

URBAN STREA

The Relationship Between Population Density and Impervious Surfaces

BY JENNIFER BROPHY-PRICE

THE EFFECTS OF DEVELOPMENT ON WATER QUALITY have been well-documented. For example, between 1994 and 2006, research from Schueler¹, Arnold², and Cianfrani³ independently concluded that changes in land use can play a major role in altering hydrology and pollutant loads. These effects can be controlled, however, and many levels of government have already taken steps or are looking at ways to legislate stormwater management to control what happens to runoff and the bodies of water that runoff enters. Surprisingly, though, another source for mitigation that should be considered in the discussion is density.



A stream next to a townhouse community exhibits urban stream syndrome from lack of stormwater controls.

M SYNDROME



The Research

Research shows that, unless properly managed, increased runoff from impervious surfaces, such as roads, sidewalks, parking lots and rooftops, is a key contributor to degraded water quality, stream channel degradation, polluted water, eutrophication and a host of other impairments. These impairments have been collectively called the “urban stream syndrome,” though despite the name, this syndrome is not limited to cities. In fact, Schueler notes that it can be seen in streams whose watersheds have as little as 10 percent impervious coverage.⁴ By comparison, a typical 2-acre, single-family house lot boasts an average of 10 percent impervious coverage.

The impact of impervious surfaces on downstream waterways can be mitigated with proper stormwater management. However, the consistent observation of urban stream syndrome from development with poorly managed stormwater systems has led many jurisdictions to introduce rules aimed at reducing the effects of the built environment on these waterways. These rules often cover stormwater management, outline best management practices and provide stream corridor protections. It turns out, however, that population density may also play a role in mitigating society’s damaging effects on streams.

Why Density Matters

Impervious surfaces increase in tandem with population density. People need places to live, work and play, and those places typically require roofs, roads, parking lots and other forms of hardscape. It is readily apparent when driving from rural western Maryland or Virginia to downtown Washington, D.C., for example, that developed areas boast a lot more hardscape than rural areas. Because impervious surfaces are a key contributor to urban stream syndrome, it is easy to assume that lower-density development encourages healthier streams. That assumption, unfortunately, is a gross oversimplification of a complex process.

One piece of this puzzle has to do with the relationship between population density growth and impervious cover growth, a relationship that is not linear. As population density grows, the rate of increase in impervious cover tends to slow down. In other words, individually, city-dwellers require less impervious cover than their rural counterparts. Therefore, if we assume that the same stormwater management techniques are in place in both scenarios, each city-dweller contributes less toward urban stream syndrome than his or her rural counterpart.

One simplified way to view the relationship is to look at it in terms of housing. The U.S. Census Bureau provides information on the average number of inhabitants in each dwelling type. This is seen in Table 1 and Chart 1.

Additionally, the Virginia Department of Conservation and Recreation's Chesapeake Bay Local Assistance Manual (1989) provides estimates of the percentage of impervious area per lot for various housing development types (from 5-acre lots to garden apartments⁵). These values can be combined with the aver-

Table 1. Average Housing Occupancy

Housing Type	People per Unit
Single-Family Homes	2.59
Townhomes	2.44
Condos/Apartments	1.73

