses surface water.[13] The remaining 34 percent of us rely on groundwater. This last figure actually underestimates the importance of groundwater to drinking water supplies, however, because on average half of the water in rivers and streams seeps in from groundwater.[14] Indeed, for streams in some areas of the country groundwater is by far the largest source of flow. [15]

Instead of providing for the local infiltration of rainfall, we treat precipitation as a waste product, directing it into storm drains and pipes and pouring it into receiving waters, often far from its place of origin.[16] The effect is to create unnaturally high peak discharges after a storm, and unnaturally low flows long after the storm has passed. Typically, high stream flow caused by runoff is the first sign of urbanization effects. Low stream flows are exacerbated by low groundwater levels, which often occur later in the urbanization process.[17] Indeed, one study found that groundwater-influenced stream flow fell to 10 percent of the regional average when the level of imperviousness in the stream watershed reaches 65 percent.[18] See sidebar, Aging Infrastructure.

Aging Infrastructure

Aging sewers and storm drains that have lost their integrity exacerbate the effects of imperviousness and cost us money unnecessarily. Groundwater infiltrates these decrepit systems, often to be discharged far from the stream it would have replenished. In many cases, we send both storm and sewer water to centralized treatment plants far from the place of origin in order to "economize" on treatment. A recent study for the Charles River watershed in the Boston area shows that during a year of typical rainfall (45 inches), the central wastewater treatment plant that serves Boston and 42 other communities treated about 380 million gallons per day (mgd) of wastewater. Of this total, 180 mgd – ***60 percent of the total* -** was determined to be potable groundwater or stormwater inflow (potential groundwater) leaking *in* to sewer pipes through cracks and fissures. Because the Charles River depends on groundwater recharge in the late spring, summer, and early fall for 60 to 65% of its flow, the sewer system is not only dewatering groundwater supplies but is also causing significant stress to the river and its water quality.

Source: R. Zimmerman Jr., *Goodbye to Tea Parties in Boston* 26, Water Environment and Technology (February 2002).

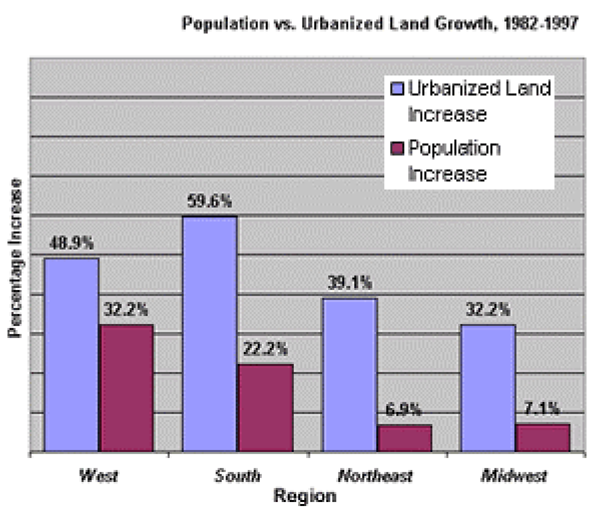
Top 20 Land Consuming Metro Areas

We have examined the relative land area of development in 312 metropolitan areas across the country, resulting in a list of "Top 20" land-consuming areas using data compiled by the U.S. Department of Agriculture (USDA), as part of its Natural Resource Inventory (NRI) database. The NRI database uses remote sensing information to determine changes in land use patterns over time. Based on this data, we have estimated the total area of new land development between 1982 and 1997 (See Appendix for more information on data and methodology).

The twenty most land-consuming metropolitan areas are ranked by total land area developed between 1982 and 1997 in Table A. Topping the list was Atlanta with an increase of as many as 609,000 acres (over 950 square miles) of new development. No region increased its developed area by less than 25 percent in that 15-year timeframe, and many areas increased significantly more than that, including Raleigh-Durham-Chapel Hill, NC (95%), Nashville, TN (103%), and Orlando, FL (105%).

Figure 2

Across metropolitan areas in all regions of the U.S., sprawl has been outpacing population growth. The disparity is greatest in cities in the Northeast and Midwest, although the total impact is most dramatic in the South.



Adapted with permission from Fulton, William, et al., "Who Sprawls Most? How Growth Patterns Differ Across the U.S.", Center for Urban And Metropolitan Policy, The Brookings Institution, July 2001.

U.S. Census population data for 1980 and 2000 show that some of the Top 20 most sprawling areas also experienced significant population growth during roughly the same period. For example, during the same 15-year period in which Orlando, Florida's developed land area increased by 105 percent, its population also grew by 51 percent between 1980 and 2000. However, the Top 20 list includes a number of urban centers where sprawl far exceeded population growth, particularly in the Northeast and Midwest, where population growth was comparatively modest, static or declining, such as Boston (12%), Chicago (12%), Pittsburgh (-9%) and Detroit (1%). Taken together, the data reveal that nearly all metropolitan areas in the Top 20 are gobbling up land out of proportion – in some cases far out of proportion – to their population growth. Figure 2 shows that in every region of the country, urbanized land increase has outpaced population growth. The disparity is greatest in the Northeast, and Midwest, although the total impact of sprawl is most dramatic in the South.

Table A: Top 20 Land Consuming Metro Areas

Metropolitan Area[a]	Land Developed, 1982-1997 (in acres)[b]	Increase in Developed Land as a Percent of 1982 Developed Land Base[c]	Population Growth - 1980 to 2000[d]
Atlanta, GA	609,500	81%	46%
Boston-Brocton-Nashua, MA - NH	433,000	52%	12%
Washington, DC	343,300	59%	21%
Dallas, TX	302,400	55%	42%
Houston, TX	291,400	39%	35%
Minneapolis-St. Paul, MN-WI	286,100	62%	26%
Chicago, IL	250,000	25%	12%
Charlotte-Gastonia-Rock Hill, NC - SC	246,200	74%	35%
Philadelphia, PA-NJ	238,800	33%	28%
Riverside-San Bernardino, CA	232,500	66%	52%
Orlando, FL	222,600	105%	51%
Nashville, TN	216,000	103%	31%
Raleigh-Durham-Chapel Hill, NC	207,000	95%	44%
Pittsburgh, PA	201,800	43%	-9%
Tampa-St. Petersburg- Clearwater, FL	199,800	50%	33%
Detroit, MI	187,200	25%	1%
Greenville-Spartanburg-Anderson, SC	166,300	67%	23%
Greensboro-Winston-Salem-Highpoint, NC	148,100	51%	24%
Phoenix-Mesa, AZ	145,600	48%	51%
Seattle-Bellevue-Everett, WA	141,000	48%	32%

Twenty metropolitan areas consumed more land for new development between 1982 and 1997 than any other areas in the country. With the exception of Phoenix, developed land area grew by more than population.

We have estimated how much groundwater recharge may be "lost" due to sprawl in the Top 20 sprawling metropolitan areas, based on a model using U.S. Geological Survey (USGS) data and other published information. Table B illustrates the effect of sprawl on potential water supplies in each of the Top 20 sprawling cities. **In Atlanta, for example, the model shows that between 56.9 and 132.8 billion gallons of groundwater infiltration may have been lost in 1997 compared to 15 years earlier.[e] That is enough water to supply the average daily household needs of between 1.5 and 3.6 million people per year.[f]**

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[a] Metropolitan Statistical Areas and Primary Metropolitan Statistical Areas as defined by the Office of Management and Budget (OMB) in guidance effective June 30, 1999 (OMB Bulletin 99-04). Northeastern County Metropolitan Areas are based on townships and were defined in the same OMB memorandum.

