AN ANALYSIS OF THE EFFECTS OF DEVELOPMENT DENSITY ON IMPERVIOUS AREA CONTRIBUTIONS IN URBAN WATERSHEDS

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INTRODUCTION

A number of research efforts have detailed the effects of development on urban watersheds (Arnold, 1996[1]; Cianfrani, 2006[2]; Schueler, 1994[3]), concluding that changes in land use associated with development activities play a major role in altering the hydrology and pollutant loadings from urbanizing watersheds. Significant sediment contributions in urban watersheds can be attributed to high in-stream erosion rates associated with increased runoff from impervious surfaces (Arnold, 1996). Impervious surfaces (i.e. roads, sidewalks, parking lots, and rooftops) in urban watersheds in Northern Virginia and throughout the Chesapeake Bay Watershed are a major contributor to degraded water quality through the transport of sediment-bound pollutants. Watershed management and land planning techniques focused on minimizing impervious areas are critically important in improving water quality and the health of the Chesapeake Bay.

EXECUTIVE SUMMARY

Impervious cover is a critical variable in determining the influence of development on the hydrologic regime and pollutant sources in urban watersheds (Schueler, 1994). This paper derives a relationship for impervious area contribution based on the relative density of development. Land use data presented in the Virginia Department of Conservation and Recreation Chesapeake Bay Local Assistance Department *Local Assistance Manual* (1989) were adapted to show the reduced impervious area contributions associated with higher density development. This analysis shows that by maximizing density, subject to market demand-based limitations, significant strides can be made in reducing the impact of development on our water resources.

METHODOLOGY

An analysis of the effect of development type on impervious area contribution was derived from information given in *Table 1. Annual Storm Phosphorous Export* as seen on page C-10 of the Virginia Department of Conservation and Recreation Chesapeake Bay Local Assistance Department *Local Assistance Manual* (LAM, 1989 – See Appendix A). The following steps were performed to calculate the impervious contribution per dwelling unit from the various densities given in LAM Table 1:

1) Dwelling unit (DU) density was calculated by dividing the number of houses or dwellings by the lot area.

   Example for 5.0 ac residential lots: $1\ house / 5\ ac = 0.2\ DU / ac$

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[1] 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.
[2] 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.
[3] Schueler, T. R. 1994. The Importance of Imperviousness. *Watershed Protection Techniques*, 1,3: 100 – 111.

Land Use	Dwelling Units	Lot Size (ac)	Dwelling Unit Density (DU/ac)
5.0 ac residential lots	1	5.0	0.2
2.0 ac residential lots	1	2.0	0.5
1.0 ac residential lots	1	1.0	1.0
0.5 ac residential lots	1	0.5	2.0
0.33 ac residential lots	1	0.33	3.0
0.25 ac residential lots	1	0.25	4.0
Townhouses*	8	1.0	8.0
Garden Apartments*	20	1.0	20.0

*Dwelling unit densities for townhouses and apartments were set at 8.0 DU/ac and 20.0 DU/ac, respectively, representing a moderate density within the range of common industry values.

Table 1. Calculation of Dwelling Unit Density.

2) The impervious contribution of each dwelling was calculated by multiplying the lot area by the percent impervious cover. This impervious area was then divided by the number of dwelling units per lot (dwelling units from column 2 above).

Example for Townhouses: $\frac{(1.0\ ac \times 0.40)}{8\ dwellings} = 0.05\ \frac{ac}{DU}$

Land Use	Lot Size (ac)	Impervious Cover (dec)	Dwelling Units	Impervious Area per Dwelling Unit (ac/DU)
5.0 ac residential lots	5.0	0.05	1	0.25
2.0 ac residential lots	2.0	0.10	1	0.2
1.0 ac residential lots	1.0	0.15	1	0.15
0.5 ac residential lots	0.5	0.20	1	0.1
0.33 ac residential lots	0.33	0.25	1	0.083
0.25 ac residential lots	0.25	0.30	1	0.075
Townhouses	1.0	0.40**	8	0.05
Garden Apartments	1.0	0.53**	20	0.026

** Impervious cover for townhouses and garden apartments was taken as the average value of the range presented in *LAM Table 1 (1989)*.