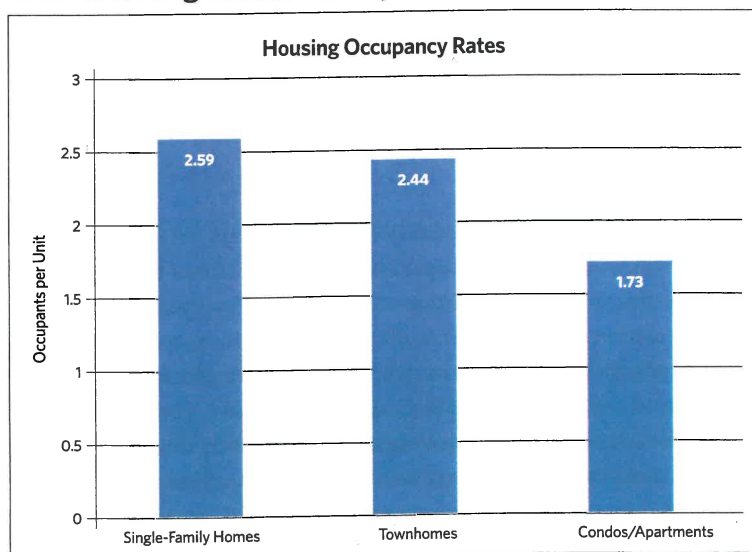
Source: www.census.gov

age number of units per lot to calculate the average impervious area per housing unit, as shown in Table 2. Note that—as lot size decreases—the percentage of impervious area per lot increases but the total impervious *acreage per housing unit* decreases. In other words, smaller lots generally hold smaller houses and have less room for driveways and parking areas, but those impervious surfaces take up more of the lot's available space because the lot itself is also smaller.

When the impervious area per unit derived in Table 2 is divided by the number of people living in each unit specified by the U.S. Census in Table 1, the results show that apartment and townhouse dwellers have a much smaller individual impervious footprint than their single-family counterparts, as shown in Table 3 and Chart 3 (pages 14 and 15). Additionally, as lot size decreases, so does each person's individual impervious footprint.

Although the analysis presented here focuses solely on housing, the trend likely carries over to other sources of imperviousness. Venues such as retail stores, restaurants and offices, especially those in high-rise buildings, tend to service more people per impervious square foot than their rural counterparts. Similarly, urban centers tend to boast more underground and multi-story aboveground parking than rural communities, which tend to rely on surface parking lots. Each of these factors contributes to a smaller individual impervious area for urban inhabitants than for rural inhabitants.

Chart 1. Average Individual Impervious Area



Looking at Results More Deeply

To gain a closer understanding of the complexities of the urban stream syndrome puzzle next requires differentiating between *individual*, *local* and *cumulative* impacts. The individual impervious footprint, as described above, is the average impervious area each person requires; this tends to decrease with increased density. At the next level is the local impervious footprint, which can be viewed as the impervious footprint of a specific area on a relatively small scale. For instance, the footprint of a city or town could be specified as a local impervious footprint. The cumulative impervious footprint is the footprint of a larger segment of society. For example, we might talk about the cumulative impervious footprint of the Chesapeake Bay watershed. Along this line, local hydrologic impacts are felt by local rivers or tributaries immediately downstream of a city or town, while cumulative



Table 2. Average Imperviousness by Housing Development Type

Housing Development Type	Lot Size (acre-ac) (a)	IA per Lot (%) [*] (b)	Units per Lot (c)	IA per Unit (ac/unit) (d = a x b / c)
5.0 ac residential	5.0	5%	1	0.25
2.0 ac residential	2.0	10%	1	0.20
1.0 ac residential	1.0	15%	1	0.15
0.5 ac residential	0.5	20%	1	0.10
0.33 ac residential	0.33	25%	1	0.083
0.25 ac residential	0.25	30%	1	0.075
Townhouses	1.0	40%**	8	0.05
Garden Apartments	1.0	53%**	20	0.027

^{*} Virginia Department of Conservation and Recreation's Chesapeake Bay Local Assistance Manual (LAM), 1989, Table 1.

^{**} Average value of the range presented in LAM (1989) Table 1.

hydrologic impacts are felt by an ultimate receiving water such as the Chesapeake Bay.

With this in mind, it's easy to see that the local impervious footprint increases as development becomes more dense. This means that the urban center itself has a high degree of local hydrologic impacts when the stormwater is not properly managed. To mitigate requires increased population density combined with effective stormwater management to lessen the impact to local waterways. However, because *individual* impervious footprints decrease with increased density, society's *cumulative* impervious footprint is also reduced, which reduces the cumulative impact to major receiving waters.