[b] Source: United States Natural Resources Inventory, Natural Resources Conservation Service, United States Department of Agriculture (USDA), 1997 (revised December 2000). Available at: http://www.nrcs.usda.gov/technical/NRI/1997/.

[c] Source: United States Natural Resources Inventory, Natural Resources Conservation Service, United States Department of Agriculture (USDA), 1997 (revised December 2000). Available at: http://www.nrcs.usda.gov/technical/NRI/1997/.

[d]1980 population data from Intercensal Estimates of the Resident Population of States and Counties 1980-1989," issued March 1992, U.S. Bureau of the Census, Population Estimates and Population Distribution
Branches, available online at: http://eire.census.gov/popest/archives/1980.php
http://eire.census.gov/popest/archives/1980.php. Year 2000 population data from "Time Series of States Population Estimates by County: April 1, 2000 to July 1, 2001," U.S. Bureau of the Census, Population Division, release date: April 29, 2002. http://www.census.gov/

[e] Depending on actual imperviousness in the area of new sprawl. This analysis assumes between 15 percent and 35 percent imperviousness – a conservative range of imperviousness in areas of suburban development, and average annual rainfall for the Atlanta area of 49.82 inches, according to the National Atmospheric and Oceanic Administration (NOAA), *Monthly Precipitation Probabilities and Quintiles, 1971-2000*, Climatology of the U.S., No. 81, Supplement No. 1.

[f] Calculation for Atlanta based on between 56.9 to 132.8 billion gallons (depending on actual imperviousness), divided by 100 gals. per person per day average household water use, divided by 365 days per year.

The Atlanta metro area takes at least 80 percent of its water from reservoirs located at the outer edge of the current metropolitan area that are fed primarily by headwater tributaries.[19] Thus, the loss of infiltration caused by Atlanta's sprawl may not yet be exerting a major impact on its own water supply.

However, some analyses of Atlanta's water supply have shown that at least 20 percent of the area's water supply is dependent on local tributaries.[20] And, because about half of stream volume on average comes from groundwater, these sources very likely *are* being deprived of rainwater recharge because of the impervious surfaces that accompany sprawl. In addition, imperviousness no doubt affects groundwater for water supplies elsewhere in the state, as well as states further downstream.

The potential infiltration lost to urban runoff is equally disturbing for other cities on the list. For metro areas like Chicago, Washington, DC, and Boston, the losses may amount to as much as 23.7 billion, 55.6 billion, and 102.5 billion gallons of water, respectively. Whether the model calculations presented in Table B capture the precise amounts is less important than the fact that an essential and costly resource is being squandered at an alarming rate.

Table B: Estimated Loss of Groundwater Infiltration

Metropolitan Area[g]	Acres Developed (1982 -1997)[h]	Impervious Acres at: 15% Imperv.	35% Imperv.	Avg. Yearly Infiltration Loss *(billions of gallons of water)*[i]
Atlanta, GA	609,500	91,425	213,325	56.9 to 132.8
Boston-Brocton-Nashua, MA – NH	433,000	64,950	151,550	43.9 to 102.5
Washington, DC	343,300	51,495	120,155	23.8 to 55.6
Dallas, TX	302,400	45,360	105,840	6.2 to 14.4
Houston, TX	291,400	43,710	101,990	12.8 to 29.8
Minneapolis-St. Paul, MN-WI	286,100	42,915	100,135	9.0 to 21.1
Chicago, IL	250,000	37,500	87,500	10.2 to 23.7
Charlotte-Gastonia-Rock Hill, NC - SC	246,200	36,930	86,170	13.5 to 31.5
Philadelphia, PA-NJ	238,800	35,820	83,580	25.3 to 59.0
Riverside-San Bernardino, CA	232,500			Model does not apply[j]
Orlando, FL	222,600	33,390	77,910	9.2 to 21.5
Nashville, TN	216,000	32,400	75,600	17.3 to 40.5
Raleigh-Durham-Chapel Hill, NC	207,000	31,050	72,450	9.4 to 21.9
Pittsburgh, PA	201,800	30,270	70,630	13.5 to 31.5
Tampa-St. Petersburg- Clearwater, FL	199,800	29,970	69,930	7.3 to 17.0
Detroit, MI	187,200	28,080	65,520	7.8 to 18.2
Greenville-Spartanburg-Anderson, SC	166,300	24,945	58,205	12.7 to 29.5
Greensboro-Winston-Salem-Highpoint, NC	148,100	22,215	51,835	6.7 to 15.7
Phoenix-Mesa, AZ	145,600	21,840	50,960	Model does not apply[j]
Seattle-Bellevue-Everett, WA	141,000	21,150	49,350	10.5 to 24.6

Estimates of groundwater infiltration lost to imperviousness show that billions of gallons of water are no longer recharging aquifers and surface waters. Table B depicts the effect of large amounts of new development and various levels of imperviousness across the Top 20 metro areas. Relative infiltration losses are the result of a combination of factors, including amount of land consumed, average annual precipitation, local climate, topography and other factors according to USGS regional groundwater data.

Important Note: This model is intended to present a basic picture of groundwater infiltration lost to sprawl and imperviousness. It does *not* differentiate relative percentages of shallow or deep aquifer recharge, or flows to rivers, streams, and lakes. Hydrogeology is extremely complex; groundwater flows and their connection to shallow and deep aquifers, as well as surface waters, can vary enormously from site to site. For more explanation on this point, see text box: "The Devil is in the Details." Further, the figures of potential groundwater recharge affected in Table B should not be construed as the amount affected *each* year between 1982 and 1997, because developed acres increased gradually over those 15 years. However, the figures do estimate annual losses in 1997, and because developed area and impervious surfaces have no doubt continued to increase in most

[g] Metropolitan Statistical Areas and Primary Metropolitan Statistical Areas as defined by the Office of Management and Budget (OMB) in guidance effective June 30, 1999 (OMB Bulletin 99-04). Northeastern County Metropolitan Areas are based on townships and were defined in the same OMB memorandum.

[h] Source: United States Natural Resources Inventory, Natural Resources Conservation Service, United States Department of Agriculture (USDA), 1997 (revised December 2000). Available at: http://www.nrcs.usda.gov/technical/NRI/1997/

[i] Gallons of lost infiltration of rainwater, rounded to the nearest 1/10 billion gallons. According to the United States Geological Survey (USGS), the average American uses between 80 to 100 gallons of water every day. Using 100 gallons per day, a billion gallons of water per year would be enough to fulfill the daily usage of approximately 27,397 people.

[j] The model does not apply to metro areas in arid regions because low rainfall and very high rates of evaporation remove much of the available rainfall before it infiltrates and replenishes groundwater. For a detailed explanation of how the figures in Table B were calculated, please see Appendix.

metropolitan areas since 1997, these figures likely under-represent the magnitude of the groundwater infiltration being lost in the ensuing years.

The Devil is in the Details: Groundwater Recharge

Infiltration of rainwater or snowmelt in a given undeveloped land area is highly variable, depending on season and weather patterns, vegetation, geographic region, local topography, and soil characteristics, among other factors. Soils, for example, can vary greatly in permeability and ability to absorb and percolate water; and once compacted, they can be nearly as impermeable as concrete. During growing seasons, as much as 70 percent of precipitation may remain in the top soil layer, where it evaporates or is taken up by tree and other plant roots and transpired into the atmosphere.

The degree to which water recharges both shallow and deeper bedrock aquifers depends on numerous factors, including soil permeability, type and thickness of surficial deposits, and bedrock geology. The extent of groundwater flow systems varies from a few square miles or less to tens of thousands of square miles. Under natural conditions, the travel time of water underground can range from less than a day to more than a million years.

