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Stormwater runoff and export changes with development in a traditional and low impact subdivision

Michael E. Dietz[a,*], John C. Clausen[b]

[a]*Nonpoint Education for Municipal Officials (NEMO), University of Connecticut, Department of Extension, 1066 Saybrook Road, P.O. Box 70 Haddam, CT 06438 USA*

[b]*Department of Natural Resources Management and Engineering, University of Connecticut, 1376 Storrs Rd., Unit 4087 Storrs, CT 06269-4087 USA*

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Abstract

Development continues at a rapid pace throughout the country. Runoff from the impervious surfaces in these watersheds continues to be a major cause of degradation to freshwater bodies and estuaries. Low impact development techniques have been recommended to reduce these impacts. In this study, stormwater runoff and pollutant concentrations were measured as development progressed in both a traditional development, and a development that used low impact development techniques. Increases in total impervious area in each watershed were also measured. Regression relationships were developed between total impervious area and stormwater runoff/pollutant export. Significant, logarithmic increases in stormwater runoff and nitrogen and phosphorus export were found as development occurred in the traditional subdivision. The increases in stormwater runoff and pollutant export were more than two orders of magnitude. TN and TP export after development was 10 and 1 kg ha^{-1} yr^{-1}, respectively, which was consistent with export from other urban/developed areas. In contrast, stormwater runoff and pollutant export from the low impact subdivision remained unchanged from pre-development levels. TN and TP export from the low impact subdivision were consistent with export values from forested watersheds. The results of this study indicate that the use of low impact development techniques on a watershed scale can greatly reduce the impacts of development on local waterways.
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Keywords: Stormwater runoff; Impervious; Export; Low impact development; Nonpoint pollution

1. Introduction

Runoff from developed areas continues to be a leading cause of impairments in the nation's waterways (US EPA, 2002). Development continues at a rapid pace throughout the country, with some cities increasing in size by up to 50% in the past 30 years (US EPA, 2001). Several research studies have documented increases in runoff volume (Jennings and Jarnagin, 2002; Waananen, 1969) and peak flow rates (Leopold, 1968) as areas were transformed from undeveloped to urban. Other studies involving computer modeling of future increases in impervious areas have also predicted increased runoff volumes (Hollis, 1977; James, 1965; Pawlow and Nathan, 1977; Sloto, 1988). In addition, numerous studies have documented decreased water quality in urban runoff (Makepeace et al., 1995).

Imperviousness has been recommended as an indicator for stream health (Arnold and Gibbons, 1996). A variety of impacts have been associated with increased impervious cover, including decreased fish species richness and abundance (Wang et al., 2001), channel morphology changes (Booth et al., 2002), decreased benthic organism richness (Roy et al., 2003) and abundance (Klein, 1979), decreased base flow in streams (Ferguson and Suckling, 1990; Wang et al., 2001), and decreased water quality (Carle et al., 2005; Roy et al., 2003). More complex predictors of stream impacts such as the multimetric urban index composed of numerous infrastructure, socioeconomic, and land cover variables have been proposed (Coles et al., 2004). However, total percent impervious area was found to correlate highly ($R^2 = 0.96$) with the urban index (Coles et al., 2004). This suggests that percent

*Corresponding author. Tel.: +1 860 345 5219; fax: +1 860 345 3357.
E-mail addresses: michael.dietz@uconn.edu (M.E. Dietz), john.clausen@uconn.edu (J.C. Clausen).

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impervious area is valid as a predictor of stream impacts, and it is a simpler indicator to use.

A degradation threshold value at about 10% imperviousness has been cited by several authors (Booth and Reinelt, 1993; Klein, 1979; Schueler, 1994, 2003; Wang et al., 2001). Watersheds with low levels of imperviousness may have a broad range of responses due to complex watershed interactions, but highly developed watersheds have uniformly poor conditions (Booth et al., 2004; Wang et al., 2001). Interpretation of threshold values in the literature should be done carefully due to the use of different measurement methods (Brabec et al., 2002). However, a definite relationship appears to exist between impervious area and multiple measures of stream health.

