Stormwater Management and Multipurpose Infrastructure Networks

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Submitted to the Department of Urban Studies and Planning
in partial fulfillment of the requirements for the degree of

Master in City Planning

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2012

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Submitted to the Department of Urban Studies and Planning on May 29, 2012 in Partial Fulfillment of the Requirements for the Degree of Master in City Planning

ABSTRACT

In urban planning and design, natural systems are a key element of explorations about how to design for sustainability. As part of these efforts, academics and practitioners have also begun to explore the ways in which the utilization of natural systems can and should change our approach to the design and function of urban areas and of infrastructure itself. As an entry point to explore the topic, this thesis focuses on stormwater management as one basic building block or fundamental component of multipurpose infrastructure development.

An increasing number of cities will seek to implement green infrastructure approaches or stormwater best management practices (BMPs) in response to new regulation, desires to improve urban quality of life, and changes in attitudes about sustainability and climate change. However, a variety of urban conditions exist within and between cities, and it is therefore necessary to consider the range of possibilities for designing and implementing green infrastructure strategies in a range of built environments. At the same time, there is also the need to address other environmental, social, and cultural goals, such as creating assets from vacant land, improving the public realm, and creating connectivity through neighborhoods. This creates opportunities to develop multipurpose infrastructure projects that utilize natural systems to address multiple objectives.

San Francisco, California; Lincoln, Nebraska; and Cleveland, Ohio represent three different types of urban conditions and serve as test locations to identify the factors that affect the development of multipurpose infrastructure. San Francisco has a dense urban environment, Lincoln expects continued horizontal growth through subdivisions, and Cleveland's decline in population has created a condition of vacancy throughout the city. These conditions present a range of constraints and opportunities and shape the planning, design, and implementation of multipurpose infrastructure based on stormwater management. As a result, they lead to three methods or approaches for planning and design of multipurpose infrastructure: the retrofitting city, the preemptive city, and the repurposing city. These three approaches highlight how stormwater management can serve as a basis to develop multipurpose infrastructure systems that function at a range of scales, serve multiples purposes and create additional value for communities.

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ACKNOWLEDGMENTS

To Alan Berger, my thesis advisor and professor, for his guidance, support, and inspiration. For pushing me to explore spatial planning and environmental design.

To James Wescoat for his thorough and imaginative approach to all things water.

To all of my interviewees, and to Rosey Jencks in particular, for sharing their experiences and ideas.

To all my other professors at MIT. I have been privileged to be here and to learn from them.

To the Massachusetts Institute of Technology for instilling a sense of innovation and creativity in all its students.

To my husband, Cris Garza, for his endless support, sense of humor and ability to help me reenergize and refocus on the task at hand.

To my DUSP classmates who never cease to impress me and from whom I hope to continue to learn from for years to come.

Thank you all.

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INTRODUCTION

Since the emergence of the first formal definition of sustainable development in 1984[1] concepts of sustainability have evolved as we have advanced our understanding of environmental systems and human interaction upon and within them. Today the concept of sustainability and systems thinking is gaining attention in many fields. In urban planning and design, natural systems are a key element of theoretical and academic explorations of how to design for sustainability, and practitioners explore the ways in which to use or mimic natural systems in their management of resources and provision of services.

As part of these efforts, academics and practitioners have also begun to explore the ways in which the utilization of natural systems can and should change our approach to the design and function of urban areas and of infrastructure itself. Part of this shift has been a new focus on the idea of multipurpose infrastructure. Most generally referring to infrastructure systems

1 The Brundtland Commission (World Commission on Environment and Development) defined sustainability as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs," in *Our Common Future*.

that serve multiple purposes or that have multiple functions, the concept also includes the use of environmental systems designed in such a way as to regenerate urban areas or function as a tool to create additional value.

As an entry point to explore the topic, this thesis focuses on stormwater management as one basic building block or fundamental component of multipurpose infrastructure development. An increasing number of cities have begun to utilize green infrastructure approaches or stormwater best management practices (BMPs) in response to environmental regulation, desires to improve urban quality of life, and changes in attitudes about sustainability and climate change.

Faced with the large price tag of infrastructure upgrades and the need to improve environmental performance to meet environmental regulations, various municipalities are pursuing or exploring the use of green infrastructure and stormwater BMPs to manage stormwater and urban runoff instead of investments in traditional grey infrastructure. As a result, progress has been made on the technical tool kit of stormwater best management practices, but the field is at a point where attention toward the planning and design approaches for stormwater management systems is due. This, in combination with fact that stormwater is regulated and that water systems are inherently networked, makes stormwater management a useful entry point to explore the development of multipurpose infrastructure networks.

This thesis, therefore, is an exploration of stormwater management and how physical planning and design approaches apply to, or emerge out of, different types of urban environments. San Francisco, California; Lincoln, Nebraska; and Cleveland, Ohio represent three different types of urban conditions and serve as test locations to identify the opportunities and constraints that their physical characteristics present. San Francisco has a dense urban environment representative of large urban centers. Lincoln expects continued horizontal growth, principally through the development of subdivisions, like many other midsized towns and suburbs. And Cleveland is a shrinking urban area whose decline in population has created a condition of vacancy throughout the city as is found in other former industrial areas. These conditions present a range of constraints and opportunities and shape the planning, design, and implementation of multipurpose infrastructure based on stormwater management.

To better understand these forces and their implications, this thesis asks: What are the opportunities for and constraints of retrofitting cities in various urban conditions? What are the physical designs and policies that organizations can employ in each type of place to create maximum value and benefit? And, in what ways can design be used to add additional functions and create a network of multipurpose infrastructure or open space? It also evaluates the entities responsible for stormwater management, the spatial strategy employed in each place, the functions they seek to add to or address with stormwater management strategies, and the financial context.

The answers to these questions may illuminate that the spatial characteristics of different urban environments will highlight either a 'surfaces' or 'small patches' strategy or a 'large target' strategy. However, innovative analysis and design strategies will be needed in all cases to address other city priorities and tie individual projects into larger functioning systems.

To explore these premises Chapter One, Stormwater Management and Multipurpose Infrastructure, outlines the concept of multipurpose infrastructure, the problem of stormwater, approaches to stormwater management, and the connection of stormwater management to multipurpose infrastructure networks. Chapter Two, San Francisco, reviews the stormwater problem in San Francisco, municipal planning efforts, and the potential to develop a multipurpose infrastructure network in one watershed. Chapter Three, Lincoln, explores the stormwater problem in Lincoln, its connection to new growth, and the potential to reshape development patterns at the subdivision scale. Chapter Four, Cleveland, reviews the water problem in Cleveland and the potential to utilize vacant land and reintroduce natural systems into an urban environment with its sewer overflow reduction strategy. Chapter Five, finally, presents lessons and conclusions along with a methodology to develop multipurpose infrastructure in each of these urbanization patterns – a retrofitting approach, a preemptive approach, and a repurposing approach.

STORMWATER MANAGEMENT AND MULTIPURPOSE INFRASTRUCTURE

ECOLOGY AND LANDSCAPE AS STRATEGY

Increasing attention has focused on natural systems and ecology as a strategy to inform the design and performance of infrastructure, particularly in urban settings, and of cities themselves. Part of this shift in attention has included valuing ecological functions and ecosystem services as well as the idea that design can mimic ecological processes for specific purposes and that it can serve as a basis for design strategy.[1] Planning and design has also pulled relevant lessons from landscape ecology that include a multi-scale approach, attention to spatial composition, and an emphasis on connectivity. The multi-scale approach refers to the notion that ecological systems function simultaneously at multiple scales; spatial composition refers to the notion that the spatial arrangement of landscape components determines how they function; and connectivity draws from the concept that ecological networks can be applied to the urban environment.[2] As a result, planners and designers have begun to apply these lessons in combination with the use of environmental projects themselves in urban environments. The convergence of concern for environmental degradation and sustainability, the breakdown of large infrastructure systems as they reach the end of their designed lifespan, and budgetary constraints have further shaped discussion about how planners, designers, and city managers should target their efforts and whether it can lead to an ecological restructuring of urban infrastructure.[3]