In urbanized areas, the composition of groundwater flows are further complicated by widescale changes to landscapes and the natural hydrologic system. For example, increased acreage of turf lawns often boosts surface runoff (as compared to natural forests or meadows), but increased lawn watering, especially during dry periods, may actually increase shallow groundwater recharge when compared to natural conditions. Leaking sewer pipes and water mains in some areas also may significantly increase shallow recharge and stream baseflow. And urbanization can dramatically change overall stream “water budgets,” as the relative contribution to water bodies from wastewater discharges increases surface flows, while groundwater recharge declines due to more imperviousness, storm drains, and other urban infrastructure.

Because groundwater is inherently complex, it is extremely difficult to provide accurate large-scale assessments of groundwater recharge to shallow and deep aquifers, as well as baseflow to streams, lakes, and estuaries. Relatively few data exist at a national or even regional scale and the national data that do exist are out-of-date. More study and information are sorely needed to understand these complex systems and the changes wrought by urbanization.

Sources: U.S. Geological Survey, *Sustainability of Ground-Water Resources*, USGS Circular 1186 (1999); Alley, W.M., *et al., Flow and Storage in Groundwater Systems,* Science, Vol. 296 (June 14, 2002); Arnold, T. and Friedel, M., *Effects of Land Use on Recharge Potential of Surficial and Shallow Bedrock Aquifers in the Upper Illinois River Basin,* USGS Water Resources Investigations Report 00-4027 (2000); Lerner, D. N., *Identifying and Quantifying Urban Recharge: A Review*, Hydrogeology Journal 10: 143-152 (2002); Center for Urban Water Resources Management, *Regional, Synchronous Field Determination of Summertime Stream Temperatures in Western Washington*, The Washington Water Resource (Winter 2002).

USING SMART GROWTH TO SAVE WATER

Converting wetlands, forests, and meadows to hard surfaces has a negative impact on watersheds and impairs groundwater recharge by reducing or eliminating the pollutant filtration and water absorption services that natural areas provide. There are, however, well-established strategies for reducing the impacts of our development patterns. They involve different community designs and regional patterns, often called "smart growth."

What is Smart Growth?

While there is no "one-size-fits-all" definition of smart growth, there are certain principles to which it should adhere. (see Sidebar, "Ten Principles of Smart Growth). They include the use of infrastructure investments like roads and sewer lines as well as economic incentives to support revitalization of existing communities and to discourage leapfrogging sprawl. Smart growth also means diversifying transportation patterns by making walking, biking, and riding public transportation realistic options for residents and workers. And it also includes a better mix of housing opportunities and jobs so that workers can live near the workplace if they choose.

The old real estate adage "location, location, location" applies equally to smart growth. Efficient location of development offers a two-pronged approach to reducing its impacts: First, by choosing more carefully where we develop, we can protect our most valuable resource lands Second, smart growth practices result in reduced driving, preventing air and water pollution and decreasing the need for new roads and parking lots.[21]

Ten Principles of Smart Growth

1. Mix Land Uses
2. Take Advantage of Compact Building Design
3. Create a Range of Housing Opportunities and Choices
4. Foster Walkable, Close-Knit Neighborhoods
5. Promote Distinctive, Attractive Communities with a Strong Sense of Place
6. Preserve Open Space, Farmland, Natural Beauty, and Critical Environmental Areas
7. Strengthen and Direct Development Towards Existing Communities.
8. Provide a Variety of Transportation Choices
9. Make Development Decisions Predictable, Fair, and Cost-Effective
10. Encourage Citizen and Stakeholder Participation in Development Decisions

These principles have been endorsed by a variety of community, environmental, political and business organizations. To learn more, visit www.smartgrowthamerica.org.

Choosing Where We Grow

Some lands, like wetlands, forests and naturally permeable soils, are especially effective in recharging groundwater supplies. A review of the literature suggests that a watershed becomes badly degraded after a mere ten percent is covered by the various impervious surfaces that come with development.[22] This counsels us to encourage development and redevelopment in those areas

Table C: Possible Land Savings Through Smart Growth[k]

Metropolitan Area	Land Saved through Smart Growth Techniques by 2025 (in acres)
Atlanta	245,338
Boston-Worcester-Lawrence-Lowell-Bracton	91,650
Washington-Baltimore	264,899
Dallas-Fort Worth	98,659
Houston-Galveston-Brazoria	116,122
Minneapolis-St. Paul	68,418
Chicago-Gary-Kenosha	45,891
Charlotte-Gastonia-Rock Hill	28,498
Philadelphia-Wilmington-Atlantic City	75,143
L.A.-Riverside-Orange	238,878
Orlando	48,801
Nashville	109,962
Raleigh-Durham-Chapel Hill	31,527
Pittsburgh	Not in study
Tampa-St. Petersburg-Clearwater	88,879
Detroit-Ann Arbor-Flint	Not in study
Greenville-Spartanburg-Anderson	Not in study
Greensboro-Winston-Salem-Highpoint	20,347
Phoenix-Mesa	34,317
Seattle-Tacoma-Bremerton	68,418

already well beyond the 10 percent threshold while focusing efforts on protecting more valuable resource lands.[23] For the sake of reducing future impacts, such a regional-level strategy is invaluable.

Recent research shows possible payoffs from adopting this strategy. Using a methodology developed at Rutgers University, Professor Robert Burchell worked with a team of researchers for several years to build two scenarios for growth from 2000-2025. One is a controlled growth scenario, and the other an uncontrolled growth scenario. In the former, it is assumed that localities and states develop plans linked to implementation tools for directing growth into or near existing communities. Specifically, the authors assumed greater use of growth management practices like regional urban growth boundaries and local urban service areas (see Recommendations Section for more details on these tools). Basically, expansions would be planned in a "location-efficient" manner. In the controlled growth scenario, about ten percent of the total predicted development units would be shifted to more urban and suburban locations.[24] This would reduce the spread of impervious surfaces, allowing for better recharge of groundwater.

Table C shows how much land could be protected under a smart growth scenario, as estimated by Professor Burchell and his team of researchers.[25] And if protection were specifically targeted to the highest-value resource lands (such as forests and wetlands), even larger positive impacts on water resources are possible.

Reducing Water Pollution through Smart Growth

The water quality impacts of urban runoff in watersheds are well-documented, and have been discussed in this report as well as in multiple books and papers. But in the past few years, researchers have discovered yet another water quality impact from urbanization – the increase of a group of suspected carcinogens, polycyclic aromatic hydrocarbons (PAHs) in some watersheds. This research suggests that the rise in the amount of driving, calculated as vehicle miles traveled (VMT), a common

[k] In order to account for the benefits of a 25-year smart-growth scenario, Burchell, *et al.,* used a broader definition of metropolitan areas than the one used in our ranking of land-consuming areas. They used economic areas (EAs) defined by the Bureau of Economic Analysis as including an average of two economic "nodes" and counties that are associated with these nodes. As they put it (at p. 49), "[t]he 172 EAs, which combine the counties into meaningful regional entities, were chosen as the unit for analyzing growth and sprawl and redirecting sprawl growth to more central locations. These areas contain interrelated economic growth as well as locations within them where growth is taking place and probably should or should not take place as much. This is perfect for an analysis of sprawl."

indicator of sprawl, is the cause of this disturbing trend. While PAH concentrations in U.S. watersheds had reached a low point in the 1970s and 1980s due to improvements in technology, by the 1990s this trend had turned around.[26] Higher PAH concentrations have been traced to the increase in the miles traveled by automobiles and trucks, due to “tire wear, crankcase oil, roadway wear, and car soot and exhaust.”[27]

