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Article *in* Environmental Science & Technology · August 2011

DOI: 10.1021/es103949f · Source: PubMed

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POLICY ANALYSIS

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Assessing Equitable Access to Urban Green Space: The Role of Engineered Water Infrastructure

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S Supporting Information

ABSTRACT: Urban green space and water features provide numerous social, environmental, and economic benefits, yet disparities often exist in their distribution and accessibility. This study examines the link between issues of environmental justice and urban water management to evaluate potential improvements in green space and surface water access through the revitalization of existing engineered water infrastructures, namely stormwater ponds. First, relative access to green space and water features were compared for residents of Tampa, Florida, and an inner-city community of Tampa (East Tampa). Although disparities were not found in overall accessibility between Tampa and East Tampa, inequalities were apparent when quality, diversity, and size of green spaces were considered. East Tampa residents had significantly less access to larger, more desirable spaces and water features. Second, this research explored approaches for improving accessibility to green space and natural water using three integrated stormwater management development scenarios. These scenarios highlighted the ability of enhanced water infrastructures to increase access equality at a variety of spatial scales. Ultimately, the "greening" of gray urban water infrastructures is advocated as a way to address environmental justice issues while also reconnecting residents with issues of urban water management.

INTRODUCTION

Green space includes natural or human-modified outdoor areas comprised of vegetation, water, and/or other permeable surfaces. These spaces facilitate hydrological processes in areas where urban development interferes with the movement, distribution, and quality of water.[1] They also provide social, health, environmental, and economic benefits, some of which include the promotion of physical activity,[2] filtration of water pollution,[3] increased control of stormwater runoff and flooding,[4] reduced loading on stormwater systems,[5] improved groundwater recharge,[6] provision of wildlife habitat,[7] and reduced need for pollution prevention measures.[8] Green space can include parks, lakes, and community gardens, as well as unconventional spaces like cemeteries and stormwater ponds, which provide some of the same benefits.

There is evidence that urban residents living in greener environments may be significantly more healthy than those living in environments with less green space,[9] and the presence of water may create even greater health improvements. Yet, inequitable urban development and the privatization of natural amenities has contributed to environmental injustices in the distribution of green space and water features, most notably for low-income and minority residents.[10,11] Collectively, this can cause disparities in health-related behaviors and obesity.[12,13] Given the health benefits related to the contact or use of green space, Mitchell et al.[14] acknowledged that disadvantaged populations with green space access may obtain some protection from the effects of poverty-related stress, possibly decreasing their mortality rates relative to similar populations that lack access. For example, people exercising in all types of natural environments experienced enhanced self-esteem and mood, with the presence of water creating the greatest improvements.[15]

While water is an important component of green space in the urban landscape, traditional water management has been compartmentalized (i.e., water supply, wastewater, stormwater) with "gray" infrastructures (e.g., stormwater ponds and channels) replacing ecosystem services and cycles (i.e., "green" infrastructure). As a result, gray infrastructures dominate many urban landscapes, concealing the urban hydrological cycle, as well as its management, from the public. With continued urbanization—an estimated 70% of the world's population is expected to reside in cities by the year 2050 [16]—urban hydrology will play an increasingly important role in water resource management, while providing opportunities to increase the availability of public green space and water features.[17] The integration of green infrastructure into urban water management has been shown to provide greater environmental, health, and social benefits than single-purpose gray infrastructure systems.[7] This has important implications for attaining decentralized stormwater management, maintaining

Received: November 30, 2010
Accepted: July 5, 2011
Revised: June 17, 2011
Published: July 05, 2011

predevelopment site hydrology, managing extreme weather events (related to climate change), and ultimately reducing the need for costly new gray infrastructure, as recommended by recent EPA stormwater runoff requirements.[18]

A few studies have highlighted the need for more ecologically designed urban water infrastructures to enhance broader environmental and social benefits,[4,19] yet these have not explicitly examined the role of unconventional green space in the built environment, particularly existing stormwater ponds, to improve access and reconnect residents to the urban watershed. By improving the understanding of, and contact with, urban water cycle management, a greater environmental awareness and stewardship can be fostered, as well as a better connection between stakeholders and critical issues of watershed protection and water reuse.[20] This has significant policy implications by facilitating collaboration between municipal departments, community groups, and universities, while addressing the issue of community well-being and establishing a more economically and environmentally sustainable mechanism for integrated water infrastructure.[21]