SUSTAINABLE AND MULTIPURPOSE INFRASTRUCTURE

In 1927, the definition of infrastructure emerged as "the set of systems, works and networks upon which an industrial economy is reliant – in other words, the underpinnings of modern societies and economies."[4] While the components of systems, works, and networks is still relevant today, academics and professionals have begun to reconsider how these components can become more ecologically sound and perform to higher standards. They have expanded their concept of systems to include natural systems, their concept of works to include both green and grey, and their concept of networks to be the connection of parts between each other and multiple functions. They have also identified that infrastructure should be flexible, that it should create and capitalize upon synergy, that it should work at multiple scales, and that it will require interdisciplinary partnerships to realize.[5] A large part of this shift is the concept that infrastructure can be multifunctional or multipurpose and that its creation should emerge from synergistic and systemic design – synergistic design being the use or creation of strategic synergies to effectively multiply functionality as a system[6] and systemic design being the connection of environmental, economic, and programmatic stresses across regional territories.[7]

While these concepts are largely visionary or academic, the idea that it is possible to address multiple needs and generate multiple benefits through a new kind of infrastructure investment resonates with practitioners.[8] The convergence of increased environmental awareness, the need for new investment in infrastructure, and budgetary realities mean that the pursuit of multipurpose infrastructure is a reasonable, if not essential, endeavor in municipalities across the country. This condition presents an opportunity to rethink the function of infrastructure systems and the use of environmental approaches or ecology as a strategy.

STORMWATER MANAGEMENT AS OPPORTUNITY

Today, stormwater management presents a useful and realistic avenue to explore the development of multipurpose infrastructure and how a redesign of infrastructure systems can meet multiple goals. This is so due to fact that the Environmental Protection Agency (EPA) regulates stormwater discharges, that water infrastructure systems make up a large part of future capital improvements, and that water systems are inherently networked.

These factors have led agencies, public institutions, and non-profit organizations to seek ways to create more cost and resource efficient projects that meet broader city objectives and generate public benefit. For these reasons, cities have begun to explore the development of multi-benefit, multifunctional, or multipurpose infrastructure projects.

REGULATION

Stormwater runoff is a major contributor to water quality degradation. In urban areas, rain that falls on roofs, streets, and parking lots cannot absorb into the ground and instead runs across impervious surfaces and gathers pollutants such as dirt, fertilizers, oil, and other chemicals. In cities with separated sewer systems, this polluted water often travels directly to rivers, lakes, and oceans. In the nation's 772 cities with combined sewer systems, runoff from heavy rains overwhelms sewer system capacity and causes them to overflow into water bodies without treatment.[9]

As a result, the United States Environmental Protection Agency (EPA) regulates municipalities and other entities under the National Pollutant Discharge Elimination System (NPDES) Permit Program of the Clean Water Act (CWA). The permit program regulates stormwater runoff for municipalities with municipal separate storm sewer systems (MS4s) and for municipalities with combined sewer systems (CSS). The EPA requires that cities either take action to reduce sewer overflows by specific amounts or develop methods to reduce pollution from surface runoff and new development. To achieve these goals, U.S. communities face $106 billion for stormwater management and combined sewer correction upgrades or improvements as well as $192 billion for wastewater treatment plants and other grey infrastructure repairs and upgrades.[10] The need for such investment has driven communities to reassess their infrastructure systems as they plan to improve their environmental performance.

GREEN VS. GREY

In light of the need to improve the environmental performance of their water systems, many municipalities have begun to adopt green stormwater infrastructure techniques in lieu of grey infrastructure investment. While grey infrastructure systems move water away from its source to centralized treatment plants in an end-of-pipe approach, green infrastructure1 utilizes an ecological approach that mimics natural hydrology and uses vegetation, soils, and natural processes to manage water.[11]

These green infrastructure measures, also called stormwater best management practices (BMPs), involve the construction of interventions at a range of scales. BMPs include tools such as site specific bioinfiltration planters to regional water treatment wetlands.

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1 At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water.

NETWORKED INFRASTRUCTURE

Although green infrastructure measures, or stormwater BMPs, are essentially a toolkit of parts, the desired outcome for green infrastructure initiatives at any scale is a network that functions as an ecological whole and is "a strategic connection of system components."[12] The need to link green infrastructure elements into a system that functionsas a whole, rather than as separate, unrelated parts is especially the case when integrated with water systems that are also networked.

In 1984, Anne Spirn noted that effective water management will only be accomplished by the cumulative affect of many individual actions throughout the city, but that those actions would be insignificant if not part of a comprehensive plan that takes into account the hydrologic system of the entire city or its region.[13] She noted that every new building, street, parking lot, and park within the city should be designed to prevent or mitigate flooding, and to conserve and restore water resources.[14] In other words, she described both the strategic application of green infrastructure measures and the nature of water systems as a network whose component parts must function as a whole.

Because of these characteristics, and that green infrastructure should also include ecological, social, and economic benefits, functions, and values,[15] green infrastructure and stormwater management are well positioned to be fundamental components of multipurpose infrastructure networks.

Stormwater management is, therefore, a practical entry point to understand the development of multipurpose infrastructure and how environmental projects can be leveraged to generate additional benefits through cities and urban regions. Agencies, public institutions, and non-profit organizations seeking cost and resource efficient projects have realized that green infrastructure approaches have the potential to meet broader city objectives and generate public benefit. Because they have identified the value of creating multipurpose infrastructure it is a pertinent time to assess their motivations, goals, and planning approaches. This assessment can then provide insight regarding how stormwater management efforts can be linked into stronger or more significant multipurpose infrastructure networks.

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SAN FRANCISCO, CALIFORNIA

San Francisco, California is an interesting case to explore the development of multipurpose infrastructure given its physical characteristics and existence of a municipal agency that has identified the desire to create multi-benefit projects. It is highly urbanized and geographically constrained area. During rain events, its dense development, and the large impervious surfaces it has created, sends hundreds of millions of gallons of stormwater into the combined sewer system that serves most of the city. Today, this system requires significant upgrades to maintain and improve service with the environmental threat of rising tides, the need to meet future environmental regulations, and the need to manage flooding during heavy rain events. The San Francisco Public Utilities Commission (SFPUC), the entity that manages the sewer system, is currently planning its capital improvement projects for the next 30 years and has identified stormwater best management practices (BMPs), including strategic creek daylighting, as one strategy to meet its water management goals.

PHYSICAL CONTEXT

San Francisco is highly urbanized and geographically bound. At 29,564 acres (46 square miles), it is home to 805,235 people, according to the 2010 census, which creates a population density of 27 people per acre (17,431 per square mile).

The majority of the city is densely covered by buildings and streets punctuated by small open spaces and large parks, often at topographic high points. Except for the downtown and financial district, low rises and single-family homes built directly adjacent to one another make up the city's residential areas. High building density, wide streets, sidewalks, and paved front setbacks create impervious surfaces that produce large, flashy flows during a rain event. According to national data, 80 percent of the city is more than 30 percent impervious, which according to city analysis is 29 percent roofs, 22 percent roofs with flat slope, 9 percent sidewalks, 2 percent large parking lots (>.5 acre), and 17 percent streets.[1]

Most of San Francisco's streams were buried in the late 1920s to make way for this development and for their function as sewers. Their former paths are still the low point of the city's eight drainage basins that closely match the City's historic watersheds.

THE ISSUE: WATER QUANTITY AND INFRASTRUCTURE UPGRADES

The City and County of San Francisco has both a combined and separated sewer system. Approximately 90 percent of San Francisco is served by a combined sewer system that leads to three sewage treatment plants before discharge into San Francisco Bay or the Pacific Ocean. The other 10 percent of the city, located along the eastern shore and two locations on the western side, has a separate sewer system that serves less than 100,000 people. During average dry-weather periods, 80 million gallons of secondarily treated effluent pass through the combined system. However, peak wet-weather events result in 433 million gallons per day – 382 of which only receive primary or decant treatment. Unlike many other cities with combined sewer systems, San Francisco has transport and storage structures that it added to the system beginning in the 1970s in response to the federal Clean Water Act. These provide storage and primary treatment for sewage before it is pumped to treatment plants. This means that when these structures overflow due to heavy rains the city does not have combined sewer overflows (CSOs), but instead has combined sewer discharges (CSDs) that flow through 36 nearshore discharge sites around the city perimeter. These discharges occur on average 10 times per year during prolonged rain events and studies have shown that they are 94 percent stormwater.[2]

While the combined system is currently in compliance with its three NPDES permits, older treatment facilities have structural and equipment deficiencies that, if unaddressed, threaten system reliability and, by extension, the ability for the City to consistently meet its discharge permit requirements in the future.[3] In addition, extreme high tides overflow into the combined sewer discharge structures for short periods. These events, which are expected to increase in the future, can degrade the sewer system and reduce the quality of effluent it discharges. Furthermore, the Central and Lower San Francisco Bay are listed by the EPA as impaired water bodies for a number of organic and inorganic pollutants and future NPDES permits and their discharge standards may become more stringent.[4] In addition, extreme storm events cause the combined sewer system to back up into city streets.

