Protecting Water Resources with Higher Density Developments

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Abstract

How and where development occurs can affect water quality. The purpose of this paper is to examine the water quality impacts from low and high-density development at the site level and watershed level. Considerable evidence in the literature demonstrates that dispersed, low-density development can exacerbate non-point source pollutant loadings by consuming absorbent open space and increasing impervious surface area relative to compact development. Some case studies have demonstrated that higher density development can minimize impacts on regional water quality by consuming less land and minimizing impervious surface cover. This paper discusses the relationship between water quality and growth patterns; uses modeling results to compare pollutant loadings from different types of residential development; and discusses measures to mitigate potential increased pollutant concentrations, which may result from higher density development

Introduction

In the face of droughts, oil spills, beach closures, and overall declining water quality, communities are increasingly concerned about managing their watersheds to maintain hydrologic integrity and water quality. The nation's aquatic resources are among its most valuable assets. Although environmental protection programs in the United States have improved water quality during the past 25 years by focusing on point sources, many challenges remain. EPA estimates that of the causes of pollution in the states' impaired waters, only 10 percent is presently attributable to point source pollution, such as industrial discharges. The rest is ascribed to non-point source pollution or some combination of point and non-point source pollution, which can include increased sedimentation from land development, stormwater runoff, and on-site sewage systems.

The *National Water Quality Inventory: 1998 Report to Congress* identified urban runoff as one of the leading sources of water quality impairment in surface waters.[1] Of the 11 pollution source categories listed in the report, emissions from urban runoff and storm sewers was ranked as the sixth leading source of impairment in rivers, fourth in lakes, and second in estuaries. In addition, recent water quality data find that more than a third of assessed rivers and streams (291,000 of 840,000 miles) do not meet water quality standards. For these impaired surface waters, urban and agricultural runoff are the primary sources of pollution.[2]

Of special concern are the problems associated with non-point source storm water runoff in our urban streams, lakes, estuaries, aquifers, and other water bodies caused by runoff that is inadequately controlled or treated. These problems include changes in flow, increased rates of sedimentation, higher water temperature, lower dissolved oxygen, degradation of aquatic habitat structure, loss of fish and other aquatic

[1] U.S. Environmental Protection Agency (USEPA). 2000a. *National Water Quality Inventory: 1998 Report to Congress*. www.epa.gov/305b/98report. Last updated October 5, 2000.
[2] U. S. Environmental Protection Agency, Office of Water. June 2000b. "Water Quality Conditions in the United States: A Profile from the 1998 National Water Quality Inventory Report to Congress" Washington, DC. EPA841-F-00-006 (also available at www.epa.gov/OWOW/305b/).

populations, and decreased water quality due to increased levels of nutrients, metals, hydrocarbons, bacteria, and other constituents.

Recent research has revealed a strong relationship between impervious cover and water quality. These studies have demonstrated that at 10 percent imperviousness, a *watershed* will become impaired.[3] In addition, water quality suffers not only from the increase in impervious surface, but also from the associated activities: construction, increased travel to and from the development, extension of infrastructure, and chemical maintenance of the areas in and surrounding the development. Oil from motor vehicles, lawn fertilizers, and other common solvents, combined with the increased flow of runoff, contribute substantially to water pollution. These findings suggest that as imperviousness increases, so do associated activities, thereby delivering an increased impact on water quality. In an effort to protect water resources, communities may apply the 10 percent impervious cover threshold from the watershed level to the site level. The purpose of this downscaling is to reduce development densities and therefore reduce overall impervious surfaces at the site level. While intended to address overall impervious within the watershed, when the 10 percent figure is applied to the individual site level within the watershed, it suggests that only lower densities can protect water quality.

This study suggests that the opposite may in fact be true-- attempts to ensure low densities at the site level can often lead, not to better, but to worse overall water quality. Other recent studies have demonstrated that dispersed, low-density development can exacerbate non-point source pollutant loadings through increased consumption of pervious open space and greater amounts of transportation-related impervious infrastructure, such as roads, driveways, and parking lots. On the other hand, a compact development approach accommodates more activity while consuming less space. In turn, this reduces overall imperviousness and helps to maintain watershed functions.

The purpose of this paper is to examine the water quality impacts from low and high-density development at the site level and then to extrapolate these findings to the watershed level. This paper discusses the relationship between water quality and growth patterns; uses modeling results to compare pollutant loadings as a function of residential density; and summarizes existing research on the subject. We conclude that accommodating new growth in a compact, higher density fashion (in undeveloped areas or developed areas) will likely be more protective of water quality than lower density development.

DEVELOPMENT'S IMPACT ON WATERSHED FUNCTIONS

One of the most noticeable trends in recent history has been the dramatic expansion in the geographic size of metropolitan areas. Virtually every urban area in the United States has expanded substantially in land area in recent decades. Between 1954 and 1997, urban land area has almost quadrupled, from 18.6 million acres to about 74 million acres in the contiguous 48 states.[4] Moreover, from 1992-1997, the national rate of development more than doubled. During this five-year period, more land was developed (nearly 16 million acres) than during 1982-1992 (about 13 million acres).[5] The newly developed land has typically come from forest land, pasture and range land, and crop land. A 1994 study by the American Farmland Trust showed

[3] See, for example, Montgomery County Department of Environmental Protection, 2000; Center for Watershed Protection, 1998; Schueler, 1994; Arnold and Gibbons, 1996.

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

[5] Ibid.

that urban development already has consumed nearly a third of the country's most highly productive farming regions.[6]

Direct environmental impacts of current development patterns include habitat loss and fragmentation and degradation of water resources. Building on undeveloped land consumes and fragments habitat and thus displaces or eliminates wildlife communities. The construction of impervious surfaces such as roads and rooftops leads to the degradation of water quality by increasing runoff volume, altering regular stream flow and watershed hydrology, reducing groundwater recharge, and increase stream sedimentation.

Watersheds and their streams and rivers provide critical ecological and economic services. Ecologically, small watersheds and streams sustain larger ecosystems. In addition, the stream corridor, with its rich flood plains, wetlands, and forests, is home to unique plant and animal species. Streams support diverse aquatic communities and perform the vital ecological roles of processing the carbon, sediments, and nutrients upon which downstream ecosystems depend. Economically, small watersheds are the ultimate source of our drinking water; watershed and riparian buffer zone soils act as filters for water that might ultimately be consumed. Slow-order streams and their associated flood plains serve as temporary storage for floodwaters, and thereby act as natural flood control. The services provided by small watersheds are maximized when their land area is maintained in a natural condition.

The extent of beneficial watershed services begins to diminish when the natural condition of land is altered through development. Construction exposes sediments and construction materials to precipitation, which then washes material into storm drains or directly into nearby bodies of water. After construction, development usually replaces native meadows, forested areas, and other natural landscape features with compacted and fertilized lawns, pavement, and rooftops. These largely impervious surfaces generate substantial quantities of surface runoff. In addition, engineers traditionally design drainage systems to move rainwater as quickly as possible by directly it over the ground towards curbs, gutters, streets, and sewers. These conventional drainage systems prevent water from flowing into the ground and filtering through soil before being released into surface and ground waters. To compound problems, traditional construction practices seek to "connect" all of the impervious surfaces in a development to direct water to a minimal number of drainage outlets. For a typical retail protect, the storm water system connects water from all rooftops, several parking lots and the interior road network. Even when landscaped islands are built into the project, the grading typically directs water away from the landscaping, thus losing any opportunity to "disconnect" the imperviousness for infiltration. This connected system instead creates more surface runoff—and this results in increased flooding, erosion, and pollution. Consequently, an urban watershed produces a greater volume of stormwater runoff, which in turn degrades the physical, chemical, and biological quality of streams.[7]

Some communities are taking steps to preserve undeveloped parcels or regional swaths of open space, in order to preserve watershed functions, among other environmental, economic, and social goals. Preserving open space can reduce total watershed impervious surfaces. Indeed, since 1998, nearly $20 billion has been approved for open space preservation in local and state referenda. Since all land has differing ecological value, some communities are beginning to develop open space conservation programs that target the most

[6] American Farmland Trust. 1994. *Farming on the Edge: A New Look at the Importance and Vulnerability of Agricultural Near American Cities*.
[7] Woodworth, James et al. 2002. *Out of the Gutter: Reducing Polluted Runoff in the District of Columbia*. NRDC: Washington, DC.

critical areas for preservation.[8] However, strategic and targeted open space preservation planning is in its nascent stages and the overall impact of these measures tends to be somewhat limited from an ecological protection standpoint. While open space preservation is certainly part of the solution for development-related water quality problems, it is critical to address overall densities in the watershed in order to minimize total land consumption.

LOW DENSITY DEVELOPMENT--BAD FOR WATER QUALITY? CRITIQUING CONVENTIONAL WISDOM

Knowing that development has the ability to impair the natural functions performed by watersheds, state and local governments are asking, "If we are going to grow, how do you minimize development's impacts on water quality? Are some patterns of development less harmful than other development patterns? Are there critical thresholds of which to be aware? How much development can a watershed absorb without significant harm occurring?"

There are some answers to these questions. Studies have demonstrated that watershed's suffer impairment at a 10 percent impervious cover. Over 25 percent, the watershed is considered severely impaired.[9] Conventional thinking has translated these findings into the notion that low-density development will result in better water quality. The reasoning behind these policies is: a 1-acre site will typically have one or two residential units with a roadway passing by the property, the driveway, a home with an average footprint of 2,265 ft^2.[10] The remainder of the site is lawn. The impervious cover is approximately 35 percent.[11] The lawn, however, while still pervious cover, contributes to stormwater runoff because of its disturbed nature, e.g., the soils have been compacted due to scraping and the traversing of construction equipment. The effects of this compaction can remain for years, and be increased due to mowing. Therefore, sites with fewer houses minimize impervious cover and maximize lawn cover or other types of variably pervious surface. Given indications that watershed impairment begins at 10 percent impervious cover, it is thought that a low-density development scenario may be one approach to the improvement of water quality. However, in a higher-density scenario, which will typically have eight to ten residential units per acre, the parcel is likely to be built out with upwards of 85 percent impervious cover.[12] The majority of this impervious cover is due to the footprints of the housing units. Lawn space is generally minimized. This scenario seems less protective of water quality because it has more impervious cover due to housing footprints.