This research examines existing and potential green space access, particularly for spaces with natural and urban water features, within Tampa and the inner-city community of East Tampa, which is well-noted for being associated with negative social outcomes, including access to health care facilities and natural amenities.[22] The City of Tampa provides an excellent area to study the integration of green and gray infrastructures with approximately 1240 stormwater ponds due to seasonal precipitation that necessitates the widespread use of engineered water infrastructure to handle high summer flows. Furthermore, the Tampa-Clearwater-St. Petersburg Metro area has undergone some of the most rapid development in the U.S. in the last three decades,[23] with the privatization of many natural water features. As a result, the ultimate goal of this research is to identify any disparities in existing access to green space, particularly for disadvantaged populations that have historically been subject to inequitable distribution of environmental risk and urban amenities, as well as to evaluate the ability for enhanced urban water infrastructure to reduce access disparities. Three development scenarios are analyzed to evaluate the impact of integrating green and gray infrastructure to improve green space and water access. This "greening" of engineered water infrastructure is proposed to address both environmental justice issues as well as to reconnect residents with the urban water cycle and its management.

MATERIALS AND METHODS

Within the City of Tampa, the innercity community of East Tampa is compared to the rest of the city to evaluate the ability for decentralized urban water infrastructures to reduce inequalities in the availability and accessibility of green space and water features. First, socio-demographic characteristics are examined at the block group level from the 2000 Census along with green space proximity data from the centroid of each block group. Three measures of access are used to examine whether different socio-demographic groups have equal green space access. Although accessibility does not imply usability, previous studies have determined that distance is an important indicator for facilitating frequent use of green space.[2,24] Second, the potential for stormwater pond revitalization projects to enhance green space accessibility is examined using three development scenarios. The scenarios evaluate improvements in access equality when either all or a specified number of ponds are converted to usable green space.

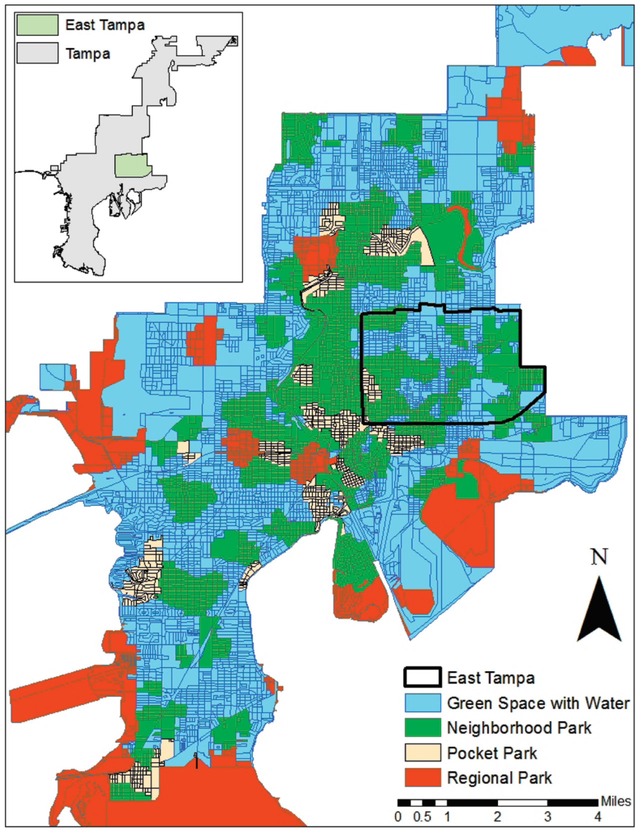

Figure 1. Nearest types of green space access for all census block groups in Tampa and East Tampa (insert shows the area that defines the City of Tampa). The types of green space most accessible to block groups are shown − water feature (blue), neighborhood parks (green), regional parks (red), and pocket parks (tan).

Despite health benefits associated with the contact and use of green space,[9,15] health outcomes were not measured directly in this study due to a lack of relevant health data at the census block group or track level.

Study Area. Within Hillsborough County, the availability and accessibility of green space and water features are compared between two study areas (East Tampa and Tampa) (Supporting Information (SI) Figure S1, also shown in Figure 1). East Tampa is a relatively small inner-city community (30,928 residents), whereas Tampa is comprised of the remaining portion of the City of Tampa *excluding* East Tampa (286 749 residents).[25] East Tampa has existing environmental justice issues[26] and socio-demographic inequalities (SI Table S1), with areas characterized by high rates of vacancy, deteriorating structures, crime, and poverty.[27] There are also an abundance of unconventional green spaces (i.e., cemeteries and stormwater ponds) within East Tampa relative to its land area and population. However, due to revitalization efforts, two ponds have been redeveloped into "community lakes", which are now widely viewed as community assets and operated by the Tampa Parks and Recreation Department.[28]

