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DISCUSSION[1]

"Is Denser Greener? An Evaluation of Higher Density Development as an Urban Stormwater-Quality Best Management Practice" by John S. Jacob and Ricardo Lopez[2]

Kenneth W. Potter[3]

Potter, Kenneth W., 2009. Discussion – "Is Denser Greener? An Evaluation of Higher Density Development as an Urban Stormwater-Quality Best Management Practice" by John S. Jacob and Ricardo Lopez. *Journal of the American Water Resources Association* (JAWRA) 1-3. DOI: 10.1111/j.1752-1688.2009.00372.x

Jacob and Lopez (2009) presents modeling results to support the conclusion that the per capita water quality impacts of urban development decrease significantly with population density. If true, this conclusion would have important implications for land use planning throughout the world. However, as discussed below, the modeling is based on questionable assumptions that likely bias the conclusion.

Water quality in this paper is defined in the context of total phosphorus, total nitrogen, and total suspended sediment load. The annual loading of each of these pollutants is estimated as the product of annual runoff and a pollutant concentration. The runoff amount is computed as the product of annual precipitation and a runoff coefficient that depends solely on impervious fraction, which in turn is assumed to depend on the number of dwelling units per area. The pollutant concentration is computed as a sole function of impervious fraction, based on regression equations from a previous study of small watersheds in the Austin, Texas area. Application of the model indicates that for all three pollutants, the annual loading per dwelling unit decreases with increasing development density. This follows directly from the sole focus on impervious surfaces, which decrease in area per dwelling unit with increasing development density, while pollutant concentrations are assumed to remain constant or increase slightly.

I have several concerns about the assumptions used to support the conclusions of this paper. By focusing exclusively on sediment and nutrient loads, the paper fails to account for other important water quality impacts that are highly sensitive to development density. The modeling does not account for the fact that the mitigation of water quality impacts depends strongly on development density, nor does it acknowledge the fact that the magnitude of water quality impacts depend on their spatial distribution. Lastly, the paper does not account for the fact that urban and suburban development of agricultural lands can result in a reduction in phosphorus, nitrogen, and sediment loads.

NEGLECTED IMPACTS

Phosphorus, nitrogen, and suspended sediment in urban stormwater can certainly impair water quality;

[1]Discussion No. JAWRA-09-0103-D of the *Journal of the American Water Resources Association* (JAWRA). DOI: 10.1111/j.1752-1688.2009.00372.x

[2]Paper No. JAWRA-08-0105-P of the *Journal of the American Water Resources Association* 45(3):687-701.

[3]Professor, Department of Civil and Environmental Engineering, University of Wisconsin, 1415 Engineering Drive, Madison, Wisconsin 53706 (E-Mail/Potter: kwpotter@wisc.edu).

but urban development has other damaging effects that propagate downstream. Increased stormwater peaks and volumes increase flow variability and cause downstream channel erosion (Booth and Jackson, 1997). Runoff from impervious surfaces contributes to thermal pollution of downstream water bodies (Galli, 1990). The combined impacts of diminished groundwater recharge and groundwater pumping deplete groundwater, reducing groundwater discharge to aquatic systems, reducing base flows in streams, and exacerbating the impacts of thermal pollution (Simmons and Reynolds, 1982). Jacob and Lopez (2009) does not consider any of these impacts.

MITIGATION ISSUES

Jacob and Lopez (2009) does not account for the fact that mitigation of the hydrological and water quality impacts of development depends on the availability of pervious area. Impervious surfaces that connect to pervious ones produce less stormwater (Alley and Veenhuis, 1983). In traditional practice, control of stormwater peaks and volumes and associated sediment and pollutants is achieved by the use of basins, the performance of which largely depends on surface area. Low-impact development commonly relies on the use of distributed greenspaces to treat and infiltrate water (Potter, 2006); performance depends largely on the surface area of pervious surfaces (Brander *et al.*, 2005). In high-density developments it is possible to substitute subsurface storage for surface basins; but such storage is costly to build and maintain. Green roofs are another alternative for high-density developments, but because they rely on evapotranspiration they do not mitigate groundwater impacts.

SPATIAL DISTRIBUTION OF IMPACTS

Jacob and Lopez (2009) bases its evaluation solely on total pollutant loads. But the ecological impacts of the water quality and hydrologic effects of development depend on their spatial distribution, particularly with respect to critical environmental resources. In general, lower density development spreads the effects over a larger area, allowing the assimilative capacity of the environment to reduce the overall impact. Pollutant load allocation in the Total Maximum Daily Load (TMDL) process uses spatially distributed watershed modeling to explicitly account for such spatial effects. Evaluation of the role of development density must do so as well.

