

Economic and Adaptation Benefits of Low Impact Development

Robert M. Roseen M.ASCE¹, Todd V. Janeski², Michael Simpson³, James J. Houle⁴, Jeff Gunderson⁵, Thomas P. Ballestero, M.ASCE⁶

Abstract:

This paper presents a range of case studies illustrating the advantages of Low Impact Development (LID) in economic terms and metrics employed in municipal decisions making. The environmental and water quality benefits of LID are commonly known however, there are also considerable economic, infrastructure, and climate adaptation benefits being overlooked or ignored. Municipalities are faced with difficult economic choices from reduced capital budgets and increasing regulatory demands. As such, there is value in understanding the substantive economic benefits—for both construction budgets and project life-cycle costs—that are increasingly being realized by municipalities, commercial developers, and others when using Green Infrastructure (GI) for stormwater management. LID is commonly misperceived as only adding expense to a project; however, this perspective fails to acknowledge the broader benefits that can be observed in terms of whole project costs for new construction, and in some instances, increased life-cycle benefits. While individually GI elements may add upfront capital expense to a project, reductions can result from a decreased need for conventional drainage infrastructure. Cost benefits are not observed in comparison with projects with few to no stormwater controls, but rather for projects consistent with new state and federal permitting requirements that address volume and pollutant reduction.

Studies examined reported cost reductions for LID designs when compared with typical designs that relied heavily upon the use of drainage infrastructure. Project cost reductions were observed from 6% in residential developments to as high as 26% in commercial projects. Municipal use of GI reported cost reductions of 21% to as high as 44%. Of significant importance is the shifting of monies from infrastructure to jobs associated with the maintenance activities. From a sustainability perspective, a range of benefits includes reductions in flood damage and increased resiliency of drainage infrastructure; as well as reductions of 33 to 50% in energy demands for heating and cooling. Additional benefits observed included a 50% reduction in time to sale, and

¹ Director, The UNH Stormwater Center, D.WRE, P.E., Ph.D., Assistant Research Professor, Department of Civil Engineering, 35 Colovos Road, University of New Hampshire, Durham, NH 03824; PH 603-862-4024; FAX 603-862-3957; e-mail: robert.roseen@unh.edu; web: www.unh.edu/unhsc/.

² Environmental Scientist, Virginia Commonwealth University, Trani Center for Life Sciences, 1000 West Cary St, PO Box 843050, Richmond VA 23284-3050, PH: (804) 828.2858 Fax: (804)828.1622 e-mail: tvjaneski@vcu.edu

³ Chair, Environmental Studies Department, Antioch University New England, Keene, NH USA 03431

⁴ Program Manager, The UNH Stormwater Center, 35 Colovos Road, University of New Hampshire, Durham, NH 03824; PH 603-767-7091; FAX 603-862-3957; e-mail: James.Houle@unh.edu; web: www.unh.edu/unhsc/.

⁵ Professional Content Writer, Portland, Or 97209, Email: jeffgun@earthlink.net

⁶ Associate Professor, Civil Engineering, P.E., Ph.D., P.H., C.G.W.P., P.G., Department of Civil Engineering; Principal Investigator, The UNH Stormwater Center, 35 Colovos Road, University of New Hampshire, Durham, NH 03824; PH 603-862-1405; FAX 603-862-3957; e-mail: tom.ballestero@unh.edu; web: www.unh.edu/unhsc/.

increased property values of 12-16%. Other benefits were incentives in the form of rebates, cost-sharing, and tax credits.

The use of LID planning and structural controls can contribute to building community resiliency in managing water resources and reducing the flood risk associated with current and projected changes in land use and climate. In one study, the implementation of LID practices reduced the number of culverts determined to be undersized by 29 to 100 percent for the 24 hr - 25 yr event. The marginal cost increase to replace such undersized culverts was also reduced by one-third. At the site scale, the use of LID as an adaptation measure can increase onsite storage of runoff compensating for increases in rainfall depths due to climate change. Onsite storage has additional benefits that increase resiliency such as increases in lag time and reducing and delaying the runoff peak discharge. Minimizing 2-year to 100-year floods with LID has the benefit to minimize stream instabilities that result from hydromodifications.

INTRODUCTION

In addition to the commonly known environmental and water quality advantages, considerable economic, infrastructure, and adaptation planning benefits are also being realized through the incorporation of Low Impact Development (LID) and green infrastructure (GI) for stormwater management. LID- and GI-based strategies can also be used as a means for building community resiliency to changing climates in a water resources management context. However, because of the need for brevity, this compilation of case studies is limited to examining projects costs and does not address the important value of ecosystem services.