The enhancement of these ponds was a collaborative undertaking between the community, university faculty and students, and the local municipality and is part of the community's long-term plan for economic and social revitalization.[29] Pond enhancements focused on adding previously absent amenities such as walking trails, landscaping, gazebos, observation towers, piers, and/or

Table 1. Green Space Types, Description and Defined Access Distances Used in This Study[35]

type of green space		description	access distance
traditional	pocket park	small landscaped informal spaces; limited passive amenities; no active amenities or facilities	$^{1}/_{4}$ mile (400 m)
	neighborhood (NBHD) park	landscaped spaces of varying size; passive and active amenities and facilities; located within residential areas	$^{1}/_{2}$ mile (800 m)
	regional park	large landscaped and/or natural spaces; wide range of amenities and facilities; access primarily via car	1 mile (1,600 m)
	large park	spaces greater than 20 acres	$^{1}/_{2}$ mile
	public transit	spaces with one or more bus stops within a quarter mile	$^{1}/_{4}$ mile
	walkable	spaces within walking distance	$^{1}/_{4}$ mile
water	natural water	contains natural water features (i.e., bay, river, lake)	$^{1}/_{4}$ mile
	urban infrastructure	water features designed for stormwater management; limited or no social amenities	$^{1}/_{4}$ mile
	total water	natural and urban-infrastructure water features	$^{1}/_{4}$ mile
public	traditional	parks, playgrounds, outdoor recreation facilities, open space	$^{1}/_{4}$ mile
	unconventional	urban water infrastructure, cemeteries	$^{1}/_{4}$ mile

exercise courses (SI Figures S2−S5). The pond revitalization also created educational opportunities around water resources for K-12 and university students and community members.[29,30] Globally there are various applications of integrated water management solutions,[1,4,31] however, the innovative work with the East Tampa community lakes provides an adaptable model for other urban communities with existing or proposed engineered water infrastructures.

Defining Green Space. Green space attributes help determine how these spaces are used and by whom. This analysis focuses on public green space where access is unrestricted and free for all (e.g., parks, open space, cemeteries). Golf courses that allow public access for activities such as walking, running, or dog walking, were also included as green space. Urban water infrastructures (e.g., stormwater ponds) were considered green space as defined previously (i.e., human-modified outdoor public spaces, comprised of permeable surfaces and water).

The most current public green spaces were identified[32,33] and populated with key attribute information: (i) presence of surface water features, (ii) types of amenities, (iii) public transit access, and (iv) size.[34] As shown in Table 1, each space was classified and subdivided into three main categories using attribute information to examine differences in green space availability and quality (SI Figure S6): (1) traditional green space (pocket, neighborhood (NBHD), regional, and large parks; spaces accessible via alternative transportation), (2) green spaces with water features (natural water and urban water infrastructure), and (3) total public green space (traditional and unconventional green space).

Measuring Green Space and Water Accessibility. The usability of green space, from the perspective of the residents, is influenced by spatial and cultural factors such as quality and quantity of spaces, user characteristics, and perception of barriers.[2] However, residents living in close proximity to green spaces are significantly more likely to be physically active than those who live beyond walking distance.[24] This has important implications for East Tampa residents, whose primary health concerns (i.e., hypertension, diabetes, and obesity) relate to sedentary lifestyles,[36] and Hillsborough County, where health disparities are present for minority, low-education, and low-income groups (SI Figure S7).

Therefore, this analysis focuses on access as a function of distance. The accepted distance that individuals are willing to walk to reach green space (i.e., access distance) is about a quarter mile (400 m), or approximately a five-minute trip[37]; at distances greater than half a mile, individuals are more likely to drive. Although access distances vary depending on the type of green space, as previously stated, distance is an important indicator for facilitating more frequent use.[2,24] As shown in Table 1, the access distances for regional, neighborhood, and large parks were the only green space types assumed to be greater than a quarter mile in this study.

A variety of methods can be used to measure accessibility to green space, with each differing in complexity and in defining what constitutes “user access”. Three methods were used to evaluate different measures of green space and water accessibility within Tampa and East Tampa: (1) container approach, (2) service area analysis, and (3) minimum distance analysis.[3,38]

The container approach method was used to establish a baseline measure of green space availability. This approach quantifies all green space within an area, with the assumption that the more green space, the greater the potential access. In both study areas, the total number of acres was determined for all green space types as well as the relative percentage of each type. The total acres of public and traditional green space were then normalized by the population of each area to evaluate aggregate access (acres per 1000 residents). Although this approach provides a common measure to compare potential access of different areas, availability does not always translate into usability. Therefore, the major limitation of this method is that it does not take into account the spatial distribution, quality, or type of green space.[39]

A second measure of accessibility involved delineating service areas around each green space to determine the portion of the population with access. This method was selected because it allowed differences in access (between socio-demographic groups), spatial distribution, and green space type to be evaluated. Service areas were defined by placing a buffer, based on access distance (Table 1), around each green space. Census block groups (CBG) whose population centroids were located within the service areas were assumed to have access. Although the portion of the population with or without access was estimated using this method, it assumes equal access along the green space boundary.[35] Therefore, the issue of preference or other potential access barriers are not necessarily taken into account. To address these limitations, different green space types and access distances were included to assess whether disparities exist within the two study areas.