Table 2. Calculation of Impervious Area per Dwelling Unit.

Figure 1, below, was created by plotting the Dwelling Unit Density from Table 1 (on the x-axis) against the Impervious Area per Dwelling Unit from Table 2 (on the y-axis). This figure shows the rapid decrease in impervious area per dwelling unit as development density increases. This indicates that high-density development such as townhomes and apartments, though typically more than 40% imperviousness, effectively limit impervious area contributions in urban watersheds when compared with lower-density developments (such as single family homes).

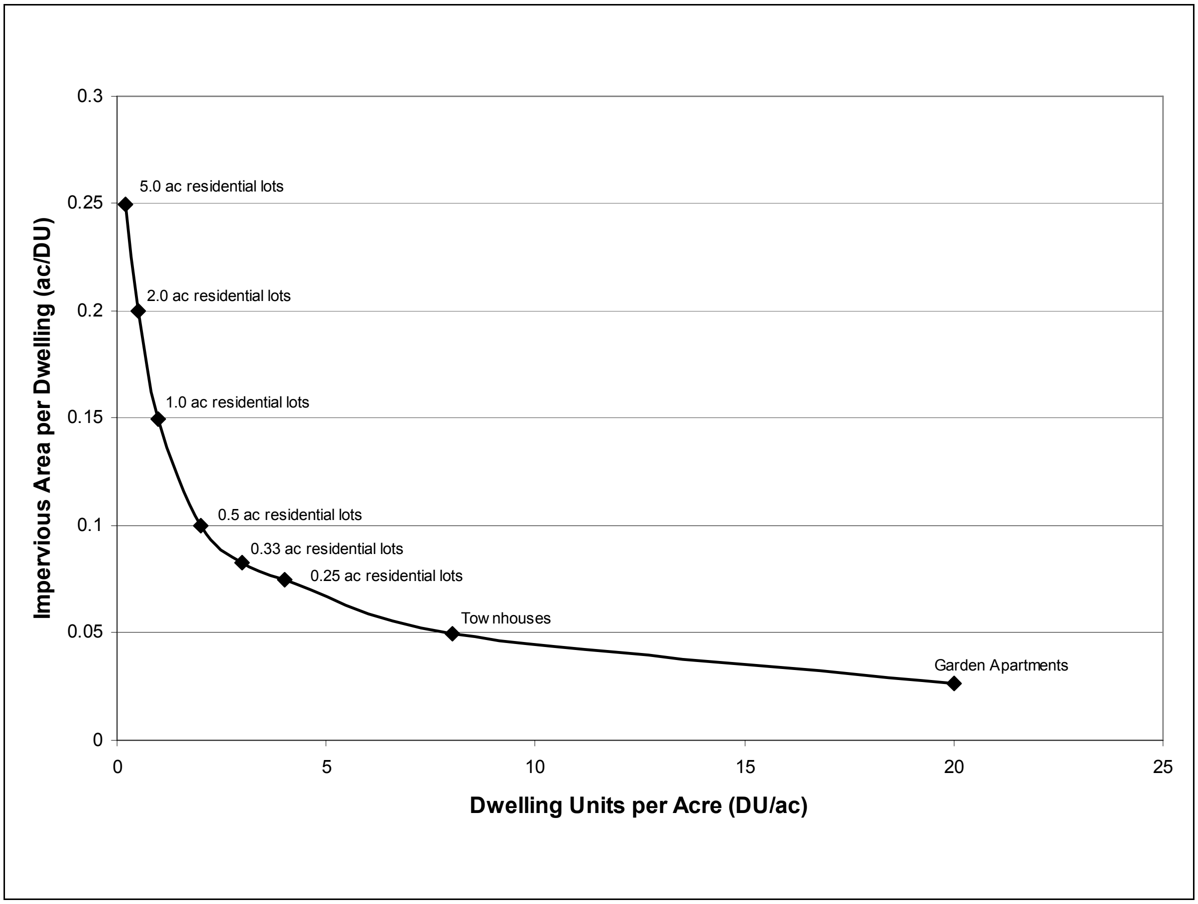

Figure 1. Effect of Development Type on Impervious Area Contribution.