Recent advances in stormwater management, including low impact development (LID) techniques (Prince George's County, 1999), have provided engineers with a variety of tools to use in place of traditional catch basins and detention ponds. The overall goal of LID is to mimic the pre-development hydrology of an area, including the runoff volumes that existed before development. Current stormwater design in most municipalities mitigates peak flow rates, but does not address the increases in stormwater volume associated with development. Cluster designs, grassed swales, rain gardens, and pervious pavements all contribute to a reduced overall impervious footprint, and encourage decentralized treatment and infiltration of stormwater runoff. Research on individual LID practices shows that pollutant attenuation, reduced flow volumes, and reduced peak flow rates can occur (Davis et al., 2001; Dietz and Clausen, 2005, 2006; US EPA, 2000). However, there is a lack of peer-reviewed studies demonstrating the effectiveness of the use of LID on a watershed scale.

Although some studies have documented increases in runoff volume as an area was developed, much of the recent research relates to the comparison of different watersheds with varying land uses. Although the information provided by such studies is valuable, it is more difficult to establish causality when data from different watersheds are analyzed at a discreet point in time. Other confounding factors such as different monitoring methods, watershed characteristics, and weather variations can make comparisons difficult. Computer modeling studies can also provide insight into potential impacts to water resources, but simplifying assumptions are often made to calibrate models, which can make it difficult to determine the significance of the results. The objective of this study was to compare stormwater runoff volume and pollutant export from adjacent traditional and LID subdivisions, as development occurred, and as impervious surfaces were added in each of the watersheds.

2. Methods

2.1. Study area

The project was located in the town of Waterford, CT, in a drainage basin contributing to a small estuary called Jordan Cove, which discharges into the Long Island Sound. The "traditional" site was a 2.0 ha subdivision containing 17 lots (Fig. 1), which was built using current regulations and construction practices. Traditional zoning was used, as was a curb and gutter stormwater collection system. A typical 8.5-m asphalt road was installed. Landscaping and turf are similar to other new subdivisions. Roof runoff was directed to lawn areas or onto driveways. Erosion and sediment controls used during construction were typical of other construction sites statewide. Construction in the traditional subdivision began in 1997, and continued through 2003. Total impervious surface coverage after construction was 32%.

The 1.7 ha LID subdivision had 12 lots (Fig. 2). Several pollution prevention measures were incorporated as part of its design. A main feature was the replacement of a traditional 8.5 m asphalt road and associated curb and gutter stormwater collection system, with a 6.1 m wide Ecostone® paver road and grassed swales. A bioretention cul-de-sac that allowed for detention and infiltration of runoff was constructed in lieu of a conventional paved area. Individual bioretention areas (rain gardens) were incorporated into each lot to detain and infiltrate roof and lot runoff. Two shared driveways and one individual driveway used traditional asphalt paving. Four driveways were constructed using alternatives to traditional asphalt: two shared driveways used Ecostone® pavers; one shared driveway and one single driveway used crushed stone (Gilbert and Clausen, 2006). Houses were constructed in a cluster layout with reduced lawns and low-mow areas. Deed restrictions were developed to prevent certain activities during the study, such as filling in of rain gardens or swales, and the addition of more impervious surface to a lot. Ongoing education programs were used to instruct owners on good housekeeping practices. Additional best management practices (BMPs) were used during construction, including locating and seeding stockpiles to prevent sediment loss, hay bales, silt fence, earthen berms, and post-storm maintenance. Construction in the LID subdivision began in 1999, and continued through 2002. After completion, total impervious area was 21%.

The project was located in a climate that is influenced by both continental polar and maritime tropical air masses (Brumbach, 1965). Average annual precipitation is approximately 1237 mm and is distributed uniformly throughout the year. Hurricanes enter the state periodically. Soils on the sites were mapped as Canton and Charlton (mesic typic Dystrudepts). The typical infiltration rate for this type of soil is 33 cm hr^{-1} (USDA, 2007).

2.2. Monitoring

Stormwater volume in the traditional subdivision was measured using an ISCO 4230 bubbler flow meter and a 38.1 cm Palmer–Bowlus flume attached to a stormwater