PRE-DEVELOPMENT LAND USE

Finally, Jacob and Lopez (2009) does not account for the fact that urban development often occurs on former agricultural lands. Agriculture is the leading cause of water quality impairment of streams in the United States (U.S.) (USEPA, 2009). Phosphorus, sediment, and nutrient pollution from agricultural lands can exceed those from urban lands. Furthermore, in the U.S., the hydrologic and water quality impacts of stormwater from developing lands are much more heavily regulated than are the impacts of stormwater from agricultural lands. State and local regulations often require that stormwater peaks from developing lands not increase above *pre-settlement* levels. The federal Clean Water Act mandates the regulation of the water quality discharges from point sources, including stormwater conveyance systems. However, the Clean Water Act leaves regulation of agricultural runoff to the states, which have generally failed to respond. Hence development of agricultural lands could in some cases *improve* downstream water quality. In such cases, the more land developed, the greater the improvement in water quality.

PERVIOUS AREA

The central weakness of the analysis in Jacob and Lopez (2009) is its assumption that the role of pervious surfaces does not change with development density. From the above discussion, this is clearly not the case. The area of pervious surfaces decreases roughly linearly with increasing development density. Less pervious surface means less opportunity to mitigate hydrologic and water quality impacts. Less pervious surface means less use of the assimilative capacity of the environment. Less pervious surfaces means less conversion of lands that might have greater adverse hydrologic and water quality impacts. Failure to consider pervious surfaces introduces an obvious bias into the analysis.

CONCLUSION

The relationship between development density and downstream water quality is far more complex than represented by modeling approach used in Jacob and Lopez (2009). In some cases, high-density development may provide water quality benefits; but the determination must be made on a case-by-case basis that explicitly considers all of the factors discussed above, particularly the role of pervious surfaces.

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DISCUSSION[1]

"Is Denser Greener? An Evaluation of Higher Density Development as an Urban Stormwater-Quality Best Management Practice" by John S. Jacob and Ricardo Lopez[2]

Glenn E. Moglen[3]

Moglen, Glenn E., 2009. Discussion – "Is Denser Greener? An Evaluation of Higher Density Development as an Urban Stormwater-Quality Best Management Practice" by John S. Jacob and Ricardo Lopez. *Journal of the American Water Resources Association* (JAWRA) 1-3. DOI: 10.1111/j.1752-1688.2009.00381.x

INTRODUCTION

In this paper, the authors make the worthy argument for denser development as a tool to address urban stormwater issues. I am in general agreement with this view. However, this paper presents a flawed approach to this issue in three distinct aspects: (1) the range of dwelling unit densities presented by the authors spans into unrealistically high densities, (2) the spatial realities of placing very high density development land adjacent to undeveloped land is not consistent with real world development, and (3) the authors have extrapolated the results of Schueler's "Simple Method" (Schueler, 1987) to densities far beyond the data on which the method is based. The result is a presentation that may be mathematically sound, but the results are not grounded in physical reality. To the extent that this work might be used to inform policies on planning for future growth, the ideas and results expressed by the authors risk producing misguided or possibly deleterious future development practices.

RANGE OF DWELLING UNIT DENSITIES

The authors describe Manhattan, New York, as the "densest census block in America" based on Belmont's (2002) population density estimate of upwards of 70,000 people per square mile. They also cite densities reported by Campoli and MacLean (2007) as ranging from 0.5 to 330 dwelling units per acre (DUA) for cities in the United States. At least one of these estimates is erroneous. Even if we assume one person per dwelling unit in Manhattan, this would correspond to a density of, at most, 109 DUA, far less than the 330 cited above and also smaller than the authors' highest two density categories of 128 and 256 DUA. Considering that typical to high residential housing densities are in the range of 4-8 DUA, I would argue that densities in excess of 32 DUA (which corresponds easily to over 40,000 people per square mile) represent the upper-end of typically observed densities in highly urbanized settings. The authors present Duany's (2002) "Urban Transect" and associate his densest "T6" urban category with DUA values of "at least 40-50" [DUA]. Duany's (2002) classification should have provided the

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[2]Paper No. JAWRA-08-0105-P of the *Journal of the American Water Resources Association* 45(3):687-701.