Because impervious surface area appears to vary with specific land use, a common approach to local land use regulation in support of water quality is to specify maximum development densities. The reasoning here is that if each site minimizes water quality impact through density alone, e.g, the number of residential unites per acre, then overall parcel-level impervious cover is regulated, with the putative benefits apparent at the watershed or regional scale.[13] While this seems to make sense, there are some significant flaws in this thinking.

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[8] Trust for Public Land and the National Association of Counties. 2002. *Volume 1: Local Greenprinting for Growth: Using Land Conservation to Guide Growth and Preserve the Character of Our Communities.*

[9] There are different levels of impairment. In general, when the term is used in EPA publications, it usually means that a water body is not meeting its designated water quality standard. However, the term can also imply a decline or absence of biological integrity, e.g., the water body can no longer sustain critical indicator species, such as trout or salmon. Further, there is a wide breadth of levels of impairment, e.g., endangered trout versus spontaneous combustion.

[10] National Association of Home Builders. 2001. *Housing Facts, Figures, and Trends: 2001*. NAHB: Washington, DC. The average house built in 2001 includes 3 or more bedrooms, 2.5 baths, and a 2-car garage.

[11] Soil Conservation Service, 1986. Technical Release No. 55 (TR-55). *Urban Hydrology for Small Watersheds*.

[12] *Ibid*.

[13] See, for example, the code for Durham, NC: www.ci.durham.nc.us/departments/planning/zoneord/Section5/556.html

1) *Density and imperviousness are not equivalent.* Depending on the actual design of the development, two houses may actually create as much imperviousness as four houses, for example. The impervious area on site associated with given number of residential dwelling units can vary widely due to road infrastructure, housing design (single story or multi-story), or length and width of driveways. For example, a multi-story apartment of 10 units on one acre can have less impervious surface than 6 single-family homes on the same acre. Even at the level of a single house, impervious area can vary widely, and therefore assumptions about the impervious area per dwelling unit are questionable. For example, in some dispersed low-density communities, such as Fairfax County, Virginia, some homeowners are paving their front lawns to create more parking space for the large number of cars each household owns.[14] This phenomenon has also been noted in some San Francisco, California neighborhoods with large households and high vehicle ownership rates.[15]

2) *Much of the "pervious" surface left on low-density development acts like impervious surface for water quality purposes.* All else being equal, undisturbed land is better for water quality than disturbed land, including lawns and other maintained areas. However, disturbed and impervious areas vary widely in the amount, speed, and type of runoff per square foot. At one time, lawns were thought to provide "open space" for infiltration of water. However, development can involve wholesale grading of the site, removal of topsoil, severe erosion during construction, compaction by heavy equipment and filling of depressions. Research now shows that the run-off from highly compacted urban lawns is almost as high as paved surfaces.[16] Therefore, a one or two acre lawn does not offer the same watershed services that a one or two acre undisturbed forest does. The idea that minimizing impervious surfaces by limiting housing structures and maximizing larger lawns does not address the loss of ecological services that the area provided before development.

3) *Low-density developments mean more off-site impervious infrastructure.* Development in the watershed is not simply the sum of the sites within it. Rather, total impervious area in a watershed is the sum of site developments plus all the infrastructure supporting those sites, such as roads, parking lots, ditches, and other impervious surface infrastructure. Furthermore, recent research has demonstrated that impervious surfaces attributed to streets, driveways, and parking lots can represent upwards of 75 percent of total site imperviousness, and this is on sites with two residential units per acre.[17] That number decreases to 56 percent on sites with 8 residential units per acre. This indicates that as density decreases, off-site transportation-related impervious infrastructure often increases. In a density-limiting policy environment, densities are generally calculated absent this infrastructure, and low-density development requires substantially higher amounts of this infrastructure per capita and per acre than do the more dense developments, which are paradoxically prohibited by some types of zoning regulation.

4) *The scale of the finding that 10 percent impervious cover impairs watersheds is for the watershed level.* Often, this finding is applied at the site level, and, as discussed in the previous point, does not take into account the transportation-associated infrastructure. Applying this finding at the site level is flawed since the research behind this finding was conducted at the watershed level, not the site level. Extrapolating from the site to the watershed would be incorrect because other factors come into play at

[14] Rein, Lisa and David Cho, "In Defense of the Front Lawn: Fairfax Attacks Crowding With Ban on Oversize Driveways," *Washington Post*, June 4, 2002, p. A1.
[15] Brown, Patricia Leigh, "The Chroming of the Front Yard," *New York Times*, June 13, 2002, p F1.
[16] Schueler, T. 2000. The Compaction of Urban Soil. *Techniques for Watershed Protection.* Center for Watershed Protection, Ellicott City, MD.
[17] Cappiella, K. and Brown, K. 2001. *Impervious Cover and Land Use in the Chesapeake Bay Watershed.* Ellicott City. MD.

the watershed level. However, what the 10 percent finding does suggest is that it is better to cluster development or to increase the density of existing communities.

5) *Growth is coming to the region, limiting density on a given site doesn't eliminate that growth*. Density limits are responses to—and attempts to manage—growth. Yet they do not in fact manage growth; they only manage *some* growth—the growth on the density-limited area. The rest of the growth that was going to come to the region still comes, but goes elsewhere. Is that elsewhere better or worse for regional water quality than accommodating the growth at the density-limited site? Rarely if ever are density limits part of a watershed plan that answers that question. If growth is coming to a region, it will come regardless of density limits in a particular place. There is a lively debate in economic development circles about whether certain types of development are especially attractive to residents and/or businesses, and will therefore draw additional growth. But no one argues that pursuing a particular kind of growth will slow or stop growth in a region.[18] (This issue is discussed in more detail in on page 11). At most, covering a large part of a region with density limits will drive growth to other parts of the region. If the excluded growth's destination is upstream from the density-limited area, then the area with the density limits will still be affected by the growth, and, depending on local conditions, may actually be made worse off from a water quality perspective than if the growth had been accommodated and well-managed in the area.

TESTING THE ALTERNATIVE: CAN COMPACT DEVELOPMENT IMPACT REGIONAL WATER QUALITY?

The debate over how best to protect water quality, and how to continue to enjoy the ecological and economic services of watersheds, begins with the expanding United States population. The Census Bureau projects that U.S. population will grow by 50 million people between 2000 and 2020.[19] Where and how these people will be accommodated is fundamental to all water quality protection strategies.

What is the alternative to the density-limiting approach? Compact development can accommodate more people on less land, leaving more undisturbed land, i.e., greenfields, available to serve critical ecological functions as previously described.[20] The fundamental debate, then, is over which scenario is better for regional, or watershed, water quality—lower density or higher density ("compact") development. The two arguments can be summarized as follows:

1. Low-density development is better for watershed water quality because it limits impervious cover at the site level.

Or

[18] There are, of course, minor exceptions to this dynamic. An area that is desirable will probably experience an increase in housing prices and would consequently experience a very modest displacement of development to other parts of the region. For example, housing prices in some neighborhoods in Manhattan, New York, San Francisco, California, or Washington, DC have increased significantly because of the urban form and high densities. It is likely that the higher housing prices have fostered development in areas further from these central locations.

[19] "Annual Projections of the Total Resident Population as of July 1: Middle, Lowest, Highest, and Zero International Migration Series, 1999 to 2100." Population Projections Program, Population Division, U.S. Census Bureau, Washington, D.C. 20233. Internet Release January 13, 2000, revised February 14, 2000 at www.census.gov/population/www/projections/natsum-T1.html.

[20] In addition, higher densities make public transit profitable, increase walkability, and generally increase other livability factors that are absent in dispersed, low-density sites. For more information on these positive externalities associated with compact development, see EPA document 231-R-01-002 "Built and Natural Environment: A Technical Review of the Interactions between Land Use, Transportation, and Environmental Quality."

2. High-density development is better for watershed water quality because overall it disturbs less land to accommodate the similar numbers of people and therefore leaves more land available to serve critical ecological functions.

Although the previous section gave numerous reasons to doubt that the density-limiting approach was protective of watershed quality, a complete evaluation needs to test the density-limiting approach against one that encourages compact development. We test the competing approaches by comparing higher- and lower-density developments by using hypothetical site plans that represent typical low-density and compact development patterns.[21]

Assumptions

In order to construct scenarios and conduct the modeling in a way that produces policy-relevant results, certain assumptions drive the analysis. Because the relevant question concerns selection of an approach that produces less runoff and pollutant loadings, the analysis examines the *comparative* differences in the impacts of low density and compact development patterns. The analysis is driven by two major assumptions:

1. *Metropolitan regions will continue to grow*. This assumption is consistent with US Census projections that the US population will grow by roughly 50 million people by 2020.[22] Given this projected population growth, communities across the country are or will be grappling with how to accommodate expected population increases to their regions.

2. *Shifting growth represents a shift in growth, not additional growth within the region*. Individual states and regions grow at different rates depending on a variety of factors including macroeconomic trends (e.g., the technology boom in the 1980s spurring development in the Silicon Valley region in California); historical growth rates; and demographic shifts. These factors are not significantly impacted by the prevailing distribution of density of development. The question for a state or a region is, "If we are going to receive X number of new jobs and X number of new residents, what is the effect of accommodating those jobs and residents in a higher density pattern of development versus a low density pattern of development?"

