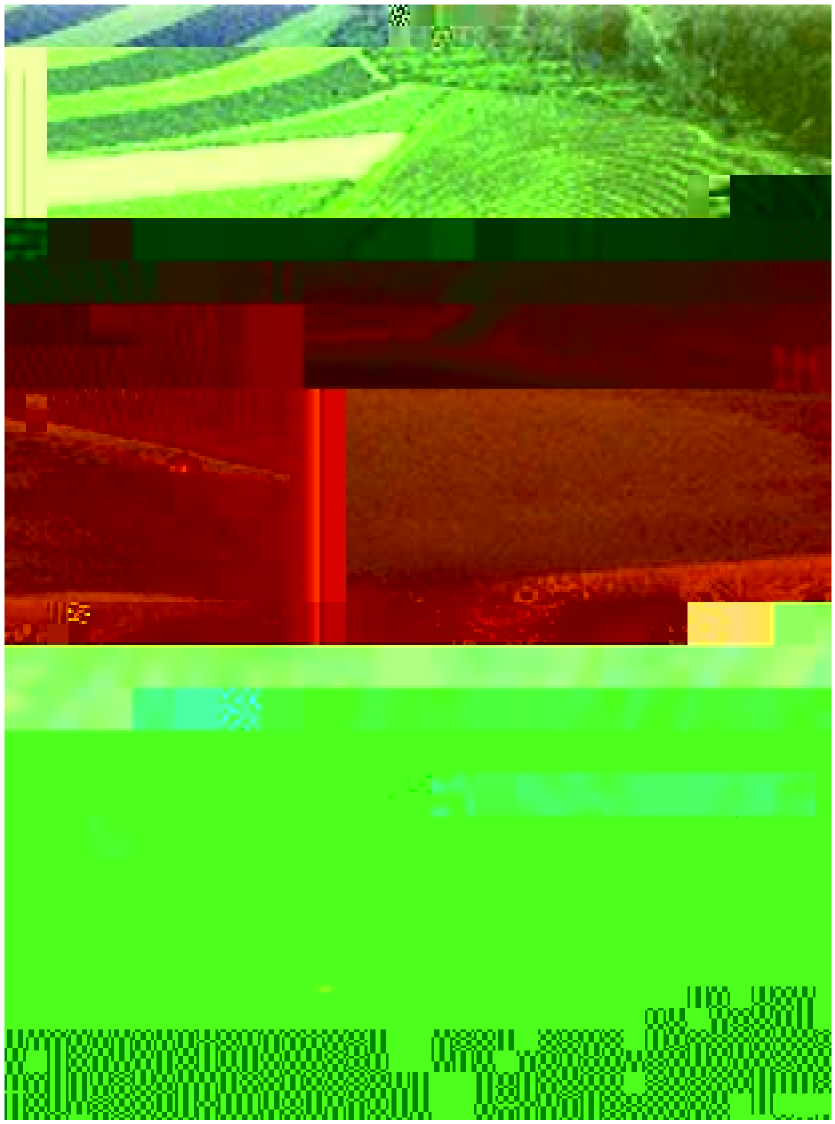
Paving Our Way to Water Shortages:
How Sprawl Aggravates Drought



Bringing Rivers to Life

We also thank our many members, individual contributors, and the following foundations for their generous support of our organizations' work:

Anonymous
The Dibner Fund
Ecolab Foundation
Gund Foundation
Hewlett Foundation
Marbrook Foundation
The McKnight Foundation
Packard Foundation
Surdna Foundation
Turner Foundation

This report does not necessarily reflect the views of the above organizations and individuals.

Cover photo courtesy of Office of Environmental Education, North Carolina Department of Environment and Natural Resources (August 2002).

American Rivers, founded in 1973, is dedicated to protecting and restoring healthy natural rivers and the variety of life they sustain, for the benefit of people, fish, and wildlife.