In the example in Figure 1 on this page, 100 people live on 5-acre residential lots, averaging 2.59 people per lot (as seen in the left-hand scenario). Their individual impervious footprint (from Table 3, next page) is approximately 0.097 acres per person, and the cumulative impervious footprint is 9.70 acres [0.097 acres/person times 100 people]. If we then define a potential 5-acre watershed (in the bottom right-hand corner of Figure 1), we can see that the local impervious footprint of that watershed is 0.251 acres [0.097 acres/person times 2.59 people/lot times 1 lot]. If we increase the density by clustering the development in garden apartments at 20 units per acre in our 5-acre potential watershed (as seen in the right-hand scenario in Figure 1), the individual footprint decreases from 0.097 acres per person to 0.015 acres per person (see

Table 3, next page); the local impervious footprint increases from 0.251 acres to 1.5 acres [0.015 acres/person times 100 people]; and the cumulative impervious footprint decreases from 9.70 acres to 1.5 acres [0.015 acres/person times 100 people].

As briefly mentioned, the effect of impervious surfaces on receiving waters can be mitigated through an effective stormwater management program, which includes best management practices that reduce the peak flow, velocity, volume and duration of runoff. These practices may include retention, infiltration

Figure 1. Theoretical Impacts of Density

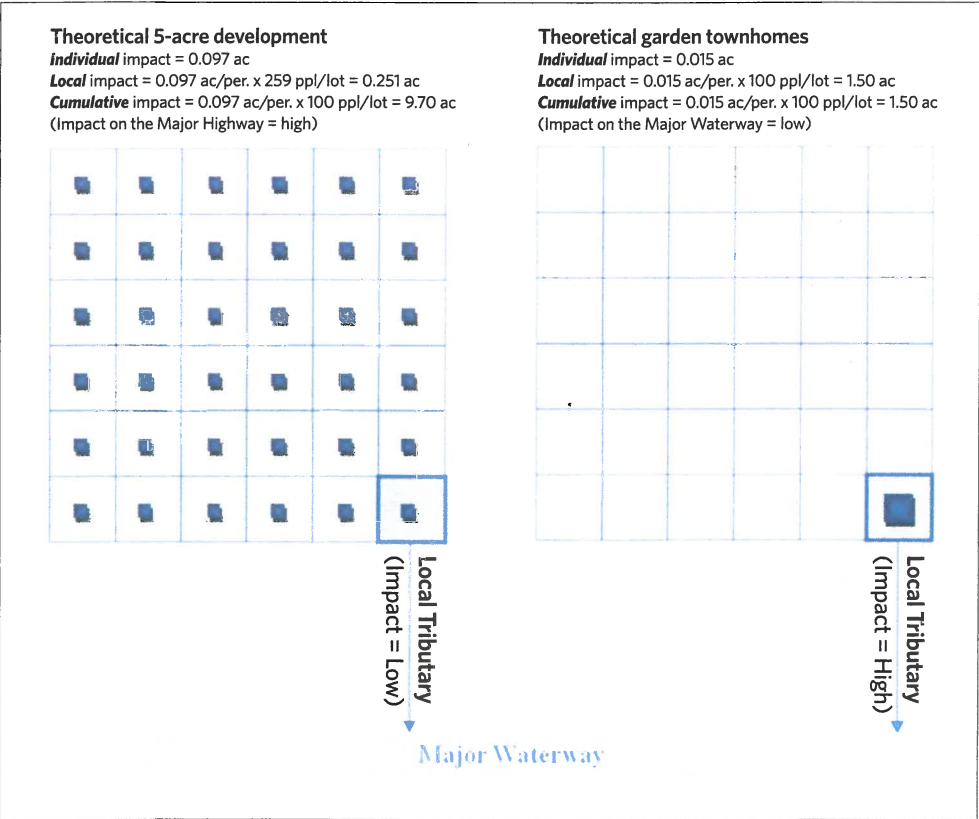


Table 3. Average Per-Capita Impervious Area (IA)