AN ILLUSTRATIVE EXAMPLE

To determine which development pattern is more protective of water quality, we have developed two scenarios in order to examine water quality impacts from a high density and lower density developments. These scenarios take place within a fictional watershed and are simplified in order to isolate and examine the impacts of density on water quality. Issues such as slope, ground water hydrology, commercial, industrial, and agricultural land uses are important to watershed health, but are not considered in these scenarios.

Two communities in this watershed are each growing by the same amount. The region's council of governments has forecasted that over the next 20 years, the metro area will grow by 270,000 persons. As the region looks to accommodate this new growth, they are also looking for ways to protect water quality and the overall health of the watershed.

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[21] For more information and other tests, please see EPA's draft document, *Minimizing the Impacts of Development on Water Quality*, 2003.

[22] U.S. Census Bureau.

Two communities in this region have different average densities. Community A is dominated by lower density development, and has an average residential density of three residential units per acre.[23, 24] Community B, the higher density area, has a density average of approximately nine residential units per acre. Each residential unit in both communities generates a certain volume of stormwater runoff and a proportional amount of pollution. For both communities, we assumed that development would have the following features:

- The entire acre is disturbed land; e.g., no forest or meadow cover would be preserved.
- Each residential unit in both communities has a footprint of 2,200 square feet.
- The same percentage of transportation-associated infrastructure, such as roads, parking lots, driveways, and sidewalks is allocated to each community acre.
- No best management practices, structural or otherwise, are implemented.

In general, impervious surfaces, such as housing footprint, driveways, and roads will have higher amounts of runoff and associated pollutants. Lawns, while pervious, still contribute to runoff due to their compacted and disturbed nature. Based on these assumptions, the overall percent imperviousness for Community A is approximately 30 percent for an average density of 3 residential units per acre and the overall percent imperviousness for Community B is 70 percent for an average density of 9 residential units per acre.[25] While these assumptions are based on an illustrative example and not on actual site plans, the size of housing units is based on national trends from the National Association of Home Builders.[26]
The percentage of infrastructure that is attributable to each acre is based on the curve number methodology from the Natural Resources Conservation Service (NRCS); and the overall site imperviousness is based on NRCS studies of urban hydrology.[27]

The model used to generate the results described below is Smart Growth Water Assessment Tool for Estimating Runoff (SG WATER)[28]—a peer reviewed sketch model that was developed specifically to compare water quantity and quality differences among different development patterns. SG WATER's methodology is based on the NRCS curve numbers,[29] event mean concentrations, and daily rainfall data.[30]

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[23] Densities at three or nine residential units per acre are conservative and used here for illustrative purposes only. Many communities now are zoning for one unit per two acres at the low-density end of the spectrum. Low density residential zoning exists in places as diverse as Franklin County, OH that require no less than 2 acres per unit http://www.co.franklin.oh.us/development/franklin_co/LDR.html#304.041) to Cobb County, Georgia outside of fast growing Atlanta that requires between 1 and 2 units per acre in its low density residential districts (http://www.cobbcounty.org/community/plan_bza_commission.htm). By comparison, some communities are beginning to allow higher densities upward to 20 or high units per acre. For example, Sonoma County, California's high density residential district permits between twelve (12) and twenty (20) units per acre (http://www.sonoma-county.org/prmd/Zoning/article_24.htm) and the City of Raleigh, NC allows up to 40 units per acre in planned development districts. (http://www.raleigh-nc.org/planning/DPRC/BROCHURES%20PDF/HIGH_DENSITY.PDF)

[24] For this example and throughout this paper, residential units instead of commercial units are compared. Most communities do not zone for density limits for commercial and retail properties.

[25] Soil Conservation Service, 1986.

[26] National Association of Home Builders. 2001.

[27] The NRSC estimate for average imperviousness for 8 units per acre is 65 percent. They do not have an estimate for 9 units per acre. Given our calculations and NRSC estimates of average site imperviousness, we are extrapolating average impervious for 9 unit per acre to be 70 percent.

[28] *Technical Approach for SG WATER: Smart Growth Water Assessment Tool for Estimating Runoff*, 2002.

[29] Soil Conservation Service. Technical Release No. 55 (TR-55). *Urban Hydrology for Small Watersheds*.

[30] Daily time-step rainfall data for the three year period (1997-1999) was used.

It does not take into account wastewater or drinking infrastructure, slope, or other hydrological interactions that the more complex water modeling tools use.

Please note that SG WATER uses a general and simple methodology based on curve numbers. One limitation of curve numbers is that they tend to under predict stormwater runoff for smaller storms. This under prediction can be significant since the majority of storms any given area experiences in any year are small storms. In addition, the curve numbers tend to over-estimate runoff for large storms. However, curve numbers will more accurately predict runoff in areas with more impervious cover because the runoff for impervious cover is similar using the curve number approach and the small storm hydrology approach.[31] For the analysis here, the runoff from the low-density site will be under predicted to a larger degree than the runoff from the higher density site because the higher density site has more impervious cover. Simply put, the difference in the numbers presented here are conservative—it is likely that the *comparative difference* in runoff between the two sites will be much greater if more extensive modeling was used.

RESULTS

In the lower-density Community A, the total average annual volume of runoff from the one-acre site, with three housing units, is 21,400 ft^3 – and the total average annual volume of runoff from Community B, with 9 housing units is 42,900 ft^3. These totals represent the amount of water measured at one hypothetical outfall. Community B, with more housing units, has a greater amount of impervious surface cover and thus generates a larger volume of runoff at the site level.

Exhibit 1: Total Average Annual Stormwater Runoff Per Acre for Both Communities. *(These totals represent the amount of water measured at a hypothetical outfall.)*

	Density	Imperviousness	Average Annual Runoff[32] per acre
Community A	3 residential units per acre	30 percent	21,400ft^3
Community B	9 residential units per acre	70 percent	42,900 ft^3

Now, looking at how much runoff each *individual housing unit* produces, we see that in Community A, each house yields 7,133 ft^3 of average annual runoff, whereas in the more dense Community B, each unit produces 4,767 ft^3 average annual runoff. Therefore, when examined at the housing unit-level, each house in Community B produces approximately 33 percent less runoff for each house in Community A. This is because houses in Community B have smaller yards and less site-infrastructure on a per unit basis. Therefore, on a per unit basis, each home in the higher-density communities contributes less stormwater runoff. Exhibit 2 demonstrates.

[31] Most existing stormwater models incorrectly predict flows associated with small rains in urban areas. Most existing urban runoff models originated from drainage and flooding evaluation procedures that emphasized very large rains (several inches in depth). These large storms only contribute very small portions of the annual average discharges. Moderate storms, occurring several times a year, are responsible for the majority of the pollutant discharges. The effects caused by these frequent discharges are mostly chronic in nature, such as contaminated sediment and frequent high flow rates, and the interevent periods are not long enough to allow the receiving water conditions to recover.
[32] Calculated by SG WATER using Atlanta, Georgia daily time step rainfall data and assuming hydrologic soil type C.

Exhibit 2: Total Average Annual Stormwater Runoff Per Housing Unit for Both Communities. *(These totals represent the amount of water measured at a hypothetical outfall.)*

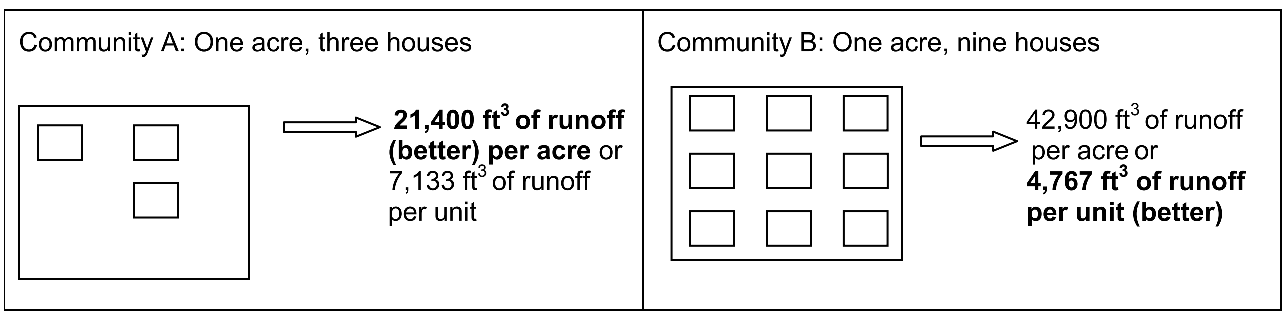
	Density	Imperviousness	Average Annual Runoff per Acre	Average Annual Runoff per Unit
Community A	3 residential units per acre	30 percent	21,400 ft^3	7,133 ft^3
Community B	9 residential units per acre	70 percent	42,900 ft^3	4,767 ft^3

In sum, our model showed that when density is tripled, total stormwater runoff doubles at the per acre level, but is decreased by one-third at the housing unit level. In other words:

- density triples; and
- imperviousness doubles; and
- *total average annual* doubles; and
- runoff *per housing unit* falls by 33 percent.

Exhibit 3 illustrates the relative differences between Community A and Community B. At the one-acre level, the lower total average annual runoff produced by Community A's low-density development would be better for water quality than the Community B's high-density development. On the other hand, at the individual housing unit level, the high-density development of Community B produces less stormwater runoff on a per-dwelling-unit basis.