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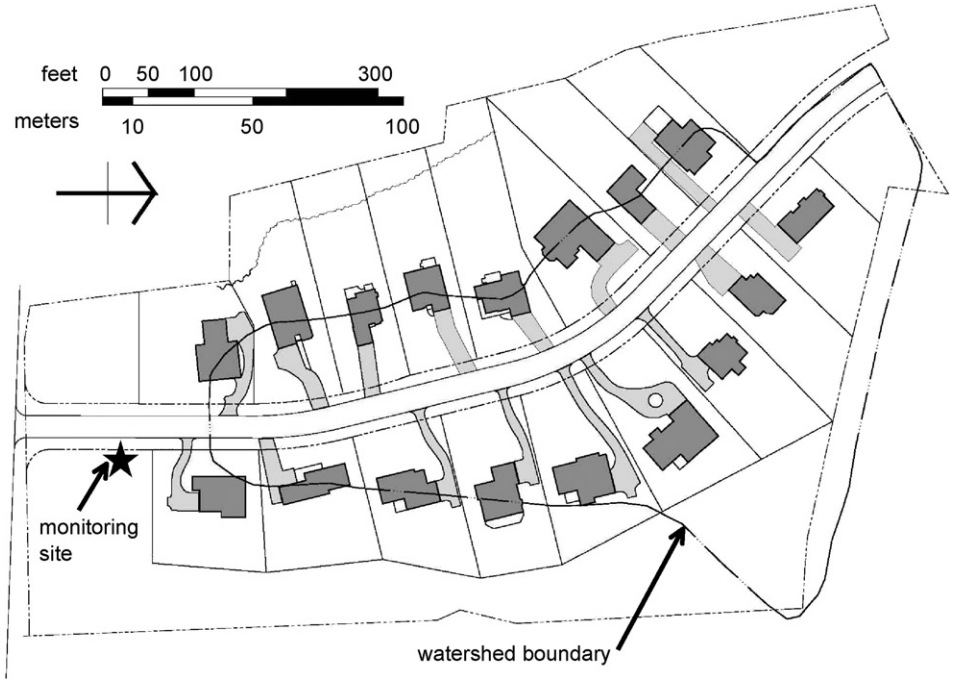

Fig. 1. Traditional subdivision layout in Waterford, CT.

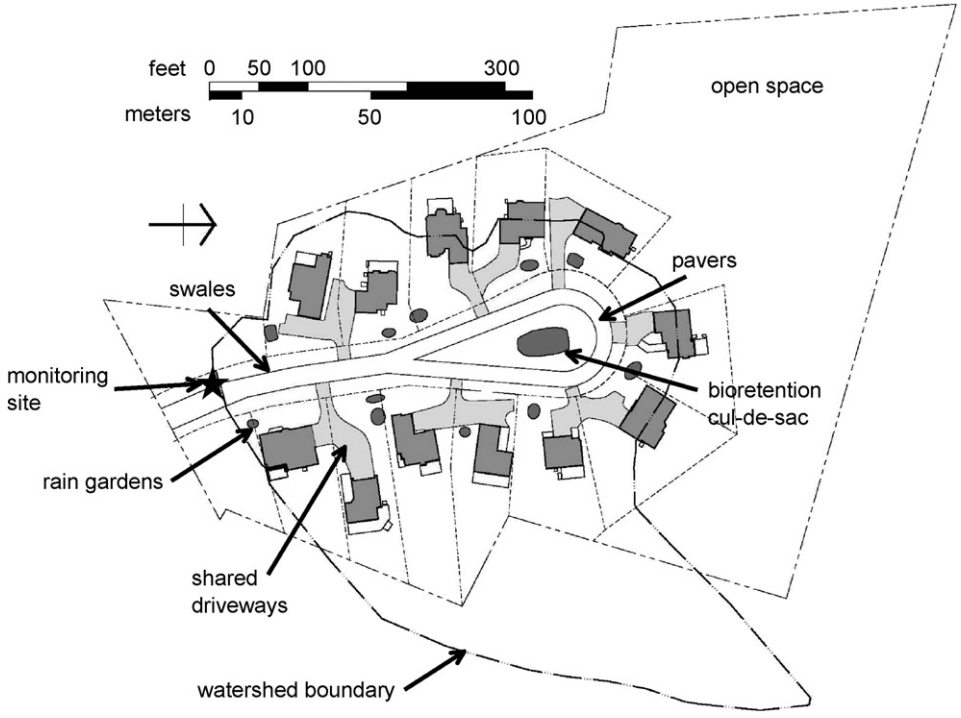

Fig. 2. LID subdivision layout in Waterford, CT.

pipe. Stormwater volume in the LID subdivision was measured using an ISCO 4230 flow meter and a 45.7 cm H-flume located at the end of a grassed swale.

Flow-weighted samples were collected automatically by an ISCO sampler, and were refrigerated in situ. Weekly samples were immediately placed in a cooler with ice packs and transported to the water quality laboratory where they were stored in a refrigerator at a constant temperature of 4 °C.