Runoff pollution occurs when rainwater and/or snowmelt moves across the landscape collecting contaminants, and discharges into a receiving water. This process is a significant source of impairment to the nation's waterways. As the landscape transitions from natural conditions to higher percentages of impervious surfaces, effective strategies are necessary to capture and treat added stormwater volumes. Without effective strategies for managing stormwater, the list of impaired waters will continue to increase. Tremendous growth pressure has created the need for municipalities and watershed stakeholders to develop strategies for managing growth and maintaining watershed health. Most of the nation's growing population is located in urban or coastal areas with highly vulnerable water resources (Woods and Poole, 2010). Increasing population and changes to the urban landscape that increase the amount of impervious surfaces are directly related to the amount of nonpoint source pollution entering our watersheds, which negatively impacts aquatic resources (Caraco et al., 1998). Coastal communities reliant on the economic engines of viable shellfish fisheries, clean swimming beaches, or eco-tourism are also often negatively impacted by nonpoint source pollution (Bricker, 2007). Many communities, at a time when municipal budgets are already strained, are burdened by the need to allocate capital resources towards addressing impaired water bodies (303d listings), separating combined sewers, implementing total maximum daily loads (TMDLs), managing municipal separate storm sewer systems (MS4s), or employing other environmental restoration programs. Stormwater is the primary source of the top five pollutants causing impairments of 303d- listed waters, which include pathogens, metals, nutrients, organic enrichment, and sediment (USEPA, 2012). These pollutants are not effectively removed through conventional stormwater management approaches. A report examining urban stormwater management in the United States prepared by the National Research Council for the EPA detailed the failings of the current standard of practice for both stormwater management and regulatory permitting.

Traditional approaches to managing stormwater have focused on the application of drainage networks for diverting rainwater from residential or commercial areas with the purpose of improving safety and protecting the public from the effects of flooding. Capital and long-term operations costs are well understood and accepted with the usage of gray infrastructure. In most cases, protecting downstream ecological conditions was not considered. As the focus on protecting those resources increased, the design philosophy moved to capturing and treating smaller, more frequent storms and providing distributed storage throughout the built environment to reduce runoff volumes. LID is based on pre-development hydrology as the benchmark for runoff rate and volume goals for new projects. The use of LID reduces the need for larger treatment practices such as expensive gray infrastructure elements that concentrate stormwater flows and contaminants. LID takes into consideration the natural landscape to maximize onsite

storage and infiltration in an effort to protect downstream aquatic habitat, maintain groundwater recharge, and reduce peak discharges and runoff volumes to receiving waters.

Combined sewer overflows (CSOs) represent major water quality threats to hundreds of U.S. cities and communities. Traditional CSO management involves the use of gray infrastructure for increasing storage and conveyance capacity. However, integrating LID into CSO mitigation is being used to can help communities achieve CSO management at lower costs. Additional benefits include groundwater recharge, water quality improvements, and reduced treatment costs. LID can help minimize CSO events and the volume of contaminated flows by keeping runoff out of combined sewers (MacMullan, 2007). Although communities rarely attempt to quantify and monetize the avoided treatment costs from the use of LID, the benefits of these practices to decrease the need for CSO storage and conveyance systems can be factored into any economic analyses (EPA, 2007).

In addition, LID can improve the ability for communities to become more resilient to changes in climate (Brekke, 2009, Binder, 2010). The economic impacts due to flooding can be staggering. Rainfall intensity, duration, and frequency are all predicted to change due to changes in climate (Frumhoff, 2007). In some areas, the storm depth for today's 100-yr storm may occur at a frequency of a 25 yr storm in the future (Stack, 2005). The hydrological consequences will be manifested by more frequent flooding and increased damage to private property and critical infrastructure such as bridges, roads, and utilities. LID and GI provide distributed storage and infiltration throughout the watershed and has a positive cumulative effect on downstream areas by protecting those critical resources. As these practices are implemented, communities will realize avoided costs associated with the replacement and maintenance of infrastructure.

Economic Background. LID can also have tremendous economic benefits that have been observed for nearly all development sectors including commercial, residential, and public. LID is commonly misperceived as only adding expense to a project; however, this perspective fails to acknowledge the broader capital benefits that can be observed in terms of whole project costs for new construction, and in some instances, increased life-cycle benefits. By combining both gray (traditional) and green (LID) approaches, the added expense of LID can be offset by the reductions in other traditional practices that rely heavily upon drainage infrastructure.

In the vast majority of cases, the U.S. Environmental Protection Agency (EPA) has found that implementing well-chosen LID practices reduced total project costs while also protecting and restoring water quality (USEPA, 2007). Specifically, utilizing LID can result in project cost savings by decreasing the amount of required, expensive, below-ground drainage infrastructure and reducing or eliminating the need for other stormwater management-related facilities.