Exhibit 3: Average Annual Stormwater Runoff in Community A and Community B. *(These totals represent the amount of water measured at a hypothetical outfall.)*

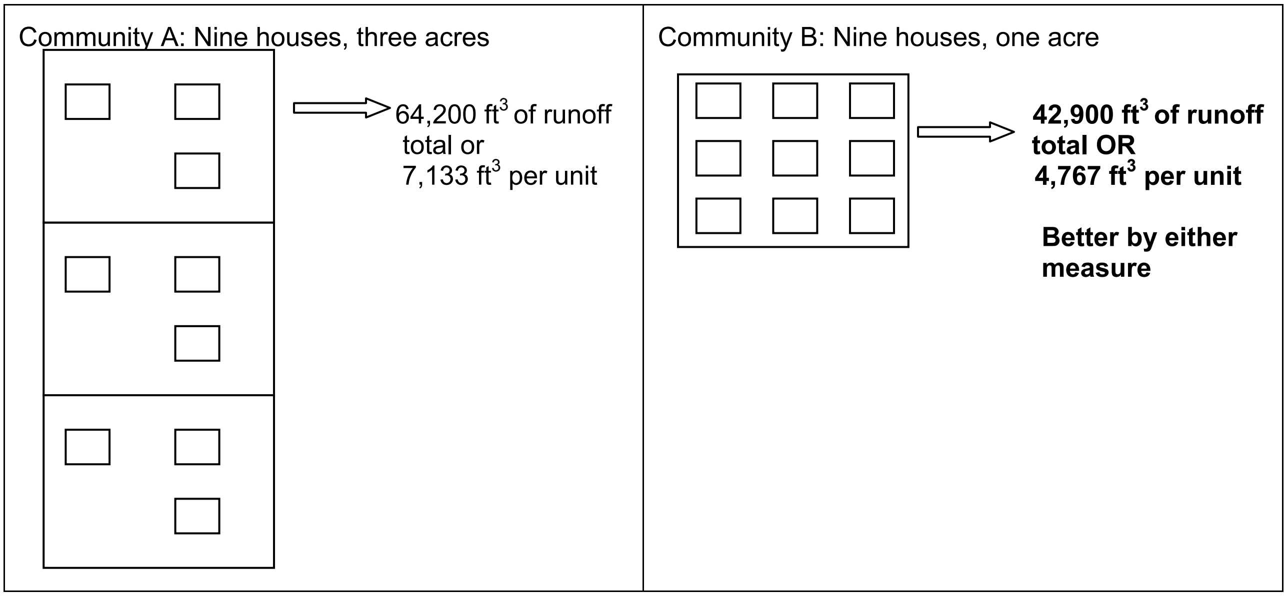


On a strict site-level basis, the density limiting approach is more environmentally protective. Recalling from the previous section the conclusion that the watershed is the correct level of analysis, rather than the site-level, we turn next to examining the implications for the watershed, by extrapolating these site-level results.

The assumptions establish that Communities A and B will grow at the same rate. Thus our initial model run, placing only three units in Community A, did not test the situation actually faced by Community A. Community A will also needs to accommodate the same nine dwelling units, so the correct scenarios must compare nine new dwelling units in Community A to nine new dwelling units in Community B.

Where is Community A put the six additional houses that Community B accommodated? Assuming the same development densities, Community A will need to develop two additional acres, or three acres total, to accommodate the same number of housing units that Community B accommodated on one acre. In this scenario, total average annual runoff from nine houses in Community A is 64,200 ft^3 (21,400 ft^3 x 3 acres), which is 50 percent more runoff as the same nine houses produce in Community B (the same 42,900 ft^3 total average annual runoff). Exhibit 4 illustrates.

Exhibit 4. Each community accommodates nine houses. *(Average annual runoff—assuming one hypothetical outfall.)*

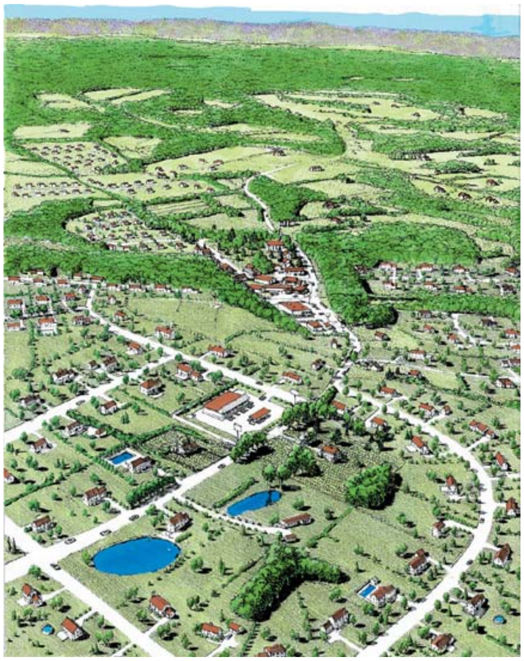


From this example, we can see that with higher densities, the per unit runoff rates are dramatically less (approximately 33 percent) than their low-density counterparts. If we only look at runoff from the 1-acre site level (not looking at the per unit rates or the rates for accommodating the same number of houses given permitted densities) we see that lower densities can create less impervious cover and produce less runoff. But if we treat the watershed as a whole—expecting that the region will be accommodating a given amount of new growth, regardless of whether that growth is low or high density-- the lower density developments will necessarily require developing further into the watershed. In turn, each low-density unit, requiring more space for driveways, roadways, and compacted lawns, will create more runoff and watershed degradation. If these impacts are extrapolated to the watershed level, Community A will develop land at a rate three times faster than Community B. Exhibit 5 is intended to illustrate the potential regional build out of these two different community scenarios. These illustrations[33] give us a pictorial view of how Community A and B might end up developing at a watershed scale. Clearly development in Community B disturbs less land, thereby preserving more critical ecological functions than the low-density development patterns in Community A. Yet, both communities are accommodating the same number of people.

[33] Provided by the New Jersey Office of Planning; http://www.state.nj.us/osp/plan2/p2full/colors00.htm.

Exhibit 5: Comparison of Watershed Build Out for Communities A and B

Community A



Community B

FINDINGS FROM THE ILLUSTRATIVE EXAMPLE

Using average densities to project stormwater runoff for two communities, we were able to demonstrate that a higher density scenario generates less stormwater runoff on a per housing unit basis. Specifically, this example illustrates:

- For a given site, less compact development can create less impervious cover, less runoff, and may better protect water quality;
- With more compact development, runoff rates per residential unit fall dramatically, to approximately 1/3 of their less compact counterparts;
- For the same amount of development, the more compact development will produce less runoff than the less compact development pattern; and
- For a given amount of growth, then lower density developments must force development further into the watershed.

Taken together, these findings lead to the conclusion that, all else being equal, including amount of growth, at the watershed level, higher densities are more environmentally protective. These results were also tested for comparative development sites at the square mile area and 10-acre area in addition to the one-acre analysis. At all levels, the ratios remain the same: when density is tripled, total stormwater runoff doubles at the per acre level, yet the housing level stormwater runoff is decreased by one-third.

Issues to consider in this analysis

1. Is growth really fixed?

A basic assumption for our modeling is that the amount of growth coming to either Community A or B is fixed—and the question to be examined is how can certain strategies influence the density and pattern of that growth. When developing and examining the consequences of regional growth trends, regional forecasters ask, "how much growth is expected to come to this region in a given period of time?" In standard regional population modeling practice, wage or amenity (a firm-location criterion based on pleasant locational attributes—such as climate or culture—rather than on transport or production cost[34]) differentials with other areas of the country seem to account for most of the ingress or egress to a metropolitan area.[35] Growth is also a function of birth and death rates in a region. Regional growth models do not typically employ density drivers of regional jobs or population. That is, growth is apparently not a function of regional development patterns. Development density is independent of regional growth, there is no reason to believe that low-density zoning limits the number of people moving to a region, and many reasons to believe that such zoning does not limit the number of people moving to a region, but rather simply pushes them further out.

Estimates of future growth are rarely precise and despite this imprecision, regions have used this fixed amount of growth to test the effects of adopting different growth planning strategies. This is possible if we accept the premise that development patterns do not significantly change the amount of regional growth. A wide variety of regions have used this approach. One of the best-known studies and planning processes is Portland, Oregon's "Vision 2040." Portland understood that the region would grow substantially by 2040; the question was not if, but where and how. In response, it developed a base case and three alternative growth concepts that all absorbed the same amount of growth; approximately 720,000 additional residents and 350,000 additional jobs in the region.[36] These four alternative futures are schematically illustrated in Exhibit 6. Although they all absorb the same amount of people and jobs, they vary substantially in infrastructure requirements, open space preservation, and impact on both the urban and natural environment. Each option was analyzed for effects on:

- land consumption
- travel times and distances
- open spaces and air quality
- various urban landscapes."[37]

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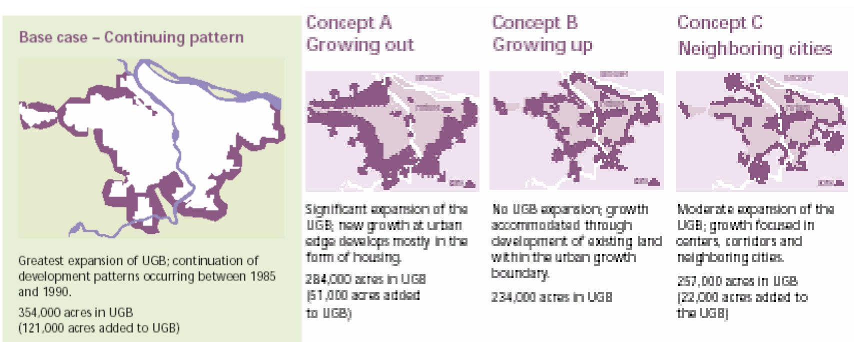
[34] Mills, Edwin, B. Hamilton. 1994. *Urban Economics: Fifth Edition*. Harper Collins College Publishers.

[35] The most widely-used such model—the REMI® Policy Insight™ model—uses an amenity variable. However, even this is implemented as an additional change in the wage rate. See www.remi.com/Overview/Evaluation/Structure/structure.html. All other regional population models in a survey by ICF use only economic and demographic drivers. The in-house model used by San Diego Association of Governments is an advanced example of the type used by COGs around the country. www.sandag.cog.ca.us/resources/demographics_and_other_data/demographics/forecasts/index.asp.

