Jim Charlier

Watersheds, Walkability, and Stormwater

The role of density BY JOHN S. JACOB

Town centers, walkable urbanism, compact growth, new urbanism: these are all terms associated with a growing movement toward walkable urban development. Above all else, this increasingly popular pattern of development implies proximity of uses, and therefore much higher density. Higher density is a necessary antecedent to walkable and vibrant urban neighborhoods. You can't have walkability without proximity. But higher density also means more impervious surface cover per acre, resulting in a higher pollutant load per acre. Recent research, however, shows that the kind of densities required for walkable urbanism may actually translate into *less* of a pollutant load, on a *per capita* basis, than that from an equivalent population at lower, suburban densities, and therefore less of a *total* pollutant load for a given population (Jacob and Lopez 2009). Very importantly, Manhattan-type densities are not required for reduced per capita loads. Narrow-lot, single-family detached homes, common in many pre-World War II neighborhoods, in most cases have

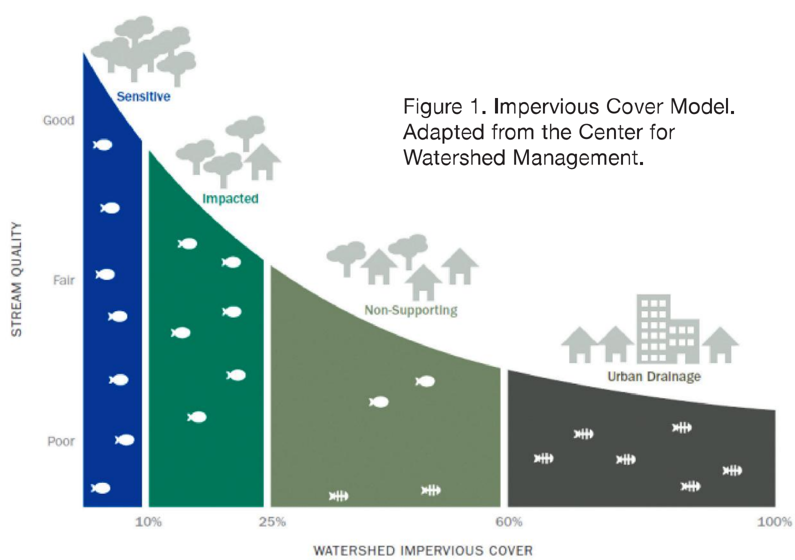

Figure 1. Impervious Cover Model. Adapted from the Center for Watershed Management.

enough density to result in significant pollutant load reductions versus standard low-density suburban housing for the same number of houses.

Imperviousness: The Prime Indicator

The best indicator for watershed health in general and for stream water quality in particular is the amount of impervious cover in a watershed: roads, driveways, roofs, etc. Polluted stormwater moving over impervious surfaces has no opportunity for infiltration into the soil, and thus remains polluted. Both runoff volume and pollutant concentration rise as imperviousness increases. The Impervious Cover Model (ICM) developed by the Center for Watershed Protection shows the relationship of impervious cover and stream quality at the *watershed* level (Figure 1). The line shown in Figure 1 is an average of many different studies. The complete data would show much more scatter, but the general relationships, including the thresholds, are solidly supported by the research.

For example, just 10% impervious cover in a watershed markedly affects stream water quality, and at 25% imperviousness, water quality and stream health are seriously compromised. Ten percent imperviousness is obtained with as little as one house per 2 acres, and 25% imperviousness with as few as one to two houses per acre.

Focus on the Site or the Watershed?

Stormwater is best managed at the watershed scale. It is watershed health, not the state of any one particular site, that should concern us most. Watershed health is directly related to the water quality of the receiving streams.

The problem is that it is extremely difficult to regulate anything at the watershed level. The multiplicity of jurisdictions in a single watershed can add extraordinary complexity. Property rights is also a major issue at this scale. If we wanted to preserve significant open space on a watershed scale, we would have to tell one group of landowners that no development is allowed on their land, while allowing it on other land, barring particular issues like wetlands.

Managing stormwater at the site level, on the other hand, is relatively straightforward. An impervious surface limit, for example, is simple to enact and it applies to everyone equally. Most jurisdictions thus rely almost exclusively on site-level management, with little attention to the watershed level. The assumption is that the requirements at the site level will scale up to the watershed level. The problem is that habitat and farmland are unintentionally fragmented because of the significantly larger lot size required in order to minimize site imperviousness, and as a result overall watershed health might be degraded.

Although some jurisdictions could exercise zoning authority to preserve open space, even those that have the power rarely use it for this purpose. A direct watershed-scale approach for stormwater regulation and management is therefore too difficult in practice for most jurisdictions.