San Francisco, therefore, faces the challenge of managing large volumes of water with an aging infrastructure within a dense urban environment.

ADDRESSING THE PROBLEM

To address these infrastructure deficiencies, environmental threats, and changes in land use that increase runoff, such as new development in old industrial areas,[5] along with future regulatory uncertainty, the San Francisco Public Utilities Commission (SFPUC) is undertaking a planning process to improve the sewer system. Planning thus far has identified green infrastructure and stormwater BMPs as one method to meet several of its service improvement goals, discussed below.

THE SEWER SYSTEM IMPROVEMENT PROGRAM AND GREEN INFRASTRUCTURE

The Sewer System Improvement Program (SSIP), with an estimated cost of $6.9 billion, includes capital improvements to treatment plants, outfalls, and sewer tunnels, as well as flood control and green infrastructure improvements in each of the

City's eight drainage basins to be implemented over 30 years.[1] As part of the larger program, the SFPUC has proposed using stormwater BMPs as one strategy to directly meet four of its five goals[2] - minimize flooding, provide benefits to impacted communities, modify the system to adapt to climate change, and achieve economic and environmental sustainability[6] - and anticipates that these efforts would require $600-800 million.[7] (There is also a $295 million five-year Interim Wastewater Capital Improvement Program initiated in 2007 to address immediate treatment and collection system improvements.[8])

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[1] Southeast Treatment Plant Improvements, North Point Wet-Weather Facility Improvements, Oceanside Water Pollution Control Plant Improvements, Treasure Island Wastewater Treatment Plant, Biosolids Digester Facility, Biosolids Drying, Biofuel, Southeast Bay Outfall Improvements, North Point Outfall Improvements, Islais Creek Basin Flood Control and Low Impact Design (LID) Improvements, Richmond Flood Control Flood Control and LID Improvements, Lake Merced Basin Flood Control and LID Improvements, Sunnydale Basin Flood Control and LID Improvements, Channel Basin Flood Control and LID Improvements, Sunset Basin Flood Control and LID Improvements, Yosemite Basin Flood Control and LID Improvements, Downspout Disconnection Incentive Program, LID Collaboration Projects, Better Streets Plan, Collection System Odor Control, Channel Tunnel, Backflow Prevention, Richmond Basin Interim Improvements.

[2] The program goals are to: 1) Provide a compliant, reliable, resilient and flexible system that can respond to catastrophic events. 2) Minimize flooding. 3) Provide benefits to impacted communities. 4) Modify the system to adapt to climate change. 5) Achieve economic and environmental sustainability.

To minimize flooding, the SSIP identifies the need to control and manage flows from a three-hour storm that delivers 1.3 inches of rain, its five-year "design storm" which is the equivalent of over 1 billion gallons. While the design standard is still relevant, actual performance for portions of the existing system has shifted due to changes in land-use patterns (e.g. new development in old industrial areas) and bayside fill subsidence.[9] To address the situation, the SFPUC has identified the need to add additional capacity through capital improvement projects that include a combination of green and grey infrastructure. At the basin level, the SSIP identifies a suite of projects necessary to meet the unique hydraulic situation of each of the City's eight drainage basins. These efforts include street modifications, downspout disconnection, and strategic daylighting, in combination with grey infrastructure improvements.

At the City level, the SSIP also includes general, or non location specific, green infrastructure projects, which include participating in the San Francisco Better Streets Plan (to be implemented over the 30-year period), downspout disconnection incentives to capture and reuse stormwater (for the first 15 years), and stormwater BMP demonstration projects (for the first 15 years).[10]

Specifically, a component of the program includes implementation of the Better Streets Plan, which includes a set of design criteria to improve stormwater management performance of streets through the use of green infrastructure.[11] The Plan sets the goal that by 2040, 15 percent of San Francisco's streets will incorporate design features such as tree basins, bioretention, and permeable pavement to capture, treat, reduce, and slow the volumes of stormwater entering the sewer system or a receiving water body. To reduce stormwater runoff and potable water demand, the SFPUC will implement an incentive program that encourages residents to disconnect their downspouts from the combined sewer system. And the SPFUC plans to develop demonstration projects as learning and education efforts to both show the benefits of green infrastructure and facilitate coordination with other city agencies in project planning, design, and implementation.

The SSIP also identifies strategic daylighting as another possible method to reduce the volume of stormwater entering the sewer system. Islais Creek, Yosemite Creek, Pine Creek, and Brotherhood Creek may be potential locations.

In addition, to minimizing flooding, green infrastructure would assist with the other goals of: 1) providing a compliant, reliable, resilient and flexible system that can respond to catastrophic events; and 2) providing benefits to impacted communities. For example, providing alternative flow routing will minimize possible impacts to public health and receiving waters in the immediate aftermath of a significant earthquake. Implementation of stormwater projects as outlined in the Better Streets Plan will create multi-purpose designs that beautify, increase pedestrian safety, and provide either passive or active recreational opportunities. Green stormwater best practices can be designed to not only slow down the flow of water and create additional capacity in the system, but also provide amenities such as increased green areas and water storage and reuse systems.

GREEN INFRASTRUCTURE AND THE SEPARATE SEWER SYSTEM

The SFPUC will build off of experience from its separated sewer system. To comply with its NPDES permit for separate sewer areas, the City has also developed Stormwater Design Guidelines and a Stormwater Management Ordinance. They apply to the separate sewer areas and require the use of stormwater BMPs for projects anywhere in the City that disturb 5,000 square feet or more since future development is likely to occur in large redevelopment areas or through large master-planned projects, like the Mission Bay development. In addition to protecting water quality, the Stormwater Design Guidelines also identify that well-designed solutions will serve multiple purposes by contributing to attractive civic spaces, open spaces, and streetscapes, and protecting and enhancing wildlife habitat.[12]

THE PLANNING PROCESS AND PROJECT SELECTION

While the SSIP broadly identified project needs in each drainage basin and possible project benefits, the next phase of project planning and design is still pending. To select specific projects and locations, the SFPUC has developed a process to assess each drainage basin, identify needs and opportunities using a hydraulic model and GIS, develop alternatives, and asses these alternatives through a Triple Bottom Line analysis.[13]

THE PHYSICAL CONTEXT OF DECISION MAKING

Given the physical context of San Francisco, the flood management and green infrastructure measures identified for each drainage basin need to be inserted into a dense urban fabric. This means that the SFPUC could look for opportunities on public land and public right of way.

While there are opportunities to retrofit the city with green infrastructure physical limitations, as the SSIP indicates, will require an approach that combines green and grey components such as bioretention and underground storage.

PROJECT OPTIONS

In order to develop project alternatives that meet the hydraulic needs of each drainage basin, the SFPUC will consider a range of project types. For example, these project types include conveyance, storage, reuse, runoff reduction, odor control, and climate change adaptation.[14] Examples of conveyance projects include auxiliary sewer pipes or creek daylighting to carry additional flows. Storage includes bioretention planters or underground detention basins to store and delay the release of stormwater. Reuse includes rainwater harvesting and greywater reuse to divert water from sewers and to productive uses. Runoff reduction includes permeable paving and rain gardens to encourage infiltration. Odor control includes sewer cleaning and flushing as well as fat, oil, and grease collection. And climate adaptation measures include accommodating sea level rise within the service limit of new infrastructure and raising combined sewer discharge structure weirs to prevent the intrusion of ocean water. All of these examples can help meet the goals of the SSIP in each drainage basin, however an effective suite of projects will need to be selected.