[3]Professor, The Charles E. Via, Jr., Department of Civil and Environmental Engineering, Virginia Tech, 7054 Haycock Road – Rm. 424, Falls Church, Virginia 22043 (E-Mail/Moglen: moglen@vt.edu).

authors with a realistic upper-bound to their presented densities. Ultimately, it seems that the highest three of the seven density classes (64, 128, and 256 DUA) examined by the authors are beyond the range of meaningful exploration.

SPATIAL REALITIES OF DEVELOPMENT PRACTICES

Without a figure from the authors, it is difficult to envision the development patterns they are proposing. It seems the authors are setting higher and higher density development surrounded by increasingly larger tracts of undeveloped land. To risk oversimplification, it is as if they are placing a high-rise apartment building in the middle of a forest. Further, because the hydrologic impacts of the development are uniformly experienced in space, this urban/non-urban mix of land uses is essentially homogenized in space, as if that high-rise is broken into little, low-impact pieces and distributed uniformly everywhere.

In reality, the landscape will be composed of a range of land use types arranged in a complicated spatial pattern dependent on proximity to urban centers, the road network, political boundaries, quality of land for agricultural purposes, and other factors. One sure thing about that pattern will be the strong spatial correlation of urbanization or housing density with itself. Put another way, the kind of land use at location x is likely to be very similar at location $x + r$, where r is a small distance measured radially from location x. So if the land use at location x is high density (say 8 DUA) residential land, then there is a strong likelihood that at a distance r in any direction from x that the land use and density will be very similar to 8 DUA.

This authors' paradigm for land development is convenient for modeling purposes but it neglects the spatial realities of actual landscape development described above. The mathematics produced by their simple spreadsheet model are sound, but they do not reflect an urbanized landscape as it is likely to exist in the real world. A given watershed may contain many high density dwellings or few low density dwellings, but, to return to the earlier example, it is not likely to contain a single high-rise dwelling surrounded by a forest.

SCHUELER'S SIMPLE METHOD

A primary rule when applying any method (or tool, or equation) is to be sure not to apply that method beyond the bounds from which the method was developed. Schueler's (1987) "Simple Method" (T. Schueler, personal communication) was based largely on observations from the Nationwide Urban Runoff Program (USEPA, 1983). That program was based on approximately 28 small urban catchments in and near cities such as Baltimore, Maryland; Denver, Colorado; and Lansing, Michigan. While there is no disputing these are urban settings, the likely upper-bound to housing densities would have been closer to the 32 DUA characterization used by the authors. Although housing densities are not reported, a similar statement can almost certainly be made about other sources used by the authors (e.g., Barrett *et al.*, 1998) based on the study sites used in that report and peak housing densities in the Austin, Texas, area. Based on housing density, the authors have extrapolated far from source data used to develop Schueler's (1987) method and accompanying loading relationships they employed.

POLICY IMPLICATIONS AND CONCLUSIONS

I concur with the authors that their work is best viewed in terms of trends, not absolute magnitudes. They write, "Given the relatively high variability of EMC values for urban runoff, is it reasonable to expect that we can confidently model runoff as a function of density? We can because in terms of policy we are interested in trends, not absolute values." However, the authors' conclusions violate their above statement. For example, the authors state, "Densities above 64 DUA (which gave a 74% reduction in Total P vs. 4 DUA) outperform the median reduction values of even the best performing BMPs." The 74% figure is not a trend, the authors are presenting an absolute magnitude that is subsequently compared to all other BMPs. The reality here is that the uncertainty in both other BMP performance values and the density model posited by the authors makes the claim of absolute dominance of the 64 DUA BMP baseless. That 64 DUA is rarely observed and the authors' density model is premised on research from site conditions smaller than 64 DUA further minimizes the foundation for their statement.

The danger in the authors' presentation lies in the potential misapplication of their work. Policies that view higher density development as more effective than other traditional BMPs run the risk of erroneously advocating this development approach. The high density BMPs presented by the authors perform best at housing densities that are rarely, if ever, realized. At commonly observed housing densities it may be that other BMPs are more effective or appropriate.

In the end, my view is not too far from the authors – higher density development can be an effective approach to reduce per capita water impacts on the environment. However, the magnitudes of these reductions need to be spatially plausible, cautiously stated, and tempered by the limitations of the research on which such reductions are based. Finally, these reductions must also be bounded by housing densities that are realistically encountered in urban landscapes.