A Per Capita Approach to Stormwater Management

The lot-scale approach to managing imperviousness and stormwater quality is standard operating procedure across the country. A per capita approach, on the other hand, might offer a more rational way to deal with imperviousness, one that puts the biggest burden for mitigating imperviousness on those who are responsible for the largest amount. Per capita imperviousness decreases as density increases. It is as simple as this: If you stack more floors on the same building footprint, every additional floor greatly reduces the per capita imperviousness. You are adding people without adding any more impervious surfaces, as far as runoff or loadings are concerned. The imperviousness/per capita fraction becomes smaller. Each additional floor increases the denominator (people) but holds the numerator (impervious surface) constant, decreasing the fraction as density increases. And the lower this fraction, the lower the overall impact of any single development in terms of pollutant load (and in terms of many other things as well, such as vehicle miles driven and carbon dioxide emissions, but that is another story). See below for a discussion of the data on density and stormwater loads.

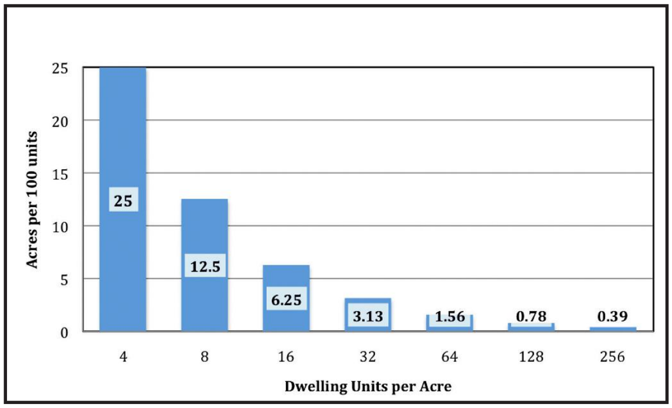

Figure 2. Acres for 100 dwelling units

Regulating impervious cover on a per capita or per-dwelling-unit basis removes the perverse incentives for sprawl that are inherent in the site-based approach. If the regulatory requirement is to minimize and mitigate per capita imperviousness, then there will be an incentive to increase density (and therefore proximity and thus walkability), because the cost of stormwater compliance will also decrease. Regulation of per capita imperviousness is not explicitly a watershed approach, but its outcomes can better match that approach, because nucleation of development is promoted, with more options for preservation and habitat as a result.

Even with a per capita-based approach, some direct watershed-level decisions still have to be made: Which lands should be avoided? What natural areas should be preserved? Nucleation of development aids that process by reducing development pressure in outlying areas. But encouraging density in any one area or even overall in a jurisdiction does not absolve managers from making other hard decisions about floodplain management and habitat protection, to name just a few.

Density: How Is It Measured?

The number of dwelling units per acre (DUA) is one of the most common ways planners measure density. This measure does not take into account streets, parking lots, parks, etc., but it does give a good feel for what different neighborhood densities might look like. Other measures, such as the floor-to-area ratio (FAR), are used for mainly for commercial districts. The FAR is the relationship of the square footage of a building to the square footage of the site. One story occupying the entire site would give an FAR of 1. A building 10 stories high occupying half the site would have an FAR of 2.5.

Density Effects on Stormwater Loadings

Higher density (e.g., walkability) serves stormwater goals in two ways. First, it saves open space, with its natural cleansing abilities. Figure 2 shows how much land 100 units would take up at different densities (discounting streets, etc). Notice the steep decline in land used at the lower end of the density scale. The biggest reductions in land used are between four and 32 dwelling units to the acre.

Second, higher density actually reduces pollutant loadings per capita (and thus total loadings for a given population). This result is of course completely counterintuitive to what most people think about runoff, because we are used to thinking about runoff in terms of per-acre loadings. Some recent modeling (Jacob and Lopez 2009) quantifies these per capita reductions. This study used a simple spreadsheet model to examine runoff under a variety of density scenarios and land-use characteristics. The main parameters modeled were percent impervious cover and the event mean concentration (EMC) of specific pollutants. EMC values have been derived for a variety of land use types.