Lastly, the minimum distance analysis determined the distance from a CBG population centroid to the nearest green space. This analysis, which takes into account all green space types, calculates the Euclidean distance to the nearest type of green space from each CBG centroid, as well as provides a count of which types are closest to the population centroids. This analysis was utilized to remove predefined service areas and provide an average access distance for each CBG centroid within both areas.

Socio-Demographic Analysis. Using 2000 census data,[25] access to each type of green space was evaluated for the following eight socio-demographic groups: (1) elderly (>65), (2) youth (<18), (3) single parents, (4) whites, (5) blacks, (6) hispanics, (7) (home) owners, (8) and renters (SI Figures S8 and S9 provide population distributions). Many of these groups, with the exception of whites and owners, were selected based on previous studies that identified a relative lack in access to, or a greater need for, easily accessible green spaces.[10,12] Housing tenure (owner versus renter) was used as a proxy for income data, which is not available at the CBG level.[35]

The total and subpopulation of each group with green space access were summed to provide the percentage with access within each area. Relative access is defined as the portion of individuals with access to green space relative to the total population, and was determined for each socio-demographic group by dividing the subpopulation with access by the total area population with access for each type of green space. These relative access percentages (average access equals 100%) were then used to differentiate six levels of access—Poor (<75%), marginal (75−89%), fair (90−99%), good (100−109%), excellent (110−124%), and outstanding (>125%)—and assigned six corresponding scores (0−5) (SI Table S2). Overall access was determined for each socio-demographic group by averaging the scores from all green space types using an equal-interval scale. This scale was defined by first calculating the total possible access score of each category (traditional green space, water, and public green space), which involved multiplying the number of green space types within each category by five (the highest possible score), and then dividing the total score by six (the number of access levels). The resulting two scales (one for the traditional green space category with six types of green space, and another for the water and public green space categories which have three each) have six equal intervals, which correspond to the six levels of access.

Development Scenarios. Three development scenarios were evaluated (using a quarter mile service area) to analyze changes in green space and water access by enhancing select urban water infrastructures with social and environmental amenities (i.e., fences removed, walking paths added, natural vegetation added, and year-round water). The first scenario (T1) assumed a greening of all stormwater ponds within the City of Tampa, thereby converting these spaces from unconventional to traditional green spaces. This scenario was developed to represent an idealized situation of what current green space access could be if all existing urban water infrastructures were designed and operated as multifunctional spaces. For the analysis, the stormwater pond attributes were first reclassified as traditional green space, and then a service area analysis was repeated to assess the improvement in walkable green space access.

The second and third scenarios were selected to evaluate the enhancement of a limited number of stormwater ponds within East Tampa based on their spatial location and size (SI Figure S10). First, areas deficient in traditional green space were identified by overlaying the census data with the green space service areas; then within these "access gaps", 21 stormwater ponds were identified (out of approximately 40) as potential revitalization sites. Scenario ET1 focused on the enhancement of four larger ponds between 3 and 16 acres (out of eight ponds larger than 1 acre), within the most heavily populated (centrally located) areas. Of the remaining nine ponds located outside of service areas, three small (less than 1 acre), dispersed ponds were selected for scenario ET2 that were in close proximity to one or more groups with disadvantages in access. As with scenario T1, the attributes of the selected ponds were modified and a service area analysis was repeated only within East Tampa. The success of the two enhanced East Tampa "community lakes" highlights the important role of community involvement in any revitalization project to ensure community needs are met and that these spaces are not perceived as inferior.

RESULTS AND DISCUSSION

Overall Green Space Access. Table 2 shows disparities in the availability, size, and diversity of green spaces between East Tampa and Tampa, but highlights the greater accessibility of certain green space types for East Tampa residents. Both areas have similar quantities of green space relative to total land area, yet the average traditional green space in Tampa is six times larger than in East Tampa. Additionally, Table 2 shows that aggregate access (acres per 1000 residents) for Tampa is more than double that of East Tampa, and almost seven times greater for traditional green space. The green space available within East Tampa also lacks diversity, almost 96% of traditional green spaces are neighborhood parks and 79% of total public green spaces are unconventional spaces.