3) The effects of development density on impervious area contributions were also quantified on a per capita basis. U.S Census Bureau Census 2000[4] data for the average number of persons per household for each development type in the Chesapeake Bay Watershed are given in Table 3.

Development Type	No. of Units	People/Unit
Single Family Homes	3,655,682	2.59
Townhomes	955,443	2.44
Condos/Apartments	1,599,460	1.73

Table 3. U.S Census Bureau, Census 2000 – Chesapeake Bay Watershed Household Summary.

Dividing the Impervious Area per Dwelling Unit from Table 2 by the number of people per unit from Table 3 yields a relationship of per capita impervious area contribution. (See Table 4, below.)

$$\text{Example for Townhouses: } \frac{0.05\,\frac{ac}{DU}}{2.44\,\frac{people}{DU}} = 0.02\,\frac{ac}{person}$$

[4] Available online at - http://www.census.gov/Press-Release/www/2002/sumfile3.html

Land Use	Impervious Area per Dwelling Unit (ac/DU)	People per Unit (people/DU)	Impervious Area per Person (ac/person)
5.0 ac residential lots	0.25	2.59	0.097
2.0 ac residential lots	0.2	2.59	0.077
1.0 ac residential lots	0.15	2.59	0.058
0.5 ac residential lots	0.1	2.59	0.037
0.33 ac residential lots	0.083	2.59	0.032
0.25 ac residential lots	0.075	2.59	0.029
Townhouses	0.05	2.44	0.020
Garden Apartments	0.026	1.73	0.015

Table 4. Calculation of Per Capita Impervious Area.

Figure 2, below, shows the per capita impervious contribution for each development type. Note that the relationship seen in Figure 2 is much like that seen in Figure 1, with the exception that the difference in impervious area contribution between townhomes and garden apartments is diminished in the per capita relationship. (This is due to the significant difference in people per unit between the two development types.)

