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May 18, 2007

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Abstract

Neighborhoods are long-term, capital-intensive investments. Today's new construction or redevelopment is expected to perform for decades into the future, and these structures, infrastructure, and entire communities will operate under different climatic conditions than those observed over the last century. Their design, construction, and operation present opportunities to ameliorate or exacerbate the local impacts of global climate change. Sustainable designs have the potential to achieve long-term performance goals despite changing conditions, particularly for climate-sensitive elements such as the management of storm water and non-point source pollution. Conversely, the performance of conventional designs may be degraded over time with significant negative consequences for the environment. Thus, when choosing between conventional and sustainable development approaches, planners should consider the benefits conferred by sustainable development in adapting to climate change.

Climate is changing across the United States. bservation Observations show that during the last century air temperatures are warming and precipitation patterns are changing (USGCRP 2000; IPCC 2001; Groisman et al., 2005). It is likely that observed trends will continue and potentially accelerate in the coming decades in response to increases in emissions of greenhouse gases (USGCRP 2000; IPCC 2001). Changes in climate mean that structures, infrastructure, and communities built today will need to perform under conditions that are very different from those observed over the last hundred years. This will require new approaches to the design of the built environment and consideration for its interactions with natural systems.

Traditional environmental impact assessments focus on the consequences of development under static climatic conditions, but emerging evidence of changes in temperature and precipitation suggests that planners should consider the implications of these changes on the performance of the built environment.

The built environment provides a physical linkage between human activities and the natural environment. The built environment thus can mediate, buffer, and to some degree insulate human activities from climatic variability and change. However, poor planning can result in built environments that not only fail to meet performance goals and expectations, but that exacerbate the impacts of climate change. This means that many potential consequences of climate change are within the control of planners, developers, and builders.

This study considers the potential for adapting to climate change through the use of sustainable neighborhood design. The concept of neighborhoods varies widely, but we have focused our study on the concept used in the U.S. Green Building Council (USGBC)'s forthcoming *Leadership in Energy and Environmental Design for Neighborhood Development* (LEED® for Neighborhood Development or LEED-ND) standards. The LEED-ND system has not yet been finalized, but it provides a useful platform for considering many of the key features of neighborhood design. In this study, LEED-ND serves as a foundation for two analyses:[1]

(1) a qualitative assessment of the potential impacts of climate change on key environmental concerns addressed by the LEED-ND standards, and

(2) a quantitative analysis of the potential performance of a neighborhood designed in accordance with many of the principles embodied in LEED-ND, compared to a conventional neighborhood design, under a range of possible future conditions.

The qualitative analysis provided an initial evaluation of LEED-ND elements to changing climatic conditions while highlighting vulnerabilities and adaptive opportunities. The quantitative analysis focused primarily on the implications of the most climate-sensitive design elements, particularly management of stormwater, non-point source pollution and heat islands.

This analysis found that approximately one-third of the prerequisites and credits in the September 2005 draft LEED-ND rating system address climate-sensitive design elements and provide opportunities for adaptation to future climatic conditions (Table 1). These climate-sensitive elements provide opportunities for adaptation (i.e., configurations that are robust to changing conditions). When focusing on water resources, this study found that a sustainable neighborhood is likely to be more resilient to climate change when compared to a conventional neighborhood design. As expected, many elements of the sustainable design also provide immediate benefits in terms of reducing non-point source pollution. Further, these benefits would continue into the future, generating less runoff volume and pollutant load despite substantial changes in precipitation associated with climate change.

Finally, the same reductions in impervious surface that decrease non-point source pollution loads also reduce the extent of unshaded surfaces, which would help reduce both air temperature (the principal manifestation of heat islands) and runoff temperature.

Understanding a changing climate

The Earth's climate is changing. Observations from weather stations and orbiting satellites have detected significant trends in key climatic variables, such as the frequency of summer heat waves and the length of the growing season. Furthermore, experiments using Global Climate Models consistently show that under almost all plausible socio-economic scenarios greenhouse gas emissions will rise in the coming decades, and that the climate system will respond with continued warming throughout the 21st century. Persistent, irreducible uncertainties concerning future climate reflect the stochastic nature of the climate system itself and our fundamental inability to predict the course of human events (e.g., decisions by nations to adopt greenhouse gas regulation). Decision makers at local and regional levels are thus faced with significant uncertainties concerning future climatic conditions (Murphy 2000).

But uncertainty should not justify inaction. Planners, developers, and builders can take steps today to reduce the potential impacts of climate change on people and the environment (in the language of climate policy, planners and builders can both *mitigate* climate change (i.e., reduce GHG emissions through urban design) and *adapt to* climate change (i.e., increase resilience to change).

Planning and infrastructure decisions are typically based on design specifications that implicitly assume that climate is static. However, it is becoming increasingly clear that

a) climate is changing -- trends are toward warmer temperatures, more frequent heat waves, more intense precipitation events, and longer, potentially more severe droughts -- and

b) these changes have significant consequences for the performance of the built environment -- designs based only on past conditions will encounter significantly different conditions during their expected service lifetimes.