Table 2 also shows that Tampa has more green spaces with water features than East Tampa (93.6% versus 72.7%), particularly natural water features (68.7% versus 0%), but also urban water infrastructure (16.9% versus 12.0%). Overall, access to natural water features was low within both Tampa (12.6%) and East Tampa (2.5%) relative to access to urban water infrastructure (48.7% and 52.3%, respectively) (SI Tables S3 and S5).

Despite existing disparities, East Tampa residents have greater access to the following types of green space relative to Tampa residents: (1) spaces accessible via alternative transportation (walking and public transit), (2) total public green space (including unconventional and traditional), (3) water infrastructure, and (4) neighborhood parks (Table 2). This highlights the importance of providing equitably distributed green space, and not just total quantity, to improve overall accessibility. However, access to larger green spaces, such as regional and large parks, as well as spaces with natural water, were significantly lower for East Tampa residents.

In terms of travel distance, the average nearest distance to green space was greater for Tampa at 337 m (maximum distance of 6673 m) compared to 257 m for East Tampa (maximum distance of 805 m). Nonetheless, the lack of nonmotorized amenities along travel corridors within East Tampa (e.g., bike lanes, sidewalks, crosswalks, and landscaping), may negate the walkability or bikeability gained by closer proximity.[27]

As shown in Figure 1, the two types of green space nearest the majority of census block groups were those with water (blue grids) (53%) and neighborhood parks (green grids) (18.5%). This illustrates the prevalence of green spaces with water throughout

Table 2. Comparison of the Quantities of Green Space and Overall Access for Tampa and East Tampa

	Tampa	East Tampa
total area (acres)		
land area (% total)	81 466 (91.9%)	4811 (5.4%)
public green space (% total)	7224 (8.9%)	398 (8.3%)
average size	75	8
traditional green space (% total)	5948 (7.3%)	84 (1.7%)
average size[a]	108	18
aggregate access (acres/1000 residents)		
public green space	25.2	12.9
traditional	20.7	2.7
percent of green space by type		
total traditional	*82.3%*	*21.0%*
pocket parks	0.8%	0.8%
neighborhood parks	14.3%	20.1%
regional parks	68.0%	0%
large parks (>20 acres)	76.5%	0%
total water	*93.6%*	*72.7%*
natural water	68.7%	0%
urban infrastructure	16.9%	12.0%
cemeteries	0.8%	67.1%
access by green space type (% population with access)		
total traditional	*37.2%*	*53.3%*
pocket park	7.0%	3.8%
neighborhood park	60.3%	95.6%
regional park	48.6%	1.9%
large parks	37.2%	0%
public transit	33.5%	62.9%
walkable	37.9%	62.9%
total water	*60.4%*	*69.1%*
natural water	12.6%	2.5%
water infrastructure	48.7%	52.3%
total public	*70.4%*	*80.3%*
unconventional spaces	50.4%	56.7%

[a] Includes cemeteries.

the City of Tampa, as well as the predominance of neighborhood parks in the urban core, and regional parks (red grids) in the outer areas. Because water infrastructures comprise the majority of water features in the most heavily urbanized areas, as is the case with East Tampa, there is considerable incentive to revitalize these existing infrastructures to reconnect residents with the urban watershed while also improving green space access, particularly in areas currently lacking these social and environmental amenities. However, there may be greater challenges to removing barriers to public acceptance of water reuse in more urbanized areas, such as East Tampa, compared to less urban areas within Tampa.

Access by Socio-Demographic Group. As previously discussed, East Tampa residents have greater access relative to Tampa residents to the three main categories of green space: (1) Traditional green space, (2) Green space with (total) water, and (3) Public green space (SI Tables S4 and S6). Although these broad categories mask individual green space access differences, their comparison provides useful insights. First, as shown in Table 3, within East Tampa there appear to be fewer disparities in access among the eight socio-demographic groups compared with Tampa, which has more variation in the level of access (fair to excellent) than East Tampa, which is relatively lower (marginal to good), but more uniform. These results also indicate that the highest need groups in Tampa have the greatest green space access, which is also true in East Tampa for the types of green space present. However, accessibility is not the same as usability and factors such as green space quality, diversity (in amenities), and size are important for encouraging greater use of these spaces. Although this analysis was not able to take into account inequities related to lower quality spaces, user congestion, or cultural barriers, environmental injustices were noted within East Tampa due to existing disparities in the available green spaces.