Due to an inconsistent precipitation record at the study site, monthly precipitation data from the National Climatic Data Center in Groton, CT (station #063207), which is

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approximately 6 km from the study site, was used as a reference (NOAA, 2006).

2.3. Sample analysis

Acidified composite stormwater samples were analyzed for nitrate + nitrite nitrogen (NO_3–N), ammonia nitrogen (NH_3–N), total kjeldahl nitrogen (TKN), and total phosphorus (TP) using a Lachat™ colorimetric flow injection system (US EPA, 1983a). Mass export ($kg\,ha^{-1}\,yr^{-1}$) was calculated by multiplying weekly cumulative flow by weekly sample concentration values, dividing by the watershed area, and summing for the year. Total nitrogen (TN) values were calculated by summing TKN and NO_3-N mass export values.

2.4. Impervious area calculation

A weekly field log was maintained on construction activities in both subdivisions, in which installation dates for driveways and roads were documented. Impervious area was calculated by hand measurements in the field. A house was considered impervious area when the roof was installed. The percent impervious of the subdivision was calculated based on total impervious area present on a weekly basis, divided by the total watershed area. An annual average of weekly percent impervious area values was calculated. Sidewalks and patios were a minute part of both watersheds, and were not included in percent impervious calculations.

Due to changes in the disturbed area on the construction site, water flow paths were altered during construction. As a result, the watershed areas for the traditional and LID sites varied during land development. Although the amount of impervious area increased continuously until completion, the overall watershed area may have been higher or lower than the previous year. Therefore, the total impervious area percentage for a given year may be higher or lower than the previous year.

2.5. Data analysis

Flow volume and pollutant export were summarized for each year, for each subdivision. Average total impervious area (%) for each year was also calculated for each subdivision. A log-normal relationship was then developed for each subdivision, with the independent variable being watershed impervious coverage (%), and yearly flow or pollutant export values being dependent variables. Each point on the graphs therefore represents a year, from 1996 through 2004. Runoff coefficients for each year were calculated by dividing annual runoff by annual precipitation, and multiplying by 100. Regression significance testing, R^2 calculations, and parameter estimates were performed in JMP (JMP, 2002) statistical package, version 5.1.

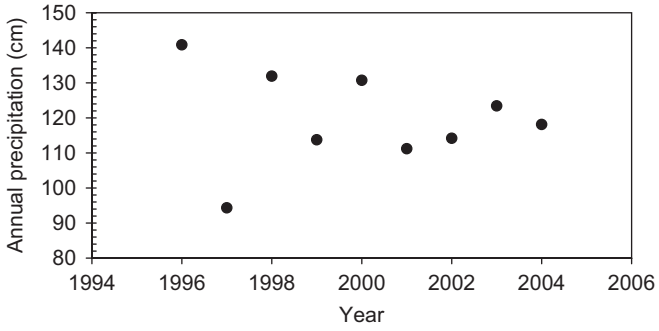

Fig. 3. Annual precipitation totals, 1996–2004, Groton, CT.

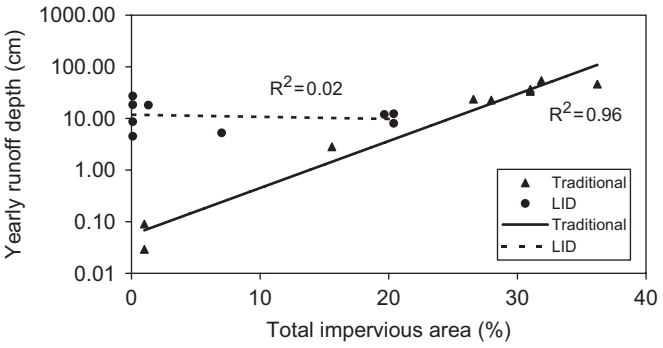

Fig. 4. Annual runoff depth vs. total impervious area, traditional and LID subdivision, 1996–2004.

3. Results and Discussion

3.1. Precipitation

Annual precipitation varied from 14% above normal in 1996 to 24% below normal 1997 (Fig. 3). For other years, variation was 10% or less of the 30-year normal precipitation (123.8 cm).

3.2. Stormwater runoff volume

Changes in stormwater volume were found as total impervious area increased in the traditional subdivision (Fig. 4). As impervious area increased from 1% to about 32%, annual runoff increased 49,000% from 0.1 cm to over 50 cm, or more than two orders of magnitude. Since precipitation during this period followed no trend, this change was due to the development of the subdivision. This regression was significant ($p = 0.001$) and logarithmic, indicating an exponential increase in stormwater volume as impervious area was added (Fig. 4). A similar exponential increase in the runoff coefficients was also found as watershed impervious area increased in the traditional subdivision (Fig. 5). The maximum runoff coefficient in the traditional subdivision was 47%, and within the range of coefficients reported by others (Novotny and Olem, 1994; Schueler, 1994).