Changes in precipitation patterns will have some of the most important implications for the built environment. Groisman et al. (2005) found that the intensity of the heaviest 5% of precipitation events has increased by 4.6% per decade from 1970 to 1999. These trends are likely to continue with significant increases in the number of days with heavy precipitation for the northern tier of the United States, as well as longer dry periods in much of the US. Intense precipitation events contribute disproportionately to storm water and non-point source pollutant loads received by surface waters.

Precipitation and runoff are fundamental considerations in the design of structures and infrastructure. More frequent intense rain events produce increased stormwater runoff volume, nutrient contamination, and sediment loading. Changes in the frequency of dry periods would exacerbate low-flow conditions for streams and rivers and reduce assimilative capacity. Increased ambient temperatures and impervious surfaces that produce runoff with elevated temperatures adversely impact streams and receiving water bodies, especially cold water habitats. These water quality and quantity impacts are key parts of the environmental performance of the built environment, and therefore often serve as key design specifications and important regulatory benchmarks (e.g., goals associated with Total Maximum Daily Load permit requirements).

Performance of the built environment

The built environment will play a significant role in determining the impacts of climate change on the natural environment. Planners can help design and approve built environments that have the ability to mitigate or adapt to climate change. The role of urban design in climate impact mitigation has been well-documented; urban form has a strong influence on energy use in transportation, residences, and commerce, and energy use in turn is the primary driver of greenhouse gas emissions (van't Veld and Plantinga 2005). The work reported here emphasizes opportunities for adaptation. Adaptation involves choices made to offset or reduce the negative impacts associated with climate change (Smit and Wandel 2006). The goal is to maintain desired levels of performance under changing conditions (e.g., goals for energy use, stormwater runoff, nonpoint source pollution). Depending on the circumstances, the design of homes, offices, and neighborhoods can exacerbate or reduce climate change impacts. For example, increases in the frequency and severity of summer heat waves may increase heat stress, compound air quality problems through increased energy use from the air conditioning of buildings, and thereby have negative effects on quality of life (Luxmoore et al. 2005). Specific features of neighborhood design, such as shading, choices of construction materials, use of pervious materials for hardscapes, and the orientation of buildings will reduce impacts at a local scale and negate or even improve local conditions despite global changes (Akbari et al. 2001; Doulos et al. 2004; Kikegawa et al. 2006).

Sustainable neighborhood design

Maintaining the performance of the built environment under changing conditions is a key goal of what has become known as sustainable neighborhood design (Engel-Yan et al. 2005;

Antrop 2006). This concept encompasses a broad range of specific practices that have been advocated by a diverse set of groups. The Congress for New Urbanism, the Natural Resources Defense Council (NRDC), and the U.S. Green Building Council (USGBC) have formed a partnership to develop the LEED-ND system. All comments and analyses in this paper refer to the draft LEED-ND standards published for public comment in September 2005.

LEED-ND will expand on green building's traditional emphasis on the environmental performance of a single structure by including additional consideration for elements such as compactness, transit orientation, housing mix, mixed uses, and walkability. The standards are designed to be applied to a whole community or a fraction of a neighborhood, and, as of this writing, the product puts no explicit restrictions on geographic size or scope. The creators of the standard hope that LEED-ND will provide an incentive for environmentally superior development practices through better location, design, and construction of new residential, commercial, and mixed-use development.

The core of LEED-ND is a set of prerequisites and credits. All projects certified under LEED-ND will need to meet minimum prerequisites, including compact development patterns, and the protection of wetlands, water bodies, and imperiled species. To earn certification, projects will also need to implement additional voluntary actions referred to as credits. LEED-ND credits include actions such as mitigation of heat island effects and storm water management strategies. Based on the credits achieved, the LEED-ND scoring system will calculate an overall score and designation of ‘certified’, ‘silver’, ‘gold’, or ‘platinum’.

Qualitative assessment of adaptive opportunities

In this study, we screened all LEED-ND prerequisites and credits based on their potential to provide opportunities for adaptation to changing climatic conditions. Our assessment emphasized elements associated with water quality or aquatic ecosystem management – areas that are directly impacted by changes in precipitation. For each prerequisite and credit, we qualitatively assessed its ability to provide an adaptive benefit under changing climate conditions, including higher ‘high flows’ (flood events), lower ‘low flows’ (drought events), and increased water temperature. For example, a development may receive LEED-ND credit for high-quality efforts to restore riparian habitat and wetlands, which is likely to help aquatic ecosystems adapt to higher surface water flows (e.g., restored wetlands slow and filter floodwaters). As such, that credit is deemed in our analysis to provide a potential adaptive benefit based on the screening criteria. Our screening analysis identified 25 prerequisites and credits that could provide adaptive benefits for water resources or aquatic ecosystems (shaded in grey in Table 1).

Quantitative assessment of neighborhood performance

The qualitative review of prerequisites and credits provided a coarse screening of the sensitivity of LEED-ND prerequisites and credits to climate change and an assessment of their potential as tools for adaptation. This assessment indicated that adaptive opportunities were concentrated among the subset of prerequisites and credits designated as “environmental,” particularly those associated with storm water management and non-point source pollution. We wanted to provide quantitative information about the potential adaptive benefits of neighborhoods that applied the principles underlying LEED-ND to the management of these environmental issues.