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REPLY TO DISCUSSION[1] by Kenneth W. Potter[2] and Glenn E. Moglen[3]

"Is Denser Greener? An Evaluation of Higher Density Development as an Urban Stormwater-Quality Best Management Practice"[4]

John S. Jacob[5,6]

Jacob, John S. 2009. Reply to Discussion – "Is Denser Greener? An Evaluation of Higher Density Development as an Urban Stormwater-Quality Best Management Practice" by Kenneth W. Potter and Glenn E. Moglen. *Journal of the American Water Resources Association* (JAWRA) 1-4. DOI: 10.1111/j.1752-1688.2009.00382.x

I welcome the discussion comments of Professors Potter and Moglen. Urban density and water quality is an emerging and potentially very controversial subject, but it is one that needs to be addressed squarely by the water quality community because compact development is emerging as *the* sustainable urbanism paradigm in many quarters. Jacob and Lopez (2009) clearly trod some new ground, and that work could stand, and hopefully will spur, further critical inquiry.

My esteemed colleagues raise a number of interesting points; some of their suggestions arise from a different way of viewing the question while others may be the result of a lack of clarity in our original arguments.

POTTER

Neglected Impacts

Our analysis of the universe of urban impacts was indeed very limited. Our intent was that this work serve as the starting point for further research into this complex area. The additional areas that Potter lists are important ones. Would higher urban densities *vs*. sprawl densities (for given populations) for the issues mentioned by Potter have the same impact pattern described in Jacob and Lopez (2009)? This is a whole area of research that needs to be addressed as we begin to seriously consider the implications of denser development.

Mitigation Issues

Our paper did not really deal with mitigation *per se*. The real issue we addressed was the relative magnitude of the impact that varying degrees of urban density would have on specific water quality parameters. We did not suggest that high density urbanization would have no impacts. We did suggest that mitigation could be scaled to match per capita impacts. This was done in the example we describe in the paper of Grand Rapids, Michigan, where a stormwater detention waiver was given for developments with densities that reduced run-

[1]Reply No. JAWRA-09-0133-Y of the *Journal of the American Water Resources Association* (JAWRA). DOI: 10.1111/j.1752-1688.2009.00382.x

[2]Discussion No. JAWRA-09-0103-D of the *Journal of the American Water Resources Association.* DOI: 10.1111/j.1752-1688.2009.00372.x.
[3]Discussion No. JAWRA-09-0101-D of the *Journal of the American Water Resources Association.* DOI: 10.1111/j.1752-1688.2009.00381.x.
[4]Paper No. JAWRA-08-0105-P of the *Journal of the American Water Resources Association* 45(3):687-701.
[5]Associate Professor and Coastal Community Development Specialist, Texas Sea Grant and Texas Agrilife Extension, Department of Recreation, Park, and Tourism Sciences, Texas A&M University, 1250 Bay Area Blvd. Ste. C, Houston, Texas 77058 (E-Mail/Jacob: jjacob@tamu.edu).
[6]Mr. Lopez, who co-authored the original paper, was unavailable to participate in this reply.

off 80% or more of what would occur with an equivalent population with a low-density sprawl pattern.

Spatial Distribution of Impacts

One of the main implications of our paper is that higher density would in fact allow for greater options in terms of spatial distribution of development, particularly in terms of "critical environmental resources." We discussed these issues at length in the paper. "The advocacy or use of high density as a stormwater BMP does not absolve stormwater or watershed managers of the necessity to [analyze] where development should go in any particular watershed" (p. 696) sums up our argument. For a given population, higher density will use a smaller, and potentially a very much smaller footprint, than densities associated with sprawl. That smaller footprint enables considerably more options in terms of arranging the spatial distribution of those impacts.

Potter states that "lower density development spreads the effects over a larger area, allowing the assimilative capacity of the environment to reduce the overall impact." One of the main points of our paper is that smaller, denser areas have less of an overall impact than larger, more diffuse areas of development for a given population, depending on the variables discussed in the paper, e.g., event mean concentrations. It is true that lower density development can make some use of the "assimilative capacity" of the environment, particularly using "low impact development" practices. But perhaps an argument could be made that a greater benefit to society and the planet would accrue from *not* using that precious assimilative capacity of the environment to ameliorate the impacts of sprawl development. An important implication of our research is that it might be possible to build better cities that are more compact and that require much less of that assimilative capacity per capita, thus preserving that scarce capacity for other needs.