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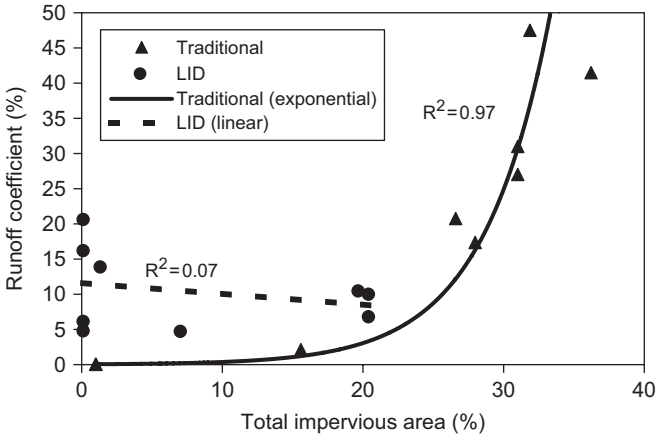

Fig. 5. Total impervious area vs. runoff coefficient, traditional and LID subdivision, 1996–2004.

Other researchers have documented stormwater volume increases of 100% (Jennings and Jarnagin, 2002) and 500% (Waananen, 1969) as impervious coverage increased in a watershed. One modeling study showed increases in runoff volume up to 12,400% as total impervious area increased 45% (James, 1965), although this increase is not typical of other values in the literature. The more dramatic increase in runoff volume found in the current study may be a result of scale: the study watershed in Waterford was 1.7 ha, whereas the catchments of the studies previously mentioned were 1320 ha (Waananen, 1969) and 6100 ha (Jennings and Jarnagin, 2002) in size. As watersheds increase in size, streamflow response (per unit area) to an event tends to become more dampened (Dunne and Leopold, 1978). Small watersheds also respond more quickly to an event, or have a shorter time of concentration. Therefore, modifications in a small watershed will result in more prominent flow changes than if similar changes were made in a large watershed. The current study shows that the impact of increased stormwater runoff on local streams due to changes in a smaller watershed can be dramatic.

Due to differences in topography and soils, the LID subdivision had more runoff before development than the traditional watershed (Fig. 4). Despite this initial difference, runoff volume and runoff coefficients in the LID watershed did not change as impervious area increased from zero to 21% (Figs. 4 and 5). A non-significant regression for the LID watershed confirms the lack of a relationship. The flow increases noted in other studies with similar increases in impervious area (Hollis, 1977; Waananen, 1969) were not found in this LID subdivision. This finding can only be attributed to the LID stormwater management techniques distributed throughout this watershed.

3.3. Nutrient export

Nutrient export showed a similar response to runoff volume. NO_3–N export increased logarithmically in the traditional subdivision with development, however no change was found in the LID subdivision (Fig. 6a). NH_3–N export from the traditional subdivision was similar to NO_3–N export, however, for the LID subdivision, NH_3-N export actually significantly decreased ($p = 0.05$) with increasing impervious area (Fig. 6b).

The change in TN export was similar to the change in NO_3–N export, with a significant logarithmic relationship for the traditional subdivision, and no relationship for the LID subdivision (Fig. 6c). TN export values for the traditional subdivision after development were approximately 10 kg ha^{-1} yr^{-1} (Fig. 6c). Average TN export in an urban watershed (1999–2001) with 27% impervious area in Maryland was 8.6 kg ha^{-1} yr^{-1} (Groffman et al., 2004). Medium density urban watersheds around the country were found to have a mean TN export of 9.6 kg ha^{-1} yr^{-1} (US EPA, 1983b). Increases in development in North Carolina have been found to cause significantly higher TN export (Atasoy et al., 2006). In contrast, TN export from the LID watershed averaged 2 kg ha^{-1} yr^{-1}, which is similar to TN export from forested watersheds (Frink, 1991). TN export from three urban/suburban watersheds in Maryland (1999–2001) with impervious area similar to that of the LID watershed was much higher at 6.0–7.4 kg ha^{-1} yr^{-1} (Groffman et al., 2004).