This quantitative assessment required a case study-based approach. We modeled the climate-adaptive performance of two site plans for the redevelopment of South Weymouth Naval Air Station (SWNAS). The site is a 1400-acre tract south of Boston, Massachusetts, that was formerly an aviation facility. It has been the largest single development opportunity in the region since the base was closed in 1997. A heavy rail commuter line runs along the site's western edge, providing the potential for transit-oriented development. Multiple site designs have been proposed for the SWNAS. We considered two in detail (Figure 1):

1. *The conventional design*. An initially approved development plan that provides a traditional mix of employment and limited residential development. The design is relatively automobile-oriented with high parking ratios and low walkability (i.e., proximity of amenities and transit to housing).
2. *The sustainable design*. A subsequent revision of the approved development plan that incorporates Smart Growth and transit-oriented features, including a more compact, mixed use configuration. This design appears more likely to be consistent with proposed LEED-ND prerequisites and credits, such as goals for the reduction of storm water runoff; compact, transit-oriented development; and habitat preservation.

The selection of these designs was based on two key considerations: 1) The designs were real plans proposed by developers and approved by local authorities; they are not hypothetical cases drawn to illustrate different design philosophies; and 2) The plans have substantially different design characteristics, one representing a typical conventional development, and the other incorporating many sustainable development principles (Table 2).

Modeling approach

Results of the qualitative assessment indicated that neighborhood design elements associated with stormwater and nonpoint source pollution were sensitive to climate change, and thus likely to offer adaptive opportunities. We considered these issues in more detail by modeling the performance of the two South Weymouth design alternatives using the Smart Growth (SG) WATER model within the INDEX PlanBuilder software package.[2] Our analysis evaluated the impacts of conventional and sustainable South Weymouth site designs using nine different precipitation scenarios: the first is precipitation data specific to the South Weymouth site; the remaining eight scenarios are based on precipitation data from eight other geographic locations around the country with varying amounts of average annual precipitation. INDEX was also utilized to estimate pervious roof and non-roof surface areas of the design alternatives as a measure of heat island contribution.

Water quality

SG WATER is a planning model that can be used to estimate the impacts of different land development scenarios on stormwater runoff and associated pollutant loads (USEPA 2005).[3] The model estimates the volume and quality of runoff and associated pollutants—total suspended solids (TSS), nitrogen, and phosphorus—for a given land use configuration based on underlying soil type, local precipitation, and management practices. SG WATER uses the Natural Resources Conservation Service (NRCS) Curve Number method for quantifying rainfall-runoff relationships, and information from the U.S. EPA’s National Urban Runoff Program (NURP) to establish pollutant loads and event mean concentrations (EMCs) for various land use categories.

We were interested in the sensitivity of the designs to geographic differences in historic climate and climate change as a demonstration of their capability to perform under expected climatic changes. To do this, we evaluated the stormwater and water quality impacts resulting from each of the two SWNAS designs under nine different climate time series from across the US. Predevelopment landcover was represented in SG WATER as open space.[4] The analysis focuses on South Weymouth as the primary location, with precipitation data from the eight other cities evaluated to provide a breadth of geographic precipitation regimes. The climate data were selected to represent fast growing cities within each of the nine National Climatic Data Center (NCDC) regions (NCDC 2006) (Table 3). SG WATER does not consider the implications of changing temperature (e.g., changes in evapotranspiration) for hydrologic calculations. Nevertheless, the key SG WATER variables measure changes in the timing and intensity of precipitation. We used two complementary approaches to modify historical precipitation data to understand sensitivity to plausible future conditions: increasing the intensity of large storm events ("flashier" precipitation) and increasing total annual precipitation (a uniformed scaling of precipitation).

Flashier precipitation scenarios are based on observed trends in precipitation patterns. Groisman et al. (2005) evaluated historic precipitation data for the US and determined that there were statistically significant nationwide increases in the intensity of the heavy (upper 5%) precipitation events. They report a 4.6% increase in event intensity per decade for the largest 5% of precipitation events; a 7.2% increase in event intensity per decade for the largest 1% of precipitation events; and a 14.1% increase in event intensity per decade for the largest 0.1% of precipitation events. In order to accurately apply these factors to scale up the most intense precipitation events, we made an algebraic adjustment for the autocorrelation in these values (e.g., the 0.1 percentile group is contained within both the 1 and 5 percentile group) and created estimates of increases in intensity for the top 5% (up to 1%) of precipitation events, the top 1% (up to 0.1%) of events, and the top 0.1% of events (see Table 4). We used these transformations to modify the nine historic precipitation records to reflect two levels of change: (1) modest change equivalent to extrapolating the observed trend for 20 years (a typical time horizon for planning) and (2) longer-term change equivalent to extrapolating the observed trend 90 years into the future (i.e., end of the 21st century, a benchmark often used in climate change analyses).

These changes were applied to a ten-year historical daily climate record (1996-2005) from each of the nine representative cities.[5] Daily meteorological observations were sorted by precipitation intensity. Precipitation events—those days with at least 0.02 inches of recorded precipitation—were then classified into the four intensity "bins" (top 0.1%, largest 1%-0.1%, largest 5%-1%, and remaining 95%). The precipitation values for the first three bins were adjusted by the 20-year or 90-year multipliers. We modified with the fourth bin – i.e., the remaining 95% – in two different ways.

