Storm Water Management Using Vacant Lots in New Haven, Connecticut

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Abstract: *Based on Ian McHarg's framework of land use planning through evaluations of ecological function, this study proposes a solution to two urban problems: storm water drainage and vacant lot management. If viewed as an untapped resource rather than a burden, a network of urban vacant lots provides an opportunity to improve storm water drainage through the implementation of Best Management Practices, such as bioswales, rain gardens, and constructed wetlands. Using a Geographic Information Systems (GIS) model, flow accumulation potential and social need are mapped within each of New Haven, Connecticut's vacant property parcels. Vacant lots are given a composite score based on their ranking in each ecological and social factor. The eleven highest-scoring lots are evaluated through site visits in order to assess the success of the model and potential impact of using ecological data to inform planning decisions in an urban context.*

Introduction

Ian McHarg's influential 1969 book titled *Design with Nature* proposed a framework of land use planning and landscape design in which the ecology of a region is taken into consideration when selecting sites for development and preservation. McHarg moves away from what he calls "plaintive bleeding heartism," (McHarg 1969: 55) making his argument against the spread of mindless destruction instead based in science and understanding of natural systems and processes. A crucial principle in McHarg's framework is that "...nature performed work for man without his investment and that such work did represent a value" (Ibid.). In his chapter "Nature in the Metropolis" McHarg applies his framework to open space planning at the metropolitan region scale, stating, "Conceivably such lands wherein exist these intrinsic values and constraints would provide the source of open space for metropolitan areas. If so, they would satisfy a double purpose: ensuring the operation of vital natural processes and employing lands unsuited to development in ways that would leave them unharmed by these often violent processes" (Ibid. 56). Open space is often threatened by development interests that do not consider the ecological function of that land in its undisturbed state. Selecting land to be designated as open space based on its ecological value, and programming it for a compatible human use appropriates land more

efficiently, and leaves land available for development that does not sacrifice the ecological functions that nature provides without man's investment.

One set of ecological functions that have been greatly disturbed by development is the natural drainage systems that move rainwater over land to rivers and then into the oceans. While urbanization degrades these systems, it does nothing to reduce rainfall, and so man has been forced to develop, at a great cost, artificial drainage systems in the form of storm drains and underground infrastructure. In the words of McHarg, "…urbanization will affect the rate of runoff, erosion and sedimentation, causing water turbidity, diminution of aquatic organisms, and reduction in natural water purification. These, in turn, will result in channel dredging costs, increased water treatment costs, and possibly, flood damages and drought costs" (Ibid.). The monetary cost associated with removing nature's drainage system is often not factored in to development, but it clearly exists. McHarg calls for his ecologically informed method to replace "The economists view of nature as a generally uniform commodity…" (Ibid.) and instead urges planners to, "…find discrete aspects of natural processes that carry their own values and prohibitions" (Ibid. 57) which are incorporated into a "single accounting system" (Ibid. 65).

In the forty years since *Design with Nature* was published, many scholars have addressed the need to assign value to ecological functions. Valuing ecosystem services has been a collaboration of ecology and economics, attempting, as Costanza et al. (1997) has done, to assign dollar values to natural capital, and devise policies that force the market to incorporate these monetary costs and benefits of development into economic transactions. Unfortunately, "Valuing a natural ecosystem, like valuing a human life, is fraught with difficulties" (Daily et al. 1997) and it has proven extremely difficult to create appropriate valuation practices and policies that keep the preservation of ecosystem services in balance. This paper presents a simpler approach,

valuing ecological function on a relative scale rather than in economic terms in order to aid publicly owned land use decision making through priority ranking. Just as McHarg used layers of paper maps to assess the spatial distribution of ecological value, this paper uses digital mapping to rank ecological and social function of specific land parcels, drawing on McHarg's call for attention to the value of natural storm water drainage systems.

New Haven, Connecticut, the study area of this paper, is a city that, like most other American cities, relies on man-made engineering works to drain rainwater off of the land surface. In order to address the high concentration of pollutants that urban runoff collects as it flows over roadways, New Haven has a Combined Sewer System in which storm water runoff drains into the underground sewer network and is treated along with municipal waste before it is released into Long Island Sound. Unfortunately, Combined Sewer infrastructure has a maximum volumetric capacity that can be treated in a period of time. When that maximum capacity is surpassed, untreated runoff and sewage is released into bodies of water at Combined Sewer Overflow (CSO) outflow points. The rise in impervious land cover that accompanies urbanization causes more frequent CSO occurrences because water travels more quickly over paved surfaces than vegetated surfaces. More rainfall reaches underground drainage infrastructure in a less time, straining the system beyond its maximum volumetric capacity. It is becoming a priority of city planners to preserve vegetated land cover and discourage increases in impervious surface in new developments.

While a great deal of New Haven's land is in a developed state, city owned vacant land, often considered a burden on municipal resources, is an untapped resource with potential to relieve some of the stress on storm drainage infrastructure. As they exist, vacant lots are known for attracting crime, being used as illegal dumping sites, and draining neighboring property

values. But they should also be viewed as spaces without roofs, roads, or parking lots, characteristics that are beneficial to storm water drainage alone, and also with potential to become highly functioning storm water management infrastructure with relatively little investment. From a purely financial perspective, city planners are anxious to return vacant land parcels to the ownership of private individuals in order to reduce maintenance expenses and increase the city's taxable property base. Alternatively, if planners consider that each vacant piece of land has a different relationship to the built and natural environment that surrounds it, they might find that some of these pieces of land are better suited to perform specific ecologic functions, if designed to do so. This paper investigates the application of McHarg's view of nature's distinct intrinsic ecological values to vacant urban land whose original ecological function has been disturbed, but may be appraised for ecological value within the urban ecosystem. More specifically, the methodology employs a geographic information system (GIS) model that determines a land parcel's ability to collect runoff based on its topography, location in relation to impervious surface, and existing storm drain infrastructure in order to evaluate potential ecological function.

In an urban context, more than just the potential ecological value must be considered. While the ecology of a site should be a key factor in its selection, the social and economic impact must be weighed appropriately in order to ensure a beneficial change to the landscape. Lovell and Johnston (2009) build on McHarg with the idea of multifunctional landscapes, defined as those that provide multiple environmental, economic, and social functions in a given area of land. Design that achieves multifunctionality is necessary to attract multiple stakeholder groups and ensure satisfaction with changes in urban landscapes. As described above, the environmental and economic benefits of redeveloping vacant lots as storm water infrastructure go hand in hand.

The strategy addresses environmental hazards associated with CSO through improving surface drainage and abates the need for costly sewer upgrades by reducing runoff rates and volumes during rainstorms. Additionally, the city can put maintenance expenditures that currently keep vacant sites crime free to use in beneficial infrastructure. Social functions are harder to identify concretely. Following the work of urbanists such as Jane Jacobs (1961) and William H. Whyte (1980), there is a general consensus that properly located, people friendly parks and public spaces stay free of illicit activity and provide a place for socializing and community building. Lovell and Johnston find that bioretention facilities such as rain gardens and larger constructed wetlands can be "designed into the landscape, to provide a wide range of ecological functions such as water infiltration, water treatment, microclimate control, wildlife habitat, and biodiversity, as well as cultural functions including education and visual quality." In this study, vacant lots first identified for their potential ecological function will be further investigated for their potential social benefit based on their location in relation to other green spaces in New Haven and the density of the surrounding population. The final product of this research presents recommendations regarding the development of a set of properties into storm water management parks, in order to improve drainage at a manageable cost to the city as well as provide quality public space.

The first section of this paper reviews the ecology and design literature surrounding storm water drainage Best Management Practices (BMPs) in order to demonstrate the need for new strategies and the effectiveness of proposed solutions. The subsequent section explores the history of vacant lots as environmental, social, and economic burdens in American cities, and then the use of GIS in vacant lot and storm water management work. The context section focuses specifically on the case of the city of New Haven and its current storm water management issues

as well as its approach to managing vacant lots over the past two decades. The methods section describes the GIS data collection and analysis steps taken in order to build a model that addresses the research question, "which of its vacant lots should New Haven re-purpose into urban-ecology and storm water management infrastructure?" Finally, an evaluation of the results of the GIS model, eleven vacant lots that rank highest in terms of potential ecological and social function, reveals conclusions about the effectiveness and impact of the study.

Literature Review

This section of the paper serves to summarize the current discussion surrounding urban storm water runoff and the use of certain Best Management Practices (BMPs) for mitigating its ecological impact by improving infiltration and biofiltration. A more focused discussion of the use of city-owned landscapes as green storm water infrastructure, interconnected networks of open spaces and natural areas that naturally manage storm water (as opposed to hard infrastructure Combined Sewer Systems) is followed by a review of the history and management of urban vacant lots. Lastly, this section discusses the use of GIS modeling as a method of locating areas suitable for BMP implementation based on ecological and social factors.

Urban Storm Water Impacts and Solutions

Urban storm water management has been characterized by several different modes of thought in the past century. The primary focus of watershed planning from the 1950s through the 1970s was to move the largest volumes of water off the land in the shortest amount of time (Carter 1961). Storm water was managed by highly engineered systems of underground piping and channeled streams. The need for storm water management arose due to the effect that urbanization has on hydrological systems. The replacement of vegetation with impermeable

surface such as roofs, paved roads, and parking lots causes more water to reach the ground without being intercepted by leafy vegetation. During and after a storm, less water evaporates via evapotranspiration from vegetated areas, and much of the water that reaches the ground surface does not filter into the soil, but rather runs over impermeable pavement, creating the need for drains that move the large volumes of water below the surface, rather than on flooded roadways (Whitford et al. 2001). While traditional storm water management systems successfully divert water from land surface, the goal of moving large volumes of storm water rapidly has many adverse impacts. The risk of flash flooding is heightened in urban areas due to the fact that infrastructure can move much of the rainfall across an urban area during a storm to the outflow point in a relatively short amount of time, causing the stream to flood (Cadenasso 2008). Additionally, the rate at which water flows through engineered infrastructure does not allow any residence time for water runoff to filter out the pollutants that it picks up from roadways.

The ability of hard storm water infrastructure to combat the drainage effects of urbanization in a sustainable manner has come into question more frequently as these systems, degraded over time, deteriorate and fail (Donofrio et al. 2009). The ecological impacts of the failure of underground infrastructure is compounded by the fact that many cities, 772 in the United States, have Combined Sewer Systems, that collect sewage and storm water runoff in the same system. These systems are designed with the intent of treating all wastewater and runoff before it enters streams, rivers, and oceans. Unfortunately, during high flow events caused by heavy rainfall, the fixed storm water management budget of a Combined Sewer may be surpassed, discharging excess wastewater directly into nearby streams, rivers, or other water bodies (EPA 2010). Combined Sewer Overflows (CSOs) contain not only storm water, but also

untreated human and industrial waste, toxic materials, and debris, and are cited as a major water pollution concern by the EPA (ibid).

Improvements to hard infrastructure are costly and only increase system capacity that may one day also be surpassed unless changes to the landscape surface are made. The ratio of pervious to impervious surface is important in modeling storm water runoff (Graham et al. 1974) and forward-thinking municipalities have drawn up zoning codes that require certain percentages of pervious surface in different land use categories (Arnold and Gibbons 1996). With less pavement, more water can seep into the ground where it falls, rather than flowing and accumulating over impervious surface. “Green” storm water infrastructure, that which targets surface runoff by increasing the amount of vegetation cover, takes on a number of different forms in the urban landscape, but all are based on the concept that extensive root systems of woody plants, perennials, and trees hold soil in place, allow greater infiltration of water, and trap sediment entering from adjacent areas (Lowrance et al. 2002; Lee et al. 2003).

A bioswale is a vegetated channel meant to slow runoff as it moves through bends and curves in the trench. Slower movement of water allows for some of the water to infiltrate into the ground and also for pollutants to be taken up through biofiltration of root systems. Rain gardens are planted depressions meant to receive water running off of rooftops that would otherwise flow onto the street. Constructed wetlands, or retention ponds, are larger areas that can be coupled with systems of bioswales or other water channels that are designed to collect large volumes of water and gradually infiltrate water into the soil and through a series of vegetation treatments so that the water exits the wetland at a slow rate and in a cleaner state.