TP export was similar to nitrogen: a significant ($p = 0.001$) logarithmic trend was found for the traditional subdivision, whereas no trend was found for the LID watershed (Fig. 6d). After development, TP export from the traditional subdivision was approximately 2 kg ha^{-1} yr^{-1} (Fig. 6d). TP export from medium density and high density urban areas was found by EPA to be 1.48 and 2.45 kg ha^{-1} yr^{-1}, respectively (US EPA, 1983b). In contrast, average TP export from the LID subdivision was 0.4 kg ha^{-1} yr^{-1}, which is much lower than the 0.99 and 1.48 kg ha^{-1} yr^{-1} reported for low density and high density urban areas in the United States, respectively (US EPA, 1983b).

4. Conclusions

A large increase in runoff volume was observed as total impervious area increased through development of a traditional subdivision in Waterford, CT. Runoff coefficients also increased. These relationships were non-linear, indicating that as imperviousness increases, annual stormwater runoff volume increases exponentially. In contrast, annual stormwater runoff volume in the LID subdivision did not change as watershed impervious coverage increased. This lack of change in flow with increased impervious area is attributed to the LID stormwater management techniques used throughout the watershed.

Pollutant export regressions were similar to runoff regressions, indicating that the flow increase in the traditional subdivision was the primary driver behind pollutant export increases. In general, pollutant export from the traditional subdivision was in line with export

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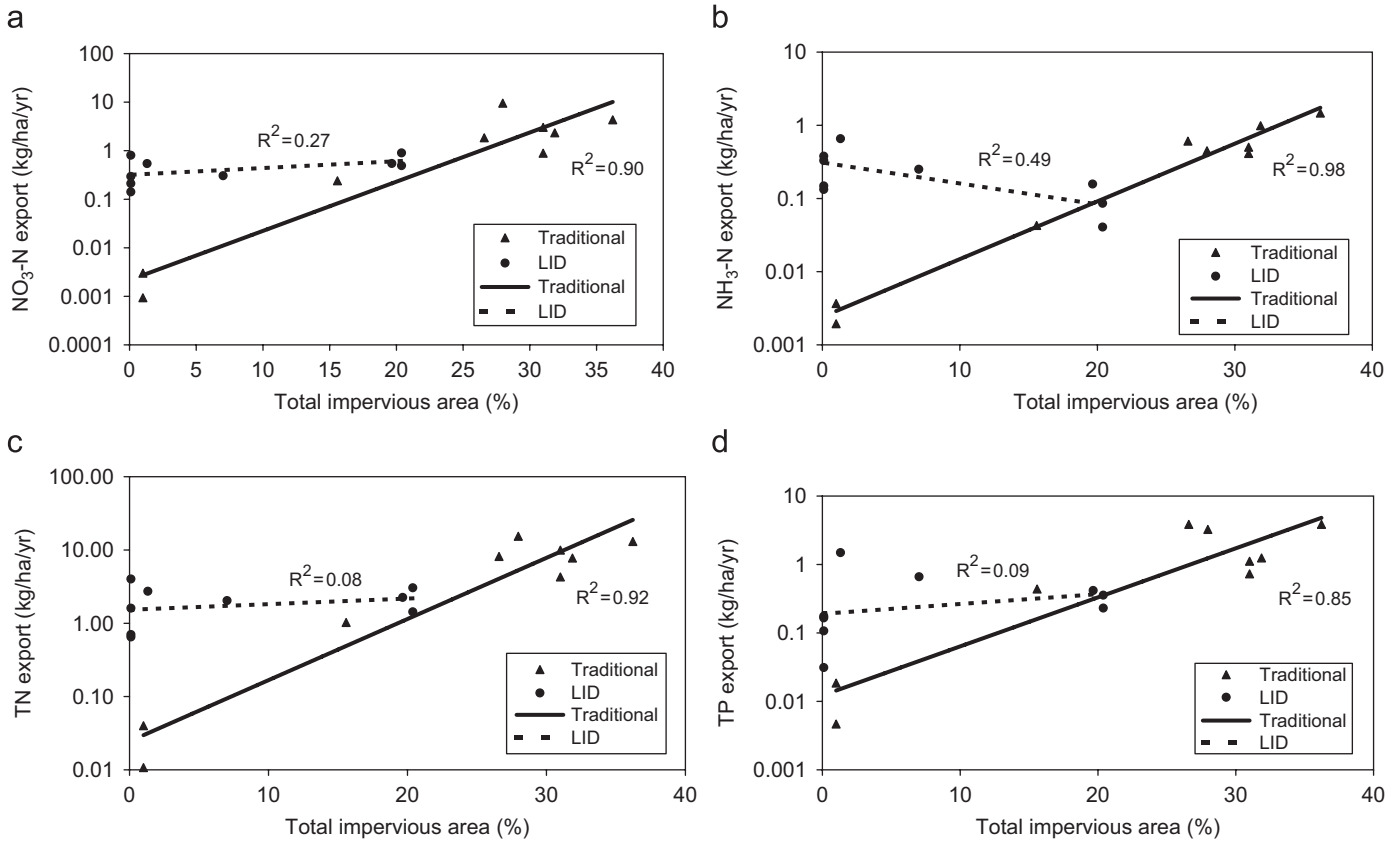