- First, for both the 20-year and 90-year scenarios, we decreased all of these events by equal proportions sufficient to compensate for the increase in rainfall for the top 5% of events. This created a 20-year "flashier" scenario with no change in average annual precipitation, and a 90-year "flashier" scenario with no change in average annual precipitation.
- Second, for the 20-year scenario we did not decrease the intensity of the lower 95% of events, resulting in a net increase in annual precipitation.

After adjusting the individual daily values, the data sets were re-ordered according to date so that the relative timing of precipitation events was the same as in the historical baseline (1996-

2005). The scaled precipitation datasets were adjusted by -20% and +20% to capture a range of potential climate change impacts on average annual total precipitation. These values were selected because they represent a reasonable range of potential shifts in total precipitation (GCRP 2002).

In total, six precipitation scenarios were developed for each of the nine representative cities (including the primary city South Weymouth). The performance of the conventional and sustainable designs was then modeled for each of the following conditions:

- Historic precipitation (1996-2005)
- Flashier (20 years, 90 years) with constant annual average precipitation
- Flashier (20 years) with increasing annual average precipitation
- Precipitation scaled -20% and scaled +20%

Air temperature/ heat island

The INDEX software used in this study has a limited set of capabilities for representing potential heat island effects. It provides the ability to quantify the differences between the designs that may drive heat gain, but not to quantify the absolute effects in terms of temperature changes. Therefore, INDEX examined the impervious surface area within the site designs and how much was shaded and unshaded. In the case of the sustainable design, it was assumed that the project's non-roof areas would be shaded or high-reflectance or permeable paving would be used on 50% of those areas; it was also assumed that no roof measures would be applied.

The sum of the area of heat-absorbing unshaded surfaces (roofs, parking lots, streets) in the conventional and sustainable designs was used as an indicator of potential contributions to surface air temperature. Surface areas such as shingled roofs, parking lots, and streets have a low albedo, or ratio of reflected light to incident light. As a result, the solar radiation from the sun is largely converted to thermal energy absorbed by ground pavement. This thermal energy is then radiated back into the environment contributing to the heat island effect (Stone 2005).

Results and discussion

Water quality benefits

The sustainable design provides uniformly superior performance with respect to storm water runoff and non-point source pollution loads. Storm water runoff volume, total suspended solids (TSS), nitrogen, and phosphorus from the sustainable design were at least 22% lower than for the conventional design across all precipitation scenarios at the SWNAS site. Expressed as a percent of development impacts (i.e., the change associated with conversion from open space to developed land), the impacts on storm water runoff, TSS, nitrogen, and phosphorus from the sustainable design were 29% - 45% lower than for the conventional design across all precipitation scenarios.

Runoff from both designs was sensitive to precipitation flashiness; however, the sustainable design generated 28 to 36% less runoff than the conventional design in current climate conditions. Based on the trends observed by Groisman et al. (2005), it would take 90 to 100 years of change in precipitation flashiness for the sustainable design to generate the same volume of runoff as a conventional design under current climate conditions. The sustainable design results in less stormwater runoff volume than the conventional design, under both historical precipitation conditions and with significant increases in the intensity of the largest events or overall precipitation amount (Figure 2). Average annual precipitation would have to increase by approximately 19% before the runoff generated by the sustainable design would exceed runoff generated by the conventional design under historical conditions. Based on observed trends in extreme precipitation events, the benefits of sustainable design persist over time – the runoff volume of the sustainable design in 90 years would be higher than in today's climate, but it would still be about 30% less than the conventional design (Figure 3).

Most of the increase in storm water flow and pollutant loads is attributable to the increase in the top 5% of storm events (i.e., those increased in the "flashier" scenarios). For example, the conventional design generates 37,700 ft^3/ac/yr of runoff under historic conditions for SWNAS; "flashing" the top 5% of events for the 90-year scenario by an average of 41% and dropping the remaining 95% of events by 17% has the effect of increasing runoff to 43,300 ft^3/ac/yr, even though total precipitation remains unchanged. Comparatively, scaling *all* events by 10% takes the total runoff to 45,100 ft^3/ac/yr. Even with the lower 95% of events being 27% lower (relatively) than the +10% scaled scenario, the 90-year flashed precipitation scenario only generates 1,800 ft^3/ac/yr less runoff volume. This indicates that the top 5% of event days (including those with zero precipitation) drive runoff results for South Weymouth.

Results for the eight additional cities were similar to those for South Weymouth. The "sustainable +20% precipitation" and the "sustainable – flashier precipitation" scenarios generally performed better than the "conventional-historical precipitation" scenario for each of the stormwater pollution metrics generated for each of the additional locations (see Figures 4 and 5). In other words, even with an increase in the intensity of the largest events, or an across-the-board increase in event size by more than 17%, the sustainable design results in less stormwater runoff volume than the conventional design with historical (less intense) precipitation. This is illustrated in Figure 4, which indicates that average annual precipitation would have to be scaled up by 17 to 21% (x-intercepts of the least and most change plots) before the runoff generated by the sustainable design in the future would exceed runoff generated by the conventional design under historical conditions. The percent change in runoff generation for each of the nine locations is presented in Tables 6 (scaled) and 7 (flashed).