[36] http://www.metro-region.org/growth/tfplan/2040.html

[37] Metro, "The Nature of 2040: The region's 50-year plan for managing growth," 2000. See http://www.metro-region.org/growth/tf/2040history.pdf

Exhibit 6: Same amount of growth, different locations and densities: Portland's Vision 2040 alternatives analysis.



The Minneapolis-St. Paul region took the same approach in its Blueprint 2030, developing alternative growth scenarios that all absorbed the same amount of growth—in this case, 280,000 households—and then forecasting the impacts associated with each scenario.[38] As in Portland's study, the growth scenarios varied substantially in where in the region they located the 280,000 new households, and how dense those households were developed in those locations. Total growth, however, was held constant across scenarios.

This approach has been used at the statewide level as well. New Jersey, in their State Plan, explicitly addressed the question whether population and jobs would change under the PLAN versus business-as-usual TREND, and found that, "It is anticipated that the TREND and PLAN scenarios will have essentially the same population and household growth at the state and regional levels, but significantly different growth by type of community and State Plan planning area. It is also anticipated that under the PLAN regimen there will be more growth in communities with more densely developed planning areas and in communities with urban, regional, and/or town centers, and that there will be less growth in these areas under the TREND regimen." So, both PLAN and TREND scenarios analyzed "Accommodating a growth of 462,000 households and 802,500 jobs over the period 2000 to 2020 [requiring] approximately 486,500 housing units and 422.5 million square feet of nonresidential space."[39]

Although these three studies are excellent examples, they are by no means only examples of this approach to regional and statewide growth planning. Other examples include:

- Puget Sound Regional Council's Vision 2020 (where and how to absorb 1.4 million people),[40]
- San Francisco Bay Area's Smart Growth Strategy,[41] developed by the Association of Bay Area Governments (where and how to absorb 1 million new residents and 1 million new jobs),
- Envision Utah (where and how to absorb 600,000 new residents by 2020),[42]

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[38] Metropolitan Council, Blueprint 2030: "[E]ach alternative future illustrates a distinct way in which the Twin Cities can accommodate the Region's next 280,000 households (approximately 580,000 people) and 360,000 jobs. http://www.metrocouncil.org/planning/blueprint2030/overview.htm
[39] http://www.state.nj.us/osp/plan2/ias/sp3economic.pdf and http://www.state.nj.us/osp/plan2/ias/ia2000en.htm.
[40] http://www.psrc.org/projects/vision/2020overview.htm
[41] Association of Bay Area Governments, "Smart Growth Strategy: Shaping the Future o f the Nine-County Bay Area," Alternatives Report, April 2002. See http://www.abag.ca.gov/planning/smartgrowth/AltsReport/SmartGrowthStrategy.pdf

While these studies have forecast the environmental impacts of a fixed amount of growth absorbed in various locations and in various densities, they have not, in most cases, looked explicitly at water impacts. The population and growth assumptions outline in this paper, then,

- Follows the standard model of growth impacts analysis by examining the impact on the environment of a fixed amount of growth, absorbed in different locations and in different densities;

- Seeks to contribute to the standard approach by demonstrating that it is both possible and important to add water to the list of impacts that is examined in this type of alternatives analysis for regional and statewide growth.

In sum, the approach in this study is both consistent with the current state of the practice, and builds on it. Finally, as we establish the assumptions for this analysis, it is important to note: we do not argue that the projected 270,000-person growth increment is necessarily the correct number and that the growth is fixed and known. It may be 240,000 persons, or it may be 340,000 persons. There is uncertainty in these projections, as in all growth forecasting. However, we also know that some amount of growth is coming, and that whatever the amount it will not vary as a result of lower or higher density development. That is the sense in which it is fixed for the purposes of this policy analysis.

2. What happens if high-density development occurs and the remaining green space is developed as well?

Higher density development performs better at the watershed level because some green space is "saved" by concentrating development regionally--see Exhibit 5 for an illustration of this dynamic. In other words, accommodating more people in closer proximity can relieve development pressures at the edge. However, critics argue that the undeveloped lands will be developed anyway, thereby further degrading water quality by allowing higher densities and by developing on all the absorbent open space. However, there are two issues with this critique:

(1) Growth is fixed. As discussed in the previous section. More growth will not arbitrarily come to a region simply because there is space to expand.

(2) Comparisons between built out densities must keep the number of housing units accommodated the same. For example, if critics argue that the high-density approach will bring more development to the remaining open spaces, that same amount of development must be added to the comparison watershed that has developed at lower densities.

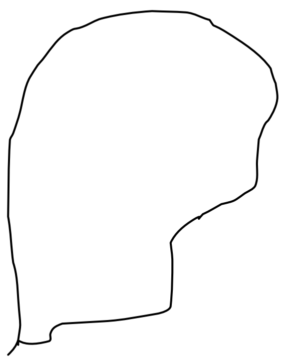
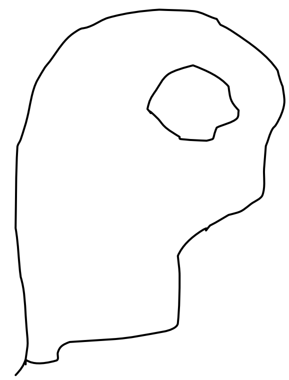
We have already explored the first issue. For the sake of exploring the second issue, we'll examine two comparative watersheds in three stages: (1) each watershed accommodates the same number of housing units but at different densities; (2) as the critics argue, the more dense watershed is fully built out, while no growth is added to the comparison watershed; and (3) the comparison watershed accommodates the growth of the more dense watershed, which means that each watershed accommodates the same number of housing units. We're assuming that the watershed in question is 10,000 acres.

The first step in this process is to examine each watershed accommodating the same number of housing units- but at different densities. Initial growth projections suggested that at 3 housing units per acre the watershed would be fully built out. However, at the higher density level of 9 housing units per acre, only one third of the watershed would be built out. The runoff associated with each of these scenarios is shown in Exhibit 7.

[42] See http://www.calthorpe.com/Project%20Sheets/Envision%20Utah.pdf

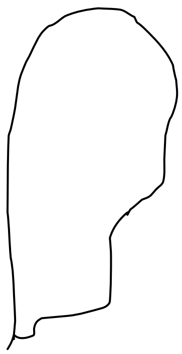
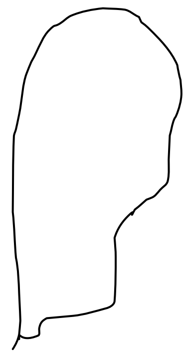
As Exhibit 7 shows, if development occurs at a lower density, e.g., 3 housing units per acre, the entire watershed will be built out. Any additional development that occurs in this community will have to go into another watershed, since this watershed is built out. This total buildout will generate 214 million ft^3 average annual stormwater runoff, assuming one hypothetical outfall. This is approximately one-third more stormwater runoff that the watershed that is developed at the higher density. In this situation, developing at the lower density seems worse for watershed water quality.

Exhibit 7: Hypothetical 10,000-acre Watershed Developed at Different Densities

	
Scenario 1: The 10,000-acre watershed is fully built out at 3 housing units per acre. 30,000 housing units are accommodated. This translates to: 10,000 acres x 3 housing units x 7,133 ft^3 of runoff **214 million ft^3 average annual stormwater runoff** **30,000 housing units accommodated**	**Scenario 2**: The 10,000-acre watershed is only partially built out because development is occurring at higher densities—9 housing units per acre. 30,000 housing units are still accommodated. This translates to: 1/3 (10,000 acres) x 9 housing units x 4,767 ft^3 of runoff **141.57 million ft^3 average annual stormwater runoff** **30,000 housing units accommodated**

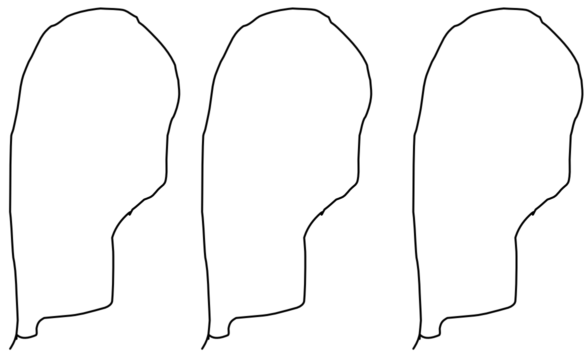
But what happens if the remaining 2/3 of the watershed in Scenario 2 is built out, as was initially suggested? Exhibit 8 examines those numbers considering the worst case situation—that the remaining land in the watershed is developed at the higher density of 9 housing units per acre.

Exhibit 8: Hypothetical 10,000-acre Watershed Developed at Different Densities

	
Scenario 1: The 10,000-acre watershed is fully built out at 3 housing units per acre. 30,000 housing units are accommodated. This translates to:	**Scenario 2**: The 10,000-acre watershed is fully built out at 9 housing units per acre. 90,000 housing units are accommodated. This translates to:
10,000 acres x 3 housing units x 7,133 ft^3 of runoff	10,000 acres x 9 housing units x 4,767 ft^3 of runoff
214 million ft^3 average annual stormwater runoff	**429 million ft^3 average annual stormwater runoff**
30,000 housing units accommodated	**90,000 housing units accommodated**

Now, both watersheds are fully built out and the watershed developed at the higher density, e.g., developed at 9 housing units per acre, is generating approximately double the total stormwater runoff. This would be worse for watershed water quality if both scenarios accommodated the same amount of growth. However, note that the watershed with the higher density is accommodating *60,000 more units of housing,* or three times the number of housing units. And, as was discussed in the previous section, growth is fixed. A region will not accommodate unlimited growth. In essence we are projecting what would happen if the regional growth is three times higher than initially projected. So, where are those additional housing units accommodated in the watershed that was developed at the lower-density? They were built in nearby or adjacent watersheds. So, to continue with the analysis, if regional forecasts were wrong and 90,000 housing units were needed and not 30,000 housing units, then the watershed developed at the lower density level, e.g., 3 housing units, will need to expand into two additional watersheds to accommodate the same growth! Exhibit 9 illustrates this situation.