This new trend is already having ecological consequences. In a study of lake soils at ten sites, six exceeded estimates of concentrations that would have adverse impacts on aquatic life.[28] Among the most sprawling cities recently investigated by the United States Geological Survey were Washington, D.C.; Seattle, WA; and Dallas, TX. Specifically, they looked at two lakes in Washington, D.C., and one lake in Seattle and Dallas. They compared regional vehicle miles traveled in the 80’s and 90’s and found a probable culprit in the increases of miles traveled over time (see Figures 3A, 3B, and 3C).[29]

Figure 3A: Relationship between Driving Increase and PAH Increase

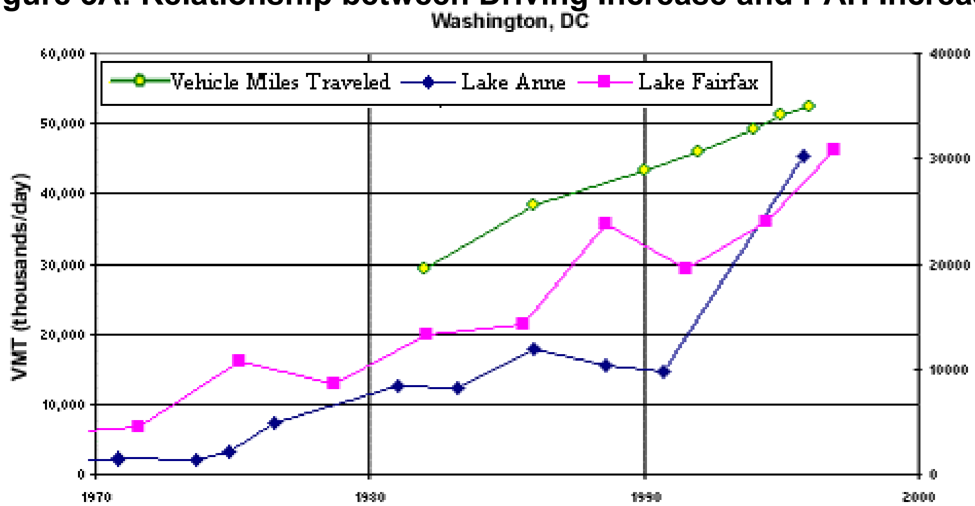


Figure 3B: Relationship between Driving Increase and PAH Increase

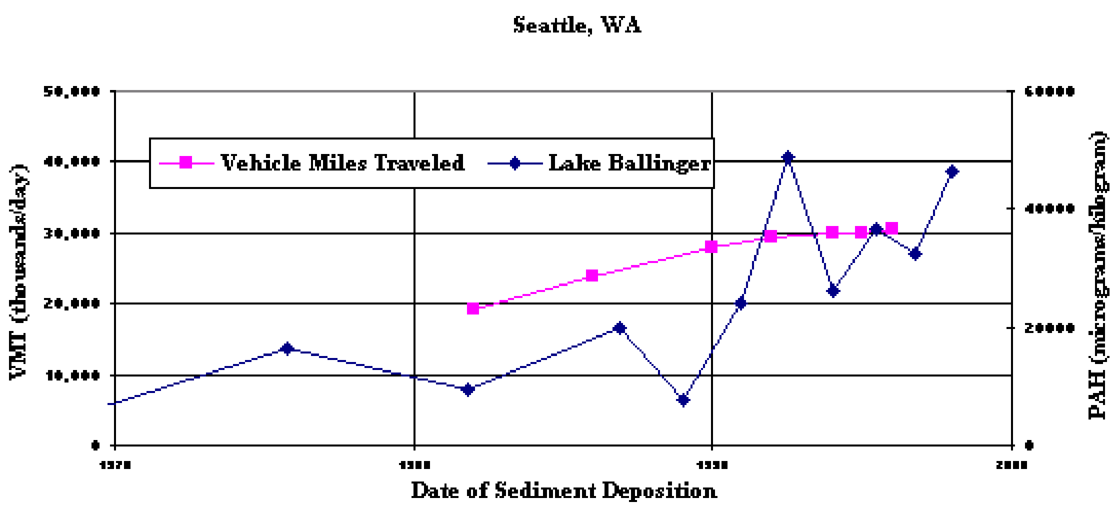
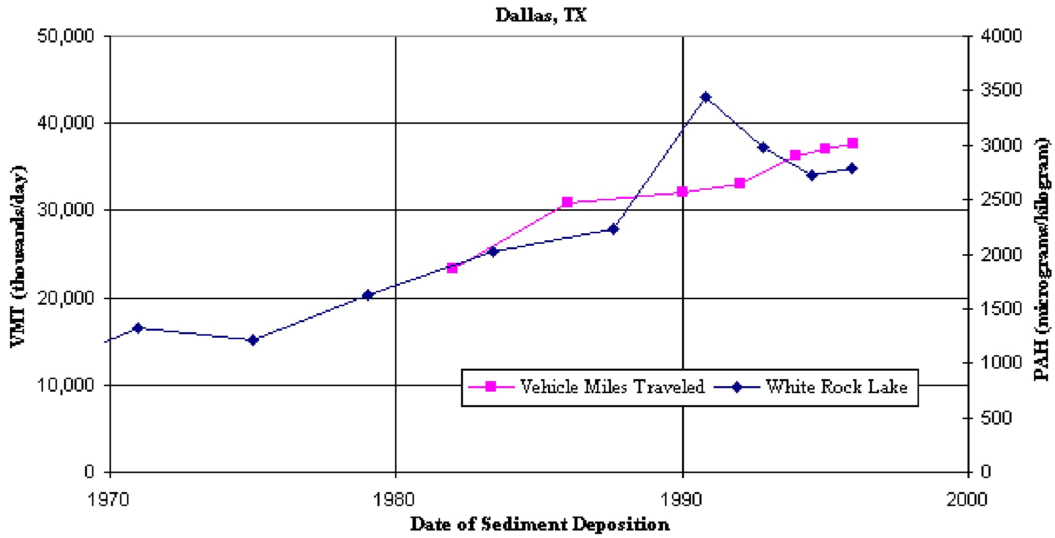
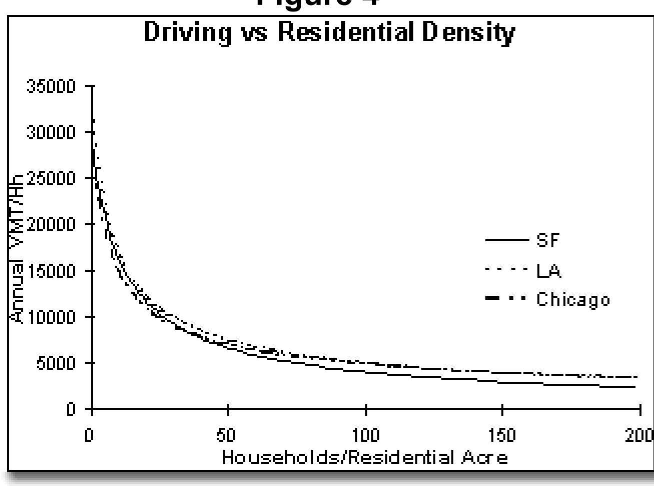


Figure 3C: Relationship between Driving Increase and PAH Increase



Smart growth can substantially reduce vehicle miles traveled. By conveniently locating opportunities to work, live, and play close to one another, and providing more transportation options for workers and residents, new community designs can reduce the need to drive.