The results from the Urban Watershed Planning Charrettes held in 2007 and 2009 demonstrate possible combinations and locations for project alternatives. Organized to generate ideas for the future of stormwater management in San Francisco, SFPUC staff, consultants, and volunteers laid out stormwater management projects from a kit of parts in each watershed.[15] The outputs illustrate a collection of project types that make up one project alternative within each drainage basin, which serve as an example of the project alternatives that will be developed and assessed through the SSIP planning process. For example, the maps developed by community and staff members for Islais Creek watershed show two different alternatives.

The Triple Bottom Line analysis that will be used in the SSIP planning process provides a method to evaluate projects, their multiple functions, and the multiple benefits they provide. In general, the assessment will evaluate the economic, environmental, and social costs and benefits of each alternative that meets the performance goals of the SSIP. While it is too early to comment on the specific weighting or methodology of the actual analysis used in San Francisco, it is worth mentioning as an evaluation technique that has the potential to improve our assessment of multipurpose infrastructure.

ADDITIONAL CONSIDERATIONS

CITY WIDE POLICY LAYERS

Multipurpose infrastructure designed for the stormwater management goals of the SSIP also has the potential to meet other City goals that have been identified in recent long-term plans or plan updates from various city agencies.

For example, the Better Streets Plan, specifically referred to in the SSIP, was adopted by the San Francisco Board of Supervisors in December 2010 in order to provide guidance for improvements to the public right of way. It serves as a City-wide guide for street design and improvement of the pedestrian environment to improve walkability, calm traffic, and improve ecological function. It directly relates to the SSIP and stormwater management as it includes stormwater management tools as one of its six core streetscape design elements. It demonstrates how stormwater BMPs fit into different types of city streets (e.g. residential or commercial) and street elements (e.g. sidewalks, curbs, and medians).[16] While the Better Streets Plan essentially acts as design guidelines for the implementation of stormwater BMPs, the SSIP could also consider other city goals in the development, evaluation, and selection of its project alternatives.

The San Francisco Planning Department updated its open space plan, the Recreation and Open Space Element (ROSE) of the General Plan of the City and County of San Francisco, in 2011. Its main objectives are to: ensure a high performing open space system; increase open space to meet the long-term needs of the city and bay region; improve access and connectivity to open space; protect and enhance the biodiversity, natural habitats, and ecological integrity of open spaces; engage communities in the stewardship of their open spaces; and secure long-term resources and management for open space acquisition, operations, and maintenance. Most of the policies developed to meet these objectives are not firmly location specific and there is potential to overlay the goals of the SSIP and Better Streets Plan to also meet the goals of the ROSE. Coordination between the agencies during their planning and design processes could therefore generate projects that meet multiple goals and add functionality to each project.[17]

The San Francisco Municipal Transportation Agency (SFMTA) produced the San Francisco Bicycle Plan in June 2009. Its main goals are to improve the safety, extent, and quality of the bicycle network across the city. The San Francisco Bicycle Coalition, a non-profit organization, assisted with this plan, and has also developed proposals for primary, secondary and tertiary cross-town routes in its own Connecting the City proposal. As part of this effort, they have also expressed interest in the creation of bicycle boulevards that include stormwater management features.[18] Again, coordination between agencies could allow for stormwater features to be designed in such a way as to improve bicycle route connectivity and safety or vice versa.

With the plans discussed above and the tools kits provided with the Better Streets Plan and the Stormwater Design

Guidelines, there is extensive opportunity to create multipurpose infrastructure projects or locate stormwater management projects in order to meet multiple agency goals. This will require agency coordination and leadership.

PILOT PROJECT SELECTION AND CAPITAL IMPROVEMENT PROJECTS

In order to coordinate the development, planning, and design of multipurpose infrastructure projects, the City agencies have organized an interagency committee to anticipate future projects and identify demonstration projects for implementation in the relatively short term. (The SSIP includes stormwater BMP demonstration projects for implementation in the first 15 years). The committee has added upcoming capital improvement projects to a common GIS database where projects drawn from various city plans and processes are marked by agency and by type of improvement. Project types include a range of activities that occur in the public right of way, such as pedestrian improvements, bicycle improvements, transit, traffic calming, sewer repairs, stormwater management, water infrastructure, light installation, repaving, streetscape improvements, curb ramp upgrades, undergrounding of utilities, and utility repairs.

An overlay analysis of scheduled projects reveals that there are several locations where multiple functions or project types could be incorporated. By identifying the fact that multiple agencies have planned capital improvement projects for the same area it is possible to coordinate efforts and achieve gains in efficiency for the planning, design, and implementation of the project.[19] For example, Cesar Chavez Street is one capital improvement project labeled as a traffic calming project that was also marked for each of the other project types. In May 2008, the Planning Department began community design workshops to bring together the SFPUC's auxiliary sewer line construction and stormwater management features, the Municipal Transportation Agency's bike plan improvements, the Department of Public Work's corridor improvements, the Planning Department's Streetscape Plan for a major cross street, and new private development.[20] This enabled the agencies to leverage planning, design, and funding sources and, today, the project is under construction.

The combination of both scheduled and possible projects reveals possibilities for multipurpose infrastructure projects. For example, improvements to Alemany Boulevard, which parallels Islais Creek – one of the creeks identified for potential daylighting in the Urban

Watershed Planning Charrettes and the SSIP – could include the full range of project types or functions included in the database. This indicates that this area has high potential for multipurpose infrastructure.

ISLAIS CREEK WATERSHED AND LINKED BEST MANAGEMENT PRACTICES

The Islais Creek watershed is the largest drainage basin in the city and houses a variety of land uses from upstream residential areas, central commercial corridors and transportation infrastructure, and industrial and logistics zones in the lower reach. Although the creek currently runs underground from Glen Canyon Park to the San Francisco Bay, its path is recognizable by the current location of Alemany Boulevard and portions of I-280.

Because areas in the drainage basin are at risk of flooding during high intensity rain events, the San Francisco Public Utilities Commission (SFPUC) has identified the need for flood control and green infrastructure improvements that include neighborhood-scale stormwater collection, storage, and reuse;

daylighting portions of Islais Creek; streetscape improvements, incentives for downspout disconnection and rainwater harvesting; and sewer system upgrades including auxiliary sewer construction and pump station improvements.[21]

The identification of these needs and additional functions included in the capital improvements database, together with the physical characteristics and range of land uses in the watershed, make the Islais Creek drainage basin an interesting case to consider the planning and design of a multipurpose infrastructure system.

Historically, the creek itself once ran from the San Miguel Hills, what is now Glen Canyon Park, through a large wetland and marsh area and into the San Francisco Bay. Eventually, it was directed underground and into the sewer system in the late 1920s to push sewage out to sea.[22] It also created a path for transportation infrastructure through the center of the watershed. In the lower reach, people filled the wetlands and slough to create stable land and a working waterfront. Although it is no longer in use, surrounding warehouse and logistics areas are still active. Elsewhere in the basin, residential uses cover the majority of the upper reach and upland areas while commercial corridors run along the center.

Today, current development has created a condition where large amounts of impervious surfaces send stormwater into the combined sewer system and can cause flooding in low-lying areas during heavy rain events. An analysis of topography and surface flow reveals the location of 'streams' that would form if water flowed uninterrupted across the surface of the watershed. These 'streams' indicate low points in topography and coincide with the location of sewer drains. They could, therefore, serve as paths to link stormwater BMPs into a larger network. For example, BMPs added to the public right of way in residential neighborhoods could connect to a daylit portion of Islais Creek, which could then lead to a constructed wetland in the lower reach, creating a system within the urbanized area.

Bioretention planters and/or tree trenches in the residential areas upstream would hold and slow the release of water from upland areas while providing aesthetic improvements to local residents. Daylit portions of Islais Creek would add additional capacity to the sewer system by removing surface flows also creating a recreational path along Alemany Boulevard and up to Glen Canyon Park. Flows from the creek would eventually lead to constructed wetlands on large parcels in the industrial areas near or along the waterfront that slow and filter water before it reaches the San Francisco Bay.