Predevelopment Land Use

Urbanization of agricultural lands will of course change the nature of water quality impacts for those lands. Whether that change could be characterized as an improvement, even from a narrow water quality focus, is very much open to discussion. Working agricultural lands, particularly prime farmlands, should be a critical element to maintain in any kind of holistic watershed management program. There is clearly a lot of pollution associated with poor agricultural practices. But we can reverse that with a variety of incentives, regulation, education, etc. On the other hand, while urbanization is not completely irreversible, there is a certain permanence to it. The question we tried to address in this paper is the urban pattern, in terms of density, that would have the least impact.

Pervious Area

We discussed this issue at length, and nowhere did we imply that pervious surfaces do not change with density.

MOGLEN

Range of Dwelling Unit Densities

Moglen claims that the high end of our residential density scale is "beyond the scale of meaningful exploration," and he suggests our numbers for what Belmont (2002) calls the densest census tract in America are erroneous. I used the U.S. Census Bureau's (USCB) American Factfinder website (http://www.factfinder.census.gov) to examine the area that Belmont describes. A quick review of this data might not only resolve the issue of whether our numbers are erroneous, but also whether our density scale is unreasonable at the upper end. I downloaded Year 2000 population and household data for Census Tract 126, a 10-block area in New York County, New York. The USCB boundaries corresponded precisely with those described by Belmont (2002) on the Upper East Side of Manhattan. I used Google Earth to determine the total area of this tract: 0.07 square miles. The total 2000 population for this tract was 12,895. Simple division gives us a population per square mile of 184,214 people. As we said "*upwards* of 70,000 people per square mile." Upwards means *at least*. Over a larger area, there are going to be commercial and other areas with no residences, so the 184,000 figure might not be reflective of a larger zone, and would obviously be much lower. But it is hard to conceive of a gross density of less than 70,000 people per square mile for this area no matter how you slice it. We discussed in the paper the difficulty of comparing gross and net densities. Net densities are measured in terms dwelling units per acre (DUA), and do not take into account streets, parking lots, etc. The USCB data for 2000 showed 9,044 housing units in this tract, which is about 45 acres in size. Simple division yields 200 DUA. But this figure includes areas such as streets and parks that are not included in calculations of DUA (see e.g., Churchman, 1999). I did not attempt a quantitative analysis of nonresidential areas, but if we assume that 25% of the area is dedicated to rights of way, parks, etc. (D. Farr, 2008, personal communication), then we would have a DUA of about 250. Belmont (2002) gives a figure of 300 DUA for this same tract, but does not detail how he made this calculation. So there may indeed be some discrepancies in the numbers, but they are inherent when converting between gross and net density, given the variability of streets, street widths, commercial areas, parks, etc. Downs (2004) lists some approximate conversions for net and gross densities. For example, 80,000 people per square mile corresponds to about 200 DUA. This is at best an approximate correspondence.

But the assertion that our density numbers are outside those typically observed in highly urbanized settings is clearly erroneous. The problem is that research within the stormwater community has not addressed the higher densities associated with emerging patterns such as transit oriented development (e.g., well in excess of 64 DUA). To suggest the densities we considered in our paper are outside the range of modern urban development does a great disservice by not encouraging research at this scale.

It is worth pointing out, however, that it is not necessary to have Manhattan-style densities of 200-300 DUA to achieve some very significant water quality benefits. Figures 8 and 9 in our paper reveal that the steepest decline in runoff volumes and pollutant loadings *vs.* standard suburban densities occur in the 16-64 DUA range, equivalent to 50-90% reductions (corresponding to a pretty wide range of data – see also Figure 10). Even by Professor Moglen's calculus this density range is not at all un-plausible for most American cities. Single-family detached houses can still be found at the lower end of that range, suggesting large reductions in future loadings could be achieved with little in the way of cultural shifts. Densities of 32-64 DUA can easily be achieved with low-rise three to four story multi-family housing. An important point here is that issues such as walkability and availability of nearby dining and shopping, as well as mass transit, become available in a very significant way at these same densities. There is a real convergence of issues in this "sweet spot" range that not only bears, but begs, for more research.

Spatial Realities of Development Practices

Moglen claims that our "paradigm for land development" "neglects the spatial realities of actual landscape development," a development pattern that is complex with a "strong spatial correlation of…density with itself." Many cities do have a very distinct edge dividing rural and urban areas. There is no basis given for Moglen's $x + r$ argument. There are edges everywhere. Central Park, close to Census Tract 126 discussed above, is but one example. Many areas are constrained by geographical features – mountains, shorelines, etc. Obviously cities have a range of densities, and there are usually clusters of higher density in one or more centers of larger cities. Whether Moglen's assertion is true or not does not have any bearing that we can discern on our density arguments.