Other benefits include reduction of land disturbance and resultant land clearing and site development preparation savings. A Maryland study by Clar (2003) detailed a number of cost saving benefits by redesigning a conventional subdivision with LID designs. This included eliminating two stormwater ponds (costing roughly \$200,000), increasing the number of buildable lots (adding approximately \$90,000 in value), and allowing a more undisturbed site design (reducing clearing costs by \$160,000).

From a sustainability perspective, a range of benefits also includes savings associated with increased flood resiliency, reduction of flood damage to drainage infrastructure, and reduction in energy demands for heating and cooling. MacMullan (2007) reported natural vegetation and reduced pavement in a Davis, CA development using LID helped lower energy expenses by 33 to 50 percent compared to surrounding neighborhoods. Further economic incentives include the potential for higher property values and reduced permitting fees. A 184-lot LID subdivision was documented as less expensive to develop (average of \$7,000 less per lot), sold faster (50% decrease in time to sale), and have higher property values (12-16%) as compared to lots in conventional subdivisions (Mohamed, 2006).

Other planning tools include rebates, cost-sharing, tax credits, and floor to area ratio (FAR) incentives for utilizing LID. MacMullan (2010) reported that the City of Portland, OR has a Green Roof bonus that provides an additional three square feet of floor area for every one square foot of green roof, provided the green roof covers at least 60 percent. King County, WA pays 50 percent of the costs, up to \$20,000, to builders who install green infrastructure (MacMullan, 2010). Similarly, Austin, Chicago, and Santa Monica provide discounts for homes that employ LID. Also, in New York City, a project can earn a one year tax credit up to \$100,000 for inclusion of a green roof on 50 percent of the structure, and in Maryland, green building credits are being used to offset property taxes and can be carried ten years forward.

Climate Background

The core principle of LID is the management of increased runoff typically through filtration and infiltration strategies to provide treatment and reduce runoff volumes. These measures will have similar affects for managing increased storm sizes associated with changing rainfall patterns resulting from climate change.

Since 1976, the National Weather Service's Climate Prediction Center has documented a trend consisting of an increase in annual precipitation ranging from 0.3 to 1.5 inches per decade for most of the Midwestern and Eastern parts of the country (NOAA/NWS, 2012). An analysis of weather records for specific locales in New England from 1970 to 2000 shows there was a 20 to 28 percent increase in the average amount of rainfall in a twenty-four hour period (Stack et al., 2005; Simpson, 2012). Additionally, numerous researchers have indicated that with an increase in mean precipitation, there will be a disproportional increase in extreme precipitation events. (Hennessy et al., 1997; Zwiers and Kharin, 1998; Groisman et al., 1999; Meehl et al., 2000; Semenov and Bengtsson, 2002; Watterson and Dix, 2003; Tebaldi et al., 2006). Examining river gauge data in New England, researchers have found that of the 15 largest flooding events since 1934, 11 occurred in the last 25 years, 10 in the last 15 years, and 7 in the last 5 years. (Scholz, 2011).

Scientists have projected rainfall shifts in the Great Lakes states where total annual average precipitation levels may not change, but seasonal distribution of rainfall amounts will. These projections include increasing precipitation in the form of rainfall during winter seasons, but with summer months forecasted to experience decreasing rainfall. This region will also experience significant increases in the frequency and intensity of extreme precipitation events, especially

under a higher emissions scenario (Kling et al, 2003). In the region encompassing Maine to New Jersey- Pennsylvania, regional projections for precipitation show a similar response with a higher frequency of days with temperatures above 90°F, less winter precipitation falling as snow, and more rain precipitation. Additionally, projections call for an earlier spring snowmelt resulting in earlier peak river flows, with an increase in the frequency of intense storms and storms with greater amounts of precipitation (Union of Concerned Scientists, 2007; Wake, 2011).

Upgrading existing drainage systems is considered to be the most expensive means of accommodating increased peak flow resulting from climate change (Blanksby et al., 2003). Alternative economical adaptation strategies include reducing peak flow through the application of LID (Coffman, 2005), best management practices (BMPs) (Urbonas and Stahre, 1993), sustainable urban drainage methods (Butler, 2000), and smart growth lot design (Daniels, 2001).

METHODOLOGY

This study used a range of approaches to develop case study information, including a social science analysis of local municipal decision makers, engineering costing studies, and land use build-out projections.