While daylighting is one option to create additional capacity in the sewer system, physical constrains within the city mean that daylit reaches would require some form of channelization, similar to that used in Zurich, Switzerland. It would impact 95.6 acres, and reduce peack flow by 3-9 percent at a cost of $2 million per mile, making it a $45 million project.[23]

ADDITIONAL BENEFITS

Bioretention planters and tree trenches hold and slow water, but also provide aesthetic benefits to residents that currently live on streets with little greenery. The stormwater features could be located to create green connections outlined in the Recreation and Open Space Element, and/or form features that add to the Bicycle Plan or Connecting the City initiative.

Daylighting portions of Islais Creek would create additional capacity within the sewer system and accommodate additional flows to prevent flooding and combined sewer discharges. If designed in conjunction with pedestrian or bicycle paths it could provide access to regional trails and the waterfront as well as access into Glen Canyon Park. In this manner it could contribute to the open space plan goal of creating green connections to open spaces and active recreation areas or become part of the Cross-Town Trail. Vegetation in and along the channel would provide water quality improvement, aquatic and terrestrial habitat, and aesthetic benefits.

Because runoff and flows that travel through the stream, now separate from the combined sewer system, would not travel to a treatment plant, the wetlands and plantings within the retention planters and stream channel would treat and purify water. In addition, wetlands would create habitat, improve the aesthetics of the waterfront and could be designed to connect with and expand the existing Islais Park, which is now along the southeastern edge of the waterfront. Depending upon location and design criteria, it could also make use of underutilized space beneath the freeway and connect to regional trails.

Together these components create a multipurpose infrastructure system that addresses environmental issues and adds value to individuals, neighborhoods and the city as a whole.

LESSONS FROM SAN FRANCISCO

The multipurpose project for the Islais Creek drainage basin highlights three types of spaces, apart from the building, that provide stormwater management opportunities within a dense urban environment: block scale interventions in the public right of way, inter-neighborhood or found spaces, or medium-large spaces (chunks) in industrial areas or existing parks or public land.

Even in a dense environment it is possible to use and develop green infrastructure and environmental systems for resource management and other area goals. Since it may not be realistic to restore or reintroduce environmental systems within the urban fabric at a large scale, the combination of green and grey infrastructure strategies becomes a necessary approach. In this sense, multipurpose infrastructure development in dense urban environments requires finding spaces and connecting opportunities.

Because there are several ways to meet stormwater management goals through various combinations of small to large and green to grey projects, the preferred alternative that emerges from the Triple Bottom Line analysis and where it falls on each spectrum will be informative. Since the SFPUC will evaluate various alternatives made up of a combination of projects it is reasonable expect to see a range of combinations/ project types included in project alternatives. Their analysis will then demonstrate what type of strategy best meets each goal or produces the most benefit in each category they consider. In other words, a breakdown of the Triple Bottom Line analysis can reveal which strategy maximizes which benefits, and which strategy maximizes a combination of benefits. Will can then see if the preferred alternative becomes an approach of small surfaces or of a few larger projects in specific areas like low lying parks or public lands.

In the case of San Francisco, addressing multiple agency goals and functions could allow for leveraging of funding and resources to develop a coordinated, multifunctional project. Funds from multiple agencies derived from rates, bonding, public funds, or project specific grants can increase or contribute to the project budget. Efficiency gains can also be made in the planning, design, and implementation of the project by reducing the number of planning processes, streamlining the design, and sequencing construction phases to reduce total construction time. To implement such projects, there will be a coordination and management learning curve, which the stormwater BMP demonstration projects included in the SSIP can help shorten.[24]

In addition, coordination could also affect the design of multipurpose projects. In order to create mutually reinforcing designs that meet multiple goals within a constrained environment, these projects should be well designed to maximize the value they create.

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LINCOLN, NEBRASKA

In contrast to San Francisco, Lincoln, Nebraska developed on the township and section system and will accommodate most of its anticipated growth through horizontal expansion. Situated at the convergence of the Salt Creek and several tributaries, many parts of the city lie within the 100-year floodplain that was recently expanded by the Federal Emergency Management Agency (FEMA). To reduce the impacts of stormwater runoff the Watershed Management Division of the City of Lincoln has promoted stormwater best management practices (BMPs). While the implementation of BMPs is voluntary, the City is working to approve their requirement in new development and redevelopment areas in order to meet environmental regulations. It also cooperates with the Lower Platte South Natural Resources District to plan and implement a citywide watershed management plan on a basin by basin basis to address downcutting and other river morphology problems in the city's 14 watersheds. It is, therefore, and interesting case to explore the design of multipurpose infrastructure through new development that seeks to address several dimensions of water management.

PHYSICAL CONTEXT

At 58,550 acres (91 square miles), it is home to 258,379 people, according to the 2010 census, which creates a population density of 4.4 people per acre (2,844 per square mile). In addition, Lincoln expects to double its population to 520,000 by 2050, which it expects to accommodate through horizontal expansion.

The current city limit includes regular blocks of small single family homes towards the center with curvilinear subdivisions surrounding them on the periphery. Parks, golf courses and large logistics areas are interspersed throughout the city. Wide streets, sidewalks, driveways and buildings create significant amounts of impervious surfaces – buildings make up 11 percent of the city, and 56 percent of the city is more than 30 percent impervious. These impervious surfaces produce large, flashy flows during a rain event.

The convergence of the Salt Creek and several tributaries make the city susceptible to flooding. Based on updated FEMA floodplain maps, 21 percent of the city falls within the 100-year floodplain. While some stream reaches in the city center were buried to make way for development, most streams still flow freely, but have been channelized or encroached upon by development.

THE ISSUE: WATER QUANTITY, WATER QUALITY, AND RIVER MORPHOLOGY

Lincoln's location along Salt Creek in combination with historic development patterns have contributed to poor water quality, changes to river morphology, and increased flood risk. Unlike San Francisco and many eastern cities, Lincoln has a separated sewer system. While this prevents severe pollution caused by combined sewer overflows, runoff from the urban area picks up pollutants and discharges into rivers without treatment. In addition, agriculture and its associated use of fertilizers and other chemicals surrounds the city. As a result, Lincoln's rivers and streams have compromised water quality with high levels of E. coli, ammonia and phosphorus. Additional pollutants of concern include total suspended solids (TSS) or total dissolved solids (TDS); turbidity; oil and grease; pH; nitrate; conductivity; dissolved oxygen; chlorine; copper; temperature; and chemical oxygen demand.[1]

Development and alterations to river paths, such as channelization, have led to changing river morphology. Channelization in downstream areas has altered the rate that water flows through streams and exacerbates incising, or downcutting, where changes in water flow deepen and widen the stream channel. These changes to the path of rivers threaten infrastructure, such as bridges and roads, and increase total suspended solids and phosphorous in water as material from the banks erodes. Over the last 80 years, many stream channels have expanded from 10-feet wide, 3-feet deep to channels 30-feet wide by 25- to 30-feet deep.[2]

The development of farmland further exacerbates these problems through increases in impervious surface area. The flashy flows created by impervious surfaces during even a 1- or 2-year storm event are of a magnitude that contributes to downcutting and sedimentation.[3] In fact, small, frequent rain events carry the majority of pollutants and are believed to cause the greatest amount of erosion and sediment deposition, which directly impacts water quality as well as aquatic and riparian habitat.[4]

While these small storms contribute to water quality and river morphology problems, the combination of large storms and impervious surfaces increases flood risk. New FEMA flood maps and city watershed management plans have shown that over the last 30 years, the area susceptible to flooding has increased substantially. Currently, there are 5,975 structures, valued at $17 billion in total and threatened with $2.2 billion in potential damage within the floodplain. While many of these structures are industrial in nature, the new FEMA boundaries include more residential properties than the previous floodplain boundary delineated in 1978. Both the value of property and the health, safety, and welfare of residents who would be displaced by a serious flood pose a substantial concern.[5]

Lincoln, therefore, faces the challenge of managing stormwater runoff, pollution, river morphology changes, and flood risk in a context where it must also accommodate additional growth and development of farmland.