Development Type	IA per Unit (ac/unit)* (a)	People per Unit** (b)	IA per Capita (ac/person) (c = a / b)
5.0 ac residential	0.25	2.59	0.097
2.0 ac residential	0.20		0.077
1.0 ac residential	0.15		0.058
0.5 ac residential	0.10		0.037
0.33 ac residential	0.083		0.032
0.25 ac residential	0.075		0.029
Townhouses	0.05	2.44	0.020
Garden Apartments	0.027	1.73	0.015

* See Table 1 ** See Table 2.

tion, and water harvesting and reuse, among others. To maintain local stream health, the practices should be applied close to the source, and they must also be tailored to the development type. For instance, bioretention cells (often referred to as rain gardens) incorporate stormwater management into landscaping features. Bioretention cells require enough surface area to capture runoff at the ground surface and allow it to pond a few inches deep; therefore, such cells might be suitable for single-family house lots with lawns, but they may require too much open space to be successful in dense apartment or townhouse developments.

In dense developments, techniques such as pervious pavement (coupled with underground detention) can do double duty by incorporating stormwater management capacity into needed parking spaces, alleys or sidewalks rather than monopolizing valuable open space or buildable space. Therefore, such techniques protect local waterways without inadvertently encouraging sprawling development.

Regulatory entities at all levels—from the U.S. Environmental Protection Agency to states and local jurisdictions—are beginning to encourage these types of best management practices, which fall under the monikers of environmental site design,

low-impact development and green infrastructure. These stormwater management rules need to be flexible enough, however, to work within the physical, economic and aesthetic constraints imposed by various development types. Overly rigid rules can result in ineffective stormwater management or unintended sprawl, both of which can be detrimental to downstream waterways. The rules must contain the flexibility to protect waterways while actually allowing growth in dense urban centers; rigid rules, on the other hand, often require techniques that require valuable land surface that could be used to increase density.

Conclusion

What is the bottom line in the comparison of development density to stream health? Urban stream syndrome is a systemic problem at nearly all levels of development, and society contributes to the problem because of the impervious surfaces people rely upon for living, working and playing.