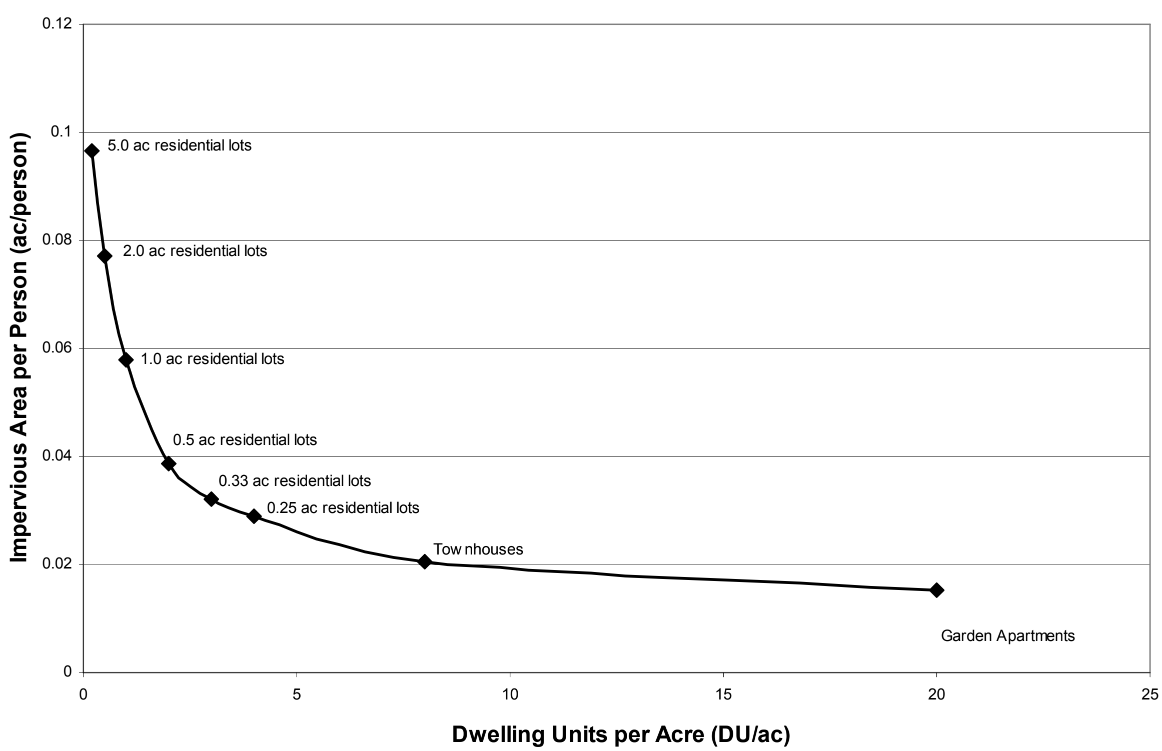

Figure 2. Effect of Development Type on Per Capita Impervious Area Contribution.

POLICY IMPLICATIONS

As described in a Wetland Studies and Solutions, Inc. report titled, "An Analysis of Impervious Area Increase vs. Population Growth in the Chesapeake Bay Watershed Between 1990 and 2000," dated February 23, 2010, impervious area has grown faster than population in the Chesapeake Bay Watershed, (and therefore, the number of people per impervious acre has decreased). Table 5 and Figure 3 below show this trend on a People per Impervious Acre basis.

	Chesapeake Bay Watershed	DE	DC	MD	NY	PA	VA	WV
1985	21.03	18.73	36.42	22.48	24.58	18.18	20.36	23.95
2002	20.14	16.55	31.74	21.73	23.06	16.69	20.38	22.80
2008	19.22	15.44	31.17	20.51	21.97	15.98	19.54	23.14

Table 5. Number of People per Impervious Acre.