ADDRESSING THE PROBLEM

A combination of the need to manage the negative externalities of growth and federal environmental regulation for water quality has led the City of Lincoln to mainly focus on new development and redevelopment. To address flooding, water quality, and river morphology issues, the City of Lincoln, has developed watershed management plans and will require the addition of stormwater best management practices as part of compliance with its NPDES permit.

WATERSHED MANAGEMENT PLANS

The City of Lincoln and the Lower Platte South Natural Resources District began efforts to create a Comprehensive Watershed Management Plan as means to address issues with current and projected growth. Through a series of watershed management plans begun in the late 1990s, they have outlined a set of actions to mitigate the negative effects of urbanization upon the area's water systems. Working basin by basin, they first created plans for watersheds expecting near to medium term development and intended them to guide sustainable growth within the City and its future growth areas.

Beal Slough Stormwater Master Plan, May 2000
Southeast Upper Salt Creek Watershed Stormwater Master Plan, October 2003
Stevens Creek Watershed Master Plan, March 2005
Cardwell Branch Watershed Master Plan, September 2007
Deadmans Run Watershed Master Plan, December 2007

Little Salt Creek Watershed Management Plan, June 2009
Antelope Creek Watershed Basin Management Plan, Summer 2011

For example, the plans propose specific capital improvement projects at river crossings to expand culverts, stabilize stream banks, or add stilling basins. They also recommend the implementation of stormwater best management practices (BMPs) to minimize runoff pollution from residential developments. The Stevens Creek Watershed Master Plan recommends non-structural measures such as maintenance of riparian habitat through stream buffers, erosion and sediment control during construction, and land development planning to ensure watershed management approaches are followed as well as the implementation of stormwater BMPs to improve water quality.

The need to manage the larger 2-, 10- and 100- year storms as well as smaller storms due to their contribution to erosion runs through several of the plans. They describe the integrated detention facility and alternative site design as two methods that address both categories of rain events by combining stormwater BMPs to manage small storms and detention basins to manage larger storms. Integrated detention facilities address small frequent storms as well as the 2-, 10- and 100- year storms by layering BMPs and detention facilities into a single feature. Alternative site design, on the other hand, uses site-specific BMPs apart from detention ponds. They identify the value of multi-benefit design by noting that the separation of BMPs from detention facilities allows them to be incorporated into site designs as landscape features, park amenities, and passive recreation amenities. In order to implement these approaches, the watershed management plans recommend changing the City's stormwater BMP program from a voluntary to mandatory program.[6]

SELECTED BMPS AND NEW DEVELOPMENT AND REDEVELOPMENT REQUIREMENTS

Because it does not have a combined sewer system, Lincoln's NPDES permit for separated sewers focuses on new development and redevelopment. Issued in 2008, the current permit requires that the City include post construction standards –performance requirements of subdivisions and other projects once they are built versus practices to reduce pollution during construction – in its stormwater management plan. To comply, the City must complete recommendations regarding the use of

BMPs in new development and redevelopment projects by August 2012. During the next permit cycle, starting after August 2012, the City will have to implement and enforce these regulations.

While detention standards already exist to manage the quantity of runoff that comes from large areas, the use of stormwater BMPs to improve water quality and manage small storms, 1.25 inches or less, could become law. In addition, the City will also make final recommendations for the use of BMPs in its own watershed plans and capital improvement projects, including addressing water quality in flood management projects.[7]

THE PHYSICAL CONTEXT OF DECISION MAKING

With population projected to double by 2050, Lincoln will experience horizontal growth. The conversion of agricultural land into new development will further threaten water quality and increase flood risk. However, the regulatory and planning efforts discussed above signal the opportunity to incorporate stormwater BMPs in new development areas to manage both water quality and water quantity. The Stevens Creek Watershed Master Plan noted that dispersed BMPs incorporated into developments are more cost effective than regional water quality control projects and that alternative site design presents the opportunity to incorporate BMPs into site designs in order to create landscape and open space amenities, which provide additional benefits to developers and homeowners. This presents an entry point for creating multipurpose infrastructure in a proactive manner, in contrast to retrofitting, with new development projects.

STEVEN'S CREEK WATERSHED AND NEW SUBDIVISIONS

The Stevens Creek watershed lies east of Lincoln just outside the city boundary and will be the location of various phases of future growth. The L2040 Plan growth tiers used to denote expected future growth areas extend into Stevens Creek watershed eventually covering its entire area after 2060. Because it is currently undeveloped and will likely see additional growth, it is a useful location to explore the design of multipurpose infrastructure with new development.

The Stevens Creek Watershed Master Plan recommends a $10 million investment to improve stream reaches within the watershed. With major investment in stream restoration, action to reduce flows that exacerbate downcutting is necessary. In the preparation of the Stevens Creek Watershed Masterplan, the City evaluated different building scenarios and found that it is possible to mimic predevelopment hydrology for small storms with the use of stormwater BMPs.[8] As a yet undeveloped area, the addition of stormwater BMPs to mitigate runoff from impervious surfaces will substantially improve the condition of the waterway when compared with current standards.

PROTOTYPE SUBDIVISION

To explore how stormwater BMPs fit into new development, a prototype location was chosen. Located along East Van Dorn Street between 84th and 98th Streets, this portion of the watershed is directly adjacent to the city boundary, is included in the City's service boundary, and is included in growth Tier I - Priority C, which means it is expected to develop by 2040. The area includes tributaries to Stevens Creek as well as portions that are within the 100-year floodplain.

Under a business as usual scenario, developers would construct a new subdivision on one or more quarter sections, grading the site to create regular sized lots and maximize the number of units. This process requires designated space for a detention or retention basin designed to hold runoff from the 2-, 10- and 100-year storm.

The watershed management plans, however, find that it is necessary to manage smaller storms. While it is possible to add small storm management into the detention or retention features, the city notes that there are benefits to separating BMPs and basins. For example, they note that a dry basin can be used for recreation since it will only fill during rare, large storms, while BMPs can be incorporated into the neighborhood for aesthetic benefit.[9] While the addition of BMPs to residential areas provides additional benefits, this recommendation implies the addition of BMPs into a standard subdivision design. However, reimagining the subdivision entirely to integrate water quality and quantity management with other functions can yield improved multipurpose infrastructure.

Based on the idea of conservation design or conservation subdivisions, water sensitive subdivisions proposed here would address water management issues and incorporate other uses or functions with a system of networked green infrastructure that breaks down large detention basins into smaller units.

In this prototype subdivision, low points in topography that drain into stream channels guide the drainage and layout of future development as an organizing element or fundamental structure. Linear bioswales at these low points create an extended network of designed tributaries and connect to the natural stream system. Roads and housing then follow this pattern since the bioswales replace the storm sewer. The swales and additional BMPs at each residential unit function to manage flows up to the 1.25-inch storm.

The bioswales lead to a series of detention/retention ponds located at the junction of tributaries sized to manage the larger 2-, 10- and 100- year storms from corresponding subwatershed areas. Instead of one large detention/retention basin, the smaller features fit between housing and the stream corridor, which is wider than the minimum requirement.[101] In larger subwatershed areas without a defined stream, low topography can be used to create a naturalized retention basin that provides an amenity and manages stormwater. Other options could be to add

1 Current requirements for the minimum flood corridor around streams are 30 feet plus three times the channel depth on either side of the channel bottom. The total stream corridor is therefore the channel bottom, plus six times the channel depth, plus 60 feet minimum. Widening this corridor could accommodate drainage features and other uses.

underground wetlands to add storage volume.

This approach changes the systemic function of the subdivision and drainage system, which produces additional benefits and makes neighborhoods more livable and enjoyable.

ADDITIONAL BENEFITS

The use of BMPs to manage small storms provides direct and indirect benefits. It reduces stream bank erosion, reduces localized flooding, increases base flows, increases biodiversity, and improves aquatic and riparian habitats.[11] Natural vegetation in the bioswales creates additional habitat area that did not exist while used for agriculture. In addition to ecological benefits, the improvement of riparian habitat also can contribute to bird watching and passive recreation.

Recreation space within the stream corridor can be coordinated with local and regional recreation trails to enhance passive and active recreation or alternative transportation routes, which add value and contribute to healthy lifestyles.