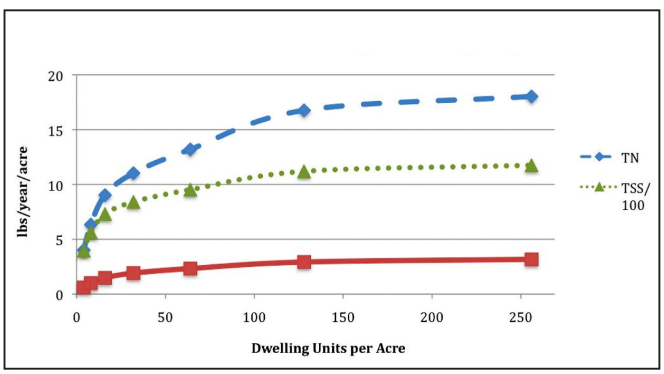

Figure 3. Pollutant load per acre per year

We present here the results from only one set of EMC and impervious coefficient values, values that we consider about "average" for most US cities. The results of other runs can be found in Jacob and Lopez (2009).

The graphs in Figures 3 through 5 demonstrate the relationship between density and runoff. These graphs compare runoff pollutant load for 100 dwelling units for increasing densities. (These load graphs are for a set of data from Austin, TX, and are from the Jacob and Lopez study.)

As expected, pollutant load per acre increases as density increases (Figure 3). But if that same load is measured per capita (or per 100 units in this case), then the curves have the opposite shape (Figure 4), with significantly less total load per 100 units versus four DUA as density increases. What these graphs show is that for a given population, the total pollutant load may be much less at higher density. (A sensitivity analysis reported in the Jacob and Lopez study showed that higher density could result in greater loads per capita above four DUA depending on watershed characteristics (amount of imperviousness and pollutant concentration factors specific to each land use), but that even with unusually high values for these parameters, at some point, usually by no more than 32 DUA, runoff volume and load were less from higher densities versus four DUA. For locally precise density/runoff relationships, specific watershed characteristics would have to be determined.)

The more-than-30-story building on the right has a significantly lower per capita imperviousness than the seven-story building on the left, but the seven-story building has a much better return on investment in terms of the environmental benefits received. The additional 20+ stories provide only marginal improvements in runoff quality versus the shorter building (see Figures 4 and 5).

For example, a 100-unit development with four houses to the acre (DUA) would yield about 4 pounds of total nitrogen (TN) per acre per year according to the scenario modeled in Figure 3. One hundred houses at this density would require 25 acres and would yield a total of 100 pounds (25 x 4) of TN. That same development of 100 units at 16 DUA would result in more than twice the pollutant load *per acre*: 9 pounds TN. But because the higher-density development requires only 6.3 acres, the total load (57 pounds TN) from these same 100 houses is just over half that of the lower-density development.

Figure 4 shows the same density relationship on a *per capita* basis. These curves are the inverse of the per-acre curves. This inverse relationship of density and pollutant load is the main point of this article. Looking at imperviousness and pollutant load from this perspective might modify how we think about managing these features.

From Figure 4, 1,000 homes in a typical subdivision (four DUA) will consume about 250 acres, and at 40% imperviousness we would have 100 acres of impervious cover, or about a one-tenth-acre imperviousness per home. Those same 1,000 homes in a townhome configuration (20 DUA) would consume only 50 acres. With a higher imperviousness of about 65%, we would have about 32 acres imperviousness, or close to three-hundredths of an acre imperviousness per home. (These calculations do not account for streets or commercial areas.) The denser 50 acres would also have less total pollutant load (e.g., 500 pounds TN) than the more open 250 acres (1,000 pounds TN). The townhome development would be seen as more problematic from a per-acre perspective, but a per capita approach would see the townhomes as having much less impact on the receiving waters, for the same 1,000 homes. Perhaps most importantly, with the higher density, we have 50 acres of development and 200 acres of undeveloped land. That is 200 acres of *no hydromodification or new disturbance of any kind*, versus the full 250 acres developed with lower density.

Both of the above scenarios could be further improved by the addition of stormwater best management practices (BMPs). But the total impact over the full 250 acres of this hypothetical project will almost certainly be much

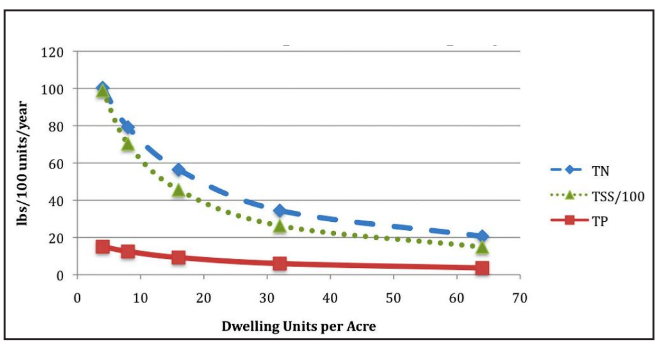

Figure 4. Pollutant load per 100 acres per year

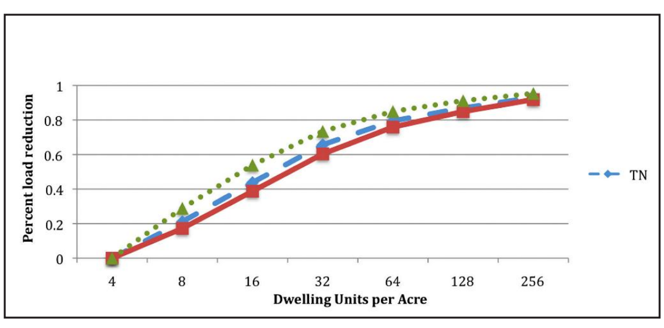

Figure 5. Percent load reduction for higher-density versus standard low-density development