Data development and analysis was conducted for the purpose of preparing cost estimates and cost-benefit analyses that compared conventional stormwater approaches to LID in the context of residential and commercial development, combined sewer overflow management, increasing levels of impervious cover (IC) and climate change. Direct interviews, market surveys, and focus groups were conducted with local municipal officials, professional educational outreach partners, and engineering professionals to capture the breadth of unpublished information for quantifying the cost benefits of LID and GI. Information for commercial and residential case studies was developed by engineering design consultants who developed and permitted each of the projects. In both instances, each project had a parallel conventional design that had been proposed initially, contested, and followed by an LID design that was ultimately approved and constructed. The design firms then performed an independent engineering costing analysis for each alternative using standard estimating approaches for project bidding based on materials quantities and labor to install.

In order to develop engineering costing analyses, the firms of SFC Engineering Partnership and Tetra-Tech Rizzo prepared alternate designs for the Boulder Hills (residential) and Greenland Meadows (commercial) projects, respectively. For both projects, hydrologic models typical of standard civil engineering were used for the site design and permitting of the project. Recognizing the high degree of error or uncertainty inherent in many aspects of stormwater modeling, the authors are cognizant of the limitations of event-based models, which are not intended to be reflective of the highest level of accuracy that is possible with continuous simulation, but rather, are indicative of engineering tools common to the permitting and design process. Modeling of stormwater runoff was performed using the Natural Resource Conservation Service (NRCS) TR-55 Curve Number (CN) method (NRCS, 1986). The CN method was selected for runoff computation because it is commonly-used, well-validated, and permits transparency-enabled facile diagnosis of the various sensitivities that can impact results. The 24-

hour rainfall runoff was calculated for the one-inch water quality event, and the two-year, 25-year, and 100-year storm events using a Type III rainfall distribution with historic and revised rainfall data sets. Revised precipitation data reflecting recent climate change through 2010 was used from the Northeast Regional Climate Center.

For the Oyster River watershed culvert vulnerability analysis, researchers utilized a geographic information system (GIS)-based watershed modeling approach to examine the hydrological impact on existing culvert infrastructure of several climate change and land use scenarios. Field data was collected on culvert capacity, vegetation cover, slope, soils, permeability, roads, and land use. The project applied standard hydrological assessment methods to estimate runoff volumes and peak flows under current and projected future precipitation and land-use patterns (Stack et al., 2010; Durrans, 2003). A curve number reduction method for LID was also used (McCuen 1983; MDEP 2008). Because there are a limitless variety of LID system applications in a design context, the CN analysis performed here is based on providing a one-inch WQV volume for all impervious surfaces. For the CN analysis, the practice type is unimportant, but storage volume is critical. This analysis applied the use of a variation of bioretention and porous pavements for design scenarios (Stack et al 2010). Individual culverts were ranked according to vulnerability and potential hazard to the community with a prioritized schedule for guiding the planning of LID ordinances and culvert upgrades.

RESULTS AND DISCUSSION

Economics

This section details the cost benefits of LID for the commercial, residential, and municipal case studies. The first two case studies show how utilizing an LID approach for site drainage engineering, specifically with porous asphalt, led to more cost-effective site and stormwater management designs; followed by a bioretention retrofit.

Residential Development (Boulder Hills): In 2009, a residential development was installed consisting of a 14-acre, 24-unit condominium community in Pelham, New Hampshire. The initial conventional design proposal had substantial wetland impacts, a conventional design with asphalt paving, and typical drainage (curbing, catch-basins, stormwater ponds, outlet structures). A second design was proposed that used widespread infiltration and filtration on the site's extensive upland sandy soils, and included rooftop infiltration trenches, porous asphalt driveways, sidewalks, and New Hampshire's first porous asphalt road. Table 1 shows construction estimate cost comparisons between both options. The LID option had a 6 percent reduction in site development expenses (\$49,000 less) as compared to the conventional option. Although materials for the porous asphalt were more expensive than traditional asphalt, cost reductions in drainage infrastructure, site clearing, and erosion control were achieved.

Commercial Development (Greenland Meadows): In 2008, a large commercial retail facility was constructed consisting of three franchise stores (home improvement, department, and grocery) and an estimated usage of 10,000 vehicles per day. The 38.4-acre retail shopping center located in Greenland, New Hampshire included a 4.5-acre porous asphalt installation (largest in Northeast), subsurface gravel wetland, and storage of rooftop runoff,. Due to limited

permeability of the underlying clay soils, a stormwater management plan had to incorporate stormwater quantity attenuation, storage, conveyance, and treatment. Table 2 presents total construction cost estimates for two options. For the LID option, there were reductions of \$71,000 for earthwork and \$1,743,000 for stormwater management costs due to a lower reliance upon conventional infrastructure. Table 3 details pipe quantities for the two options. The LID design required nearly 10,500 less linear feet of 36"-48" diameter pipe than the conventional design. A crushed stone reservoir within the pavement system was used in place of the pipe. The LID option was calculated at \$930,000 less compared to the conventional option, a 26 percent reduction in site development expenses.