Fig. 6. Nutrient export (1996–2004) from traditional and LID subdivision: (a) NO_3–N, (b) NH_3–N, (c) TN, and (d) TP.

from urbanized watersheds, whereas pollutant export from the LID subdivision was more consistent with export from forested watersheds.

This paper did not examine peak flow rates or the responses of the different subdivisions to extreme events. The focus was the impact of the LID approach on the annual hydrologic budget. These findings indicate that the use of LID techniques on a watershed scale can significantly reduce the impacts of development on downstream water bodies.

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References

Arnold Jr, C.L., Gibbons, C.J., 1996. Impervious surface coverage: the emergence of a key environmental indicator. Journal of the American Planning Association 62 (2), 243–258.

Atasoy, M., Palmquist, R.B., Phaneuf, D.J., 2006. Estimating the effects of urban residential development on water quality using microdata. Journal of Environmental Management 79 (4), 399–408.

Booth, D.B., and Reinelt, L.E., 1993. Consequences of urbanization on aquatic systems-measured effects, degradation thresholds, and corrective strategies. Proceedings of Watershed '93: A National Conference on Watershed Management, March 21–24, Alexandria, VA.

Booth, D.B., Hartley, D., Jackson, R., 2002. Forest cover, impervious-surface area, and the mitigation of stormwater impacts. Journal of the American Water Resources Association 38 (3), 835–846.

Booth, D.B., Karr, J.R., Schauman, S., Konrad, C.P., Morley, S.A., Larson, M.G., Burges, S.J., 2004. Reviving urban streams: land use, hydrology, biology, and human behavior. Journal of the American Water Resources Association 40 (5), 1351–1364.

Brabec, E., Schulte, S., Richards, P.L., 2002. Impervious surfaces and water quality: a review of current literature and its implications for watershed planning. Journal of Planning Literature 16 (4), 499–514.

Brumbach, J.J., 1965. The climate of Connecticut. Department of Agriculture and Natural Resources, University of Connecticut.

Carle, M.V., Halpin, P.N., Stow, C.A., 2005. Patterns of watershed urbanization and impacts on water quality. Journal of the American Water Resources Association 41 (3), 693–708.

Coles, J.F., Cuffney, T.F., McMahon, G., and Beaulieu, K.M., 2004. The effects of urbanization on the biological, physical, and chemical characterstics of coastal New England streams. United States Geological Survey, Professional Paper 1695.

Davis, A.P., Shokouhian, M., Sharma, H., Minami, C., 2001. Laboratory study of biological retention for urban stormwater management. Water Environment Research 73 (1), 5–14.

Dietz, M.E., Clausen, J.C., 2005. A field evaluation of rain garden flow and pollutant treatment. Water, Air and Soil Pollution 167 (1–4), 123–138.

Dietz, M.E., Clausen, J.C., 2006. Saturation to improve pollutant retention in a rain garden. Environmental Science and Technology 40 (4), 1335–1340.

Please cite this article as: Dietz, M.E., Clausen, J.C., Stormwater runoff and export changes with development in a traditional and low impact subdivision, Journal of Environmental Management (2007), doi:10.1016/j.jenvman.2007.03.026