Photos by John Jacob

Left: Approximately 30 units to the acre. Alexandria, VA.

Above: Eight to 10 units per acre. Mueller Airport development, Austin, TX.

lower for the walkable development, even with no additional treatment, because of the reduced total load and because 80% of the area would have no impact.

A very valid question now arises: What about those undeveloped acres in the denser scenario? What is going to keep another dense project from filling in those acres? If the denser development is going to be allowed, shouldn't the developer be required to set that land aside? The answer is that there is no need to set the land aside to accrue a benefit, and a developer building a more compact development shouldn't be penalized for putting together a land-saving project. Developing less land is a benefit of compact development, but how undeveloped land is preserved is another question altogether. For the hypothetical 200 acres not developed in the above scenario, it would be highly likely and even preferable for another compact development to be built adjacent to the first project. Compact development has the benefit that it lessens the overall pressure on the land. Where and how to preserve land are very important decisions that have to be made independent of the stormwater management process.

Figure 5 shows the actual load reductions we might expect for higher-density versus standard low-density development (defined here as four units to the acre). This is looking at higher density as a BMP, because BMPs are about load reductions. It is important to point out again that these curves could change depending on EMC and imperviousness values chosen. But what we found is that even after we assigned very high EMC and impervious values to densities above four DUA, even in the worst cases there was a reduction in pollutant load, versus the low-density scenario for a given population, at densities of 16 or 32 DUA and greater.

Because four DUA development is a rough average for standard suburban development, it is a good basis for comparing how well density stacks up against other BMPs, low impact or otherwise. BMP efficiency varies greatly, depending on the pollutant, its concentration, the BMP type, and the design of the BMP. A BMP that consistently removes 50% of a pollutant would be considered an effective BMP by any accounting.

According to Figure 5, a 50% reduction in pollutants (TN, total phosphorus, and total suspended solids) versus four DUA development is achieved at densities between about 16 and 24 DUA. In other words, a 100-unit townhome development (16 DUA) with no other BMPs has about the same runoff load as 100-unit development at four DUA where the runoff is treated by a stormwater BMP removing on average 50% of these constituents. The townhome development, of course, disturbs 18 fewer acres (a 72% reduction) than the low-density development.

Even just a simple doubling of density can deliver about a 20% reduction in pollutant load versus low-density suburban development, a not insignificant reduction, and one that can be obtained with single-family detached homes—well within the cultural norm of most Americans.

At the other end of the density scale, 40 to 50 DUA gets about the best bang for the buck in terms of load reduction versus low density. Above this density, incremental reductions in pollutant loading get quite small. This is actually quite a notable inflection point because 60 DUA is roughly in the range of about seven or so story buildings, which is where in most jurisdictions much stronger code restrictions kick in, making taller buildings much more expensive to construct. This means that we can get the best load reductions from density in a very accessible building range. Densities of 40 to 50 DUA are consistent with many downtown districts in mid-size and small cities, and most transit-oriented developments.

John Jacob

Mixed use with approximately 50 units to the acre. Calgary, AB.

Daniel Zack

Seventeen units to the acre. San Francisco, CA.

Implementing Density As a Stormwater BMP

The most straightforward way that density can be established as a stormwater BMP is to grant complete or partial waivers for treating runoff for developments that have specific density levels. For example, the city of Grand Rapids, MI, grants a stormwater detention waiver for any development that results in 80% reduction of the "equivalent impervious area" of the same number of units at low density (five DUA in this case) (Lemoine 2007). This usually requires a development of about 38 DUA, in the neighborhood of three to four stories. This waiver is for stormwater volume detention only, and not stormwater quality.