The effectiveness of bioswales, rain gardens, and constructed wetlands has been studied by researchers and shown to make considerable improvements to pollution, removing suspended

solids, nutrients, and heavy metals from urban runoff before it eventually enters a lake or stream (Mungasavale and Virarghavan 2006). Studies of the ability of constructed wetlands to remove phosphorous have results ranging from 13 percent to 66 percent total removal, averaging at 35 percent removal (Comings et al. 2000; Kantrowitz and Woodham 1995; Gain 1996; Wu et al. 1996; Maristany 1993). In Winnipeg, Ontario, a system of retention ponds set within its suburban housing areas serve as an effective storm water management system and have been estimated to result in savings of 600 percent over conventional systems (Ministry of the Environment 1977)**.** Overall there is support for the use of BMPs, but also an understanding that there is no single solution and that green infrastructure is best implemented in a variety of forms in order to create a larger system of storm water management, a hydrologically functional landscape that mimics natural hydrologic regimes (Brabec 2002; Prince Georges County 1999).

Green Storm Water Infrastructure in the Urban Landscape

Urbanization has destroyed the ability of watersheds to drain themselves properly, and has increased the abundance of pollutants that are channeled into water bodies. Studies of Best Management Practices (BMPs) indicate that returning pieces of the urban landscape to a natural, vegetated state would mitigate problems of flooding and pollution. Due to the compact nature of cities, it is somewhat difficult to envision the incorporation of natural hydrological management features into the built environment, but the concept is catching on. In Seattle, Washington a municipal program called “SEA Streets” (standing for Street Edge Alternatives) has developed a number of bioswales along residential streets, contributing to a better system of channeling road runoff into Seattle’s Combined Sewer (Seattle Public Utilities 2010). Cairns and Palmer (1995) suggest the conversion or “recycling” of vacant lots as natural habitat parks in order to put abandoned properties to good use and increase pervious land cover. In Los Angeles, a “storm

water park" has been proposed at the site of a vacant lot. The lot will be depressed to increase storage capacity for capturing water from its 14-acre contributing area (Sayre et al. 2006). In Philadelphia, five vacant lots were cleared and planted with vegetation and then monitored to determine their impact on storm water retention. Meters measuring infiltration rates showed improvements at all sites and a simulation of annual rainfall events demonstrated a 30 percent average runoff reduction from all sites, translating into more than 25,000 cubic feet of total runoff detention storage on the five sites during a rainfall event (Yang and Myers 2007). Cities are beginning to look to vacant lot greening as a practical approach to managing storm water. The practice is encouraged, but there has yet to be an effort on a citywide scale to create an extensive system of green infrastructure dedicated to storm water management.

Vacant Lot History and Management

The causes of vacant lots in the United States can be traced back to federal policies that subsidized the initial outmigration of much of the middle class from central cities in the aftermath of WWII. This trend was perpetuated throughout the remainder of the 20th century by a feedback mechanism of the declining appeal of inner city neighborhoods and declining tax base. Federal housing policy favored new construction over existing developments and created easy access to cheap land on the urban fringe with the development of the new interstate highway program. Huge developments of inexpensive, easily accessible detached single family homes such as Levittown in Long Island, NYC drew inner city residents to the suburbs in vast quantities, with adverse consequence for cities (Gelfand 1975).

The housing choices that people make have to do with a combination of population density, land use mixture, public safety, and quality of schools, social services, and the natural environment. For residents whose income does not restrict their housing choices to the inner city,

it is often a rational decision to avoid central city neighborhoods. As residents leave the inner city, demand for housing declines, the population becomes disproportionately poor, and the rents that landlords can charge plummet. The point at which the cost of maintenance and property taxes outweighs the rent being earned by a property, abandonment becomes an economically rational decision (Accordino and Johnson 2000). While property abandonment was initially considered a symptom of urban disinvestment, planners have come to view property abandonment as, if not a cause, a contributing factor to a vicious feedback cycle of neighborhood decline that operates as follows: vacant and abandoned properties impose a significant externality on neighboring property owners by lowering the market value of their properties, which reduces their equity and thus their wealth, and makes resale of their properties very difficult. As market value decreases, so does assessed value, forcing central cities to either raise property taxes or suffer from reduced tax revenues (Goldstein et al. 2001). The increase of taxes perpetuates abandonment of properties earning low rents, and may also drive remnants of the middle class to the suburbs where property taxes are lower. If a city does not raise taxes, there are fewer resources available to devote to public improvements, maintenance in neighborhoods, and social services that attract residents in the first place. Beyond the economic hardships that vacant properties bring upon communities, vacant lots have adverse social impacts, as they tend to serve as "magnets for crime" (Spellman 1993), bringing negative reputations to communities and furthering the exodus of residents. Accordino and Johnson’s (2000) survey of 147 city officials ranked neighborhood vitality and crime prevention efforts as the community qualities most affected by vacant and abandoned property.

Municipal policies regarding vacant property often take the form of code enforcement that heavily penalizes owners of derelict properties in order to encourage upkeep through fear of

consequences. Improving the effectiveness of these policies, while important, is outside the scope of this research. Instead, this paper focuses on already existing vacant properties whose ownership has been ceded to the city and whose future use is undetermined.

Cities have taken on a variety of approaches concerning the use of reclaimed vacant land. The City of Providence, Rhode Island implemented a series of reforms after its Vacant Lot Task Force discovered over 4,000 vacant parcels, half of which were unmaintained and also presented imminent health and safety hazards to the public. The city budgeted for routine maintenance of city owned parcels and created a $1/Lot program through which lots could be cheaply and easily sold to neighborhood residents or nonprofits with specific redevelopment intentions (Goldstein et al. 2001). In the 1990s Baltimore found itself struggling to maintain its 6,000 acres of city owned park land, which includes approximately 14,000 vacant lots. With the help of the local Parks and People Foundation, vacant lots were adopted and maintained by community groups through the Neighborhood Open Space Management Project (Parks and People Foundation 2000). In the New Kensington neighborhood of Philadelphia, the New Kensington Community Development Corporation runs a similar lot greening program that, in addition to cleaning lots, designated several parcels as community gardens, and facilitated the sale of other lots to private owners as side yards (Goldstein et al. 2001). Reclaimed and restored lots do not detract from neighborhood vitality; instead they are a space for socializing and community building.

In both Baltimore and Philadelphia, lot regeneration was spurred by nonprofit organizations interested in improving their communities. While these organizations have support and in some cases funding from their respective cities, the need for third party intervention in dealing with vacant lots highlights the degree to which cities have not been able to successfully address the problem themselves. But perhaps the narrative of vacancy, as described above, has

inhibited cities from making significant changes. Land without buildings is not inherently bad, rather the implications associated with vacant land, that it has been abandoned due to neglect, must be addressed. If vacant lots are viewed only as spaces that no longer provide tax revenue and attract crime, solutions to vacant lots will be based on fixing those problems by returning vacant land to private ownership or encouraging collective stewardship by the surrounding community. These approaches, while somewhat successful, do not consider the potential ecological value of vacant land. By focusing on returning vacant lots to their developed state, cities forfeit the opportunity to restore ecological function to the urban landscape that is embedded in the thousands of vacant parcels spread across inner cities. This study proposes a new approach that considers vacant land not only in the context of what it once was, but also in terms of the infrastructural and environmental needs of a city, and how each parcel can best contribute. Within the framework of multifunctional landscapes, this research acknowledges the social benefit of ecological restoration through enhancing public space, and prioritizes vacant lot selection based on both ecological function and social need.

GIS as a Tool for Storm Water Modeling and Social Need Mapping

The use of digital mapping in this study facilitates the conceptualization of vacant lots as a network of storm water management resources with varying degrees of social impact within their urban context. This section reviews approaches to storm water modeling and the use of Map Algebra as tools for decision making regarding the use of vacant lots. In order to encourage interest in comprehensive green storm water management, GIS tools have been utilized to simulate changes in runoff due to land cover changes and also to select appropriate sites for green infrastructure.

GIS models incorporating topography and soil composition data have been used to simulate rainstorms and runoff for several decades. Berry and Sailor's study of a small watershed applied the flow simulation model to a hypothetical conversion of open space to a residential subunit, showing the increased potential for flooding (Berry and Sailor 1987). Other studies focus on the use of GIS as a method of locating available land that is suitable for conversion to storm water infrastructure (Gemitzi et al. 2007). GIS has the advantage of allowing researchers to approach an urban area from a bird's eye perspective, rather than on a project-by-project basis.

The results of larger scale modeling and simulations can be compelling evidence supporting the implementation of Best Management Practices (BMPs). Some models aim specifically to influence policy and planning decisions by converting the loss or gain of impervious surface and vegetation into dollar amounts based on the ecological services, such as storm water retention, that they provide. For example, the US-based nonprofit organization, American Forests, has created an extension for ESRI's ArcGIS program that calculates the economic value of urban forests. The tool incorporates ecosystem service values based on the ability of urban forests to improve carbon sequestration, air pollution removal, energy conservation through shade provision, biodiversity, and storm water runoff retention (American Forests 2010). Because the majority of a municipality's budget comes from property taxes, the appropriation of land for non-tax-generating uses must be considered against the opportunity cost of not collecting taxes on that property as it stands currently, as well as its potential to generate taxes if developed in different ways. In order to address tradeoffs between the cost of implementing BMPs and storm water reduction benefits, Perez-Pedini et al. (2005) developed a curve showing diminishing marginal returns of peak flow reduction of additional BMPs in a watershed. The peak flow reduction of the 200th BMP was much lower than that of the 25th,

demonstrating the opportunity for planners to make strategic decisions regarding the designation of land use that maximizes environmental and economic benefit.

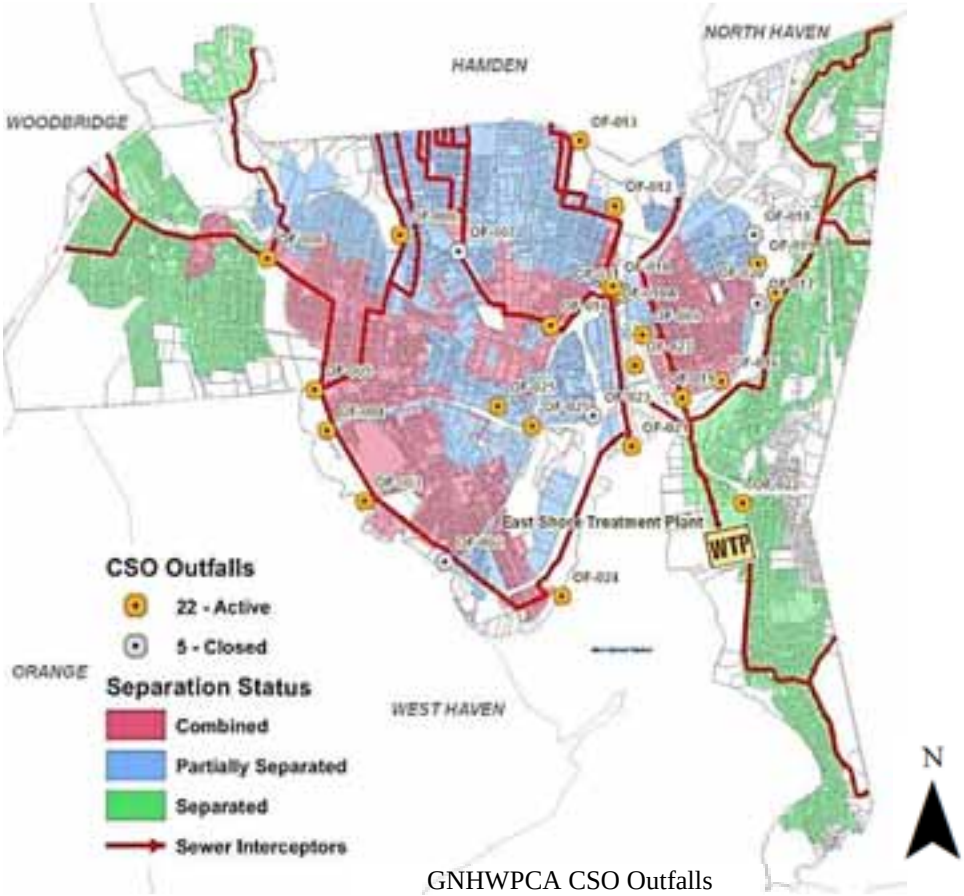
While this study does not extend to economic cost/benefit analysis of the development of particular lots, GIS is used to rank lots based on ecological and social factors in order to identify their relative benefit in terms of storm water management potential and social need. Map Algebra, the technique of combining multiple layers of information of the same geographic area through basic mathematical operations, such as addition, was developed by Dana Tomlin in the 1980s. In this study Map Algebra is the final step of the analysis, used to add each separate ecological and social ranking factor together in order to produce a composite score, the highest of which represent those lots with the most potential to address ecological and social concerns.