Dunne, T., Leopold, L.B., 1978. Water in Environmental Planning. Freeman, San Franciso, CA.
Ferguson, B.K., Suckling, P.W., 1990. Changing rainfall-runoff relationships in the urbanizing Peachtree Creek watershed, Atlanta, Georgia. Water Resources Bulletin 26 (2), 313–322.
Frink, C.R., 1991. Estimating nutrient export to estuaries. Journal of Environmental Quality 20, 717–724.
Gilbert, J.K., Clausen, J.C., 2006. Stormwater runoff quality and quantity from asphalt, paver, and crushed stone driveways in Connecticut. Water Research 40, 826–832.
Groffman, P.M., Law, N.L., Belt, K.T., Band, L.E., Fisher, G.T., 2004. Nitrogen fluxes and retention in urban watershed ecosystems. Ecosystems 7, 393–403.
Hollis, G.E., 1977. Water yield changes after the urbanization of the Canon's Brook catchment, Harlow, England. Hydrological Sciences Bulletin 22, 61–75.
James, L.D., 1965. Using a digital computer to estimate the effects of urban development on flood peaks. Water Resources Research 1 (2), 223–234.
Jennings, D.B., Jarnagin, S.T., 2002. Changes in anthropogenic impervious surfaces, precipitation and daily streamflow discharge: a historical perspective in a mid-Atlantic subwatershed. Landscape Ecology 17, 471–489.
JMP, Version 5 2002. SAS Institute Inc., Cary, NC, 1989–2005.
Klein, R.D., 1979. Urbanization and stream quality impairment. Water Resources Bulletin 15 (4), 948–963.
Leopold, L.B., 1968. Hydrology for urban land planning—a guidebook on the hydrologic effects of urban land use. Geological Survey Circular 554.
Makepeace, D.K., Smith, D.W., Stanley, S.J., 1995. Urban stormwater quality: summary of contaminant data. Critical Reviews in Environmental Science and Technology 25 (2), 93–139.
National Oceanic and Atmospheric Administration, 2006. Climatological Data Summary, Groton, CT, Station #063207. National Climatic Data Center, Asheville, NC.
Novotny, V., Olem, H., 1994. Water Quality: Prevention, Identification, and Management of Diffuse Pollution. Van Nostrand Reinhold, New York.
Pawlow, G.R., Nathan, K., 1977. Impact of suburban development on the rainfall-runoff relationship. Proceedings of International Symposium on Urban Hydrology, Hydraulics, and Sediment Control. University of Kentucky, Lexington, KY July 18–21.
Prince George's County, 1999. Low-impact development design strategies: an integrated design approach. Prince George's County, MD Department of Environmental Resources.
Roy, A.H., Rosemond, A.D., Paul, M.J., Leigh, D.S., Wallace, J.B., 2003. Stream macroinvertibrate response to catchment urbanisation (Georgia, USA). Freshwater Biology 48, 329–346.
Schueler, T.R., 1994. The importance of imperviousness. Watershed Protection Techniques 1 (3), 100–111.
Schueler, T.R., 2003. Impacts of impervious cover on aquatic systems. Watershed Protection Research Monograph No. 1, Center for Watershed Protection, Ellicott City, MD.
Sloto, R.A., 1988. Effects of urbanization on storm-runoff volume and peak discharge of Valley Creek, eastern Chester County, Pennsylvania. Water-Resources Investigation Report 87-4196. United States Geological Survey, Harrisburg, PA.
USDA, 2007. Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Official Soil Series Descriptions [Online WWW]. Available URL: 〈http://soils.usda.gov/technical/classification/osd/index.html〉 (accessed 26 January 2007).
US EPA, 1983a. Methods for chemical analysis of water and wastes. United States Environmental Protection Agency, EPA 600/4-79-020. Office of Research and Development, Cincinatti, OH.
US EPA, 1983b. Results of the nationwide urban runoff program. United States Environmental Protection Agency, NTIS PB84-185552.
US EPA, 2000. Low impact development (LID), a literature review. United States Environmental Protection Agency, EPA-841-B-00-005.
US EPA, 2001. Our built and natural environments. United States Environmental Protection Agency, EPA 231-R-01-002.
US EPA, 2002. National water quality inventory, 2000 report. United States Environmental Protection Agency, EPA-841-R-02-001.
Waananen, A.O., 1969. Effects of watershed changes on streamflow. In: Moore, W.L., Morgan, C.W. (Eds.), Urban Effects on Water Yield. University of Texas Press, Austin, London, pp. 169–182.
Wang, L., Lyons, J., Kanehl, P., Bannerman, R.T., 2001. Impacts of urbanization on stream habitat and fish across multiple scales. Environmental Management 28 (2), 255–266.

Please cite this article as: Dietz, M.E., Clausen, J.C., Stormwater runoff and export changes with development in a traditional and low impact subdivision, Journal of Environmental Management (2007), doi:10.1016/j.jenvman.2007.03.026