1025 Vermont Avenue NW

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,

- 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.

areas.[8] Indeed, the city of Olympia, Washington found that

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 tim

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

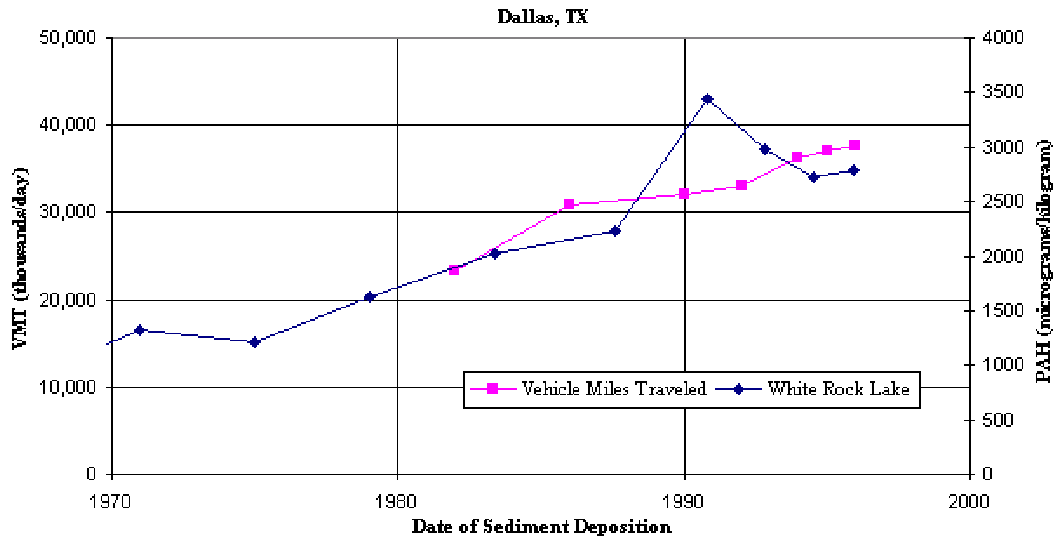
Estimates of groundwater infiltration lost to imperviousness show that billions of gallons of water are no longer recharging aquifers and surface waters. Table B depicts the effect of large amounts of new development and various levels of imperviousness across the Top 20 metro areas. Relative infiltration 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

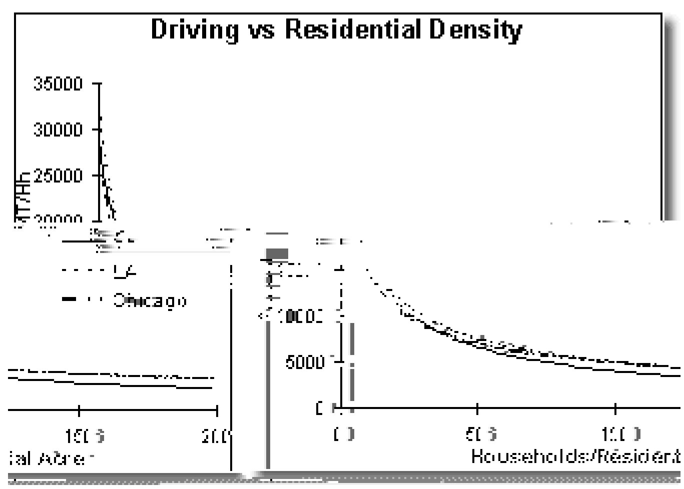
Converting wetlands, forests, and meadows to hard surfaces has a negative impact on watersheds and impairs groundwater recharge by reducing or eliminating the pollutant filtration and water absorption services that natural areas provide. There are, however, well-established strategies for reducing the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

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 already well beyond the 10 percent threshold while focusing efforts on protecting more valuable resource lands.[23]

indicator of sprawl, is the cause of



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.[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]

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.

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

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").

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.

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]

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]

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.

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 subsid

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]

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.

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

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]

[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
[4] Charlotte Observer, *Counties Water Restrictions Go To The Next Level*, 3U (August 11, 2002).
[5] *See*, *e.g.*, American Rivers website http://www.amrivers.org/instreamflowtoolkit/droughttoolkit.htm
[6] Kaid, B.F., *et al.*, *Once There Were Greenfields: How Urban Sprawl Is Undermining America's Environment, Economy and Soil Fabric*, Natural Resources Defense Council and Surface Transportation Policy Project (March 1999).
[7]

[24] Burchell, R.W., *et al.*, *Costs of Sprawl – 2000*, Transit Cooperative Research Program Report 74, Transportation Research Board, National Research Council (2002). 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."

[25]

[52] Johnson, D.,

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.

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.

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 m a6mounts of land under new suburba

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 50th 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 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 “Infiltrat