Context: New Haven, Connecticut

Storm Water Impact and Management

Every year in New Haven, CT, an average of 240 million gallons of untreated combined sewage overflows into the Mill, West, and Quinnipiac Rivers or directly into New Haven Harbor (GNHWPCA 2007). During dry weather, sewage runs through the East Shore Treatment Plant, which manages a maximum of 60 million gallons of sewage daily, where it is disinfected before being released into New Haven Harbor. During heavy rains, the high volume of storm water runoff can cause the system to back up, at which point sewage and runoff leaves the sewer system untreated through the 22 active CSO outfalls shown in the map below. New Haven's Combined Sewer System is managed by the Greater New Haven Water Pollution Control Authority (GNHWPCA) which includes the neighboring towns of Woodbridge, East Haven, and Hamden, but all of the CSO outfalls are located within New Haven. The Connecticut Department of Public Health monitors water quality at the 66 public beaches along the Connecticut coastline

and issues warnings and sometimes closes beaches in the event of elevated concentrations of contaminants. In 2009, 81 percent of beach closing days were caused by storm water (NRDC 2010). Following EPA mandate, The GNHWPCA has set a 15 year Long Term Control Plan (LTCP) in motion in order to address the high volumes of untreated discharge. The $300 million plan, 40 percent of which is to be financed by the City of New Haven, will improve flow to the East Shore Treatment Plant during rain events and install off-line combined sewage storage tanks that can be pumped to the East Shore Treatment Plant during dry weather (GNHWPCA 2007). While increasing the volumetric capacity of the system will surely reduce the amount of discharged untreated runoff and sewage, improvements to the storm water treatment system merely address a symptom, not a cause of the problem. Rain storms would not place as great a stress on the system in the first place if more of the runoff were absorbed by porous surfaces. A comprehensive solution must address the land cover impacts of urbanization rather than merely continuing to accommodate larger and larger volumes of runoff.



GNHWPCA CSO Outfalls

Storm water on Everit Street, Oct. 1, 2010
Courtesy Melissa Bailey, NH Independent

Aside from reducing pollution caused by rainstorm-induced CSO, storm water BMPs intended to increase surface infiltration also address the simple need to remove standing water from roadways. The picture above demonstrates the extent to which rain can create dangerous conditions. Since December 2010 the City of New Haven has been discussing the creation of a Storm Water Authority which would bill property owners according to their impervious surface coverage. By redistributing the burden of paying for runoff removal to those properties with the greatest impact, this policy would help to inform individuals of the impacts of landscaping choices. Revenues earned by the Storm Water Authority would pay for sewer improvements. A portion of the budget could be well spent on implementing innovative approaches to storm water management in public places as an educational tool for homeowners seeking to decrease runoff generated by their properties.

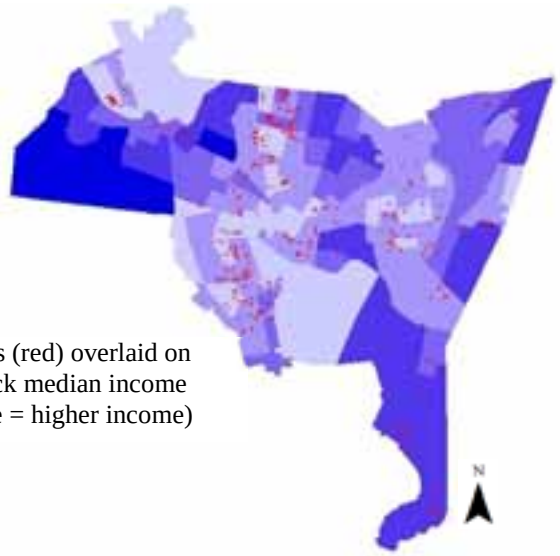
Vacant Lot Management

City owned properties on which New Haven could implement storm water Best Management Practices (BMPs) exist in abundance in the form of vacant lots. In 2010 there were

618 vacant lots in the care of the Livable Cities Initiative (LCI), an arm of the municipal government in charge of managing public housing and open space. In 1998 the City created the Vacant Lot Task Force, collaborating with several nonprofit partners such as the Urban Resources Initiative and the New Haven Land Trust in order to develop a strategy for eliminating blight on all vacant lands. While there are ongoing attempts to reduce the number of vacant lots owned by the city as well as restore those in the City's care, no single policy has or will solve the problem. Like vacant lot management strategies discussed above, New Haven's approach has focused mainly on regaining property taxes and reclaiming lots through community building. In 2009 LCI started a "sliver lot" sale through which vacant properties can be purchased by adjacent homeowners with plans to maintain the lot for $1. The goal behind the sliver lot sale is to rid LCI of the burden of maintaining the lots and eventually earn more property taxes. As one might expect, the majority of vacant lots are in poorer neighborhoods, and despite the almost nonexistent cost of acquiring the lots, many homeowners do not have the financial means to pay increased property taxes or maintain the lots, so many remain in the hands of LCI. Despite the fact that LCI lists residential off street parking as a priority for sliver lot conversions, many purchased lots have been turned into side yards (Trachten 2011). From an environmental perspective, it is preferable that sliver lots are not being converted into parking spaces, and considering the recent focus on storm water, it would make sense for the sliver lot policy to include guidelines specifying acceptable uses for sliver lots that do not include increasing impervious surface.

The Urban Resources Initiative (URI) has been one of the City's primary nonprofit partners involved in restoring vacant lots. Similar to the case of Baltimore, URI's approach to vacant lot restoration is based heavily in community building, and attributes successful lot

regeneration almost completely to the presence of strong community interest, a factor that limits the number of projects which can be undertaken. Currently, URI facilitates community



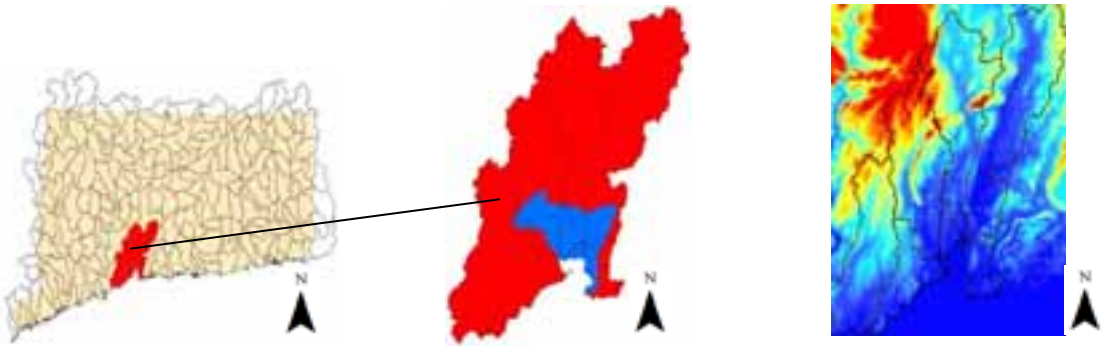
Vacant Lots (red) overlaid on census block median income (darker blue = higher income)

stewardship of 25 restored vacant lots. In a working paper investigating strategies for restoring vacant land, URI encourages a “multi-pronged strategy for treatment” that does not rely solely on the community based model if all 600 lots are to be addressed (Taylor 2000). The environmental impacts associated with storm water runoff and the current availability of vacant land with which runoff could be reduced present an opportunity to address two concerns simultaneously. The following section presents the GIS methodology used in this paper to identify a vacant lot with high ecological potential for storm water management, defined by its accumulation of runoff during a rain event, as well as potential social benefit, defined by a neighborhood’s need for green space based on the lack of nearby parks and population density. In addition to identifying specific vacant lots that could be regenerated for the specific use of storm water management, demonstrated here is an approach to land use planning in which urban ecology informs the appropriation of vacant land.

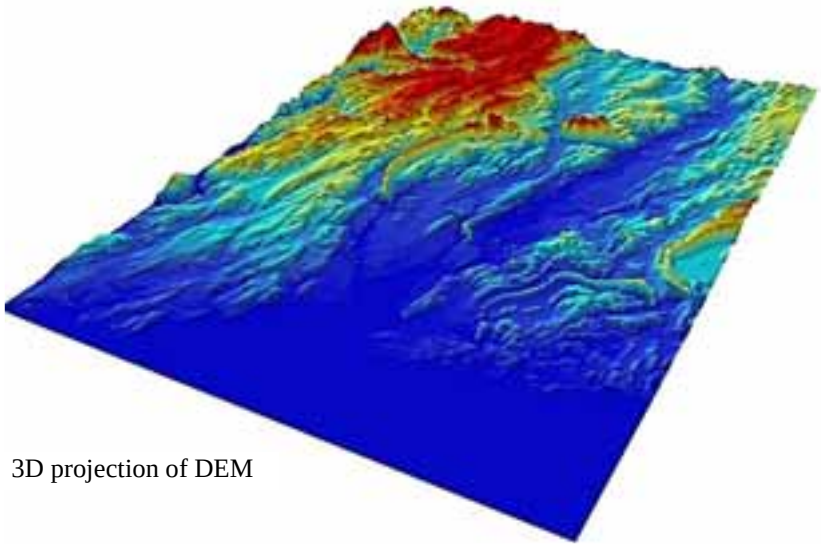
Methods:

I. Creating a watershed drainage surface: The topography, surface permeability, and storm drain points in New Haven were entered into a model that could then be used to simulate the flow of water over its surface and determine areas that acquire more water during rainfall events.

a. A map of Connecticut watersheds was overlaid with a boundary map of New Haven to determine which watersheds contribute to area within the municipal boundary of New Haven. Once identified, 10’x10’ LIDAR data was collected to be used as a Digital Elevation Model (DEM).



Connecticut Watersheds New Haven Watersheds DEM of New Haven Watersheds



3D projection of DEM

b. The “Fill” operation was used to eliminate any unintentional “sinks” due to errors in the LIDAR data collection and ensure that flow models could be calculated over a continuous surface.

c. A point file of storm drain locations was acquired from the Greater New Haven Water Pollution Control Agency (GNHWPCA), converted to raster, and reclassified so that each pixel containing a storm drain took on a value of “-500” and each pixel without a storm drain took on a value of “0.” The storm drain grid was added to the DEM using “Raster Calculator” so that the elevation of pixels containing storm drains was reduced by 500, creating deep sinks at each storm drain point. This serves to create a topographic surface that takes existing drainage infrastructure into account, so that water flowing over the surface will “sink in” if it runs over a storm drain.

Storm Drains

Exaggerated 3D projection of DEM including storm drains; each below-ground spike represents a sink at the location of a drain

d. A map containing Landcover data was obtained from the Urban Resources Initiative. This grid of New Haven classifies pixels as integer values corresponding

to tree, grass, dirt, roof, pavement (non-road), road surface, or water. The numbers associated with each landcover type were reassigned values (see Table 2) according to Curve Number classifications developed by the USDA Soil Conservation Service (1986) displayed in Table 1. Curve numbers rank the permeability of certain types of landcover overlaid on hydrologic soil groups from 1-100 with 1 being highly permeable and 100 being highly impermeable. Hydrologic soil groups categorize soil types in terms of their rates of infiltration A, B, C, or D with group A having a high infiltration rate, and thus low runoff potential and group D having a low infiltration rate and thus high runoff potential. While the US Geological Survey provides soils data for the study area, the process of converting it into a format that can be used in ArcMap is highly labor intensive and was not used in this study.

Instead, curve numbers were assigned as if all soils in the study area were part of the same hydrologic soil group A. This still allowed for the distinction between runoff potentials for grassy versus paved areas, although it did not take into account the underlying soil type. As can be seen in Table 1, the curve number rankings differ greatly depending on landcover type and less so depending on hydrologic soil group, so it is reasonable to assume that the flow model was roughly accurate.