Parking Lot Bioretention Retrofit: A bioretention retrofit was performed at the University of New Hampshire campus. In certain instances using existing resources, simple retrofits can be performed at minimal expense. This retrofit involved the installation of a bioretention system within the vegetated median in the parking lot and subsequently connecting the system directly to adjacent drainage infrastructure. Facilities operations can often provide both labor and equipment for retrofitting existing infrastructure. In this instance, and many others with municipal staff, retrofit expenses were limited to design and materials costs only, while installation expenses for labor, equipment, and some infrastructure can be potentially avoided. Total project cost per acre of impervious cover was \$14,000. With labor and install provided, costs were limited to materials and plantings at \$5,500 per acre of impervious cover.

Conventional CSO Abatement: Conventional storage, pumping, and treatment are extremely effective yet resource intensive for both construction and long-term operations. The Narragansett Bay Commission (NBC) in Providence, Rhode Island, under EPA direction, initiated a phased CSO Abatement Plan for mitigating CSOs and protecting the Narragansett Bay and the region's urban rivers. Phase I of the project included a \$365 million, three-mile, 30-foot diameter deep rock tunnel with an estimated 62 million gallons of capacity for reducing overflow volumes by approximately 40 percent. The associated operational and maintenance costs of Phase I are \$1 million per every one billion gallons of stormwater and sewage flow, or \$1 for every 1000 gallons (Brueckner, 2009). Phase II of the CSO abatement plan includes two near-surface interceptors for conveying flow at an estimated capital costs of \$250 million.

Green Infrastructure and Municipal CSO Management

Portland Oregon: The City of Portland, Oregon is considered by many to be a national leader in the implementation of innovative stormwater management strategies and designs. In June of 2000, the city was faced with the need to upgrade an undersized sewer pipe system in the Brooklyn Creek Basin, extending 2.3 square miles from Mt. Tabor to the Willamette River. The city considered a new separated stormwater collection system at a cost of \$144 million (2009 dollars), using gray infrastructure to support undersized pipes in this basin. A second plan was developed and ultimately chosen that included a basin redesign using a combined gray infrastructure and LID approach. Including \$11 million allocated for green solutions, the cost estimate for this integrated approach was \$81 million, a 44 percent capital savings of \$63 million (Portland, 2009). Responding to federal and state requirements, including Clean Water Act stipulations, the city constructed two CSO tunnels and a new pump station in order to significantly reduce CSO events. However, more projects and programs were needed for providing additional CSO mitigation. The city considered a range of stormwater management

solutions (Table 4) including LID strategies, evaluating options based on cumulative capital costs, marginal costs for gallons removed, and cumulative volume that could be removed. Cost-effectiveness was determined by an inflection point that compared costs to stormwater volume that could be diverted. Projects/programs costing at or below this marginal cost (determined to be about \$4 per gallon), were recommended for implementation for long-term CSO control (first 7 listed in Table 2). As shown, 5 of these programs included LID strategies.

The \$4 per gallon marginal cost is also considered as the avoidance cost associated with facilities maintenance and operations for constructing a larger CSO tunnel. In life-cycle cost analyses, this “savings” can reduce capital costs of other LID facilities that the city builds for objectives other than CSO control (e.g. water quality improvements, basement flooding relief), but still removes stormwater from entering the CSO tunnels (Owen, 2009).

Kansas City, Missouri: Challenged by the significant expense of CSO reduction using gray infrastructure, the City of Kansas City (KC), Missouri began a feasibility assessment of integrating green solutions as part of a National Demonstration Project funded by USEPA. Under a USEPA mandate, the cities nationwide are required to update their networks of aging sewer infrastructure in order to address overflows from combined and separate sewer systems. For KC, this amounts to 6.4 billion gallons annually. The original, estimated costs associated with overhauling KC’s total sewer system were \$2.4 billion dollars. Yearly operations and maintenance costs (O&M) of the upgrade were estimated at \$33 million. In considering cost-effective alternatives, the city explored the feasibility of incorporating LID strategies in combination with gray infrastructure improvements and subsequently submitted a new plan that proposed a total of \$80 million in green solutions programs. Based on city analyses, it was determined that replacing gray infrastructure with green solutions would be cost-effective in portions of the 744-acre Middle Blue River Basin (MBRB). Two CSO storage tanks could be eliminated by the use of distributed storage using LID without increasing costs or reducing CSO control performance (Leeds, 2009). Compared to an estimated \$54 million gray infrastructure design capable of providing 3 MG of storage, a revised MBRB Plan consisting of gray infrastructure and LID with distributed storage of at least 3.5 MG was estimated at \$35 million – a 35 percent reduction (\$19 million less) in estimated capital costs as compared to the original gray infrastructure plan.