The state of West Virginia recognizes that higher-density development strategies can be "part of the process of reducing stormwater runoff and improving water quality." Five specific development types, listed below and defined in the permit, can each receive a "credited reduction" of 10% of the volume of relevant runoff reduction, and with some additional incentives a reduction of up to 75% for a single project can be obtained:

- Redevelopment
- Brownfield redevelopment
- High density (>7 units per acre)
- Vertical density (FAR of 2 or >18 units per acre)
- Mixed-use and transit-oriented development (within one-half mile of transit)

Leadership in Energy and Environmental Design (LEED) is a well-known and internationally recognized green building certification program. LEED for Neighborhood Development (LEED-ND) is a new rating system that incorporates the principles of smart growth and new urbanism. One of the critical criteria within this rating system is density (Table 1). A municipality or MS4 (municipal separate storm water sewer system) could choose to link stormwater-quality improvements or volume-reduction requirements to specific density levels such as those in the LEED-ND system. LEED-ND includes many more characteristics than density, such as density of intersections. In terms of compact development, however, density is the single best predictor of environmental performance. The additional very important characteristics of LEED-ND ensure that there really is walkability.

Table 1. LEED-ND DUA Thresholds
10
13
18
25
38
63

The Rural to Urban Transect, usually referred to simply as the Transect, is a recently developed conceptual model that recognizes a gradient of conditions from the rural edge to hyper-urban cores (Duany and Brian 2005). New Urban practitioners suggest that a different set of codes should be used in each T zone. The Transect, particularly through the medium of the Smart Code (*www.smartcodecentral.org*), could provide a framework for a municipality or other stormwater entity to tailor quantitative stormwater requirements for each zone in the Transect. The density thresholds for the Smart Code are not as precise as those of the LEED-ND system, but the ranges shown give some idea of the nature of the T zones (Table 2). Higher lot-based pervious surface percentages, for examples, could be required of suburban T-2 and T-3 zones. An article describing the Light Imprint framework, which is based on the Transect, will appear in the next issue of *Stormwater*.

Table 2. Transect Density Ranges

T Zone	Density Range
T1	–
T2	0.5–2
T3	2–6
T4	4–12
T5	6–24
T6	12–96+

There is a large body of scientific work demonstrating the negative impacts of impervious surfaces, more than sufficient to back up municipal ordinance-making in this area. The density curves shown here could be used to developed a schema for variable treatment of stormwater with respect to density. Having local runoff data correlated with land-use and density would add strength to a stormwater density ordinance. But precise local data is expensive to obtain, and fairness and consistency based on general data might be more important in any event.

John Jacob

Transit oriented development with approximately 80 to 100 units to the acre. Alexandria, VA.

How a *Lot-Based* Stormwater Treatment Requirement Could Facilitate Density

A lot-based stormwater treatment requirement will limit density if no provision is made for offsite mitigation. If the pervious surface or other treatment requirements can be purchased offsite, say through construction of a stormwater wetland or other neighborhood- or district-scale BMPs, then the lot-based requirement would actually encourage density, because a higher number of units on the lot would decrease the per-unit cost of the stormwater treatment requirement. This kind of offsite mitigation can be tied to a particular watershed or subwatershed where there might be an impairment, perhaps under total maximum daily load (TMDL) constraints, for example.

The densest census tract in the US, with 300+ units to the acre. New York City.

What About Infiltration and Low-Impact Development?

Recognizing and codifying the benefits of high density with respect to stormwater does not mean that additional treatment may not be necessary. There are plenty of opportunities for infiltration even in a dense, hyper-urban environment. These opportunities might be especially important in cities where combined storm and sanitary sewers require employment of every possible reduction in stormwater flows. The point, however, is to not require more mitigation per capita or per unit for compact, walkable developments than for suburban developments with much higher per capita imperviousness.

It is important to recognize that *all* development has a very high impact on the natural environment. It is not possible to put a subdivision on a prairie or in a forest without some very significant impacts, regardless of what kind of infiltration practices are put into place. These practices can help lessen the impact, but they cannot begin to make up for all of the ecological services lost. That suburban or urban development can in any sense be "low impact" is an illusion that may distort how we think about best management practices, particularly in thinking about the best context for each one.

The ultimate stormwater practice is to build a better place: a walkable, compact place. Compact development does more to reduce water-quality impacts, and many other impacts, for a given population than just about any infiltration practice currently available. A compact, walkable city still needs greenery. Properly designed infiltration and bioretention techniques do have a place in the compact urban environment. But the first step is to build for people, not cars.

Resources

The Transect: *http://www.transect.org*
Smart Code: *http://www.smartcodecentral.org*
LEED-ND: *http://www.usgbc.org/DisplayPage.aspx?CMSPageID=148*
West Virginia fact sheet on stormwater permits: *http://ehs.wvu.edu/r/download/53907*
Stormwater Wetlands: *http://www.urban-nature.org/publications/documents/StormwaterWetlands1209sm.pdf*

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