Additionally, the cover types associated with curve numbers did not match up directly with the landcover types in the New Haven data set. Curve Number estimates for tree, grass, and dirt cover were assigned as follows: trees took on the ‘good condition’ open space curve number due to the increased

evapotranspiration that would be associated with tree cover, grass took on the "fair condition" curve number and dirt took on the "poor condition" number. Reclassification of landcover types to curve numbers by color can be seen in the maps below.

Table 1: Runoff Curve Numbers for Urban Areas

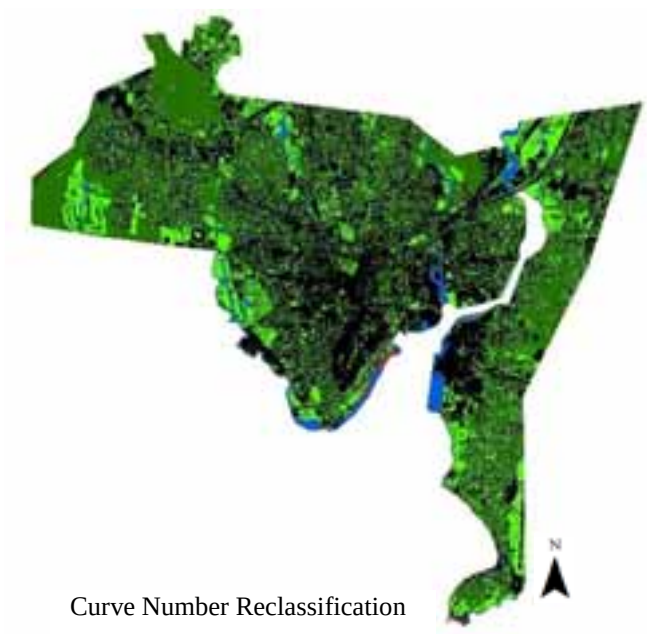
Cover Type and Hydrologic Soil Group	A	B	C	D
Open space (lawns, parks, golf courses, cemeteries, etc.):				
Poor condition (grass cover < 50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)	49	69	79	84
Good condition (grass cover > 75%)	39	61	74	80
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)	98	98	98	98
Streets and roads:				
Paved; curbs and storm drains (excluding right-of-way)	98	98	98	98
Paved; open ditches (including right-of-way)	83	89	92	93
Gravel (including right-of-way)	76	85	89	91
Dirt (including right-of-way)	72	82	87	89

Adapted from USDA SCS 1986 TR-55

Table 2: Curve Numbers Assigned to Landcover

Landcover	Curve Number
Trees (dark green)	39 (dark green)
Grass (light green)	49 (light green)
Dirt (brown)	68 (brown)
Roof (red)	98 (black)
Pavement (gray)	98 (black)
Road Surface (black)	98 (black)
Water (blue)	100 (blue)

URI New Haven Landcover



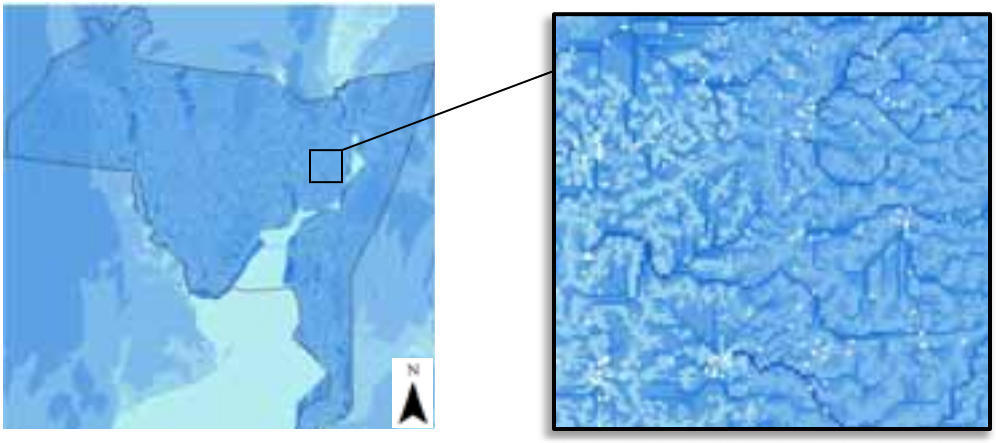
Curve Number Reclassification

e. With the DEM and the curve number grid, a “Flow Accumulation” model was created. The “Flow Accumulation” function simulates a rain event in which a single rain drop falls on each pixel. Then, according to the topography, each raindrop either stays in place (if its neighboring pixels are all at higher elevations) or moves to the neighboring pixel that is lowest in relation to itself. Once the neighboring pixel has summed all of the raindrops upstream of itself, it takes on that number value of raindrops. The DEM allows the direction of flow to be calculated and the curve number grid serves as a weighted “friction grid”.

The friction grid adds a layer of complexity to the model that accounts for the permeability of different surfaces. Instead of each pixel containing one raindrop to start, each pixel contains the number of raindrops equal to its assigned curve number. If a pixel with a high curve number is at the top of a hill, the flow accumulation model drains more raindrops down into a valley than if a pixel with a low curve number is at the top of a hill. This represents the fact that a larger volume of water runs off the area that it originally falls onto if the surface is pavement than if it is grass or tree cover, in which case it is intercepted by vegetation or infiltrated into the ground.

Streams of water that pass over storm drains fall into the sinks as discussed previously. In order to observe the accumulation of water that does *not* drain into the underground sewer system, pixels at the bottom of storm drain sinks, where much of the water accumulates, were assigned a value of “NoData” by reclassifying the original storm drain grid to values of “NoData” (for pixels with storm drains) and “0” (for pixels without storm drains) and adding the

resulting grid to the Flow Accumulation grid. Because the sum of any number and NoData is equal to NoData, any pixel containing a storm drain, and thus a high flow accumulation below ground, took on a value of NoData so that non-storm drain areas above ground that collect large amounts of water could be identified. The "Flow Accumulation" operation does not provide a volumetric calculation of runoff, but provides a map of wet and dry areas based on the topography and land cover. Pixels that took on high values in the flow accumulation map are places where water flows toward, and is not captured by pervious surface or storm drains en route.

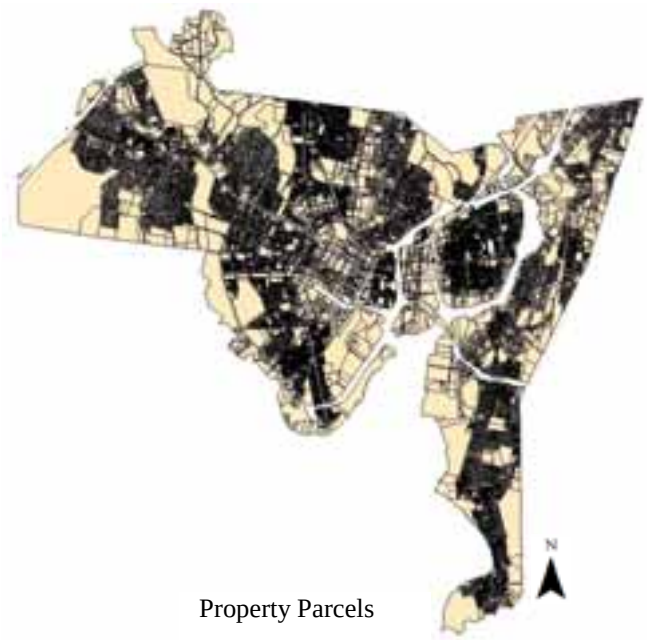


Flow Accumulation

Zoomed in: darker blue pixels have higher flow accumulation; white pixels are NoData

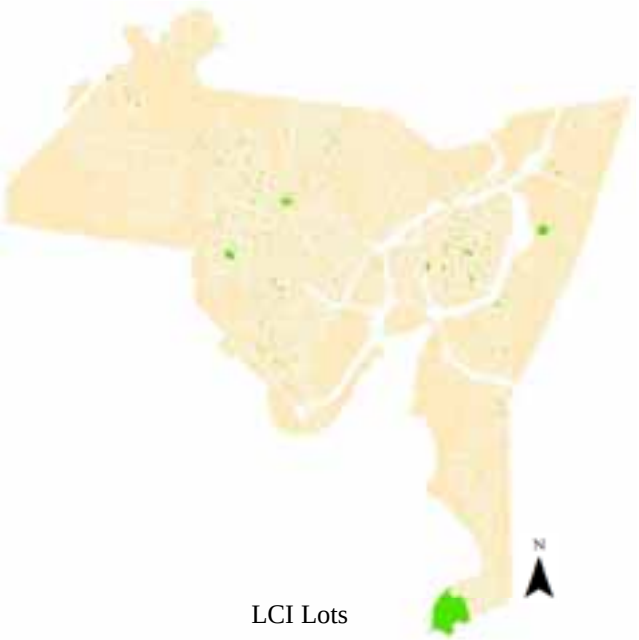
II. Identifying Flow Accumulation Zones: The following steps were taken in order to identify pixels that sit on the perimeters of vacant lots in New Haven. This was necessary in order to determine the relative amount of water flowing into a lot from the surrounding watershed aside from the water simply falling onto that lot during a rainstorm.

a. A shapefile of property parcels and an excel table of vacant properties were acquired from the City of New Haven and the Livable Cities Initiative (LCI), respectively.

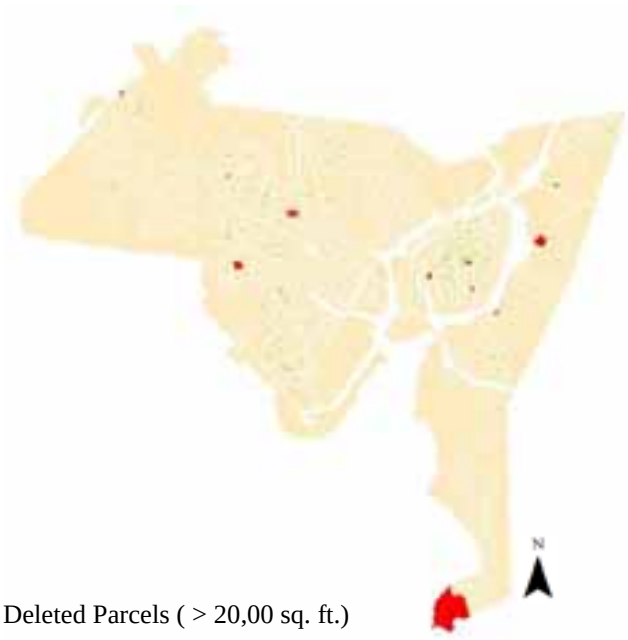


Property Parcels

b. The “Join” function was used to add the excel data denoting parcels classified as vacant from LCI to the properties shapefile. Vacant parcels were isolated into a separate shapefile. Some properties managed by LCI are not, in fact, residential lots. In order to pair the data set down to just vacant lots, parcels larger than 20,000 square feet were removed from the data set.