Chicago, Illinois: The City of Chicago has been focused on the use of LID for reducing combined sewer system volumes. The city is committed to managing stormwater more sustainably, and has implemented LID initiatives such as the Chicago Green Alley Program for facilitating infiltration, improving water quality, and diverting water from the combined sewer system, thus reducing energy demands associated with pumping and treating sewage. LID and other BMP measures are also used for limiting stormwater volumes and reducing the frequency and intensity of CSO events. In 2009, based on City of Chicago estimates, BMP designs (including LID strategies) effectively diverted 70,182,000 gallons of stormwater from the city’s combined system.

New York City, New York: New York City has furthered the analysis in their 2010 Green Infrastructure Plan, which details a range of operations and maintenance benefits, including sustainability metrics. A very significant element is the extension of economic benefits in terms

of lower O&M costs and a greater distribution of costs towards jobs, resulting in job creation. The plan also details reducing energy costs, increasing property values, lowering O&M costs in terms of energy demand, improving air quality, and reducing CO₂ production. This would be largely accomplished by the capture and infiltration of one-inch of rainfall on 10 percent of impervious cover in combined sewersheds by 2030. The City modeled CSO volume projections for both gray infrastructure and GI strategy. The GI strategy implemented over 20 years would reduce CSO volumes by nearly 2 billion gallons per year (bgy) as compared to the gray infrastructure approach (19.8 bgy vs. 17.9 bgy). The long-term capital costs associated with full implementation of the GI strategy are forecasted at 22 percent, or \$1.5 billion, less compared to the gray infrastructure strategy over the next 20 years. In terms of a unit cost basis, the GI option is \$0.45 per gallon vs. \$0.62 per gallon for the gray strategy.

In addition, the Green Infrastructure Plan shows a greater distribution of funds to support maintenance-related activities in the form of salaries and benefits. This is an important finding as job creation is one element of sustainability that is often overlooked. The NYCDEP also estimated a range of associated sustainability benefits including lower energy costs, reduced CO₂, better air quality and increased property values. The total accumulated value of these benefits is projected from \$139 to \$418 million over 20-year implementation.

Climate Change

For many regions of North America, projections call for an increase in the depth, frequency and duration of precipitation events, which in turn can translate into significant environmental impacts to natural and human built systems (NRC, 2001). Projected changes in climate and associated impacts through this century should be considered when planning for development and redevelopment. By adding distributed storage and infiltration throughout project sites, LID and GI can have a cumulative positive effect on a watershed and can be used as an adaptation tool for building resiliency to extreme events.

With Boulder Hills, LID planning and structural controls were used to minimize increases in runoff volumes due to development. In addition, this site can demonstrate impacts on stormwater runoff for both post-development and for increased storm depths under potential climate change scenarios. For the Boulder Hills site design, recharge volumes for pre-development and the LID design are very similar, whereas the conventional design demonstrates a tremendous increase in storm runoff volumes. For water quality volume (in most regions equivalent to the one-inch, 24 hour rainfall event), many LID designs yield no additional runoff, thus replicating pre-development conditions. This is significant because in the New Hampshire region, 92 percent of the storms are less than one-inch from which no runoff would be generated. For larger storms where runoff is observed, the volume retained from LID designs is actually greater than pre-development. This impact is most notable with increasing storm depth, and in part, is due to added infiltration and storage built into the LID landscape, as well as the tremendous lag time that occurs using porous pavements. The use of porous pavement systems adds substantial storage capacity because they are usually designed to serve for transportation functions (load capacity and resistance to frost depth in cold climate zones) as well as for stormwater management. This represents additional resiliency and explains why the peak flow rates and

runoff volumes for the LID site are lower than pre-development conditions. Similar improvements could also be expected to a varying degree for higher density sites with similar system and site characteristics.

Changes in climate and related impacts were analyzed with respect to stormwater conveyance infrastructure in the southern NH Oyster River watershed, to examine the relationship among land use impacts, a changing climate (higher frequency of larger precipitation events), and the use of LID as an adaptation tool to mitigate projected increased runoff (Stack, et al 2010). Oyster River is a 19,857-acre watershed which includes portions of six townships and a population density of 304 persons per square mile (United States Census Bureau, 2010). Population growth, at 8.6 percent, had been vigorous for an 8-year period ending in 2008, equaling 10.8 percent per decade. This exceeds the growth rate through the 1990s of 0.8 percent per decade. Climate change scenarios were developed, which included costing estimates for upgrading conveyance systems to compensate for the changes in hydrology, and focused on the impacts to culvert sizing using climate change precipitation scenarios based upon the IPCC optimistic A1B and pessimistic A1Fi scenarios, named “Balanced Growth” and “Fossil Fuel Intensive Growth”, respectively. Culverts were determined to be undersized if the actual cross-sectional area of the culvert currently in place was less than the cross-sectional area modeled for a given scenario.