Moglen suggests our argument is akin to placing a high-rise apartment in the middle of a forest. We recognize that does not often happen, but as an oversimplification it might have some conceptual power. Let us take the 44 acres of CT-126 on the Upper East Side of Manhattan. It is pretty much all high- and mid-rise structures. We could put a population of about 13,000 people or 9,000 dwelling units just like that out in the forest. And we could then hypothesize and model the impacts that small area of urbanization would have on the forest and downstream receiving waters. Let us further oversimplify and take that same population and put them out in that same forest at suburban densities of, say, 4 DUA. We would have to consume at least 2,250 acres for this same amount of people, and more likely in excess of 3,000 acres given right of ways, etc. Which has the greater impact? This kind of oversimplification makes for a rather stark comparison of the two patterns, and may help illuminate some of the tradeoffs that must be considered when evaluating different density patterns. That was the whole point of our paper. Again, though, it is not necessary to achieve a 50-fold difference in land consumption to obtain significant water quality reductions and other benefits. Just a 2 or 3 to 1 difference could have a large impact in terms of reduction of loads.

The more pernicious oversimplification is the idea of a *single* high rise in the forest. This is close to the idea that the modernist architect and urban planner Le Corbusier (1987) used to propose demolishing mid-rise Paris (i.e., the Paris we love) in the 1920s and replacing it with a series of high-rises surrounded by open space and high-speed automobile corridors. Not only is this idea antithetical to walkable, liveable urban fabric, it is destructive of ecologically functional habitat because of the fragmentation it results in.

Schueler's Simple Method

It is true that the Simple Method was based on limited observations. We struggled to find data from dense urban areas corresponding to the densities we modeled. But the Simple Method is based on some rather simple parameters – pollutant concentration factors associated with specific land uses, and impervious cover, are the main controlling parameters. We recognize we had a limited dataset to work with, and these limitations are clearly set forth in the paper. The Simple Method really makes no assumptions at all about population density. It is all about imperviousness and the nature of the pollutant stream discharging from given land uses. We made the assumption that high density residential zones would be similar to commercial districts, for which there is some EMC (event mean concentration) data. Given what the Simple Method is based on, what physical basis is there to assert that it could not model urban runoff on the Upper East Side of Manhattan, for example? If I have, for example, a low-rise, one story multifamily residential zone, say with an imperviousness of 70-80%, and then I add another floor, and then another and another. Is there some inherent point of density which would impede me from accurately modeling the runoff per capita in such a scenario? If an assertion is going to be made that a model does not work at a certain density scale, then a physical or mathematical argument should be made for why that would be so. Yes we have extrapolated farther than others. Further research could explore whether this extrapolation is warranted and demonstrate the utility or limitations of the Simple and other methods for examining urban runoff data.

Policy Implications

Moglen correctly recognizes that we have tried to place our work in terms of trends. We clearly stated that results would vary based on which EMC (event mean concentration) and imperviousness coefficients were selected. Moglen then asserts that we violate our intent because we make the statement that densities of 64 DUA resulted in a 74% reduction in Total P *vs.* 4 DUA. We clearly did not present this as an "absolute magnitude," and in fact stated in the sentence immediately following the one he cites that "there is considerably more slack and overlap than is implied by the comparison of a few data points." We also said that DUAs of 64 and higher appeared to provide better TP reductions than other BMPs based on "this data."

CONCLUSION

The compact urban pattern associated with Smart Growth and New Urbanism is fast emerging as *the* sustainable paradigm for a host of sustainability issues (Farr, 2008), including health (Frumkin *et al.*, 2004), global warming (Ewing *et al.*, 2008), air quality (Lyons *et al.*, 2003), and quality of life (Yang, 2008). The literature in these areas is truly voluminous. In contrast, the water quality and watershed management community has barely touched these issues. The contention of Professor Moglen that the upper end of our density scale is outside the range of meaningful exploration is more than erroneous; it is highly disturbing in the light of the lack of research by our community in this area. If our conclusion that compact density has potentially much lower per capita loadings than equivalent low-density development is erroneous, then let it be demonstrated by rigorous and factual research. This is an area the water resources research community is sadly lacking in, and sorely needs to take on. I thank both Professors Moglen and Potter for engaging in a debate that I hope will engender much needed further research in this area.

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