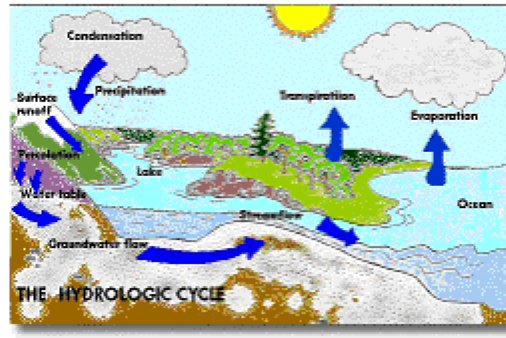
Figure 4[30]



A recent analysis of travel in areas with differing densities in three major metropolitan areas measures the extent to which Americans will take advantage of opportunities to get out of traffic, if it is convenient. Studying different development patterns in the San Francisco, Los Angeles, and Chicago regions, researchers found remarkable correlations among density, urban form, and driving levels. In areas with smart-growth characteristics, such as small lot sizes, transit services and walkable neighborhoods, families find it less necessary to drive (see Figure 4). In other recent studies, EPA has found that "infill" development and redevelopment of older suburbs would reduce vehicle miles traveled (VMT) per capita by 39 to 52 percent (depending on the metropolitan area studied) compared to sprawl.[31]

THE VALUE OF FRESHWATER RESOURCES AND HOW SPRAWL DAMAGES THEM

The Hydrologic Cycle and Freshwater Scarcity



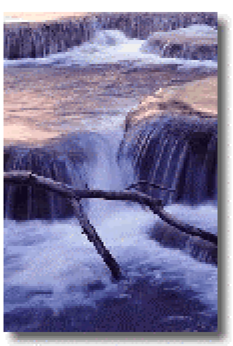
Source: http://www.ec.gc.ca/water/en/nature/prop/e_cycle.htm

Water is essential to all life. The hydrologic cycle moves water from the ocean to the atmosphere, where it forms clouds as it evaporates, cools and condenses. Clouds transport water around the globe and return it to the surface of the earth as precipitation. Some precipitation evaporates immediately to the atmosphere, some runs off the land to rivers, lakes, or directly to the oceans, and some percolates into (infiltrates) the soil, where it is either taken up by plants (and transpires to the atmosphere) or becomes groundwater, some of which is eventually discharged to rivers and streams (which flow to the oceans), or directly to the oceans.[32]

Freshwater, even in water rich, non-drought years, is a precious resource that is naturally scarce. Less than 3 percent of the water on earth is fresh water and 66 percent of that is locked in polar ice caps and glaciers. We already use more than half of what is left in rivers, lakes, marshes, and aquifers[33]

Healthy River Systems are Critical to People

We take it for granted, but water is a river's most essential element. "Instream flow" refers to the water in a river's channel. In a healthy river, water levels fluctuate naturally. The flow of a river is cyclical, varying greatly on a time scale of hours, days, years, decades, and longer. Flow varies from place to place, depending on regional differences in climate, geology, and vegetation. Every river is different with its own seasonal pulse. Like a sculptor, flow shapes the river, and defines its size, location and course. Flow controls where the river meanders and it establishes a river's pools, riffles, side channels, and backwaters, all of which are critical to the life cycles of aquatic organisms, vegetation in the near river ("riparian") zone, and other water dependent plants and animals. Flow determines the amount and type of habitat that exists in and around the river, creating food sources, groundwater recharge areas, spawning and rearing grounds, and migration routes for wildlife, fish, and other aquatic species. The plants, fish, and wildlife in any given river have evolved to adapt to that river's unique rhythms. Altering natural flow can harm these species.



And rivers are the source of most people's drinking water, with about half of their flow coming from groundwater.

Too many rivers today are being deprived of water because of excessive diversions to serve the demands of agriculture, hydropower, and growing cities. Indeed, the EPA has found that changes to the hydrology of rivers are second only to the effects of agriculture in the degradation of river systems.[34] The long-term needs of rivers and the long-term demands of humans are best served by a continual supply of healthy, clean water. Ensuring that rivers maintain flows that are close to natural conditions is the best way to provide and maintain a consistent, healthy supply of water.

Freshwater and its associated fish, wildlife, plants, and habitats provide many goods and services to humanity. The benefits fall into three broad categories: (1) direct use by humans for drinking and other household needs, irrigation, and industrial processes; (2) benefits themselves dependent on freshwater, such as fish, shellfish, waterfowl, and other wildlife; and (3) "in place" benefits, such as recreation, transportation, hydropower, flood control, water quality control, and the enjoyment of the outdoors.[35]

While the value of all services provided by freshwater systems on earth is difficult at best to quantify, studies suggest that it ranges around several trillions of dollars annually, a significant proportion of the gross world product.[36] For instance, American anglers alone spend roughly $24 billion annually on their sport, generating $69 billion for the nation's economy. And the nation's $45 billion commercial fishing and shellfishing industry relies on clean water to deliver products safe to eat.[37] But while we can calculate some of the benefits of freshwater systems to people, the value of clean and healthy drinking water to humanity is inestimable.

We Are Losing Natural Areas at an Alarming Rate

More than 2.1 million acres of land are developed each year in the United States, and these developed areas are increasing at an alarming rate compared to population growth.[38] The amount of urbanized land leaped 47 percent between 1982 and 1997 while population only increased 17 percent.[39] The conversion of natural landscapes to developed cityscapes eradicates or damages natural functions provided by small headwaters streams, wetlands, forests, meadows, and other open spaces. In many cases, natural lands have already been altered by agriculture, but even farm and ranch landscapes maintain some natural features, such as water infiltration and storage capacity, that suburban development eliminates. Developing wetlands, forests and meadows has many negative impacts, among them, the loss of the enormous water storage capacity of natural areas. These are some of the mechanisms at work:

- Small streams, which make up the vast majority of stream miles in the United States, slow the movement of water as it flows downstream into larger streams and rivers.[40] They collect both surface precipitation and groundwater seepage. When the water table is low, they actually discharge water back into groundwater aquifers. In urbanizing areas, however, we fill or bury many of our small streams in underground pipes (some studies say as many as one-third) to make way for buildings, roads and parking lots.[41] This causes rain that runs off from the impervious surfaces of urbanized areas (roads, parking lots, roofs) to move downstream at a much faster rate.

The Value of Trees

In 2000, the group American Forests reported that existing tree cover in Garland, Texas saved the city $5.3 million a year (including residential energy savings, runoff reduction, and air pollution removal). The study determined that increased tree cover could save even more. For example, if the tree canopy on a medium-size (approximately 4- ac.) residential site were increased from only eight percent to 35 percent, runoff would be reduced by four times. As a rule, American Forests recommends that cities maintain a 40% tree cover. American Forests has conducted similar analyses for Washington, DC, Atlanta, GA, Charlottesville, VA, Harrisburg, PA, Houston, TX, Canton-Akron, OH, Portland, OR, Chattanooga, TN, and the Puget Sound and Chesapeake Bay regions.

Source: *Stormwater* (March 2002).