The flashed scenarios demonstrated more variability across the nine locations. Figure 5 indicates that under flashier conditions projected 90 years into the future, the sustainable design generates 18% less to 2% more runoff volume than the conventional design with current precipitation, depending on the location. This wide range of results for the flashy scenarios indicates that there are varying degrees of influence for the top 5% of events in relation to total annual precipitation. Bakersfield, CA and Sioux Falls, SD had the highest rate of increase in runoff generation in response to flashing the top 5% of events, while Salem, OR and South Weymouth, MA had the lowest rate of increase.

Air temperature/ heat island

The approach for analyzing air temperature / heat island effects was to compare shaded and unshaded impervious surface area for the two designs (see Table 5). In the case of the conventional design, there is 362 acres of unshaded impervious surface area (or 70.9% of the total footprint). For the sustainable design, only 155 acres (37.9% of the total footprint) is unshaded impervious surface area. The sustainable design results in 207 fewer acres of unshaded impervious area that would absorb sunlight and contribute to the heat island effect. This reduction in unshaded impervious area would also reduce the temperature of runoff during hot summer conditions, yielding a water quality/ aquatic ecosystem benefit.

Conclusions

Climate change is often portrayed as a distant concern. Certainly it is rarely foremost in the minds of most local and state leaders as they plan for their communities' growth and infrastructure needs. However, mounting scientific evidence suggests that today's neighborhoods will need to perform under climatic conditions that are significantly different from those we have experienced in the recent past. Uncertainties about the details of future climatic conditions remain significant, particularly at local and regional scales, where planning decisions are made. However, it is clear that climate change is under way, and past observations and personal experience will not be reliable guides to future conditions. Consequently, it is necessary to consider how we can develop robust and resilient neighborhoods that will meet performance expectations across a range of future conditions.

To incorporate climate change adaptation into sustainable neighborhood development, planners, developers, builders, and their colleagues must first identify which decisions associated with the planning or development processes are climate-sensitive and likely to provide opportunities for adaptation. This study showed that nearly one-third of the design elements under consideration for the LEED-ND framework are likely to address resources sensitive to climate change and may provide adaptive opportunities. The detailed analysis of neighborhood elements associated with water resources and aquatic ecosystems suggest that a sustainable design can provide significant reductions in stormwater volume and nonpoint source pollution under present and estimated future conditions.

This research also points to an inherent linkage between sustainable design and climate change adaptation. Sustainable designs typically strive to minimize their adverse impact on the natural environment – impacts that are frequently driven by climatic conditions. By reducing the sensitivity of those processes to climatic conditions, such as runoff from intense precipitation events, sustainable development concepts provide an adaptive benefit with respect to climate change. Sustainable design concepts may be a key component of addressing global climate change because they can reduce sensitivity to future climatic conditions, facilitate adaptation, and reduce greenhouse-gas emissions associated with energy use in transportation and building operation.

Improving neighborhood sustainability requires a realistic assessment of incentives facing developers, planners, and consumers. Climate change is an atypical environmental problem with considerable uncertainty, large long-term risks and few incentives for near-term action (King 2004; Pielke and Sarewitz 2005). However, planners are often in a position to encourage developers to prevent long-term problems through careful action during neighborhood design and construction. Furthermore, regardless of future climate change, these actions will provide environmental benefits. To encourage sustainable design, consumers will need to find reliable market signals, such as LEED-ND certification, to indicate properties that have acceptable levels of long-term performance. This will encourage developers to be more proactive in identifying vulnerabilities and marketing their ability to offset or abate them through specific design features.

Acknowledgements

The views expressed in this paper are those of the authors and do not reflect the policies of the US Environmental Protection Agency.

Notes

1. The LEED for Neighborhood Development rating system is expected to begin a one-year pilot phase in 2007. The current version of the rating system can be found at at www.usgbc.org/leed/nd
2. INDEX PlanBuilder planning support software, Criterion Planners, Inc., www.crit.com.
3. SG WATER is a component of INDEX, but it is also a stand-alone product (as of 2002).
4. The open space category defined as being 75% or more grass cover with zero imperviousness for the runoff curve number; and is based on the generic NURP definition for EMC values. Please refer to the SG WATER manual (USEPA, 2005) for additional details on land use classifications.
5. All of the precipitation datasets are based on daily records from January 1, 1996 to December 31, 2005 from the National Climatic Data Center (NCDC). The period was selected to correspond with the statistical period examined by Groisman et al. (2005). Preliminary analysis indicates that results for this period are qualitatively similar to results for the period of record at South Weymouth.

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Table 1. Draft LEED-ND prerequisites and credits. Climate-sensitive elements for potential for climate adaptation are indicated with gray shading.