The value of integrated water systems also comes from the savings it produces. Since the bioswales function to manage runoff, the need to install or maintain storm sewer infrastructure (grey infrastructure) is eliminated. The incorporation of stormwater BMPs into the initial development process can even lower overall development cost compared to a more conventional subdivision due to reduced costs in storm drainage infrastructure and grading. Furthermore, past examples of lot sales in Lincoln and around the nation have shown that many lots next to outlots and natural areas sell faster and for more than other properties.[12]

This prototype subdivision can be applied throughout new growth areas to positively affect Lincoln's various watersheds.

LESSONS FROM LINCOLN

The negative impacts of urbanization upon water systems and flood regimes demonstrate the need to rethink growth patterns and how development can accommodate both housing demand and natural systems.

The addition of BMPs within subdivisions is an important strategy for water quality and water quantity management, but also provides opportunity for generating additional benefits. To maximize these, however, their addition into a typical subdivision is not sufficient. Their form and location should be planned to maximize benefits beyond the individual resident and even shape the design of the subdivision itself. This multipurpose infrastructure approach will allow for the development of community benefits in addition to regional benefits.

It is also a preemptive strategy where a focus on new development can prompt rational planning with a McHargian[13] approach. To ensure that developers create subdivisions multifunctional infrastructure instead of a series of simple tubs for detention basins, the City of Lincoln should amend its city ordinance and permitting regulations. This would require action by the city upfront, but would have significant impacts upon water systems and the future landscape of Lincoln. Given that the San Francisco Public Utilities Commission and other agencies are now planning how to retrofit the city and reintroduce streams it buried in the 1920s, it is even more prudent to shape new development using natural drainage and BMPs. If San Francisco had followed similar principles it would not be expending resources as it is now. Because much of the country is developing in a similar pattern to that of Lincoln, it is also an important lesson for much of the country.

The case of Lincoln reveals how environmental regulation and long-term watershed planning to address growth issues can drive change. In other words, a systemic view is advantageous to address large scale problems and to create multifunctional infrastructure at various scales.

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CLEVELAND, OHIO

Cleveland, Ohio presents an interesting case to explore the development of multipurpose infrastructure given that it is a region with high levels of vacancy and is served by a regional sewer district that must take action to reduce its combined sewer overflows. The Northeast Ohio Regional Sewer District (NEORSD or Sewer District) has entered into a consent decree with the EPA and other agencies to reduce CSOs. Due to the location of the combined sewer system and overflows, the Sewer District must act principally within the City of Cleveland. It has identified green infrastructure as one strategy to reduce CSOs and is investigating ways to utilize vacant land and create additional community benefits with green infrastructure projects.

PHYSICAL CONTEXT

Cleveland can be characterized as a 'shrinking' or post-industrial city that has lost half of its population since the 1950s. At 50,200 acres (78 square miles) it is now home to 396,815 people, according to the 2010 census, which creates a population density of 7.9 people per acre (5,113 per square mile). This density was once 18.4, with a population over 900,000. The decline in population and manufacturing jobs has created a collection of over 20,000 vacant lots throughout the city.[1]

Today, the majority of the city is made up of long narrow blocks that once held densely arranged single family homes set back from the street. While some blocks still house a majority of homes, others may only hold a few. The commercial and industrial rail corridors that run through the city towards the downtown on Lake Erie, also have abandoned or demolished structures. This two types of abandonment create a variety of vacant sites throughout the city from large parcels to small, scattered lots.[2] According to national data 77 percent of the city is more than 30 percent impervious.

THE ISSUE: COMBINED SEWER OVERFLOWS

Cleveland is one of the nation's 772 cities with a combined sewer system. In the 1970s, Cleveland released 9 billion gallons of effluent through combined sewer overflows (CSOs). Today, the region has cut this amount to 4.5 billion gallons, mainly through the construction of separate sewers.[3] However, these 4.5 billion gallons continue to pollute the city's waterways and Lake Erie. As a result, the Environmental Protection Agency (EPA) has found the Northeast Ohio Regional Sewer District (NEORSD or Sewer District), the sewer system provider for the Cleveland Region, to be in violation of the Clean Water Act because not all discharges have been controlled to required levels. The Sewer District has therefore entered into a consent decree with the Department of Justice, the EPA, the Ohio Environmental Protection Agency, and the Ohio Attorney General's Office to execute a program called Project Clean Lake in order to further reduce its CSOs and comply with the Clean Water Act.

While the Sewer District services the greater Cleveland region, the combined sewer system and the majority of CSOs exist within the City of Cleveland. This means that the Sewer District must act within the city and has the opportunity to utilize vacant space or address other city priorities as it implements green infrastructure projects within the particular physical context of Cleveland.

ADDRESSING THE PROBLEM

Project Clean Lake is a 25-year, $3 billion program intended to reduce the total volume of raw sewage discharged from 4.5 billion to 494 million gallons a year. To accomplish this goal, the program includes grey infrastructure investment for tunnels and treatment plant upgrades as well as $42 million for green infrastructure and stormwater control measures.[4]

The consent decree requires that the Sewer District develop a green infrastructure plan to control an additional 44 million gallons of CSO volume over the reduction created through grey infrastructure investment. Because the implementation of grey infrastructure measures would still result in 500 million gallons of CSOs, green infrastructure provides a way to further reduce the negative environmental effects of the region's sewer system.[5] The decree requires that the Sewer District spend at least $42 million on green infrastructure and that project construction must be complete by July 7, 2019 (8 years from the decree date). The Project Clean Lake: Green Infrastructure Plan from December 2011 outlines how the Sewer District intends to do so.

THE PLANNING PROCESS AND PROJECT SELECTION

In order to locate green infrastructure projects, the Sewer District identified three main priorities and used them to develop project selection criteria. The priorities include: 1) identify areas with the highest volume of CSOs remaining after grey infrastructure measures are implemented; 2) identify areas where land ownership would be conducive to permanent green infrastructure projects such as parcels that could be acquired from the City of Cleveland Landbank Program, the Cuyahoga County Land Reutilization Corporation, and the City of Cleveland Industrial-Commercial Land Bank; and 3) identify the possibility for green infrastructure projects to improve socioeconomic conditions in areas with low household income or concentrated minority populations. These priorities reveal the desire of the Sewer District to utilize infrastructure investment to meet multiple needs and to create multipurpose infrastructure that addresses broader city concerns.

Using these overall priorities, the Sewer District developed a green infrastructure index to geographically screen and select green infrastructure priority areas. The index included two sub-indexes. The first index included seven variables to evaluate spatial and social factors for green infrastructure implementation: available land parcels from the City of Cleveland Landbank Program; targeted redevelopment zones in the Cleveland Citywide Plan and development plans from community development corporations; public land in the form of greenways or parks larger than 3 acres; large parcels with single owners; and well drained soils. The second index measured potential to reduce CSO volumes and included: the volume of remaining annual CSO volume after the implementation of grey infrastructure improvements and the potential to reduce the amount of impervious areas directly connected to the sewer system (directly connected impervious area [DCIA]). These two indexes were then combined to create the green infrastructure index used to rank and select priority areas throughout the city. This method led to the identification of 38 priority areas.

Within each priority area, the Sewer District identified, evaluated, and prioritized possible green infrastructure projects1 based on their performance and general cost, along with the guiding principles of removing stormwater from the sewer system (offloading), incorporating community and transformational benefits, repurposing vacant land, and supporting viable partners.[6] The top 20 green infrastructure project areas from this prioritization, representing 95 million gallons of CSO reduction at approximately $102 million, will go forward for further evaluation. Of these 20 priority project areas, 14 are in environmental justice areas, 13 utilize vacant land, and 18 could be tied to community redevelopment initiatives. All require cooperation with the City of Cleveland and 14 require community development cooperation or private partnerships (commercial or industrial). Specific measures identified for each project area include the use of detention and storm sewer separation (all 20 areas), green

[1] The Project Clean Lake Green Infrastructure Plan includes and appendix of example green infrastructure control measures such as: dry detention basins, wet detention basins, constructed wetlands, irrigation ponds for rainwater harvesting, infiltration basins, bioretention swales, green streets, pervious pavement, vacant lot repurposing with use of green infrastructure control measures, green roofs, impervious surface removal and reforestation, open channels/swales, and overland flow on sloped streets with other green infrastructure measures. The appendix also includes storm sewers even though they are not green infrastructure.

streets (19 areas), repurposing vacant land (8 areas), overland flow (6 areas), and pervious pavement (1 area).[7] Each of these project areas could see the implementation 10-15 specific measures or projects on the general scale of 1-5 acres that treat 70-acre drainage areas.[8] The Sewer District is currently undergoing a second phase of planning to select and design these specific efforts.