• Wetlands slow water runoff and allow water to infiltrate groundwater storage areas. Indeed, an acre of wetlands can store 1-1.5 million gallons of water.[42]And they also cleanse pollutants from water, and provide rich feeding places and spawning and rearing habitats for fish and birds. Each year, however, development, drainage, and agriculture eliminate as many as 290,000 acres of wetlands.[43] Once they are drained, filled, or otherwise altered by development, wetlands can no longer provide essential water storage, filtration and wildlife habitat services. Tampa, Florida is experiencing severe water shortages, as wetlands that once stored and gradually released water to groundwater aquifers are converted to home sites and roads.[44]

• Forests and woodlands provide significant water storage, aquifer recharge, and flood protection benefits. An 11 to 100 percent loss (depending on site characteristics) of natural groundwater recharge, along with an 11 to 19-fold increase in stormwater occurred at one site when woodlands were converted to residential and commercial use. [45] At another site, conversion of forest to impervious cover resulted in an estimated 29 percent increase in runoff during a peak storm event.[46] Even urban trees play an important role in managing stormwater runoff (see Text Box, "The Value of Trees").

RECOMMENDATIONS

Applying the principles of smart growth (see "Ten Principles of Smart Growth" sidebar) can significantly boost a region's water supplies. Some of the most effective policies and practices are listed below.

Protect Open Space, Especially Critical Aquatic Areas

All levels of government must do more to identify and protect undeveloped areas because of the many services they provide, particularly water absorption and pollution filtration. Land preservation efforts should be especially targeted toward critical aquatic areas (groundwater recharge zones, wetlands, streamsides, floodplains, small tributary streams). Local governments can protect these areas from development by aligning zoning, establishing protected areas, and changing development guidelines to use land more efficiently. States and counties should also offer tax incentives and direct sources of funding for land purchases or easements.

On the federal level, the Land and Water Conservation Fund (LWCF) provides money to federal, state and local governments to purchase land, water and wetlands for inclusion in the National Forest System. Given the freshwater challenges we face, targeting LWCF funds to better protect headwater streams and riparian buffer areas would be a prudent strategy for the 21st Century. Some other federal programs for which funding should increase include:

- The Wildlife Habitat Incentives Program (WHIP), which helps landowners develop and implement practices to protect and restore important wildlife habitat;
- The Conservation Reserve Program (CRP), which supports land retirement for 10-15 years;
- The Wetland Reserve Program (WRP), which supports permanent and long-term retirement and restoration of wetlands;
- The Conservation Reserve Enhancement Program, which offers special incentives in designated priority areas that focus on programs identified by the States; and
- The Farmland Protection Program, which provides matching funds to state and local farmland protection programs.[47]

The annual *National River Budget*, supported by hundreds of groups across the country, provides information and funding recommendations for myriad programs that protect our freshwater resources.[48]

In addition, Congress should clarify its intent to protect isolated wetlands, which are critical for groundwater recharge, water purification, flood control, wildlife and ecosystem health.[49] The U.S. Supreme Court recently endangered millions of acres of these wetlands by eliminating federal protection under the Clean Water Act. New "nationwide permits" recently issued by the Army Corps of Engineers also pose a problem, because they allow many activities destructive of wetlands.[50]

Practice Sound Growth Management

States and regions should manage growth in a sensible manner, with particular attention to how development impacts water supplies. Growth management comes in a variety of forms, such as comprehensive state growth management legislation, smart growth incentives, and urban growth boundaries. State legislation appears to be gaining popularity. To date, eleven states have enacted statewide standards for sensible land use planning and implementation.[51] Between 1999 and 2001, roughly 400 planning reform bills were passed by state legislatures, and 15 states were in the midst of implementing substantial reforms.[52]

As of 1997, only two states included water supply or recharge measures in their planning statutes.[53] However, the California legislature recently enacted two laws that place the burden on land developers to find adequate water supplies, the first of which prohibits approval of subdivision maps, parcel maps or development agreements for subdivisions with more than 500 units unless there is a "sufficient water supply." The second requires cities and counties to prepare detailed "water supply assessment reports" in the environmental review process for large development projects.

Some other states focus on channeling resources to existing communities, rather than subsidizing sprawl. The best-known example is Maryland's 1997 Smart Growth and Neighborhood Conservation initiative, which requires all counties to designate priority funding areas (PFAs) which are then favored to receive state infrastructure investments, such as roads and schools.[54] Some localities achieve the same thing by designating growth areas that are eligible for water, sewer, transportation and other services. This is hardly a new practice – Fayette County, Kentucky, which includes Lexington, for example, has had designated growth areas since the 1950s.

Another effective approach is the establishment of urban growth boundaries, which are regional agreements on where growth should and should not occur. The best-known example is the one surrounding Portland, Oregon, which is credited with preventing leapfrog development, enhancing quality of life, and protecting valuable open spaces.[55]

Integrate Water Supply into Planning Efforts

Government agencies should consider water supply in all land-use-related planning activities, including transportation, housing, and all other types of construction. Such coordination is extremely rare. In Seattle, Washington, for example, a recent low-income housing redevelopment plan – over 100 acres – came to the attention of the City's stormwater program only after the project was under development. Although certain management practices, such as infiltration of stormwater in right–of-way and parking lot areas could still be implemented, it was too late in the redevelopment process for others. For example, many home sites were built on the most permeable soils, sacrificing an essential groundwater infiltration opportunity.[56] If coordination with water resource and quality agencies during the planning process had been a requirement of any public funding supporting the redevelopment, such essential design considerations would not have been left to chance.

Invest in Existing Communities

By reinvesting in existing communities to accommodate new growth, we can meet the demand for development and protect critical aquatic areas. This is a core smart growth principle that encompasses a broad array of policies and practices, including infill development, brownfield redevelopment, and transit-oriented development, among others.

Such approaches also correct past inequities and misguided subsidies for sprawl development. For example, metropolitan Detroit has a water system that was installed largely in the middle of the 19th

Century, but funding to retrofit the system has been delayed to support the laying of additional pipes and treatment facilities for its sprawling suburbs. A recent study of state and federal infrastructure investments in Western Pennsylvania found that they strongly favored building new infrastructure in rural and suburban areas over its repair and rehabilitation in urban communities.[57]

Programs like the Clean Water and Safe Drinking Water State Revolving Loan Funds should aim to solve existing water problems, not to subsidize new suburban sprawl. Priority should be given to rehabilitation and repair of existing sewers and water mains, because studies confirm that not only are we losing potable water from water delivery infrastructure, but also that groundwater is infiltrating sewer lines that would otherwise recharge aquifers. We are then paying to treat the sewage, which amounts to a double waste of resources.[58]

Encourage Smart Growth Development

Communities should facilitate smart growth development that minimizes impervious cover and maximizes groundwater recharge and baseflows. For example, some communities have adopted “performance zoning” (a.k.a. “cluster zoning” or “conservation zoning”), which include standards for open space, development densities, narrower streets, impervious surfaces, and other water-related considerations. Unfortunately, many communities have yet to adopt such innovative policies, even though consumers increasingly favor their outcomes. A diverse group of stakeholders – developers, new homeowners, and rural residents – supports market-based cluster zoning in which everyone wins. Residents gain access to open space, developers and local governments save money on infrastructure investments such as roads and sewers, and local governments get an additional community amenity at limited cost, because home buyers pay for preserving open space.

Some communities are creating direct incentives for smart growth development. The city of Austin, Texas, for example, created a program that rewards developers for locating projects within the city’s existing neighborhoods and downtown. Under this “Smart Growth Matrix” program, developments are awarded points for a variety of attributes, such as transit access, brownfield redevelopment, whether or not water and sewer lines exist on site, and good urban design.

Manage Stormwater Using Innovative Approaches

Communities should adopt low-impact development measures so that stormwater is handled through a variety of techniques, including on-site storage and infiltration through permeable native soils and bioengineering techniques that facilitate evaporation and transpiration, instead of conveyed through large structural systems. Such measures have proved effective in a variety of places.