	Location Efficiency	
1	Prerequisite: Transportation Efficiency	
2	Prerequisite: Water and Stormwater Infrastructure Efficiency	▨
3	Credit: Contaminated Brownfields Redevelopment	
4	Credit: High Cost Contaminated Brownfields Redevelopment	
5	Credit: Adjacent, Infill, or Redevelopment Site	
6	Credit: Reduced Automobile Dependence	
7	Credit: Contribution to Jobs-Housing Balance	
8	Credit: School Proximity	
9	Credit: Access to Public Space	
	Environmental Preservation	
10	Prerequisite: Imperiled Species and Ecological Communities	▨
11	Prerequisite: Parkland Preservation	▨
12	Prerequisite: Wetland & Water Body Protection	▨
13	Prerequisite: Farmland Preservation	▨
14	Prerequisite: Erosion & Sedimentation Control	▨
15	Credit: Support Off-Site Land Conservation	▨
16	Credit: Site Design for Habitat or Wetlands Conservation	▨
17	Credit: Restoration of Habitat or Wetlands	▨
18	Credit: Conservation Management of Habitat or Wetlands	▨
19	Credit: Steep Slope Preservation	▨
20	Credit: Minimize Site Disturbance During Construction	▨
21	Credit: Minimize Site Disturbance Through Site Design	▨
22	Credit: Maintain Stormwater Runoff Rates	▨
23	Credit: Reduce Stormwater Runoff Rates	▨
24	Credit: Stormwater Treatment	▨
25	Credit: Outdoor Hazardous Waste Pollution Prevention	
	Compact, Complete, & Connected Neighborhoods	
26	Prerequisite: Open Community	
27	Prerequisite: Compact Development	▨
28	Prerequisite: Diversity of Uses	
29	Credit: Compact Development	▨
30	Credit: Transit-Oriented Compactness	
31	Credit: Diversity of Uses	
32	Credit: Housing Diversity	
33	Credit: Affordable Rental Housing	
34	Credit: Affordable For-Sale Housing	
35	Credit: Reduced Parking Footprint	▨
36	Credit: Community Outreach and Involvement	
37	Credit: Block Perimeter	
38	Credit: Locating Buildings to Shape Walkable Streets	
39	Credit: Designing Building Access to Shape Walkable Streets	
40	Credit: Designing Buildings to Shape Walkable Streets	
41	Credit: Comprehensively Designed Walkable Streets	
42	Credit: Street Network	
43	Credit: Pedestrian Network	
44	Credit: Maximize Pedestrian Experience	▨
45	Credit: Superior Pedestrian Experience	▨
46	Credit: Applying Regional Precedents in Urbanism and Architecture	
47	Credit: Transit Subsidy	
48	Credit: Transit Amenities	
49	Credit: Access to Nearby Communities	
50	Credit: Adaptive Reuse of Historic Buildings	
	Resource Efficiency	
51	Credit: Certified Green Building	
52	Credit: Energy Efficiency in Buildings	
53	Credit: Water Efficiency in Buildings	▨
54	Credit: Heat Island Reduction	▨
55	Credit: Infrastructure Energy Efficiency	
56	Credit: On-Site Power Generation	
57	Credit: On-Site Renewable Energy Sources	
58	Credit: Efficient Irrigation	▨
59	Credit: Greywater & Stormwater Reuse	▨
60	Credit: Wastewater Management	
61	Credit: Reuse of Materials	
62	Credit: Recycled Content	
63	Credit: Regionally Provided Materials	
64	Credit: Construction Waste Management	
65	Credit: Comprehensive Waste Management	
66	Credit: Light Pollution Reduction	
67	Credit: Contaminant Reduction in Brownfields Remediation	
	Other	
68	Anticipated Accredited Professional Innovation Credit(s)	
69	Anticipated Innovation Credit(s)	

	Credits shaded in grey present a climate change adaptation benefit	▨

Draft credit list as of September 2005 (USGBC)

Table 2. Summary of statistics for the design alternatives

Design Characteristic	**Conventional**	**Sustainable**
Population (residents)	1,540	5,958
Employees	7,214	2,438
Development Area (ac)	1,400	1,400
Open Space (% total area)	64.7	68.5
Park Space Supply (ac/1000 residents)	45.0	16.1
Jobs to Housing Balance (jobs/dwelling unit)	10.3	1.0
Amenities Proximity to Housing (ave. walk - feet)	5,021	1,266
Transit Proximity to Housing (avg. walk-feet)	5,702	452
Imperviousness (% of total area)	35.4	16.2

Table 3. Case study locations

NCDC Region	**City/Location**	**Average Annual Rainfall (inches)**
North East	South Weymouth, MA	54.4
South East	Raleigh, NC	45.1
North West	Salem, OR	40.7
South	Austin, TX	35.0
Central	Springfield, IL	33.4
East North Central	Madison, WI	31.6
West North Central	Sioux Falls, SD	25.0
West	Bakersfield, CA	6.7
South West	Phoenix, AZ	6.5

Table 4. Adjustments for "flashier" precipitation (based on Groisman et al. 2005)

Range of Event-Days	**Increase per Decade**	**Increase over 20 years**	**Increase over 90 years**
>99.9 percentile	14.1%	28.2%	126.9%
99 - 99.9 percentile	6.4%	12.8%	57.6%
95 - 99 percentile	4.0%	8.0%	36.0%

Table 5. Heat island contribution

	Conventional Design		Sustainable Design	
	Acres	**% of Total Footprint**	**Acres**	**% of Total Footprint**
Non-roof Impervious Area	185.9	36.5	145.6	35.6
Shaded Portion	*0*	*0*	*72.8*	*17.8*
Unshaded Portion	*185.9*	*36.4*	*72.8*	*17.8*
Roof Impervious Area	175.6	34.4	82.2	20.1
Total Unshaded (=unshaded non-roof + roof)	**361.5**	**70.9**	**155.1**	**37.9**

Table 6. Percent change in runoff volume for sustainable design/ scaled precipitation, with respect to conventional design/current precipitation