Exhibit 9: Hypothetical 10,000 acre Watershed Developed at Different Densities

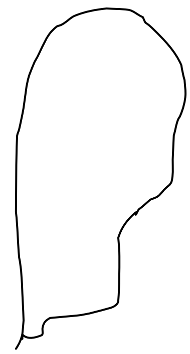


Scenario 1: The 10,000-acre watershed is fully built out at 3 housing units per acre. But an additional 60,000 housing units must be accommodated. This will require total build out of another 2 entire watersheds. This translates to:

10,000 acres x 10,000 acres x 10,000 acres x 3 housing units x 7,133 ft^3 of runoff

642 million ft^3 average annual stormwater runoff

90,000 housing units accommodated



Scenario 2: The 10,000-acre watershed is fully built out at 9 housing units per acre. 90,000 housing units are accommodated. This translates to:

10,000 acres x 9 housing units x 4,767 ft^3 of runoff

429 million ft^3 average annual stormwater runoff

90,000 housing units accommodated

As Exhibit 9 demonstrates, accommodating an additional 60,000 housing units requires disturbing and developing another 2 watersheds. Total average annual stormwater runoff from accommodating 90,000 housing units at 3 housing units per acre generates 642 million ft^3 average annual runoff. While the watershed developed at the higher density, e.g., 9 housing units per acre, has still just disturbed one watershed and is generating approximately one third less stormwater runoff—or 429 million ft^3 average annual runoff.

3. Urban water infrastructure is failing — how can it accommodate more users?

It is better to preserve public investments by investing where the public has already invested. It is a poor strategy economically and environmentally to divert development away from any area because infrastructure is failing. For example, in a report by the Office of Technology Assessment, one official of a large western city reported that it costs the city $10,000 more to provide infrastructure services to a house on the suburban fringe than one in the urban core.[43] Myron Orfield, a member of Minnesota's House of Representatives, calculated that by 1992, the central cities of Minnesota were paying over $6 million annually to subsidize growth in edge areas. This was especially troubling to areas like Minneapolis, which had 22 percent existing sewer service that in 1990 remained undeveloped. Rather than directing growth to this area, between 1987 and 1991, the region provided new capacity to 28 square miles of land at the cost of $50 million per year.[44] The capacity went primarily to serve expansion into the development affluent

[43] US Congress, Office of Technology Assessment, *The Technological Reshaping of Metropolitan America*. Washington, DC: US Government Printing Office, 1995. OTA-ETI-643.

[44] Orfield, Myron. 1997. *Metropolitics: A Regional Agenda for Community and Stability*. Washington, DC: Brookings Institution Press.

southwest suburbs. This kind of infrastructure spending subsidizes and encourages development at the fringe.

The implications of building new infrastructure instead of maintaining existing infrastructure is that it is apparently more important to provide new infrastructure than to maintain good service in existing communities. This signal leads to an unwillingness to invest on the part of private owners. Thus, a catch-22 situation begins—an area is degraded and no one, including the local government, wants to invest in it, which causes further degradation of the area. The result of this type of disinvestment causes the movement of people and businesses out of the community to newer developed areas. This movement can lead to sprawl even in the absence of significant population growth. This has been evidenced in numerous cities such as Buffalo, New York, Cleveland, Ohio, and Pittsburgh, Pennsylvania. All these cities experiences population loses at the same time as their land consumption and urbanized area grew. The result of this outward growth, with or without population growth, is a significant increase in watershed or regional impervious cover, which will further degrade regional water quality.

4. Shouldn't increasing densities be accompanied by open space offsets?

This question essentially asks that if the benefits of density are derived from undeveloped open space, shouldn't there be a requirement that this land be preserved? Earlier, we discussed the issue that the resulting open space will be developed in addition to the higher density development is in essence a fear that the region will receive more growth than anticipated. The implication here is that without some active preservation, the open space will be developed anyway. As discussed, this growth would have come to the region in either the low density or the higher density scenario and we asked which density development pattern would accommodate this new growth with the least impact to water quality.

There is a fixed amount of growth coming to any given region. Once that growth is accommodated, developers (in the private or public sector) will not continue to develop land independent of the demand for that development. For example, if the market anticipates that 1,000 new households will be coming to the region, it will supply 1,000 new units of housing. Once those units are supplied the market will not then add another 1,000 units. This is unaffected by the density at which the 1,000 are supplied. Thus, the open space remains undeveloped simply by virtue of the fact that the higher density development alleviates the need for the development of additional land. If, on the other hand forecasts are incorrect and an additional 500 units of housing comes to the region, then we are left with the original question, "What is the best way to accommodate this growth?"

The second problem with *linking* open space preservation requirements to higher density development is that it can create unintended consequences that may harm water quality. For example, there are two ways to link open space preservation to higher density development: require the developer to provide the open space offsets of some type, or use public tools such as downzoning or open space purchases to achieve preservation while increasing densities elsewhere. Either approach adds a barrier for the developer who wants to build higher density development. The "high-density" developer would be faced with the additional time and cost of complying with these rules while the "low-density" developer would have no such barrier or cost. In essence, either strategy puts an extra burden on the development product that is, by itself, more protective of water quality. Water quality professionals are not in the business of making developments easier for developers to build. However, by tilting the playing field towards "low density" developers, it is likely that more low density projects will be built, thereby further consuming absorbent open space, increasing transportation-related impervious cover, and overall, increasing the footprint of a region. As a result, in an attempt to guarantee water quality benefits by linking open space preservation to higher density development we actually hasten water quality declines. One could argue that it is more important is the role of open-space offsets in low-density zoning environments. Given that low-density development drives subsequent development further into undisturbed land, it would appear more important to attach offset requirements to low-density zoning than to the land-conserving approach of compact development.

The question underlying this issue is how can communities determine where to develop and where to preserve? In all development scenarios, ensuring adequate open space for water quality, flooding mitigation, sports and recreation, habitat, and biodiversity is a critical part of the planning process. Hydrologically speaking, it is generally accepted that more open space is needed, and specifically removal of development from flood plains. Not all land has equal ecological value and it is critical for local governments to determine where the critical ecological systems exist within their region and to take steps to preserve these areas. Once this process of determining how to minimize new development and maximize retention and reclamation of open space, a community will perhaps have in place a significant network of green infrastructure.[45]

In addition, open space preservation specialists argue that for an open space plan to be effective, preserved parcels must be large enough to serve a critical environmental function and, if possible, connected. By requiring any development to have an open space offset, a community has the potential of creating a hodge podge of spaces that may or may not have significant environmental value. In addition, open space offsets, in the worse case scenario, cause leapfrog development. What some communities have done to address the issue of preserving open space in the face of mounting development pressures is to require all new developments, high and low densities, to pay a fee into a general fund. The local government then uses these funds to acquire or purchase the lands they have identified as having high environmental, economic, or social value.

5. Do infill sites (such as brownfields and greyfields) represent a particular opportunity?

This paper has demonstrated that compact development produces less stormwater runoff on a per-unit basis than does low-density dispersed development. Communities can enjoy a further reduction in runoff if they take advantage of underutilized properties, such as infill, brownfield, or greyfield[46] sites. For example, an abandoned shopping center (a greyfield property) is often almost completely impervious cover, and is already producing high volumes of runoff. If this property is redeveloped, the net runoff increase will likely be zero since the property was already predominately impervious cover. In many cases, redevelopment of these properties will break up or remove some portion of the impervious cover, converting it to pervious cover and allowing for some stormwater infiltration. In this case, redevelopment of these properties can produce a net improvement in regional water quality by decreasing total average annual . Exhibit 11 illustrates this opportunity.

[45] For more information on the environmental and ecological benefits of preserving open space, please see Trust for Public Land's " Economic Benefits of Preserving Open Space;" and "Local Greenprinting for Growth: Using Land Conservation to Guide Growth and Preserve the Character of Our Communities."

[46] Greyfield sites generally refer to abandoned or underutilized shopping malls, strip malls, or other areas that have significant paved surface and little or no contamination (in order to distinguish it from brownfield sites). For more information on greyfield sites and the potential for redevelopment, please see Urban Land Institute's publication, "Turning Greyfields into Goldfields."

Exhibit 10: Redevelopment of a Greyfield Property

Before Redevelopment

After Redevelopment

Utilization of brownfield and greyfield sites can reduce regional land consumption and ensure accommodation of projected growth thus decreasing its environmental impact. A recent George Washington University study found that for every brownfield acre that is redeveloped, 4.5 acres of open space are preserved.[47] In addition to redeveloping brownfield sites, regions can identify underutilized proprieties or land, such as infill or greyfield sites, and target those areas for redevelopment. For example, a recent analysis completed by King County, Washington demonstrated that property that is vacant and eligible for redevelopment in the county's growth areas can accommodate 263,000 new housing units—enough for 500,000 people.[48] Redeveloping this property represents an opportunity to accommodate new growth without degrading water quality. As discussed, much of the abandoned properties in areas are already close to 100 percent impervious cover. By taking advantage of these properties, a community experiences the benefits of growth without the costs of water quality degradation. Finally, in addition to water quality benefits, if these properties are developed at higher densities, a local government can ensure that more people are accommodated in areas with existing infrastructure, housing choices, and transportation choices.