The baseline scenario indicated 5 percent of culverts are currently undersized for the amount of run-off generated by a 25-year, 24-hour rain event based on historic rainfall. When build-out is considered, and utilizing the precipitation amounts from the historic rainfall records, an additional 7 percent are undersized for the “most likely” 25-year, 24-hour event. A maximum of 35 percent of culverts are projected to be undersized under full-build-out, with no LID methods.

These culvert vulnerabilities are projected to increase with climate change. The analysis, using an optimistic future scenario of higher rainfall (A1b), estimates that the “most likely” 24-hour, 25-year event for the mid-21st century will be 35 percent greater than the 24-hour, 25-year baseline precipitation event; the “most likely” 25-year more pessimistic future scenario of increase in rainfall (A1Fi) will be 64 percent greater than the 25-year baseline precipitation event.

The incorporation of LID under the more moderate modeled precipitation amounts resulted in a 29 to 100 percent reduction in the number of culverts within the watershed that are undersized. However, for the more pessimistic A1Fi climate change model, the efficacy of LID in reducing the number of undersized culverts decreases. This becomes apparent when considering a static effective storage capacity of one inch was utilized when incorporating LID into the buildout scenario and storage capacity is exceeded as future climate change scenarios delivered progressively greater and greater precipitation. A marginal cost analysis was performed which detailed the increases in runoff from build-out by 22 percent per-culvert. With the use of LID, the marginal cost increased 14 percent, or a 33 percent reduction. Study findings indicated that a set of LID methods that is modest but achievable can mitigate the impacts of climate change and population growth.

SUMMARY AND CONCLUSIONS

Numerous quantifiable economic benefits exist for the usage of LID and GI strategies for both planning and implementation. Better education for the development and design communities can communicate a broader understanding of the range of benefits that are being observed nationally. Benefits include water quality and habitat protection, increased resiliency in the developed landscape, and the economics of water management. Economic benefits are realizable in both the short-term sense of project capital costs as well as in long-term sustainability metrics such as reduction of energy needs for heating and cooling, and lower O&M costs of municipal wastewater treatment including ecosystem services. Capital benefits are commonly observed as a result of an economy of high priced gray infrastructure in combination with the generous use of LID and GI techniques. Of significant value is the use of LID and GI as an adaptation measure to increase community resiliency in managing water resources and reducing the infrastructure and marginal costs due to increased runoff associated with current and projected changes in land use and climate.

LIMITATIONS AND FUTURE RESEARCH

There are many limitations to the use of LID, in particular the unrestrained use around sensitive resources. LID is not a replacement for natural resource protection and conservation. The use of LID can in some instances allow development access to areas that would have been prohibited by conventional designs due to standard regulatory and zoning limitations on volume and impervious cover.

Limitations of the project methodology include the usage of standard, non-controlled, design and permitting approaches as a data source. The limitations extend from the project structure which was to survey and compile existing projects and data sources nationally. This is distinct from controlled verifiable experimental design. Research grade experimental design would use the best available practices for hydrologic modeling, rather than tools common to design and permitting. The economic data was derived from design sources using professional judgment and standards in common practice. Engineering and project reports are referenced for documentation.

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Sustainable Infrastructure Administrator for the City of Chicago Department of Water Management, Maine Department of Environmental Protection and the USEPA

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FIGURES AND TABLES

Table 1: Comparison of Material Unit Costs

Item	Conventional	LID	Difference
SITE PREPARATION	\$23,200	\$18,000	-\$5,200
TEMP. EROSION CONTROL	\$5,800	\$3,800	-\$2,035
DRAINAGE	\$92,400	\$20,100	-\$72,273
ROADWAY	\$82,000	\$128,000	\$45,918
DRIVEWAYS	\$19,700	\$30,100	\$10,386
CURBING	\$6,500	\$0	-\$6,464
PERM. EROSION CONTROL	\$70,000	\$50,600	-\$19,460
ADDITIONAL ITEMS	\$489,700	\$489,700	\$0
BUILDINGS	\$3,600,000	\$3,600,000	\$0
PROJECT TOTAL	\$4,389,000	\$4,340,300	-\$49,000