For example, Seattle, Washington reduced runoff by 97 percent at a 2.3 acre site the year after converting an open ditch stormwater drain to an attractive roadside swale garden, decreasing the width of the adjacent street, planting native vegetation, and simulating native soils. Such opportunities exist where stormwater systems are either not fully developed or will be redeveloped. Roughly 25 percent of Seattle’s stormwater drains are unimproved and therefore great candidates for these sorts of infiltration projects, which reduce the volume of polluted stormwater flow and improve groundwater recharge.[59] They are among the most effective *structural* solutions to stormwater impacts, infiltrating up to 98 percent of stormwater, removing excessive nutrients and contaminants, and cooling the water.[60]

To ensure the adoption of these measures, the EPA must insist that municipal stormwater permits issued by the states require nonstructural solutions and on-site infiltration techniques. The permits should be crafted to the specific conditions of the local government, *e.g.*, newly developing areas require different approaches, such as preservation of open space and cluster development, than do existing urban areas, which may have opportunities like that described above for Seattle, which involve retrofitting for on-site infiltration of stormwater. The Clean Water Act's state revolving loan fund can also be used to prioritize these kinds of approaches and techniques by creating incentives for smart growth and other "more natural" solutions to stormwater runoff.

State legislatures can and must, if we are to protect our precious water supplies, do exactly the same with their funding of infrastructure improvements and stormwater solution (see Text Box, Parking Lot Redesign: A Success Story).

Regional water management authorities should also develop strategies for revealing the true economic costs of stormwater management, such as utility bills that reflect the amount of stormwater resulting from impervious cover or the degree to which local governments, developments and large land owners have adopted local infiltration approaches.

Parking Lot Redesign: A Success Story

Oregon's Museum of Science and Industry (OMSI) was built on a former industrial site located on the Willamette River in downtown Portland in 1990. Although there were no specific site design requirements for stormwater discharging into the river at that time, staff from Portland's Bureau of Environmental Services (BES) approached OMSI to request that the museum voluntarily redesign its landscape and parking lots to minimize stormwater runoff. BES suggested an adjustment to site grading and an alteration to landscaped medians to have vegetated swales receive stormwater runoff. Once OMSI understood the benefits, it requested that the medians be designed to retain water for longer periods. Fourteen acres of the completed parking lot now drain to vegetated swales planted with native wetland species. Net construction costs fell an impressive $78,000, and OMSI's parking lot now has capacity sufficient to infiltrate almost 0.5 inches of rainfall every time it rains. There are benefits for larger storms, too, however, as all runoff from the parking lot now filters through vegetation, which slows and cleans the stormwater before it is discharged to the river.

Source: Personal Communication, Tom Liptan, Environmental Specialist, Portland Bureau of Environmental Services, August 12, 2002.

Fund Research and Database Needs

The nation should fund research to help communities better understand the interactions between land use and water supply issues. Water scarcity is already a high national concern, as demonstrated by the National Research Council which reported last year that:

> [i]n this new century, the United States will be challenged to provide sufficient quantities of high-quality water to its growing population. Water is a limiting resource for human well-being and social development, and projections of population growth…suggest that demands for this resource will increase significantly. These projections have fueled concerns among the public and water resources professionals alike about the adequacy of future water supplies, the sustainability and restoration of aquatic ecosystems, and the viability of our current water resource research programs and our institutional and physical water resource infrastructures.[61]

And the USGS recently told the Congress that the U.S. is lacking a national assessment of water availability with indicators of the status and trends in storage volumes, flow rates, and water uses. The Survey's testimony contends that the development of a new data reporting system for water availability and use is as important as other major federal data programs that track national economic, demographic, and health trends.[62]

We urge Congress to fund this comprehensive research by the USGS. As is evident from some of the studies we have cited in this report, the relationship between impervious cover and groundwater recharge and baseflows is complex, and existing research is limited. Some of the studies that have examined these issues are handicapped by the lack of data regarding pre-development conditions, annual water budgets, imported water, and other confounding influences, such as leaking infrastructure.

The USGS should be tasked and sufficiently funded by Congress to assess the state of the nation's ground and surface water resources and the major impediments to their sustainability, including a comprehensive assessment of the impacts of urbanization.

CONCLUSION

One of Mark Twain's famous idioms was that "everybody complains about the weather, but nobody ever does anything about it." As drought conditions become more prevalent, they are seriously affecting communities across the nation. We may not be able to do too much about the weather in the short-term, but by using our land resources more wisely, we can protect our water supplies for the long-term. By applying smart growth principles, we can not only protect this critical resource, but also create better places for people to live.

ENDNOTES

[1] http://www.planetark.org/dailynewsstory.cfm/newsid/17252/story.htm
[2] http://www.uswaternews.com/archives/arcconserv/2cangeo8.html
[3] http://www.planetark.org/dailynewsstory.cfm/newsid/17252/story.htm
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APPENDIX

Methodologies Used in This Report

Background

This report provides an estimate of metropolitan areas that have consumed the most land for development in the period from 1982 to 1997. This report also provides estimates of the effects of sprawling development added to existing urban areas between 1982-1997 on groundwater infiltration in 20 major metropolitan areas studied. Although we have identified a number of small-scale analyses of the effect of imperviousness on groundwater infiltration, we were unable to find any comprehensive data or estimates by metropolitan region of the impact on infiltration. We therefore developed a model to estimate groundwater infiltration losses using national databases and other published data, and in consultation with experts in natural resource and urban planning, hydrology, groundwater systems, and stormwater management.

Calculation of Metropolitan Areas that Consumed the Most Land 1982 - 1997

Step 1: We looked at all counties in Metropolitan Statistical Areas and Primary Metropolitan Statistical Areas as defined by the Office of Management and Budget (OMB) in guidance effective June 30, 1999 (OMB Bulletin 99-04). We used this most recent definition to ensure that we include all of the urbanization in these metropolitan areas from 1982-1997. The Northeastern County Metropolitan Areas are based on townships and were defined in the same OMB memorandum.

Step 2: We aggregated the county-level urbanized land totals from 1982 and 1997 data sets of the Natural Resources Inventory of the United States Department of Agriculture into the 312 metropolitan areas as defined above.

Step 3: We subtracted the 1982 totals from the 1997 totals, arriving at the difference in urbanized land area.

Step 4: We ranked the metropolitan areas accordingly. Those featured in the report are the top twenty most land consuming metropolitan areas.

These metropolitan areas do not necessarily define the most sprawling areas of the country, because this ranking does not account for measurements such as decreases in density, lack of transportation options, and other items that qualify an area as sprawling. However, those areas listed in the Top 20 in this report do include many of the most sprawling areas and are the metropolitan areas that have increased their urbanized area and impervious surface area the most.

Model Calculation to Estimate Groundwater Infiltration Losses

We took the following steps to calculate the estimates of gallons of infiltration of precipitation "lost" in each metropolitan area studied. Detailed descriptions of data used for each step in the calculation are presented below.

Step 1: Calculate amounts of land under new suburban development in individual counties and then aggregate to entire metropolitan area for years 1982 and 1997. Subtract amount for 1982 from amount for 1997 to arrive at acres developed in fifteen year period.

Step 2: Multiply the result of Step 1 by a range of imperviousness for new suburban development (15% low end of range-35%, high end of range) to determine acres of new imperviousness between 1982-1997 within each metropolitan area.

Step 3: Calculate average infiltration rates by dividing average "runoff" inches by average precipitation in inches from USGS national groundwater report for each metropolitan area. *(Note: USGS uses the term "runoff" to denote the portion of precipitation that does not evaporate or transpire into the atmosphere.)*

Step 4: Multiply the result of Step 3 by local 30-year average precipitation in inches to determine average inches of infiltration of precipitation falling over one acre for each metropolitan area.