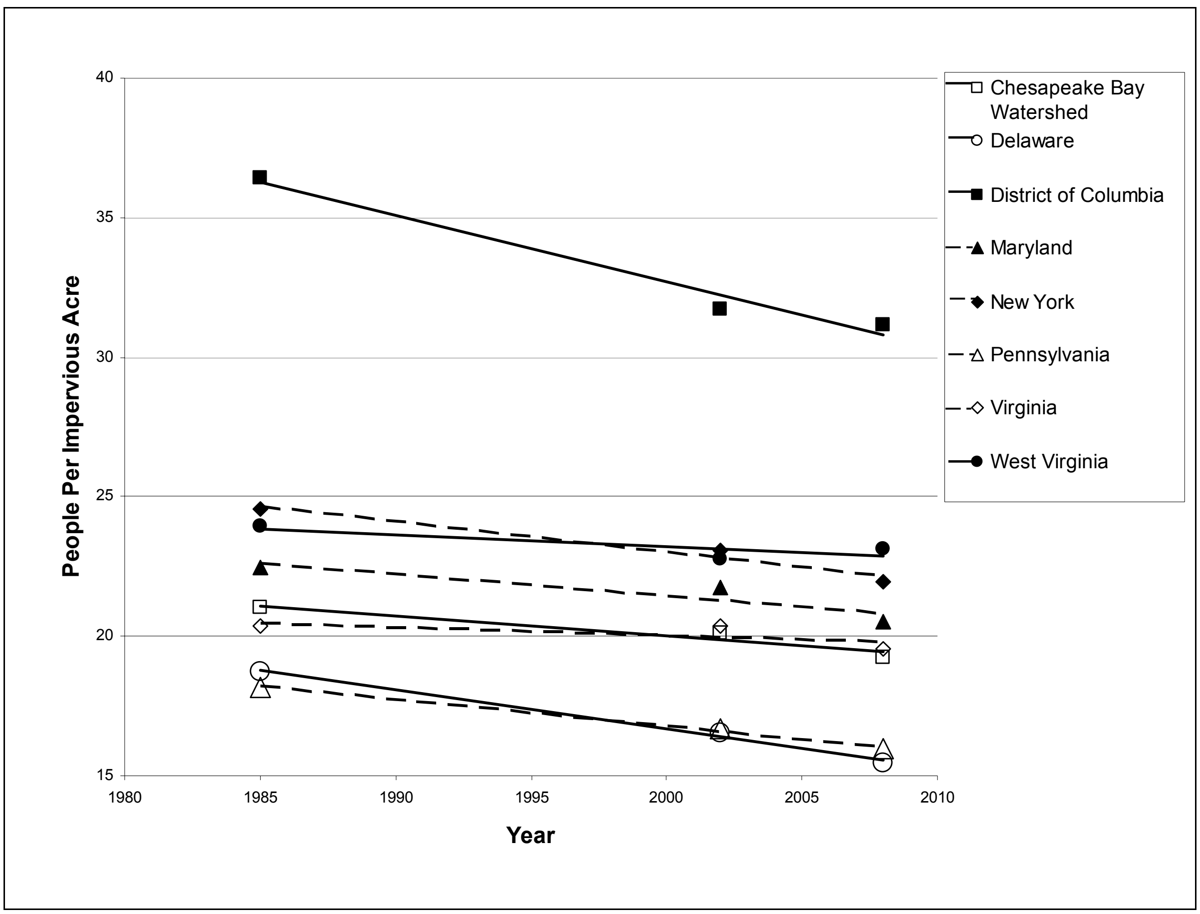

Figure 3. Number of People per Impervious Acre with Linear Regression.

These trends above demonstrate that, as expected, a higher-density city (such as Washington, D.C.) has more people per impervious acre than lower-density jurisdictions, and thus, these residents contribute less (per person) to the stormwater runoff problem than residents of lower-density jurisdictions. These trends could be reversed, thereby decreasing the per-person stormwater runoff problem, by obtaining higher-density development patterns. Since local land use policies have focused, to a large degree, on limiting density, market-based demand could be utilized to reverse this trend if regulatory barriers are removed.

CONCLUSION

When analyzing the relationship of development density and impervious area, the advantages of high-density development are immediately apparent. As shown in Figure 1, the impervious area contribution from single-family homes on half-acre lots is half that of homes built on 2.0-acre lots. Similarly, townhomes and apartments create only one-forth of the impervious area of single-family homes on half-acre lots.

Intuitively, it would seem reasonable that larger lot sizes and single-family homes might hold an advantage over high-density development when analyzed on a per capita basis because more family members can fit in a larger single-family home than in a townhouse. However, U.S. Census Bureau Census 2000 data shows a difference of only 0.15 members per household between single family homes and townhouses. Apartments have a slightly lower occupancy rate of 1.73 persons, which does slightly increase the impervious area contribution for apartments when considered on a per capita basis. However, the trend shown in Figure 1 is maintained in Figure 2, indicating that the ability to fit more people in a home does not necessarily equate to a smaller impervious footprint per person.

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Appendix A

ANNUAL STORM PHOSPHOROUS EXPORT **TABLE 1**

LAND USES	IMPERVIOUS COVER (%)
	0
5.0 acre residential lots	5
2.0 acre residential lots	10
1.0 acre residential lots	15
	16
	17
	18
	19
0.50 acre residential lots	20
0.33 acre residential lots	25
0.25 acre residential lots	30
Townhouses	35
	40
	45
Garden Apartments	50
	55
	60
Light Commercial/Industrial	65
	70
	75
	80
Heavy Commercial/Industrial	85
	90
	95
Asphalt/Pavement	100

Appendix A. Excerpt taken from page C-10 of the Virginia Department of Conservation and Recreation Chesapeake Bay Local Assistance Department *Local Assistance Manual*.