6. What about localized hot spots?

One of the largest benefits about developing at higher densities are the other community opportunities that become more viable because of more people living in closer proximity to each other. For example, bus transit becomes viable at 7 units an acre, while light rail and subway become viable at 15-20 units an acre.[49] Mixed use, such as first floor retail, becomes viable only at higher densities. And, community walkability and livability increase dramatically as densities increase.[50] Increasing densities on a regional scale is more

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[47] Deason, Jonathan, *et al*. "Public Policies and Private Decisions Affecting the Redevelopment of Brownfields: An Analysis of Critical Factors, Relative Weights and Area Differentials." Prepared for US EPA Office of Solid Waste and Emergency Response. The George Washington University, Washington, DC. September, 2001. Available at www.gwu.edu/~eem/Brownfields/project_report/report.htm.
[48] Pryne, Eric. "20 Years' Worth of County Land?" Seattle Times, Monday, May 20, 2002.
[49] Ewing, Reid. "Pedestrian and Transit-Friendly Design: A Primer for Smart Growth. ICMA: Washington, DC. 1999.
[50] For more information on the other benefits of density, please see, ICMA's publication, "Getting to Smart Growth: 100 Policies for Implementation;" www.smartgrowth.org; and www.smartgrowthamerica.org.

protective of water quality, overall, but has the potential to create localized hot spots that affect proximate water bodies. EPA estimates that over 70 percent of urban water bodies are impaired. If a local community increases densities in their development patterns, while better for overall regional watershed health, there is a real potential to increase pollutant loadings in water bodies new or adjacent the new development. Of course, even with low-density development, creating hotspots is also a real potential, but because of the slightly higher runoff and pollution levels of the higher-density development patterns, as demonstrated, localized hot spots are a greater concern.

This paper suggests that the answer to this question is to protect pristine watersheds and overall watershed health through compact development and mitigate hot spots. There are two approaches for mitigating hotspots:

(1) Address increased pollutant loads at the site- and development-level, reducing the amount of runoff and associated pollutants entering the system through structural or non-structural best management practices, such as riparian buffer zones or conservation easements, or low-impact development; and

(2) Reduce the overall levels of "background" pollution, thereby allowing the streams and water bodies to absorb more pollution from localized hotspots while still maintaining water quality standards.

EPA and other organizations, such as the Center for Watershed Protection, have written extensively about numerous best management practices and low-impact development techniques that reduce site- or development-specific stormwater runoff and associated pollutants.[51] For example, low-impact development is increasingly recognized as one mechanism to reduce effective impervious cover and to allow natural features to serve their ecological functions. Some LID techniques include:

- Rain gardens and bioretention;
- Rooftop gardens or simple roof storage;
- Tree preservation and planting;
- Vegetated swales, buffers, and strips;
- Roof leader disconnection;
- Rain barrels and cisterns;
- Impervious surface reduction and disconnection;
- Soil amendments;
- Permeable pavers; and
- Pollution prevention and good housekeeping.[52]

The Center for Watershed Protection recently released a document that details 11 techniques for reducing water quality impacts from development. While this document, "Redevelopment Roundtable Consensus Document,"[53] is geared for urban infill redevelopment opportunities, many of the practices described, such as, "Design sites to maximize transportation choices in order to reduce pollution and air and water quality," can also be applied to high-density greenfield developments.

[51] See, for example, www.bmpdatabase.org and www.stormwatercenter..net.
[52] Woodworth, "Out of the Gutter."
[53] For more information on this document, please see http://www.cwp.org/pubs_download.htm.

Unlike reducing site-specific impacts that only require innovation and desire on the part of the developer, reducing background levels of pollution generally require some type of local government involvement. For example, stormwater management utilities provide an opportunity for the local government to address the most pressing stormwater problems. Residents, commercial, and industrial users of wastewater treatment plants pay into this fund, giving the localities the funds and flexibility to address the area's most severe problems. Other regional examples include:

- Variable sewer hookup fees, such as in Sacramento, California, which recently changed its hookup fees to vary by location and type of development. This results in developers having to pay almost twice as much to hook up sewer lines in fringe or edge areas as in urban areas.

- Maine charges "compensation fees" to residents and commercial entities for not meeting statewide phosphorus reduction requirements. These fees enable the state to address the increasing phosphorous problem at the source—either in locations with hot spots or at the waste water treatment facility.

- North Carolina has established density averaging of non-contiguous parcels, and density trading with buffer zones. The goal of this program is to encourage density in clusters, that is, encourage density without a net increase in watershed development density.

These and other regional policies are described in an EPA document, "*Protecting Water Resources with Smart Growth: 100 Policies*."[54] This report describes both site-specific and regional policies that local communities have put in place to address localized hotspot and associated water quality issues.

To demonstrate the importance of these principles in reducing site- and development-related hot spots, the *University of Oregon* conducted a study entitled: "Measuring Stormwater Impacts of Different Neighborhood Development Patterns."[55] The study site near Corvallis, Oregon, was created to compare stormwater management strategies in three common neighborhood development patterns.[56] For example, BMPs, such as disconnecting residential roofs and paving from the stormwater system, introducing swales and water detention ponds into the sewer system, and strategically locating open space had significant impacts on peak water runoff and infiltration. The study concludes that:

> "Some of the most effective opportunities for reducing stormwater runoff and decreasing peak flow are at the site scale and depend on strategic integration with other site planning and design decisions.
>
> "Reduced street networks of narrower streets and planting strips significantly reduce the amount of pavement and as a result, runoff, in urban areas. Best management practices such as swales, constructed wetlands and ponds integrated with urban streets and open space networks are also important to collect, clean, store and slow the flow of runoff. However, these facilities and their physical relationships must be planned early to be well orchestrated and effective."[57]

[54] This document will be ready for distribution by June 1, 2003.
[55] Study description and results on neighborhood.uoregon.edu/projects/research/owrri/owrri.html.
[56] The University of Oregon used the PCSWMM model developed by Computational Hydraulics, in Guelph, Ontario, Canada.
[57] http://neighborhood.uoregon.edu/projects/research/owrri/owrri_conclusion.html

7. Won't increasing densities create sacrifice zones?

In the mid-1990's advocates for the environment, affordable housing, farmland preservation, transportation reform, and community reinvestment started calling on communities to develop in new ways. Since then, citizens across the nation are demanding it -- in polls, in the market, and at the ballot box. Americans want fewer hours in traffic and more opportunities to enjoy green space; housing that is both affordable and close to jobs and activities; healthy cities, towns and suburbs; air and water of the highest quality; and a landscape our children can be proud to inherit. Increasing densities and determining where we should develop and where we should preserve offers the best chance of attaining those goals. Not only will our communities thrive economically and socially, but also environmentally. Increasing densities provides a mechanism for communities to accommodate growth, enjoy economic development and jobs in the most environmentally protective way possible.

WHAT HAS OTHER RESEARCH FOUND?

Current research suggests that compact development and/or redevelopment in existing areas will impact water quality less than scattered, low-density development. Several site-specific studies have been conducted across the country to predict the runoff and pollutant loading responses to changing land use. This section highlights five case studies that approach the research question with varying levels of complexity. Jordan Cove in Connecticut; Belle Hall in South Carolina; a statewide analysis of New Jersey; Chicago in Illinois; and an analysis done by the Chesapeake Bay Foundation each analyze the differences in runoff and associated water pollution from different types of development.

Researchers at *Jordan Cove*[58] development in Waterford, Connecticut are finding that, when compared to high-density design development, the large lot development, or low-density design, produces 95 more runoff during construction. Using monitoring data from two study sites and a control site, these paired sites will evaluate "Traditional" suburban development, "BMP" development, and the control subdivision. Early results from storm events during construction indicate that construction of the large lot neighborhood is causing significant impacts on runoff quality and quantity, including observed increase in mean weekly flow volume (99 percent), runoff frequency (from 16 to 95 percent), and mean weekly peak discharge (79 percent).

The Belle Hall study, completed by the South Carolina Coastal Conservation League (1995), examined the water quality impacts of two development alternatives for a 583-acre site in Mount Pleasant, South Carolina. In the "Sprawl Scenario," the property was analyzed as if developed along a conventional suburban pattern. The "Town Scenario," was analyzed if using the development incorporated traditional neighborhood patterns instead. In each scenario, the overall density and intensity (the number of residential unit, square feet of commercial and retail space, and so forth), was held constant, although the building types and sizes vary. The results found that "Sprawl Scenario" consumed 8 times more open space,

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[58] Cote, M.P., Clausen, J., Morton, B., Stacey, P., Zaremba. S. 2000. *Jordan Cove Urban Watershed National Monitoring Project*. Presented at the National Conference on Tools for Urban Water and Resource Management Protection, Chicago, IL. See also Engdahl, J. 1999. *Impacts of Residential Construction on Water Quality and Quantity in Connecticut*. University of Connecticut, Storrs, CT.
h2osparc.wq.ncsu.edu/96rept319/CT-96.html
www.epa.gov/owow/estuaries/coastlines/summer98/jordancove.html
www.canr.uconn.edu/jordancove/

generated 43 percent more runoff, 4 times more sediment, almost 4 times more nitrogen, and 3 times more phosphorous as compared to the "Town Scenario" development.[59]

New Jersey's State Plan calls for increasing densities in the state by directing development to existing communities and existing infrastructure ("Plan"). Researchers at Rutgers University analyzed the water quality impacts from "Trend" versus "Plan" development. The study found that compact development ("Plan" development) would generate significantly less water pollution than low-density development ("Trend" development) for all categories of pollutants.[60] The reductions ranged from over 40 percent for phosphorus and nitrogen to 10 percent for lead. The smaller impervious areas would produce 30 percent less runoff, and concentrating this development in areas served by sewers would reduce its impact on the environment by another 10 percent.[61] These conclusions supported a similar statewide study completed in 1992 that concluded that compact development would result in 30 percent less runoff and 40 percent less water pollution than would a sprawl scenario.[62]

Researchers at Purdue University examined two possible project sites in the Chicago, Illinois area.[63] The first site was in the urban core and currently consists of a mix of residential, industrial, and commercial properties. The second site was on the urban fringe. The results found that placing a hypothetical low-density development at the Chicago fringe area would produce 10 times more runoff than a higher-density mixed-use development located in the urban core.