	Change in Annual Precipitation		
City/Location	**-20%**	**0%**	**20%**
South Weymouth, MA	-55%	-29%	1%
Raleigh, NC	-56%	-30%	2%
Salem, OR	-54%	-28%	3%
Austin, TX	-52%	-28%	2%
Springfield, IL	-57%	-31%	-3%
Madison, WI	-56%	-31%	-2%
Sioux Falls, SD	-57%	-32%	0%
Bakersfield, CA	-59%	-34%	-2%
Phoenix, AZ	-61%	-36%	-2%

Table 7. Percent change in runoff volume for sustainable design/ flashier precipitation, with respect to conventional design/current precipitation

City/Location	**Projection Period (years)**		
	0	**20**	**90**
South Weymouth, MA	-29%	-27%	-15%
Raleigh, NC	-30%	-27%	-12%
Salem, OR	-28%	-25%	-14%
Austin, TX	-28%	-25%	-9%
Springfield, IL	-31%	-28%	-15%
Madison, WI	-31%	-27%	-8%
Sioux Falls, SD	-32%	-27%	2%
Bakersfield, CA	-34%	-29%	-3%
Phoenix, AZ	-36%	-33%	-19%

Figure 1. Conventional and sustainable designs for South Weymouth Naval Air Station

Conventional

Sustainable

Figure 2. Percent change in runoff volume with respect to conventional design/current – scaled precipitation scenarios

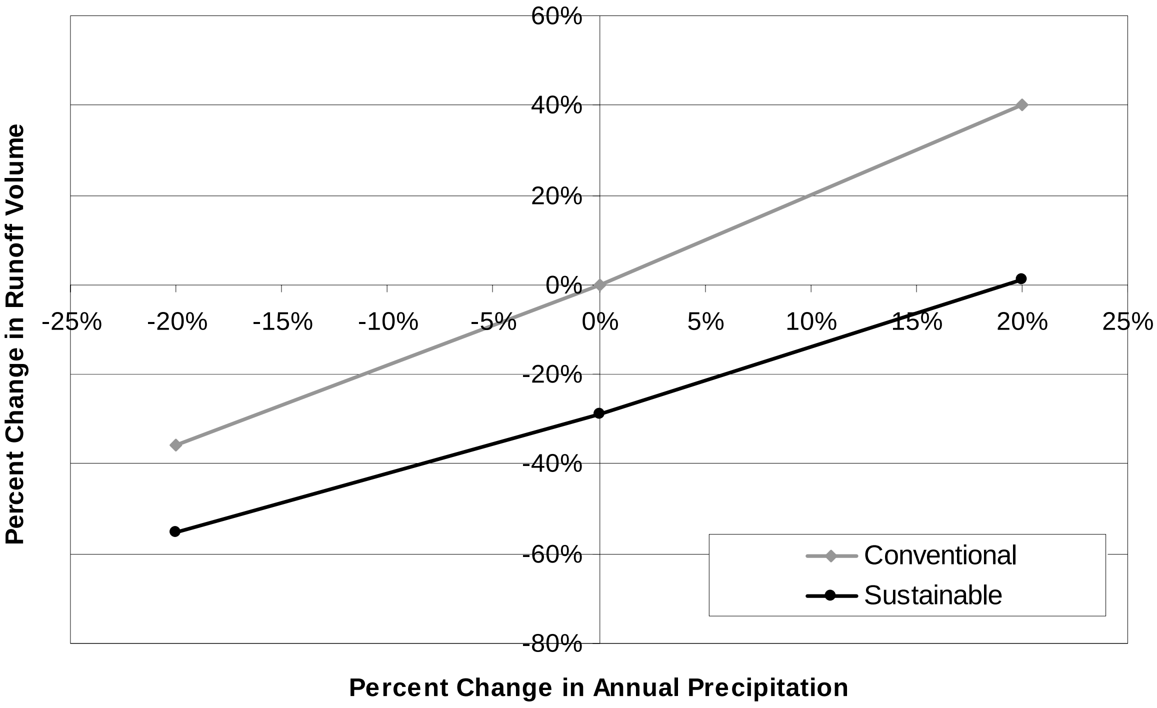

Figure 3. Change in runoff volume with respect to conventional design/current precipitation for 20-year and 90-year "flashier" scenarios (total precipitation held constant)