Chart 2. Average Imperviousness by Housing Development Type

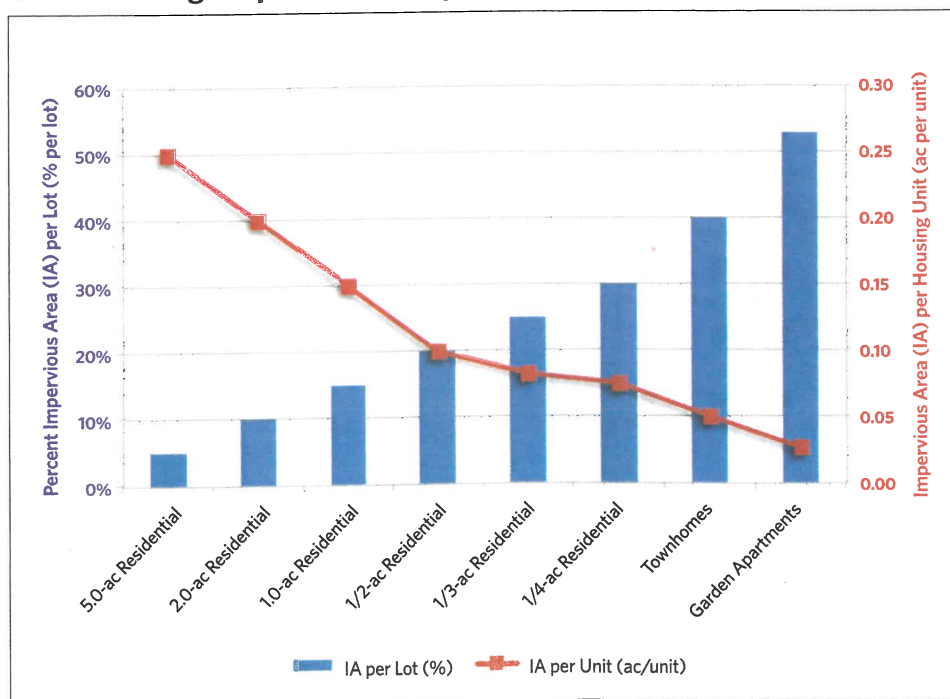
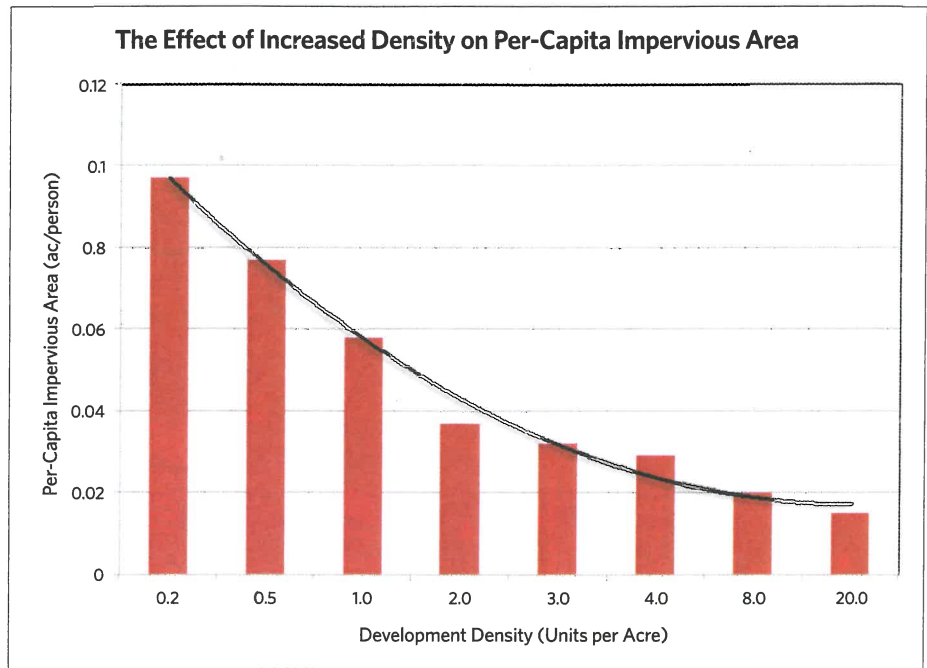




Chart 3. Average Per-Capita Impervious Area



Dense urban development has the potential to reduce society's individual and cumulative impervious footprints, which reduces the cumulative impact to major waterways.

However, densification does increase society's local impervious footprint, which in turn increases the negative impact on local waterways and tributaries. This impact can be fought through effective stormwater best management practices, which reduce stormwater runoff volume and velocity before it enters local streams.

Not all stormwater best management practices are cost-effective for dense urban development, however, so jurisdictions must keep the rules flexible enough that designers can effectively manage stormwater within the economic, physical and aesthetic constraints of urban development. Managing stormwater in high-density developments is challenging, and rigid rules may unintentionally create sprawl, which also negates the intrinsic benefit of densification.

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ENDNOTES

¹ Schueler, T. R. 1994. The Importance of Imperviousness. *Watershed Protection Techniques*, 1,3: 100 – 111.

² Arnold Jr., Chester L. and Gibbons, C. James. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association*, 62: 2, 243 – 258.

³ Cianfrani, Christina M., Hession, W. Cully and Rizzo, Donna M. 2006. Watershed Imperviousness Impacts on Stream Channel Condition in Southeastern Pennsylvania. *Journal of the American Water Resources Association*, August 2006: 941 – 956.

⁴ Schueler, T. R. 1994. The Importance of Imperviousness. *Watershed Protection Techniques*, 1,3: 100 – 111.

⁵ Impervious area information was not available from the U.S. Census Bureau. Maryland's Critical Areas Commission provides maximum allowable impervious area per lot but not existing average impervious area by development type. Therefore, this analysis uses information from Virginia's Department of Conservation and Recreation.



Bioretention is an effective stormwater management practice. In this picture, for example, the water from the parking lot flows into a landscaped depression and is filtered through soil media. Also, the pavement in the foreground is pervious concrete, which allows water to drain through the surface into a gravel substrate, where it is detained and filtered.