Finally, a study published by the Chesapeake Bay Foundation in 1996 comparing conventional and clustered suburban development on a rural Virginia tract found that clustering would convert 75 less land, create 42 percent less impervious surface, and produce 41 percent less stormwater runoff.[64]

CONCLUSIONS

As metropolitan areas continue to grow in population, the area of the region's built environment will continue to expand. How and where this development occurs will have a profound impact on water quality. EPA believes that increasing densities of all developments can minimize water quality impacts from development. Nationwide, state and local governments are considering the environmental implications of development patterns. A growing body of research clearly documents that the creation of impervious cover causes a predictable and profound decline in critical elements of aquatic ecosystems.[65] Conventional low-density development and its attendant infrastructure consume previously undeveloped land and create stretches of impervious cover throughout a region. In turn, these land alterations are not only likely to degrade the quality of the individual watershed, but are also likely to degrade a larger number of watersheds.

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[59] South Carolina Coastal Conservation League, EPA, NOAA, SC Department of Health and Environment; Town of Mount Pleasant. 1995. *The Belle Hall Study: Sprawl vs. Traditional Town: Environmental Implications*. Dover, Kohl, and Partners, South Miami, FL.
[60] *Ibid.*
[61] University of Rutgers. 2000. The Costs and Benefits of Alternative Growth Patterns: The Impact Assessment of the New Jersey State Plan. Center for Urban Policy and Research.
[62] Pollard, Trip. "Greening the American Dream." Planning Magazine: American Planning Association, October 2001.
[63] Harbor, J., Engel, B., et al. "A Comparison of the Long-Term Hydrological Impacts of Urban Renewal versus Urban Sprawl." Purdue University: West Lafayette, IN. 2000.
[64] Pollard.
[65] See Arnold, Chester L. Jr., C. James Gibbons. See also EPA, Urbanization and Streams: Studies of Hydrological Impacts. Washington, DC: EPA Office of Water. 1997. EPA # 841-R-97-009.

Concentrating development in urban areas maintains the functions of smaller watersheds because at the regional or watershed scale, impervious cover is minimized and undisturbed open space is maximized. Further, development decisions can often affect transportation-related imperviousness across multiple watersheds. While a low-density scenario often subjects numerous watersheds to possible degradation, a compact scenario can limit the number of watersheds affected by development.[66] This review of the effects of different development densities on water quality suggests three conclusions:

1. Compact development is better good for water quality than less compact development. It minimizes the consumption of land needed to support critical watershed functions, which in turn minimizes the creation of impervious surfaces that lead to increased runoff, and associated pollutants. And intensifies activity in a smaller area – e.g., less motor traffic outside of cities.

2. There is no reason to expect that lower density development reduces total or even necessarily (depending on site design and building type) site-level runoff,[67] or are protective of watershed water quality. Rather, this paper and the literature suggest that, all else being equal, accommodating new growth through higher densities will likely be more protective than lower density development.

3. The denser development should be given preference, because its lower per-unit runoff minimizes the impact of a given increment of growth, and leaves more room for additional growth.

4. Regions can enjoy a substantial bonus from re-using existing brownfields, greyfields, and other sites that are already impervious. Building on these saves land elsewhere, can often accommodate higher densities, and can reduce flows from the developed parcel.

In sum, compact development is an environmental protection strategy, and should be included in any set of such strategies that are reviewed as part of a search for ways to protection water quality, whether at the local, state, or national level.

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[66] See review of several cases in US EPA, Development, Community and Environment Division, *Our Built and Natural Environments: A Technical Review of the Interactions between Land Use, Transportation, and Environmental Quality*, EPA #123-R-01-002, 2001. pp. 41-43.

[67] Keeping the number of housing units similar to a higher density development.

References

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

Arnold, C. L. and C. J. Gibbons. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association* 62(2) 243-258.

Association of Bay Area Governments. 2002. Smart Growth Strategy: Shaping the Future of the Nine-County Bay Area, *Alternatives Report*. See http://www.abag.ca.gov/planning/smartgrowth/AltsReport/SmartGrowthStrategy.pdf

Brown, Patricia Leigh, "The Chroming of the Front Yard," *New York Times*, June 13, 2002, p F1.

Cappiella, K. and Brown, K. 2001. *Impervious Cover and Land Use in the Chesapeake Bay Watershed.* Ellicott City. MD.

Center for Watershed Protection (CWP). 1998. *Rapid Watershed Planning Handbook—A Comprehensive Guide for Managing Urban Watersheds.* Ellicott City, MD.

Chesapeake Bay Foundation. 2001. State of the Bay Report. Annapolis, MD.

Cote, M.P., Clausen, J., Morton, B., Stacey, P., Zaremba. S. 2000. *Jordan Cove Urban Watershed National Monitoring Project.* Presented at the National Conference on Tools for Urban Water and Resource Management Protection, Chicago, IL.

Deason, Jonathan, *et al*. 2001. *Public Policies and Private Decisions Affecting the Redevelopment of Brownfields: An Analysis of Critical Factors, Relative Weights and Area Differentials.* Prepared for US EPA Office of Solid Waste and Emergency Response. The George Washington University, Washington, D.C.

Engdahl, J. 1999. *Impacts of Residential Construction on Water Quality and Quantity in Connecticut.* University of Connecticut, Storrs, CT.

Ewing, Reid. 1999. *Pedestrian and Transit-Friendly Design: A Primer for Smart Growth*. ICMA: Washington, D.C.

Krugman, Paul. 1991. *Geography and Trade*. MIT Press, Boston, MA.

Krugman, Paul . 1995. *Development, Geography, and Economic Theory*. MIT Press, Boston, MA.

Harbor, J., Engel, B., et al. 2000. *A Comparison of the Long-Term Hydrological Impacts of Urban Renewal versus Urban Sprawl.* Purdue University: West Lafayette, IN.

McGrath ,Daniel T. 2001. 2025 Urban Land Area Forecasts for the US Top 20 Coastal Metropolitan Regions. Great Cities Institute, unpublished, available at http://iisgcp.org/research/cbe/2025forecast.htm.

Metropolitan Council, Blueprint 2030. http://www.metrocouncil.org/planning/blueprint2030/overview.htm

Mills, Edwin, B. Hamilton. 1994. *Urban Economics: Fifth Edition*. Harper Collins College Publishers.

Montgomery County Department of Environmental Protection. 2000. *Stream Conditions Cumulative Impact Models for the Potomac Subregion*. MCDEP, MD.

National Association of Home Builders. 2001. Housing Facts, Figures, and Trends: 2001. NAHB: Washington, DC.

New Jersey Office of Planning. 2002. http://www.state.nj.us/osp/plan2/p2full/colors00.htm.

Orfield, Myron. 1997. *Metropolitics: A Regional Agenda for Community and Stability*. Brookings Institution Press, Washington, D.C.

Pollard, Trip. 2001. *Greening the American Dream*. Planning Magazine: American Planning Association.

Portland Metro, 2000. The Nature of 2040: The region's 50-year plan for managing growth." See http://www.metro-region.org/growth/tf/2040history.pdf.

Pryne, Eric. "20 Years' Worth of County Land?" Seattle Times, Monday, May 20, 2002.

Rein, Lisa and David Cho, "In Defense of the Front Lawn: Fairfax Attacks Crowding With Ban on Oversize Driveways," *Washington Post*, June 4, 2002, p. A1.

Schueler, T. 1994. The Importance of Imperviousness. *Watershed Protection Techniques* 1(3): 100-111.

Schueler, T. 2000. The Compaction of Urban Soil. *Techniques for Watershed Protection.* Center for Watershed Protection, Ellicott City, MD.

Soil Conservation Service. 1986. Technical Release No. 55 (TR-55). *Urban Hydrology for Small Watersheds.* Washington, DC.

South Carolina Coastal Conservation League, EPA, NOAA, SC Department of Health and Environment; Town of Mount Pleasant. 1995. *The Belle Hall Study: Sprawl vs. Traditional Town: Environmental Implications*. Dover, Kohl, and Partners, South Miami, FL.

Trust for Public Land and the National Association of Counties. 2002. *Volume 1: Local Greenprinting for Growth: Using Land Conservation to Guide Growth and Preserve the Character of Our Communities.*

University of Rutgers. 2000. The Costs and Benefits of Alternative Growth Patterns: The Impact Assessment of the New Jersey State Plan. Center for Urban Policy and Research.

U.S. Census. 2000. *Annual Projections of the Total Resident Population as of July 1: Middle, Lowest, Highest, and Zero International Migration Series, 1999 to 2100.* Washington, D.C.

U.S. Congress, Office of Technology Assessment. 1995. *The Technological Reshaping of Metropolitan America*. Washington, D.C., 1 OTA-ETI-643.

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

U.S. Environmental Protection Agency. 1997. *Urbanization and Streams: Studies of Hydrological Impacts*. Washington, DC: EPA Office of Water. EPA # 841-R-97-009.

U.S. Environmental Protection Agency (USEPA). 2000a. *National Water Quality Inventory: 1998 Report to Congress*. www.epa.gov/305b/98report. Last updated October 5, 2000.

U. S. Environmental Protection Agency, Office of Water. June 2000b. *Water Quality Conditions in the United States: A Profile from the 1998 National Water Quality Inventory Report to Congress.* Washington, DC. EPA841-F-00-006 (also available at www.epa.gov/OWOW/305b/).

Woodworth, James et al. 2002. *Out of the Gutter: Reducing Polluted Runoff in the District of Columbia*. NRDC: Washington, DC.