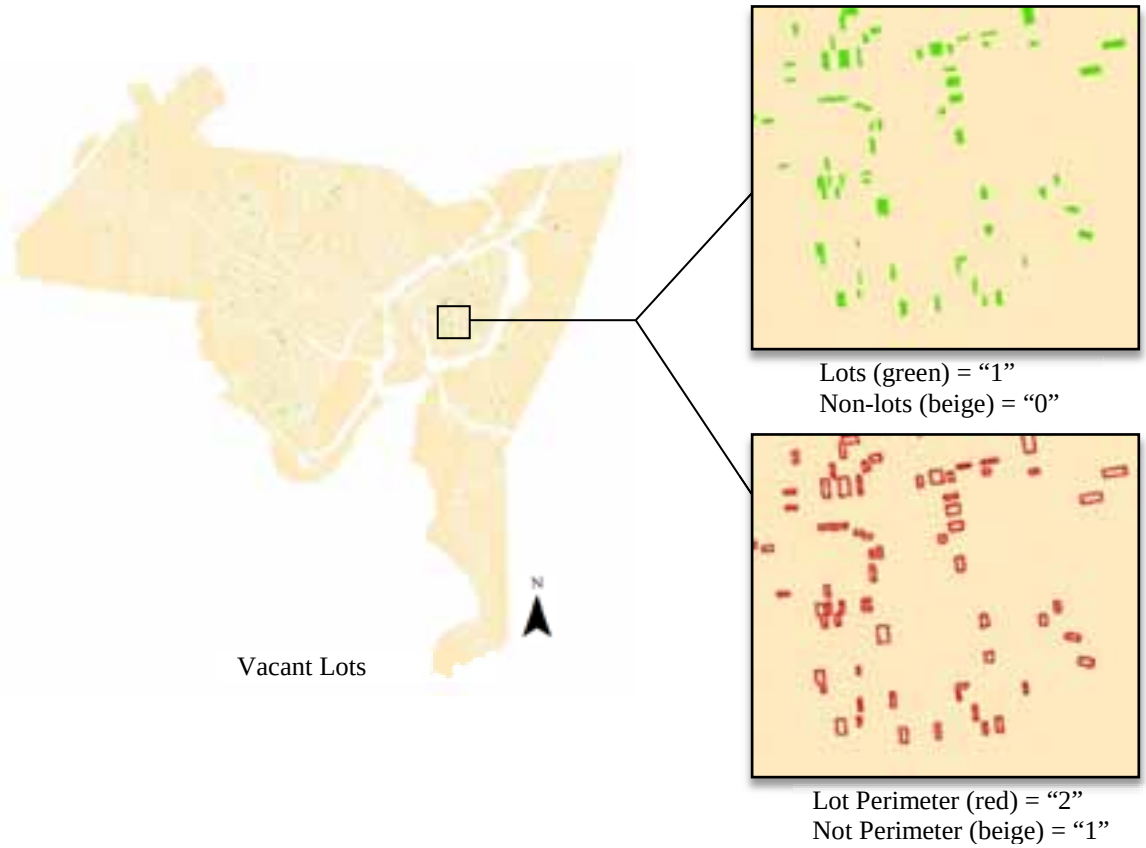


LCI Lots

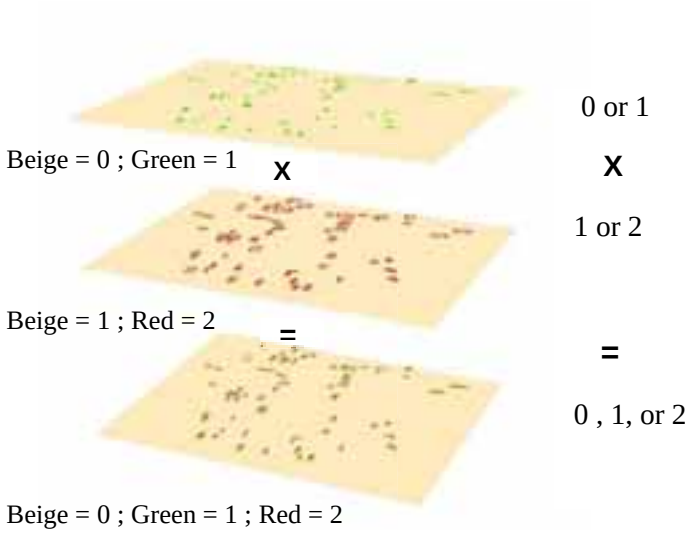


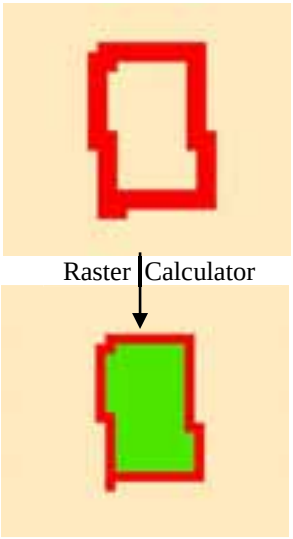
Deleted Parcels (> 20,00 sq. ft.)

c. The shapefile of just vacant lots was converted to a raster grid using the same output cell size as the DEM (10’x10’). The “Reclassify” function was used to assign values of “1” to pixels within vacant lots and values of “0” to pixels not in vacant lots. The “Focal Statistics: Neighborhood Variety” operation was used to identify pixels at the perimeter of the lots (variety = 2 because it has neighbors both in the lot and outside the lot), and pixels not at the perimeter (variety = 1 because its neighbors are either all inside the lot or all outside the lot).



d. The neighborhood variety function assigns a value of “2” to pixels that are at the edge of a lot, within the lot, and also to pixels at the edge of a lot, outside of a lot. In order to identify solely pixels that are at the edge of a lot and within that lot, the raster of neighborhood variety was multiplied by the raster with pixels classified as “Lot” = 1 and “non-lot” = 0. When multiplied together using “Raster Calculator” the pixels that are at the edge of the lot, but not inside the lot take on a value of “0” while those at the edge of the lot and inside the lot take on a value of “2.” Pixels inside the lot retain a value of “1.”



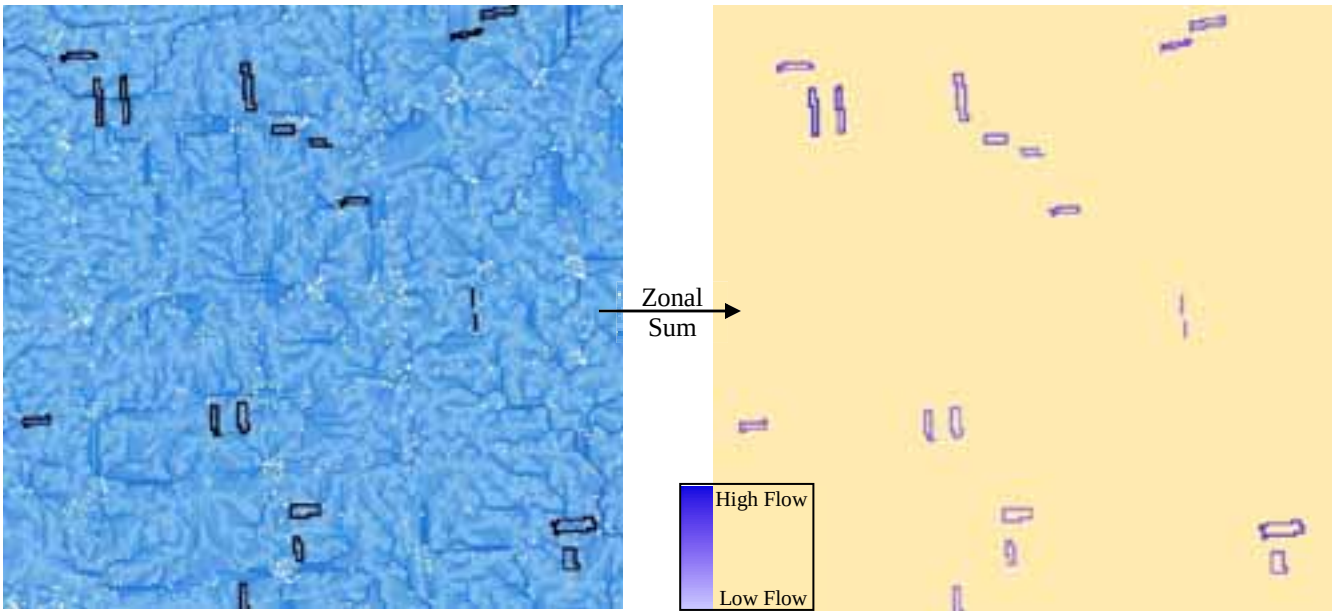


Note that the perimeter shown to the left loses one ring of red "perimeter" pixels during the Raster Calculator" operation because the outer pixels that are at the edge but not on the lot are multiplied by zero and thus take on a value of zero (beige).

e. Lot Edges were reclassified into values of "1" and non-edges were reclassified as "NoData." The "Region Group" tool was used distinguish each lot as a separate entity on the grid.

III. Calculating Flow Accumulation Within Each Lot

a. The region grouped Lot Edges layer was overlaid onto the flow accumulation layer. The "Zonal Sum" operation was used in order to count the values of flow accumulation under each perimeter pixel, and sum them for each lot. Each lot takes on the value of the sum of the flow accumulation on its perimeter, indicating which lots have relatively higher amounts of volume flowing into them than others.



Lot Edges overlaid on Flow Accumulation Grid

Flow Accumulation in each lot

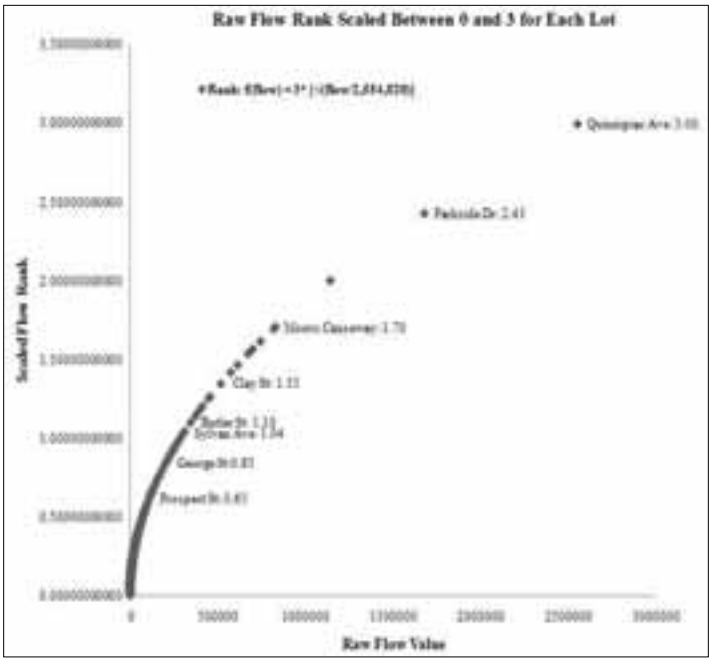
b. The flow accumulation value determined by the "Zonal Sum" operation is highly dependent on the number of pixels in the perimeter of a lot. From a planning perspective, it is useful to know both the flow accumulation potential of a lot per lot as well as per unit area. A regression analysis of the flow accumulation value and the lot perimeter length showed a strong correlation (P value = 0), suggesting that a ranking of the lots based on their raw flow accumulation value may simply show the largest lots having the highest ecological potential. In order to account for this, the full model (including social need factors discussed below) was run twice: once using the raw flow ranking and once using what will henceforth be referred to as the normalized flow ranking. The normalized flow ranking reports "flow accumulation per 10 feet of perimeter," created by using "field calculator" to divide the raw flow ranking by the number of pixels (each of which measures 10'x10') in each lot's perimeter.

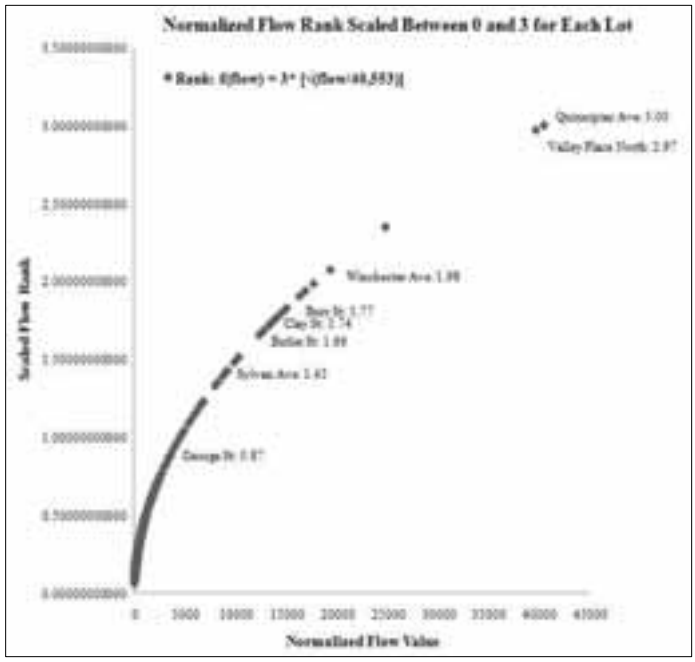
c. Each lot's raw flow ranking, which ranged from 35 to 2,554,820, and normalized flow ranking, which ranged from 18 to 40,553, was scaled to a value between 0 and 3 by using the "Field Calculator" operation to compute the following respective functions:

$$f(rawflow) = 3 \times \sqrt{rawflow \div 2{,}445{,}820}$$

$$f(normalizedflow) = 3 \times \sqrt{normalizedflow \div 40{,}553}$$

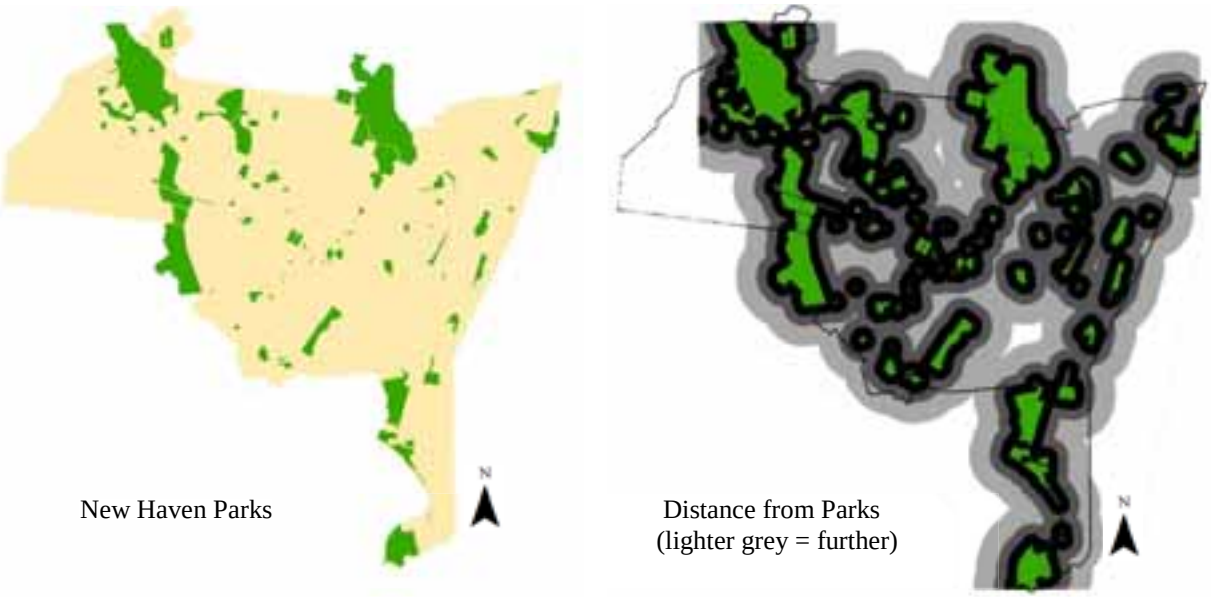
By dividing each lot's flow by the maximum flow value, the formula determines the percentage of the total possible flow that is found in that lot. A square root was applied to this percentage so that the rank spacing was narrower between small values than between large values. The multiplier of 3 scales the values to a short range that can eventually be tallied in the composite score. Below are graphs of the scaled flow ranking as a function of the raw or normalized flow ranking, with labeled data that eventually ranked highest in the composite scores.





IV. Mapping Social Need

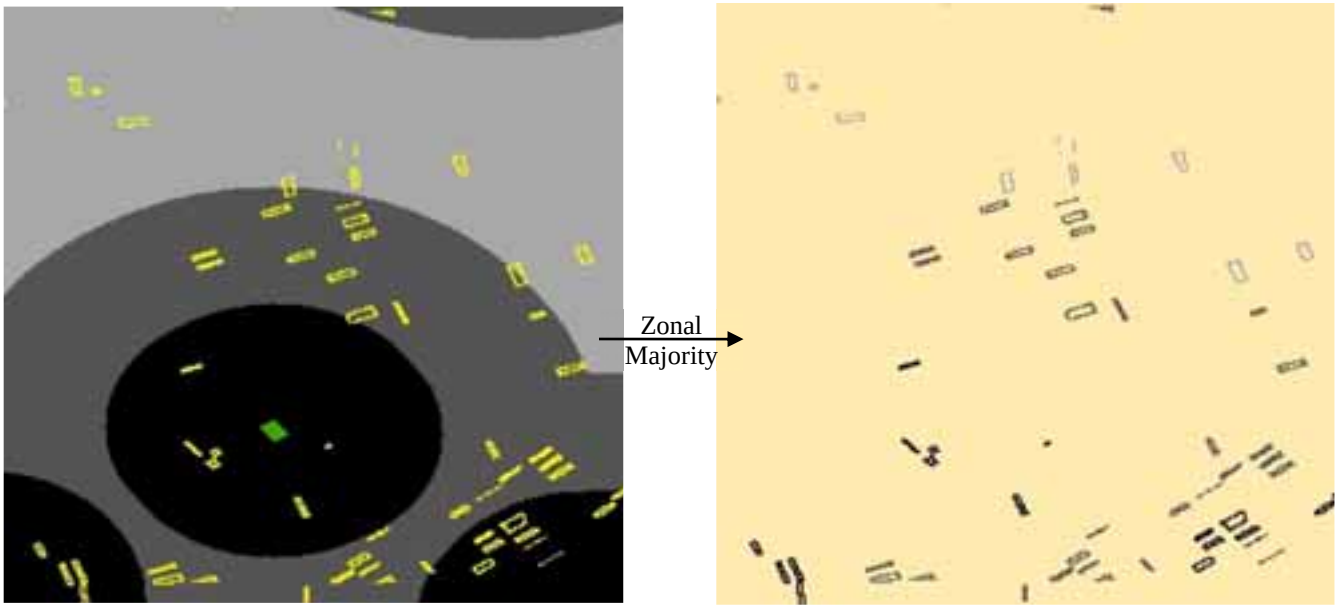
a. The first characteristic used to define social need was distance from existing parks. A shapefile of parks was obtained from the City of New Haven and subjected to the "Euclidean Distance" operation so that each pixel took on the value of its straight-line distance from park polygons. The distance raster was reclassified into categories so that pixels within ⅛ mile of an existing park took on a value of "0." Pixels between ⅛ and ¼ mile took on a value of "1", pixels between ¼ and ½ mile took on a value of "2", and pixels more than ½ mile from a park took on a value of "3."



New Haven Parks

Distance from Parks
(lighter grey = further)

b. The grid of region-grouped vacant lots was overlaid onto the distance grid and, using the "Zonal Statistics: Majority" function, each lot was assigned the most common distance value within its perimeter



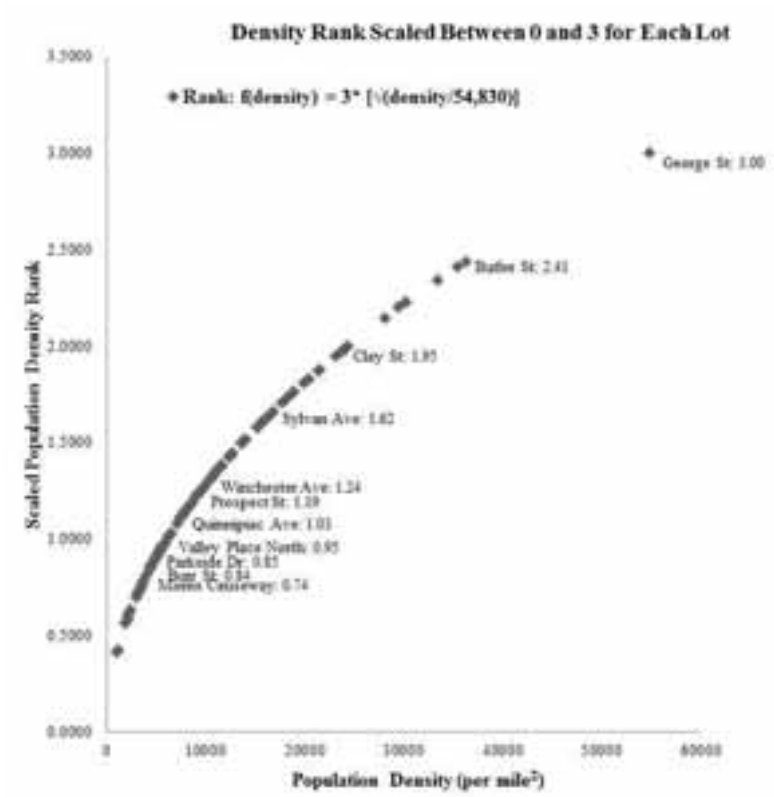
Vacant lots overlaid on Park Distance Grid

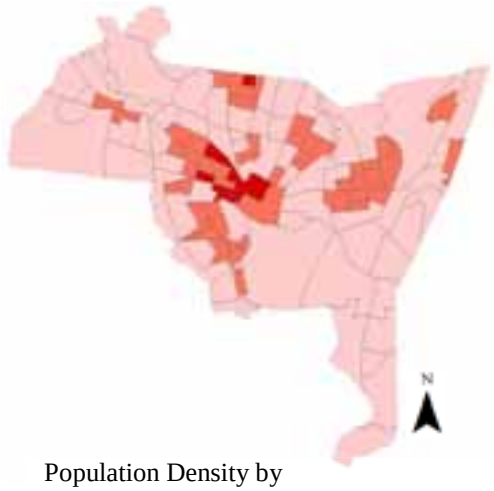
Lots colored according to distance from parks

c. In order to assess the number of people that potential vacant lot regeneration would serve, population density in the vicinity of each vacant lot was incorporated into the analysis of social need. A shapefile of population density by census block group was obtained from SimplyMap.com showing population density ranging from 1,047 to 54,830 people/mile^2. Population densities were scaled to values between 0 and 3 by using "Field Calculator" to compute the following function:

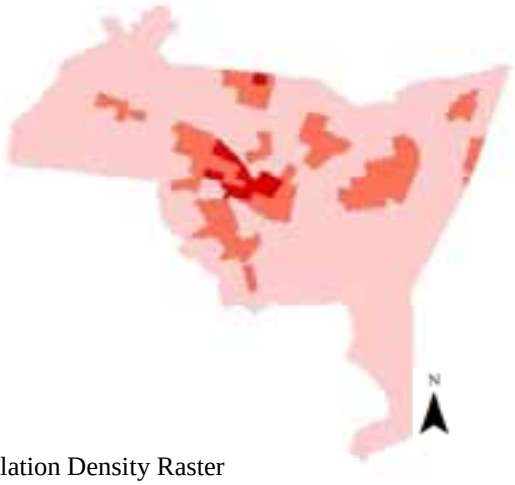
$$f(density) = 3 \times \sqrt{density \div 54{,}830}$$

The formula uses the same logic of the flow rank formula with the flow maximum replaced by the density maximum. A graph of the scaled density rank as a function of the raw population density is displayed below with data points that eventually ranked highest in the composite scoring labeled.