Inequalities in water access were also noted, with access to water features (including natural water) above average for hispanics, youth, and renters and below average for elderly and owners in both areas. Interestingly, access by blacks differed significantly between East Tampa (excellent water infrastructure access, poor natural water access) and Tampa (fair water infrastructure access, outstanding natural water access) (SI Tables S4 and S6). Therefore, the enhancement of urban water infrastructures could reduce existing disparities in water access (i.e., low access to natural water, high access to "undesirable" engineered water infrastructure) for blacks, elderly, youth, single parents, and owners in East Tampa. In general, these same disparities do not exist within Tampa (with the exception for elderly and owners).

Development Scenarios. Although about half of all Tampa and East Tampa residents are within walking distance of urban water infrastructure (Table 2), in their current state, the approximately 1240 stormwater ponds have limited social benefits and environmental functions beyond flood control. The three development scenarios analyzed the greening of these gray infrastructures by assuming an enhancement of their social and/or environmental amenities to improve green space and water access.

The first development scenario, T1, evaluates changes in accessibility when all stormwater ponds are converted to traditional green space. This resulted in a significant improvement in walkable traditional green space access by 33% for Tampa and by 25% for East Tampa. While this scenario may have economic constraints, it illustrates the importance of designing and planning for integrated water and landscape management to achieve greater social and environmental benefits.

The East Tampa scenarios, ET1 and ET2, examined the enhancement of a limited number of stormwater ponds at different spatial scales and sizes following a similar analysis as the T1 scenario. These enhancements are assumed to include social amenities (i.e., walking paths, benches, gazebos) and natural features (i.e., native vegetation, year-round water). Scenario ET1 (revitalization of four large stormwater ponds) increased the amount of traditional green space from 21% to 28% and natural water green space from 0% to 7%, respectively. Although this increased the aggregate traditional green space access for East Tampa residents, it is still low compared to Tampa (3.6 versus 20.7 acres/1000 residents). Due to the pond sizes, this scenario provided East Tampa residents with greater access to larger and more diverse green spaces that were previously inaccessible, particularly among groups with the lowest natural water access. Although scenario ET2 (revitalization of three small ponds)

Table 3. Overall Level of Access by Each Socio-Demographic Group and Green Space Type for Tampa

	% with access[a]	white	black	hispanic	elderly	youth	single parents	owners	renters
Traditional Green Space Access									
Tampa	37.2%	fair	excellent	excellent	good	good	excellent	fair	fair
East Tampa	53.3%	marginal	marginal	fair	marginal	marginal	marginal	marginal	fair
Water Access									
Tampa	60.4%	fair	good	good	fair	good	excellent	fair	good
East Tampa	69.1%	fair	fair	fair	marginal	good	good	fair	good
Public Green Space Access									
Tampa	70.4%	fair	good	good	fair	good	good	good	good
East Tampa	80.3%	marginal	good	marginal	good	good	fair	good	fair

[a] Percent of the population with access (Table 2).

did not provide significant increases in the amount of traditional green space or natural water features, it did result in noteworthy increases in access for both types of green space (SI Table S7). Additionally, as illustrated by the redevelopment of two East Tampa stormwater ponds, integrating green and gray infrastructure provides new opportunities for reshaping how residents view and participate in urban water management, including broader goals of promoting watershed protection and water reuse.[30]

Overall, the results support previous studies that have evaluated environmental justice issues of unequal access to urban green space and other environmental amenities[3,39] and the integration of green and gray infrastructure to achieve more sustainable urban water management and improve urban quality of life.[7,19] Although disparities were not found in overall accessibility between the two study locations, inequitable access was apparent when quality, diversity, and size of green spaces were considered. For example, East Tampa residents had significantly less access to more desirable, larger spaces and water features. Results also showed how the enhancement of engineered water infrastructures can increase access equality at different spatial scales. This research also demonstrated the ability to improve environmental justice, particularly for disadvantaged residents, by enhancing or designing engineered stormwater ponds as multifunctional spaces.

Although access disparities were noted between East Tampa and Tampa, the results from the development scenarios indicate potential access improvements and illustrate two key points. First, access improvements do not necessarily require large increases in the overall quantity of green space; they can be made through more equitable distribution of smaller spaces. This can also be applied to other engineered infrastructures such as travel corridors or parking lots to improve on-site hydrology, community well-being, and health benefits (through contact with greener environments).[9] Second, water infrastructure may provide unique opportunities to reconnect inner-city residents to the urban water cycle, while also improving green space access. This puts forth the challenge to urban planners and water managers to design and implement infrastructures that enable the urban landscape to mimic natural processes and structures.[4]

Ultimately, incorporating social and environmental amenities into engineered water infrastructure should improve justice issues related to green space access and associated health and well-being of communities, with additional benefits associated with reconnecting city residents with the urban watershed. Efforts to integrate green and gray infrastructure also present opportunities to engage diverse stakeholders in the design, implementation, and operation of these urban features. This should lead to more integrated and sustainable deployment of water management policies and schemes that are required for an increasingly populated and urbanized world.