Step 5: Multiply the result of Step 4 (inches of infiltration) by the result of Step 2 (acres of new imperviousness – two calculations, for 15% and 35% imperviousness, respectively) by 27,154.25 gallons per inch per acre of precipitation to estimate the amount of precipitation in gallons potentially "lost" to imperviousness.

Metropolitan Area Developed Acres – 1982-1997

See "Calculation of Metropolitan Areas that Consumed the Most Land 1982 – 1997" above.

Acres of Imperviousness

Levels of imperviousness vary by specific land use in suburban areas, according to various studies. One study published by the Pew Oceans Commission, *Coastal Sprawl: The Effects of Urban Design on Aquatic Ecosystems in the United States,* found an average of 40 percent imperviousness in areas of new development. Another study prepared by the Center for Watershed Protection for the U.S. EPA calculated the range of imperviousness by land use types across many sites in the Chesapeake Bay region. This study found a range of imperviousness by land use type from 14 percent for low-density residential development (one- and two-acre home lots) to 34.7 percent for commercial development, 37 percent for medium-density residential (½ and ¼-acre lots), and as much as 46.5 percent for light industrial development. These general ranges of imperviousness are borne out by other studies of suburban development around the country.

We purposely used a conservative range of 15 percent to 35 percent imperviousness for our model estimates to ensure that we are not overstating imperviousness for suburban development in various areas across the country.

Infiltration Rate

Infiltration rate is a general term that includes all water that infiltrates into the ground. Our model focuses on estimating the amount of water that would likely have infiltrated a given acre of land under natural conditions, before the hard surfaces that accompany development covered it. The model does not differentiate relative percentages of shallow or deep aquifer recharge, or flows to rivers, streams, and lakes. These flows can vary tremendously from site to site based on local soils, climate, vegetation, topography, type and thickness of deposits of gravel, sand, rock and other materials, underlying bedrock, and many other factors.

To calculate infiltration rates we used the only comprehensive resource we were able to find that provides a relatively consistent set of data for the entire U.S. : the United States Geological Survey's (USGS) *Ground Water Atlas of the United States* - a series of publications with detailed assessments of ground water conditions (including information on precipitation, runoff, geology, aquifers, and groundwater withdrawals) for 14 regions of the U.S., published between 1990 and 2000 (available online at: http://capp.water.usgs.gov/gwa/gwa.html). We note that data in the *Ground Water Atlas* are based on large-scale regional assessments and were not developed to provide a detailed analysis of local or metropolitan area conditions. However, this was the only consistent set of data with detailed, national information that we found to be available from any source.

We looked at two sets of data to determine average infiltration rates. First, we estimated the range of precipitation for each metro area, based on map figures from the *Ground Water Atlas* depicting average annual precipitation levels. We calculated average annual precipitation from these ranges and checked these figures against the 30-year average (1971-2000) precipitation ranges from NOAA-NCDC data (see "Precipitation" below) to ensure that they were roughly comparable.

Second, we estimated the range of what USGS calls "long-term average annual runoff," or what we term "infiltration" in our model and throughout this report. We based our estimation of these ranges on map figures from the *Ground Water Atlas* depicting average annual "runoff," where USGS states that "part of the runoff is direct surface runoff, and part is water that infiltrates the land surface, percolates to the water table, recharges the ground-water system, and moves through aquifers to discharge into streams as base flow."

Our calculation relies on the basic equation: Precipitation = Evapotranspiration (-) Infiltration, where evapotranspiration is water that evaporates or is transpired by plants and lost to the atmosphere, and infiltration (or "runoff" in USGS terms) is the remaining water that soaks into the ground. Thus, we divided the average annual runoff in inches by the average annual precipitation in inches to determine an average infiltration rate for each metropolitan area. We checked this methodology with staff at USGS' Office of Ground Water to ensure that we were properly interpreting what the data from the *Ground Water Atlas* suggest about regional groundwater infiltration rates.

Precipitation

Average annual precipitation figures used to calculate potential gallons of groundwater infiltration lost in the model were taken from data available online through the National Oceanic and Atmospheric Administration's (NOAA) National Climatic Data Center (NCDC). We used 30-year average annual 50^{th} percentile precipitation figures for weather stations at each main metropolitan airport from NOAA-NCDC's report, "Monthly Precipitation Probabilities and Quintiles, 1971-2000, Climatology of the United States, No. 81, Supplement No. 1." Data for multiple weather stations within metro areas suggest that precipitation amounts often vary within metro areas, but for the purposes of this model, we chose to use a single, consistent data point across all metro areas.

Ranges of precipitation data from USGS' groundwater report (see "Infiltration Rate" above) that were used to calculate average infiltration rates were not used for this part of the model calculation. This was done for two reasons: (1) in many cases the precipitation data in the USGS report were at least 15 years old; and (2) these data were not intended to give precise precipitation amounts by metropolitan area.

Constants Used in Calculations

1 acre foot=325,850 gallons

An acre foot of water is defined as the amount of water necessary to cover one acre of land with 12 inches of water.

1 in. of precipitation over one acre = 27154.25 gallons

Divided by twelve inches in one acre-foot of water, this measure gives the amount of water in an inch of precipitation over one acre of land, rounded to the nearest ¼ gallon.

The average American's household use of water = 80-100 gallons of water per day, (according to United States Geological Survey, see: http://ga.water.usgs.gov/edu/qahome.html)

One billion gallons = annual average daily usage of approximately 27,397 people *((1,000,000,000 / 100 gals./day) / 365 days)*

1 year=365 days

Interpreting the Results – Important Caveats

As we stated in the report, the figures calculated through this model are intended to present a basic picture of groundwater infiltration lost to sprawl and imperviousness. **The estimates presented in this report should *not* be considered actual or precise amounts of groundwater infiltration for each metropolitan area**. Such exact figures would require detailed field observations, data analysis, and far more complex modeling tailored to the specific conditions of the area. This was not our intent.

The model also does *not* differentiate relative percentages of shallow or deep aquifer recharge, or flows to rivers, streams, and lakes. Hydrogeology is extremely complex; groundwater flows and their connection to shallow and deep aquifers, as well as surface waters, vary substantially from site to site.

In calculating the infiltration "lost" in converting natural land to development, we did not make any adjustment in our calculations for the possibility of direct surface runoff (see USGS definition of "runoff" under "Infiltration" above). This is because there were no data that allowed us a reasonable method for doing so that could be consistently applied across all metro areas. Thus, the model may overstate the infiltration "lost" in converting natural land to development in areas with significant slopes and other conditions that increase direct surface runoff. However, we have been quite conservative in other aspects of the model, such as imperviousness percentages, so that we believe the estimates calculated are reasonable even without this adjustment.

The model estimates also do *not* take into account any techniques in place in metropolitan areas to capture and infiltrate precipitation on-site. According to experts with whom we consulted, although some communities and metro areas have begun to employ approaches to promote infiltration and minimize effective imperviousness (e.g., disconnecting roof downspouts from storm drains and directing roof runoff into storage or infiltration systems), these are not in widespread use and thus have not yet made an appreciable difference in reducing infiltration losses from imperviousness.

We did not apply the model calculations to two metropolitan areas in arid areas – Riverside-San Bernardino, CA, and Phoenix, AZ. The warm, dry climates in these regions combine low average rainfall with high evaporation and plant transpiration rates. Thus, different groundwater infiltration and recharge conditions apply in these areas than in more humid regions of the country, which were the basis for this model.