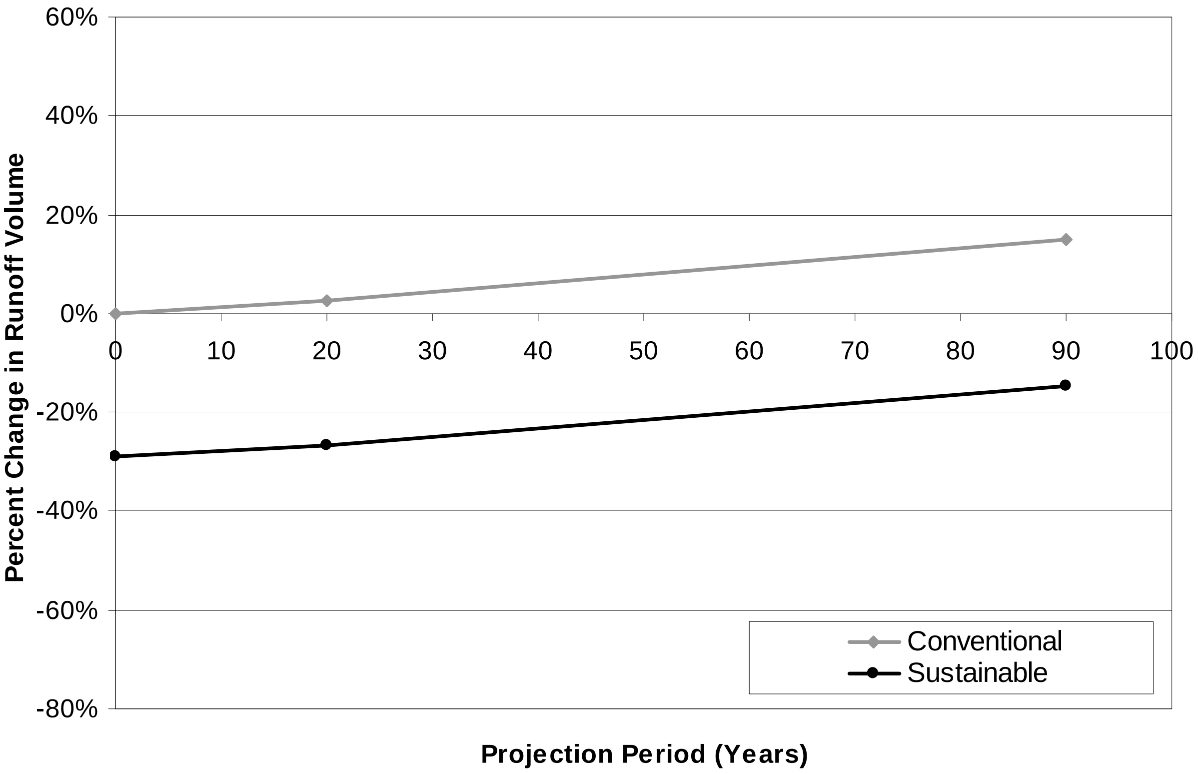

Figure 4. Change in runoff volume for sustainable design/ scaled precipitation, with respect to conventional design/current precipitation

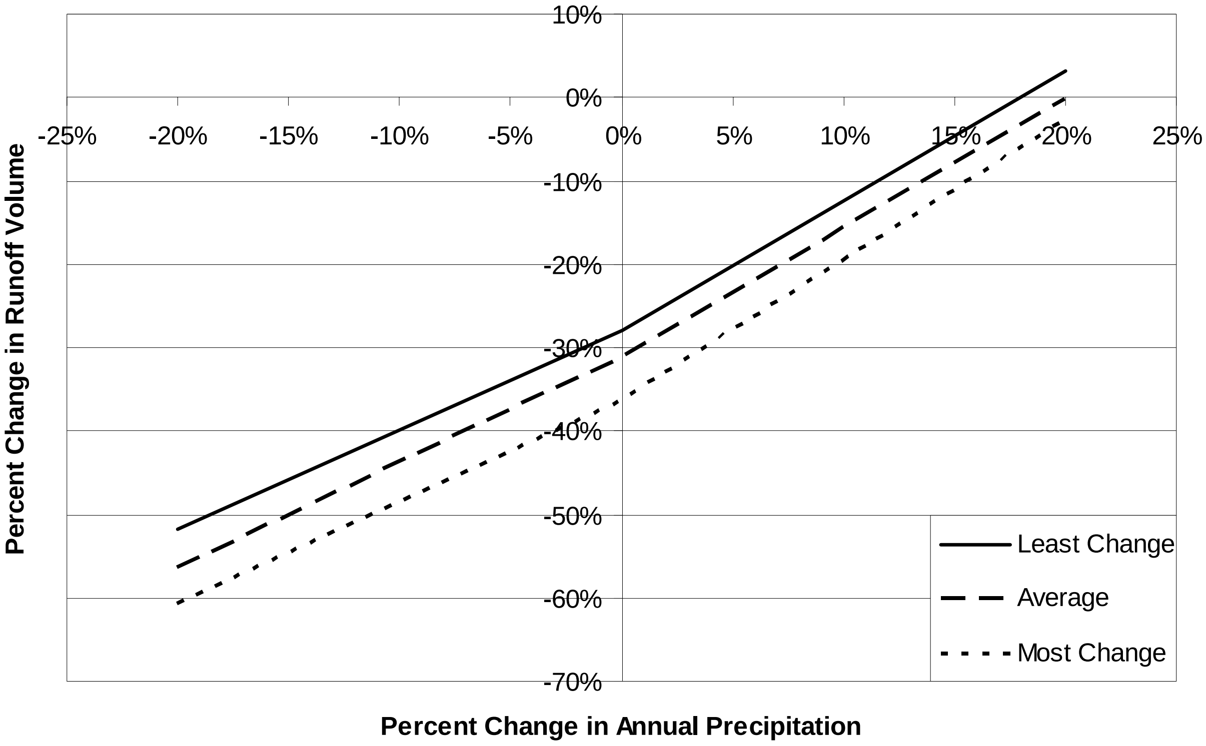

Figure 5. Change in runoff volume for sustainable design/ flashier precipitation, with respect to conventional design/current precipitation