■ ASSOCIATED CONTENT

Supporting Information. Map of the study areas, green spaces, and water features; table of socio-demographic and land use characteristics; pictures of revitalized East Tampa stormwater ponds; illustration of the types of green space and water features; major health indicators in Hillsborough County; scale for green space access levels; maps of socio-demographic population percentages; map of East Tampa development scenarios; tables of individual and overall access levels; results from East Tampa development scenarios. This material is available free of charge via the Internet at http://pubs.acs.org.

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■ ACKNOWLEDGMENT

We acknowledge the U.S. National Science Foundation for support of this project through the Graduate Research Fellowship Program. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

■ REFERENCES

(1) Niemczynowicz, J. Urban hydrology and water management - present and future challenges. *Urban Water J.* **1999**, *1* (1), 1–14.

(2) Giles-Corti, B.; Broomhall, M. H.; Knuiman, M.; et al. Increasing Walking -- How important is distance to, attractiveness, and size of public open space? *Am. J. Prev. Med.* **2005**, *28* (2), 169–176.

(3) Boone, C. G.; Buckley, G. L.; Grove, J. M.; Sister, C. Parks and People: An Environmental Justice Inquiry in Baltimore, Maryland. *Ann. Assoc. Am. Geogr.* **2009**, *99* (4), 767–787.

(4) Hill, K. Urban ecological design and urban ecology: An assessment of the state of current knowledge and a suggested research agenda. Paper presented at *Cities of the Future: Towards Integrated Sustainable Water and Landscape Management*; Racine, WI; June 12−14, 2007.

(5) Raucher, R., Clements, J. A Triple Bottom Line Assessment of Traditional and Green Infrastructure Options for Controlling CSO Events in Philadelphia's Watersheds. Paper presented at *Water*

Environment Federation Technical Exhibition and Conference; New Orleans, LA; October 2−6, 2010.

(6) Sherer, P. M. *The Benefits of Parks: Why America Needs More City Parks and Open Space*; The Trust for Public Land: San Francisco, CA, 2006.

(7) Ahern, J. Green infrastructure for cities: The spatial dimension. Paper presented at *Cities of the Future: Towards Integrated Sustainable Water and Landscape Management*; Racine, WI; June 12−14, 2007.

(8) Callaway, E.; Green, D.; Anderson, M.; Yap, A., Gaschler, S. Integrated Infrastructure Planning, A New Approach for the New City of Damascus, Oregon. Paper presented at *83rd Annual Water Environment Federation Technical Exhibition and Conference*; New Orleans, LA; October 2−6, 2010.

(9) de Vries, S.; Verheij, R. A.; Groenewegen, P. P.; Spreeuwenberg, P. Natural environments -- healthy environments? An exploratory analysis of the relationship between greenspace and health. *Environ. Plann. A* **2003**, *35*, 1717–1731.

(10) Heynen, N.; Perkins, H. A.; Roy, P. The political ecology of uneven urban green space. *Urban Aff. Rev.* **2006**, *42* (1), 3–25.

(11) Moran, S. Cities, creeks, and erasure: Stream restoration and environmental justice. *Environ. Justice* **2010**, *3* (2), 61–69.

(12) Kipke, M. D.; Iverson, E.; Moore, D.; et al. Food and park environments: Neighborhood-level risks for childhood obesity in east Los Angeles. *J. Adolesc. Health* **2007**, *40*, 325–333.

(13) Powell, L. M.; Slater, S.; Chaloupka, F. J. The relationship between community physical activity settings and race, ethnicity and socioeconomic status. *Evidence-Based Prev. Med.* **2004**, *1* (2), 135–144.

(14) Mitchell, R.; Popham, F. Effect of exposure to natural environment on health inequalities: an observational population study. *Lancet.* **2008**, *372* (9650), 1655–1660.

(15) Barton, J.; Pretty, J. What is the best dose of nature and green exercise for improving mental health? A multi-study analysis. *Environ. Sci. Technol.* **2010**, *44* (10), 3947–3955.

(16) UNFPA. *State of World Population 2007: Unleashing the Potential of Urban Growth*; United Nations Population Fund, 2007.

(17) EPA. Urban Waters; http://www.epa.gov/urbanwaters/ (accessed June 16, 2011).