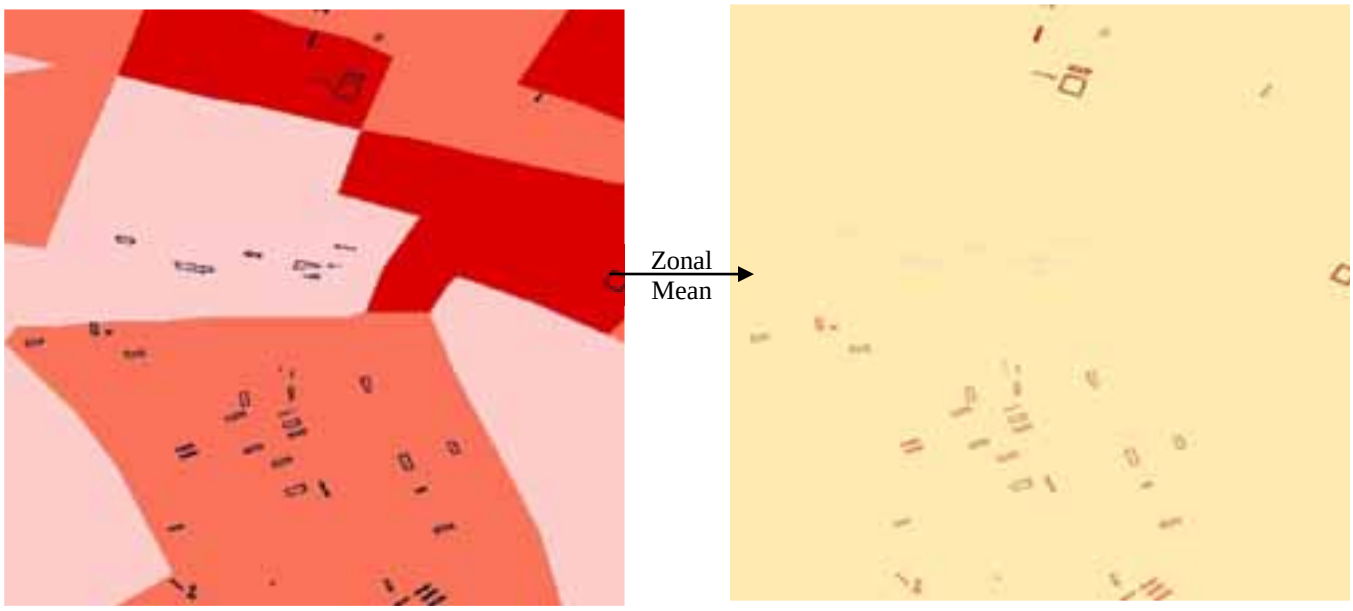


Population Density by Census Block Group



Population Density Raster

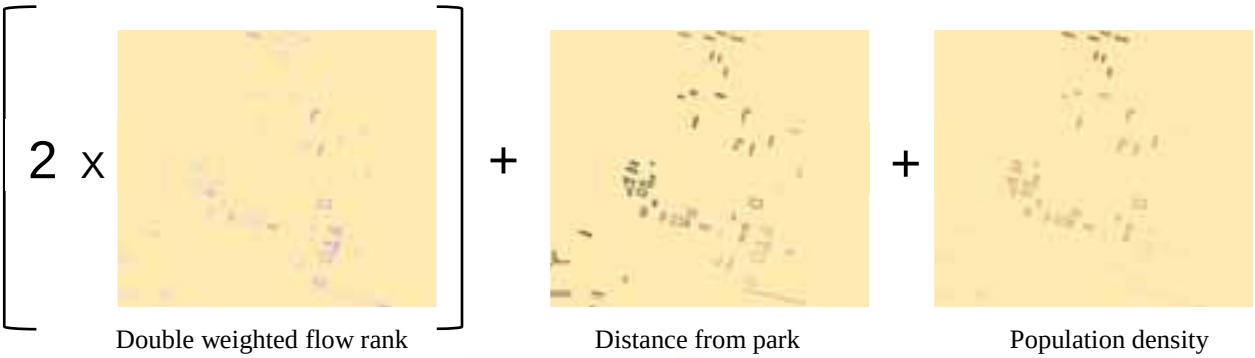
d. The shapefile of ranked population density was converted to raster and then the grid of region grouped vacant lots was overlaid. Using the "Zonal Statistics: Mean" function, each lot was assigned the number value of the average population density rank in its spatial area.

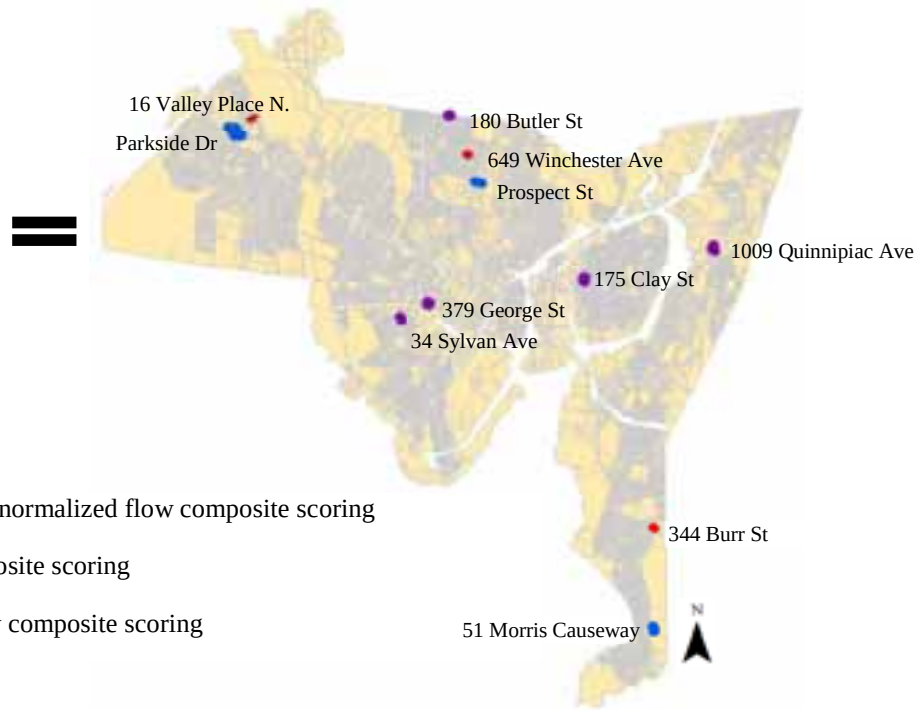


Vacant lots overlaid on population density grid

Lots colored according to population density

V. Compiling Flow, Distance, and Density Rankings: The grids of lots valued according to flow accumulation, distance from existing parks, and population density categories were added together using "Raster Calculator" once using the raw flow rank grid and once using the normalized flow rank grid as the flow accumulation factor. In both cases, the flow accumulation rank was double weighted in order to balance the fact that there are two social factors in the model and only one environmental factor, leading to the following calculation: (Flow x 2) + Distance + Density = Composite Score. The maximum possible value was 12 (max flow = 3, max distance = 3, and max density = 3). The maps below highlight the eight sites with the highest scores in each run of the model (raw and normalized flow). The histograms display the frequency distribution of composite scores in each trial.

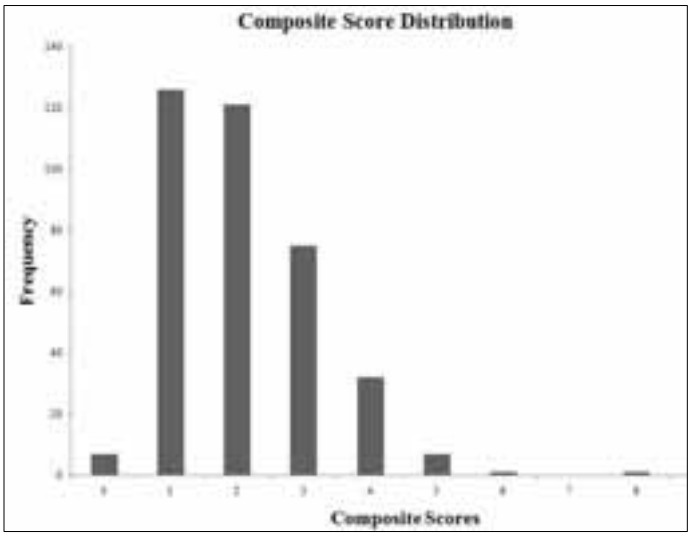




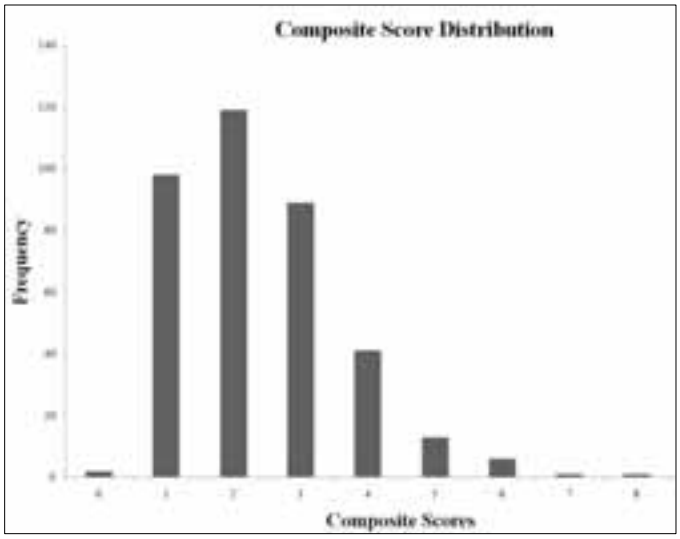
Purple: top 8 in both raw and normalized flow composite scoring

Blue: top 8 in raw flow composite scoring

Red: top 8 in normalized flow composite scoring



Raw Flow Ranking



Normalized Flow Ranking

Results

This section provides a brief description of each site selected by the model in order to illustrate, more specifically, potential restoration projects as well as shortcomings of the model. Table 3 shows a summary of each property and its ranking using both raw and normalized flow data, indicating composite scores in the top eight of both models, only the raw flow model, and only the normalized flow model, with purple, red, and blue, respectively. Visits were made to sites shaded in gray on February 25th, 2011, a day of heavy rains and 45 degree temperature, causing snow melt and standing water everywhere. These circumstances represent exactly the type of scenario that leads to the capacity of sewers to be surpassed, resulting in Combined Sewer Overflow. Visits were made to all other sites on April 1st, 2011, a day of 44 degree temperature and light showers following a night of consistent rain. Several sites were found to be unsuitable for development of storm water management parks due to their context, size, or current use, suggesting a need to refine the vacant lot data set. Still, two of the eleven sites were thoroughly inundated, demonstrating not only their current use as informal storm drainage infrastructure and thus the importance of keeping them vegetated, but also their potential to become effective storm water management sites.

Table 3: Selected Vacant Lots

Property Name	Area (ft^2)	Raw Flow Rank	Normalized Flow Rank	Distance Rank	Density Rank	Raw Total	Normalized Total
175 Clay St.	4792	1.35	1.74	1	1.95	5.65	6.43
180 Butler St.	3920	1.10	1.66	1	2.41	5.61	6.73
1009 Quinnipiac Ave.	29621	3.00	3.00	1	1.03	8.03	8.03
34 Sylvan Ave.	5556	1.05	1.43	2	1.62	5.72	6.48
379 George St.	14541	0.86	0.87	2	3.00	6.72	6.74
51 Morris Causeway	7841	1.70	1.67	1	0.74	5.14	5.08
Parkside Dr.	131147	2.43	1.04	0	0.85	5.71	2.93
460 Prospect St.	3920	0.65	0.68	3	1.19	5.49	5.55
649 Winchester Ave.	1109	0.43	1.98	2	1.24	4.10	7.20
344 Burr St.	1913	1.02	1.77	2	0.80	4.84	6.34
16 Valley Place N.	2614	1.54	2.97	0	0.95	4.03	6.89

175 Clay Street

175 Clay Street is one of several vacant lots on Clay Street. Of the top eight sites in the raw and normalized model, this site ranked 5th and 7th in respective composite scores. The flow value was 4th highest in the raw model and 5th highest in the normalized model. The lot had a distance score of 1, and the 3rd highest density score of the eleven sites, 1.95. There were no obvious drainage problems within the lot, but the street had a fair amount of standing water on both sides and few storm drains. The sidewalks on Clay Street are entirely paved and do not have curb strips or street trees. A combination of curb cuts and bioswales designed to divert roadway and sidewalk runoff into retention gardens in the vacant lot might serve this street well.

180 Butler Street

The lot at 180 Butler Street sits on the edge of the municipal border of New Haven in the Newhallville neighborhood. The lot placed 6th and 5th within the top eight raw and normalized composite scores respectively. The flow value ranked 5th in the raw model and 6th in the normalized model. The distance score was 1 and the density score, 2.41, placed 2nd of the eleven sites. A church sits to the north of the lot and a house lies to the south. While there were no particularly outstanding drainage issues, the high population density may justify the creation of a park and the Church next door may represent a source of community support and stewardship.

1009 Quinnipiac Avenue

This triangular lot is bordered at the back by an elevated rail bed that passes over Quinnipiac Avenue at the northern corner of the lot. This lot ranked 1st in both raw and normalized composite scores. It has the highest flow accumulation score, 3, of all of the vacant lots in the data set, a distance score of 1, and the 7th highest density score of all top eleven lots. The lot is highly vegetated with mature trees and shrubs and a steep slope leading up to the rail bed. The high flow ranking was justified by the pool of water, several inches deep, at the base of the slope. While the lot's proximity to the rail road tracks makes it an undesirable place for a residence, it has great potential as a constructed wetland. Considering the amount of water that it currently collects during rain events, the lot clearly provides an ecological service which could be maximized with the addition of pollutant-filtering vegetation and design for storm water retention. Currently overgrown, the lot could become a much more inviting and social space with landscaping that engages the surrounding context.

34 Sylvan Avenue

When visited, it was discovered that since the last updating of the vacant parcel data set used in this study (2010), a house has been built on the lot at 34 Sylvan Avenue. While this lot is no longer vacant, it is worth considering the impact that this development may have on drainage. Aside from the footprint of the house, the lot surface has been left impervious, but its infiltration could be greatly improved through remediating the compacted earth and adding vegetation both on the property itself and in the empty curb strips.