Table 2: Comparison of Material Unit Costs

Item	Conventional Option	LID Option	Cost Difference
MOBILIZATION / DEMOLITION	\$555,500	\$555,500	\$0
SITE PREPARATION	\$167,000	\$167,000	\$0
SEDIMENT / EROSION CONTROL	\$378,000	\$378,000	\$0
EARTHWORK	\$2,174,500	\$2,103,500	-\$71,000
PAVING	\$1,843,500	\$2,727,500	\$884,000
STORMWATER MANAGEMENT	\$2,751,800	\$1,008,800	-\$1,743,000
ADDITIONAL WORK-RELATED ACTIVITY (utilities, lighting, water & sanitary sewer service, fencing, landscaping, etc.)	\$2,720,000	\$2,720,000	\$0
PROJECT TOTAL	\$10,590,300	\$9,660,300	-\$930,000

* Costs are engineering estimates and do not represent actual contractor bids

Table 3: Conventional and LID Options Piping

Design	Function	HDPE Pipe Size (in)	Quantity (linear feet)	Cost
Conventional	Distribution	6 to 30	9,680	\$298,340
	Detention	36 and 48	20,800	\$1,356,800
LID	Distribution	4 to 36	19,970	\$457,780
	Detention*	--	0	\$0

*Costs associated with detention in the LID option were accounted for under "earthwork" in Table 2.

Table 4: CSO Control Alternatives Costing for Portland, OR

Project/Program	Marginal Cost (\$/Gallon)	Cumulative Volume Removed (MG)	Cumulative Capital Cost
Extended Downspout Disconnection Program (can include LID)	\$0.89	7.45	\$6,633,000
School Disconnection*	\$1.10	9.22	\$8,587,000
Church Disconnection*	\$2.12	10.18	\$10,618,000
Beech-Essex Sewer Separation	\$2.78	11.58	\$14,507,000
ES Curb Extensions (LID)	\$2.87	15.87	\$26,830,000
Tanner Phase 3 Sewer Separation	\$3.47	18.97	\$37,598,000
ES Roof & Parking IC (LID)	\$4.08	36.61	\$109,645,000
NWN Pre-design – Tanner North Sewer Separation	\$5.12	36.83	\$110,772,000
Carolina Stream & Storm Separation	\$5.21	37.85	\$116,090,000
NWN Pre-design – Tanner South Sewer Separation	\$6.16	38.11	\$117,693,000
NWN Pre-design – Tanner Central Sewer Separation	\$7.60	38.14	\$117,962,000
NWN Pre-design – Nicolai/Outfall Sewer Separation	\$11.76	38.68	\$124,283,000
NWN Pre-design – Nicolai/Outfall 13 Sewer Separation	\$12.04	39.36	\$132,500,000
Green Roof Legacy Project (LID)	\$13.65	40.4	\$146,679,000
NWN Pre-design – Nicolai/Outfall 15 Sewer Separation	\$17.98	40.77	\$153,225,000
Holladay Sewer Separation	\$20.94	41.45	\$167,585,000
NWN Pre-design – Balch Neighborhood Sewer Separation	\$55.06	41.59	\$175,249,000
NWN Pre-design – Balch/Forest Park Storm Separation	\$93.82	41.72	\$187,275,000

* Church and School Disconnection programs assumed downspout disconnection and drywells would remove this stormwater volume. The former is an LID method.

Table 5: Summary of Cost Analysis across Precipitation, Land-use and Antecedent Soil Conditions

Moisture Condition	Precipitation Scenario	Land-Use Scenario	Precipitation (in)	Undersized Culverts	Replacement Cost	Upgrade Cost	Marginal Cost	% Difference	Cost per Culvert	
AMC II	Baseline	Current	5.4	4	16,900	24,600	7,800	46%	1,900	
		Build-Out	5.4	8	56,600	88,300	31,800	56%	4,000	
		LID	5.4	6	28,900	50,500	21,600	75%	3,600	
	A1b	Current	6.9	9	75,700	101,200	25,600	34%	2,800	
		Build-Out	6.9	16	145,800	204,300	58,600	40%	3,700	
		LID	6.9	12	110,900	152,600	41,800	38%	3,500	
	A1fi	Current	8.3	17	147,200	203,800	56,700	38%	3,300	
		Build-Out	8.3	19	171,600	234,400	62,900	37%	3,300	
		LID	8.3	18	160,700	222,300	61,600	38%	3,400	
	AMC III	A1b	Current	6.9	18	151,400	208,900	57,600	38%	3,200
			Build-Out	6.9	20	175,800	239,500	63,800	36%	3,200
			LID	6.9	19	165,000	227,400	62,500	38%	3,300
A1fi		Current	8.3	22	191,900	273,200	81,400	42%	3,700	
		Build-Out	8.3	25	224,800	321,400	96,600	43%	3,900	
		LID	8.3	23	201,000	269,900	68,900	34%	3,000	
							+95%			
							c.i.:	48%	3,565	
							Mean:	42%	3,317	
							-0.95	37%	3,070	

FIGURES