(18) EPA. *Technical Guidance on Implementing the Stormwater Runoff Requirements for Federal Projects Under Section 438 of the Energy Independence and Security Act*; US Environmental Protection Agency: Washington, DC, 2009; http://www.epa.gov/greeningepa/documents/epa_swm_guidance.pdf.

(19) McGuckin, C. P.; Brown, R. D. A landscape ecological model for wildlife enhancement of stormwater management practices in urban greenways. *Landscape Urban Plan.* **1995**, *33*, 227–246.

(20) Macpherson, L. Education: Gateway to reuse acceptance begins with us. *Water Reuse Desalin.* **2010**, *1*, 1.

(21) Maheepala, S.; Blackmore, J.; Diaper, C.; Moglia, M.; Sharma, A., Kenway, S. Towards the adoption of integrated urban water management approach for planning; *Water Environment Federation Technical Exhibition and Conference*: New Orleans, LA, 2010.

(22) USF Brownfields Center for Research and Redevelopment. *Mapping East Tampa: Health, Brownfields, and Population*; University of South Florida: Tampa, FL, 2009.

(23) U.S. Census Bureau. Population Estimates: Metropolitan and Micropolitan Statistical Areas; http://www.census.gov/popest/metro/metro.html (accessed October 3, 2010).

(24) Gordon-Larsen, P.; Nelson, M. C.; Page, P.; Popkin, B. M. Inequality in the built environment underlies key health disparities in physical activity and obesity. *Pediatrics* **2006**, *117* (2), 417–424.

(25) ESRI. Census 2000 TIGER/Line Shapefiles: Florida; http://arcdata.esri.com/data/tiger2000/tiger_statelayer.cfm?sfips=12.

(26) Stuart, A. L.; Mudhasakul, S.; Sriwatanapongse, W. The social distribution of neighborhood-scale air pollution and monitoring protection. *J. Air Waste Manage.* **2009**, *59*, 591–602.

(27) City of Tampa. *East Tampa: Existing Conditions Report*; Department of Business and Housing Development: Tampa, 2003.

(28) *East Tampa Strategic Action Plan*; City of Tampa and the East Tampa Community Revitalization Partnership: Tampa, 2009; https://www.tampagov.net/dept_economic_and_urban_development/files/east_tampa/ET_SAP_Final.pdf (accessed October 3, 2010).

(29) Trotz, M. A., Thomas, K. D. Sustainability concepts through an applied environmental engineering laboratory: Studying stormwater ponds at the university and local communities. Paper presented at *American Society of Engineering Education (ASEE) Annual Conference & Exposition*; Austin, TX; June 14−17, 2009.

(30) Mihelcic, J. R.; Trotz, M. A. Sustainability and the environmental engineer: implications for education, research, and practice. *Environ. Eng.: Appl. Res. Pract.* **2010**, *10* (27), 1–10.

(31) Maimone, M.; Smullen, J.; Marengo, B., Crockett, C. The role of low impact redevelopment/development in integrated watershed management planning: Turning theory into practice. Paper presented at *Cities of the Future: Towards Integrated Sustainable Water and Landscape Management*; Racine, WI; June 12−14, 2007.

(32) City of Tampa. Park Facilities; http://www.tampagov.net/dept_geographic_information_systems/information_resources/Data_Downloads_and_Metadata/location/index.asp (accessed October 3, 2010).

(33) Florida Geographic Data Library. *FGDL Metadata Explorer*; University of Florida GeoPlan Center.

(34) City of Tampa. City Parks and Playgrounds Search; http://www.tampagov.net/parks_search_webapp/ParksList.aspx?cscRedirectID=231 (accessed October 3, 2010).

(35) Nicholls, S. Measuring the accessibility and equity of public parks: A case study using GIS. *Manage. Leisure* **2001**, *6*, 201–219.

(36) *Community Health Through Brownfields Redevelopment: A Community Listening Session to Shape Your Neighborhood Vision*; *City of Tampa*: East Tampa, Florida, September 18, 2008.

(37) Murray, A. T. Strategic analysis of public transport coverage. *Socio-Econ. Plann. Sci.* **2001**, *35*, 175–188.

(38) Talen, E. Neighborhoods as service providers: a methodology for evaluating pedestrian access. *Environ. Plann. B.* **2003**, *30*, 181–200.

(39) Sister, C.; Wilson, J., Wolch, J. *The Green Visions Plan for 21st Century Southern California. 15. Park Congestion and Strategies to Increase Park Equity*; University of Southern California GIS Research Laboratory and Center for Sustainable Cities: Los Angeles, CA, 2007.