379 George Street

The parcel shown on the map below at 379 George Street does not in fact exist today as a sliver lot. It is owned by University Towers Owners Corporation and has been subsumed by the larger surrounding lot to provide paved parking for a high rise apartment complex. According to city records, the parcel was sold to University Towers Owners Corporation for $35,315 on November 8, 2002. The fact that this parcel was erroneously included in the data set of vacant lots demonstrates one of the major challenges associated with GIS modeling, relying on other institutions' record keeping in obtaining data. Its inclusion in both the raw and normalized model's top eight composite scores (ranked 2nd and 4th, respectively) was heavily influenced by

the fact that its distance ranking was 2, and its density ranking was the highest possible, 3. It ranked a low 7th and 8th in terms of its raw and normalized flow scores.

51 Morris Causeway

This lot is surrounded to the south and east by the New Haven Airport and to the west by the Morris Cove Pump House, owned by the GNHWPCA. The model ranked this sight 8th in the raw composite score and was not part of the top eight normalized composite values. The lot's raw flow score ranked 3rd highest at 1.7 and had a distance score of 1 and a density score ranked 11th (last) of 0.74. It is not immediately discernible where the property lines fall around this lot, but the fence shown in the pictures below most likely delineate the airport property. It also appears as if the GNHWPCA maintains this site, which is a small patch of grass and possibly serves as a driveway for the Pump House. Immediately east of the property fence is a waterway that flows eventually into Long Island Sound. This lot could potentially serve as a biofiltration buffer for runoff from the neighboring roadways to be cleansed before draining into this river. The low density and proximity to the airport do not present an ideal location for public space and the site seems to be well cared for by the neighboring property owner. As it currently exists, this lot is not detracting from the community and would not necessarily bring a significant social benefit to the community if redeveloped.

Parkside Drive

As can be seen on the map below, the Parkside Drive site is very large due to the fact that it is actually 13 separate property parcels that are juxtaposed. This presents a small problem with the model: the conversion of vacant lot data from polygon features to a raster grid does not allow for adjacent parcels to be distinguished from one another. In most cases this is not an issue because vacant lots are seldom side by side, but here the model reads these vacant lots together as one large parcel, which inevitably accumulates large amounts of storm water based on sheer length of the perimeter. The raw composite score for this site ranked 4th among the top eight, but was by far the lowest of the three sites not included in the normalized top eight with a composite score of 2.93.The raw flow value ranked 2nd highest with a score of 2.43 while the normalized score was 1.04. The distance score was 0 and the density score, 0.85, ranked 9th out of the eleven sites. The northwest area of the site is situated next to McConaughy Terrace, a public housing project, and none of the parcels have public access from the street. Most are in what appears to be a ravine behind houses that face Parkside Drive. Immediately to the south of the site is the West River Open Space. While the model ranked this site fairly high in the raw composite ranking, its lack of public access and size make it difficult to determine the degree to which it

would in fact be an asset to the community if redeveloped. These lots are probably best left as they are, in a natural state.

460 Prospect Street

This lot is a narrow strip of land bordering the Prospect Gardens that runs along Division Street. It ranked 7th in the raw top eight composite scores and was not included in the top eight normalized scores. The raw flow value ranked lowest of the eight, it had the highest distance score of 3, and its density score ranked 6th of the eleven total. There was no obvious separation between the property line of Prospect Gardens and this vacant strip of land. While a strong need for managing storm water in this area might justify the implementation of a bioswale along the side walk, this lot had the lowest flow value, and was ranked highly mostly due to its relative distance to existing parks. A bioswale does not provide the kind of public space that could meet social need, so there does not appear to be a lot that should be done with this site, especially since it is practically part of the Prospect Gardens and seems to be adequately maintained.

649 Winchester Avenue

As can be seen on the map below, the lot at 649 Winchester Avenue in the Newhallville neighborhood is very skinny, and wedged between two houses. It is impossible to tell where the lot begins and ends and is likely that the neighboring households do not know that a strip of that land is city owned. The lot ranked 2nd in the normalized composite score and was not included in the raw top eight. The lot's normalized flow value, 1.98, ranked 3rd, its distance score was 2, and its density score ranked 5th out of the eleven lots. While it is unclear what part of the land between the two houses is the vacant parcel, it is interesting to see two approaches to yard landscaping side by side. The property to the left is grassy pervious cover while the house to the right is paved asphalt. The property is being maintained so it would not be in the city's interest to reclaim the small strip of land, but this does demonstrate the need for regulatory limitations on impervious surface area of residential lots.

344 Burr Street

The lot at 344 Burr Street is similar in form and context to the Winchester lot discussed above. It is a small strip of land between two houses that is cared for by the neighboring property owners, who are perhaps not aware that the lot exists. If the property lines in the photo below are delineated by the brick walls framing each house's lawn, then the 'vacant lot' is the strip of

asphalt currently serving as a driveway. In the top eight normalized composite scoring, the lot ranked 8th, with a flow value of 1.77 ranking 4th, a distance score of 2, and a density score of 0.8 ranking 10th out of the total eleven sites. Across the street from this site is the property of Tweed Airport, along which the same waterway that was discussed with the Morris Causeway site flows. Again, there is need for biofiltration of pollutants in order to prevent roadway runoff from contaminating Long Island Sound-bound water bodies, but this site does not present an ideal location. It would not be in the city's interest to attempt to reclaim this land given that it exists in a primarily private realm between the two houses.

16 Valley Place North

16 Valley Place North is a long skinny lot that connects to Rock Creek Road in the Northwest corner of New Haven near West Rock Park. The top eight normalized composite scoring ranked this lot 3rd, with a 2nd place flow score of 2.97, a distance score of 0, and a density score of 0.95, ranking 8th out of the eleven sites total. The lot is currently a grassy path lined by fences on either side with three concrete steps leading up to Rock Creek Road. At the base of the steps there is a culvert through which a large amount of water was rushing. While the combined social need factors only total 1, the high flow and linear form of the lot present an ideal location

for a bioswale that might slow the water and relieve the stress it places on the storm drains that it eventually flows into.

Discussion

Out of the eleven total sites selected by both raw and normalized versions of the model, four are good examples of the type of lots that could be restored as parks designed with storm water management as a priority. Two of the lots turned out to be privately owned, emphasizing the importance of using data that is up-to-date. Three of the lots were merely thin slivers of land, indiscernible from their neighboring properties. The Morris Causeway site could bring ecological benefit, especially considering its proximity to the waterway, but it had fairly low ranking social factors. The Parkside Drive site demonstrated a flaw in the model due to the merging of 13 adjacent lots, creating an unrealistic lot area and thus flow value. While it is tempting to think that the model accurately predicted the presence of large amounts of water at 1009 Quinnipiac Avenue and 16 Valley Place North (both had the highest flow scores in the raw and normalized models), many more sites would have to be observed and cross referenced with the model output in order to verify its accuracy. The parks and density data used to map social need, on the other

hand, serve as decent justification for the creation of new public space in order to evenly distribute investment in parks and recreation across the city.

Evaluation of Methods

The flow accumulation model is simple in comparison to most hydrologic flow models, and its usefulness was limited by several factors. First, the resolution of the DEM, 10'x10', while considered very high in many GIS applications, is not ideal for modeling the extremely heterogeneous urban landscape. Roofs, freeway overpasses, and curb cuts present many opportunities for water to run in one direction or another and the flow model may not be able to account for to the subtle elevation changes that would lead to excess storm water accumulating in specific areas such as vacant lots. Higher resolution elevation data would certainly improve the accuracy of the flow model. Additionally, inclusion of hydrologic soil type data would help identify the existing conditions underneath the surface, and provide information about the ability of surfaces identified as pervious by the land cover data set to actually infiltrate water.

Due to the time and resource constraints of this research project, site visits were made during quite different weather conditions. While February 25th was an extremely wet day, April 1st was only mildly wet from the previous night's rain. This provided perhaps an unfair basis of comparison of different sites' ecological function, though all of the sites visited on April 1st were deemed unsuitable for various reasons un-related to ecological potential. The sites were evaluated simply based on their context and visual condition. In order to provide a more rigorous assessment of the ecological function in particular, it would be useful to collect soil samples from each site and compare their saturations. An even more intensive assessment of the sites would be to measure the compaction of the soil and infiltration rate, as was done by Yang and

Meyers (2007). This way, the data presented by the model could be verified through a scientific evaluation on the ground.

Model Optimizations

The choice to run the model twice, once using the raw flow ranking and once using the normalized flow ranking, was based on two concerns. First, considering the variable sizes of the lots, it seemed necessary to create flow rankings that favored lots that accumulated large amounts of water total (raw rank) as well as large amounts of water for their size (normalized rank). From a planning perspective, the opportunity cost of barring a lot from a potential sale to a private owner (as would be the case when developing a lot into a park) is based on the square footage value of land. The normalized flow provided a rank of ecological value per unit area of lot, which could potentially be compared to the monetary gain of selling per unit area. In other cases, such as flat costs associated with the liability and maintenance of a site, it would be useful to rank the lots based on their total value. This eliminates the potential problem of disregarding a large lot with a very wet corner that does not rank as highly in the normalized scoring. It also allows planners to view the value of a lot as a whole, rather than its ecological efficiency per unit area.

The second concern was to demonstrate a degree of model robustness by presenting two different optimizations of the data and comparing their results. Robustness in this case refers to the ability of the model to give stable answers when adjusted, and assess the reliability of model output as an indicator of storm water drainage potential. While the fact that only eight data points from each model were compared does not lend any basis of statistical significance, it is a good sign that five of each model's top eight sites were the same. This demonstrates a degree of stability in the model output, but also the ability of the model to reflect changes in conditions.

The results show that both the raw and normalized models have problems associated with the size of lots selected. The raw model selected an extremely large lot that had a high flow accumulation score because of its size. The normalized model selected two very small lots that may have had high flow rankings per unit area, but probably would not have a lot of impact. A solution to this problem would be to divide the vacant lot data set into categories based on size, and adjust the social conditions accordingly. Very small lots that could not serve as parks, for example, would be ranked solely based on their ecological potential, while larger lots would incorporate the social factors used in this study.

Feasibility

While the scope of this research did not involve making recommendations to New Haven officials directly, it is worth noting that the recent surge in interest concerning storm water management in the city presents an encouraging atmosphere in which this sort of project could be undertaken. LCI is responsible for so many parcels that it is in their interest to look for ways to return land to productive uses. A major barrier is, of course, funding and personnel for implementation, but if approved, the storm water authority will collect funds from residents that could be put toward improvement of storm water management systems on publicly owned land. Collaboration between LCI and the storm water authority could pair funding for best management practices with available land for redevelopment. With some improvements, the model in this study could facilitate decisions about which land parcels to redevelop by pinpointing high priority sites.

Conclusion

The methods used in this study, while somewhat primitive, present a useful decision making framework based on the need to consider the ecology of the city as a basis for land use

planning. Any number of variables could be exchanged with or added to the ecological and social factors and weighted differently according to their importance to the community. The cost of maintenance, or potential for property tax generation if sold back to a private owner, for example, could be factored into this model simply by assigning an appropriate score to each lot. The answer to the original research question, "which of its vacant lots should New Haven re-purpose into urban-ecology and storm water management infrastructure?" was expressed in terms of the highest scoring lots. The specific answers to this question, while informative regarding the development of the model, are perhaps less significant than the question itself.

Various scholars have acknowledged that ecological services are imbedded in urban greenspaces, and that redeveloping vacant lots as greenspaces may bring greater ecological benefit to urban areas. Few have weighed the costs and benefits of re-purposing specific lots from a city planner's point of view, or attempted to pinpoint the intrinsic values and constraints that make a particular lot more or less suitable for conversion. This study draws attention to the importance of evaluating properties in their ecological and social context, and presents a realistic method of doing so on a city-wide scale. Because equivalent data sets to those used in this study are available in many cities, the methodology created may be applicable to further studies of the ecological value of vacant lots.

The environmental impacts of storm water runoff will not be remediated by any single solution nor will cities ever have the resources to turn all of their vacant lots into green spaces. By prioritizing concerns and finding spaces with potential to address those concerns, cities will be able to use land more efficiently and successfully. Managing storm water runoff through vacant lot restoration brings multifunctionality to the landscape, reminding us of the layers of natural, built, and human ecosystems that interact within the urban environment.

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