While measures for the project areas included green streets, it is likely that the Sewer District will choose other project measures, such as detention, separating sewers to lead to water quality basins, or linear bioretention facilities, in the next phase of planning. This is due to the requirement of the Sewer District to maintain the projects in perpetuity, their desire to avoid future coordination issues with other users of the right-of-way, such as gas, electric, and cable utilities, and their need to meet the eight-year construction deadline.[9]

They have also found it advantageous to work with a single landowners or partners for ease of coordination and for the ability to address large volumes.[10] For example, the Sewer District developed an early action project with a local community development corporation to develop a hotel and create a chamber system under pervious pavers that captures water from the entire site up to the 100-year storm, infiltrating approximately one million gallons in a typical year.[11]

PHYSICAL CONTEXT OF DECISION MAKING

Through its selection criteria and the green infrastructure control measures it includes in the plan appendix, the Sewer District has revealed the preference to pursue a large patch strategy. The selection of large parcels will enable it to maintain and control green infrastructure projects through direct ownership or permanent easement and treat large volumes of water with fewer projects. Because Cleveland has experienced population decline, resulting in many neighborhoods that have distressed properties or vacant land, the Sewer District anticipates that it will be easier to implement projects in these areas than neighborhoods without vacant land.[12]

ADDITIONAL CONSIDERATIONS

CITYWIDE INTERESTS

Given Cleveland's particular physical context, the utilization of vacant land is one key benefit that the Sewer District could address through the implementation of its green infrastructure program. Various efforts within the city have identified redevelopment zones and other potential uses for vacant sites. These include the City's Connecting Cleveland 2020 Citywide Plan, the Reimagining Cleveland initiative, and Green City Blue Lake in addition to other community development organizations exist throughout the city.

The Sewer District has identified the desire to support city efforts to address vacancy and leverage economic development opportunities in redevelopment corridors to the extent possible.[13] The Sewer District notes that this approach could reduce the cost of the program while it simultaneously enhances neighborhoods, provides economic development opportunities, and helps rebuild the community.[14] In addition, the Sewer District anticipates additional benefits. The implementation of green infrastructure projects could lower lifecycle costs, improve habitat, control flooding and erosion, improve access to green space, increase property values due to the creation of neighborhood amenities, provide recreational benefits, reduce carbon footprint, contribute to energy savings, improve air quality, improve aesthetics, and create jobs and green infrastructure expertise.[15]

While there is high potential to create multipurpose infrastructure projects, partnerships and coordination will be necessary to maximize the benefits of these projects due to the fact that the Sewer District can only pay for infrastructure items as they relate to their CSO reduction goals.[16] As a result, the Sewer District must rely on community groups or other entities to find ways to provide for benches, artwork, and other desirable elements in order to add functions or benefits to each project. Through the planning and design process, it hopes to meet with community groups to learn about specific ideas and priorities to incorporate into project planning and design.[17]

COORDINATION

Since the Sewer District is a regional agency, coordination with the City of Cleveland and other organizations will be necessary to align interests and strategize investments. To facilitate this process, the Sewer District established the Cleveland Green Stormwater Management Team, which later became the City/Northeast Ohio Regional Sewer District (NEORSD) Green Infrastructure Steering Committee. Made up of 10 representatives from the Sewer District and five City of Cleveland offices[2], the team met four times during the development of the green infrastructure plan. The 19-member steering committee, that expanded to add more city representatives and include three local non-profit organizations that focus on economic and community development and quality of life[3], will continue to work with the Sewer District through project planning, design, and implementation. To specifically address vacant land use, the 60-member Vacant Land Use Steering Committee of the Re-Imagining Greater Cleveland planning initiative agreed to serve as the Green Infrastructure Advisory Committee and meet with the Sewer District twice a year to act as a communication conduit between community organizations and the Sewer District to help ensure that their efforts build upon and support larger community

2 City of Cleveland Planning Commission, Community Development-Division of Neighborhood Development, Economic Development, Office of Capital Projects, and the Mayor's Office.

3 City of Cleveland Public Works, City of Cleveland Public Utilities, Kent State Urban Design Collaborative, Neighborhood Progress Inc., and ParkWorks.

goals and objectives.[18] In this manner, the Sewer District seeks to build upon existing efforts to utilize vacant land and produce community benefits. Through planning and design these groups will face the challenge to see if vacant land and community development efforts can effectively line up with CSO volume reduction opportunity locations.[19]

VACANT SPACES, NEW URBAN STREAMS AND ENVIRONMENTAL SYSTEMS

The Sewer District is in a unique position to not only repurpose vacant land, but to do so in such a way that it encourages or generates investment and development. Hopefully, the advice and participation of the steering and advisory committees will provide useful expertize and vision for how to design specific green infrastructure improvements or incorporated them into larger development efforts for maximum benefit and transformation of affected communities. To meet these larger goals it will be necessary that designs move away from the mowed detention basin and instead become community gardens, parks, reforested areas, or wetlands or other natural areas.

Additionally, Cleveland is a case where it could be possible to reintroduce or develop larger environmental systems into the city. The Sewer District's strategy of scattered large patches provides the opportunity to create bioinfiltration basins, wet ponds, or constructed wetlands that add vegetation and infiltration capacity to specific areas. While this approach addresses points throughout the city, a project called Emerald Fibers from the Cleveland Urban Design Collaborative at Kent State University outlines a larger scale policy approach. It would assemble and re-vegetate vacant land over the actual or approximate location of buried or culverted streams. Together, these paths could form a network of green connections through the city to connect residents to the Cuyahoga River or Lake Erie and create an attractive amenity for development. In the long run, as culverts fail or as new funding sources become available, it could also be possible to daylight the buried streams for added ecological and community benefit. These emerald fibers could be located along Doan Brook, Dugway Brook, and/or Mill Creek and would be appropriate for vacant parcels that can be assembled, but that have no demand for redevelopment. [20]

While the current project areas do not currently overlay buried streams in a significant manner, additional green infrastructure investment could contribute to these networks over time. Two years after the construction deadline, the Sewer District will have to complete an assessment of the costs and effectiveness of each type of project. If green infrastructure projects are found to perform well and be cost effective, the Sewer District could reduce the amount of grey infrastructure investments and increase the amount of green infrastructure projects it uses to meet is CSO reduction goals as part of the green for grey swap allowed in the consent decree.[21] Given that green infrastructure investment has the potential to utilize vacant land and support economic and community development priorities, such a shift could represent significant improvements for Cleveland, and allow for the reintroduction of environmental systems into the City if planned and designed well.

ADDITIONAL BENEFITS

The size of project areas allows for the development of relatively large green infrastructure measures such as bioinfiltration basins or swales, infiltration basins, irrigation ponds, constructed wetlands, or forested areas. These types of interventions provide for the treatment of large volumes of water and will contribute to CSO reductions. They also provide patches of habitat areas and the addition of tree canopy reduces the urban heat island effect, which reduces energy costs for adjacent communities or developments.

Furthermore, these interventions would utilize vacant sites to remove a burden on communities, create aesthetic benefits to neighborhood residents, and can provide or add to existing open space. The strategic location of these projects with economic development zones also adds value to urban areas and contributes to the revitalization of Cleveland.

In the long-term, future projects add up to build linear systems that provide additional stormwater management, provide recreational connections, and the potential daylighting of streams. They reintroduce larger environmental systems into the city that can also help build regional green space amenities and components of the Cuyahoga County Greenspace Plan: Greenprint.

LESSONS FROM CLEVELAND

Cleveland is a case that requires the addition of new infrastructure to an existing urban environment, but its abundance of land reveals and requires a different strategy than the type of retrofitting required in San Francisco. Instead of retrofitting, it is a case of repurposing land to new functional uses.

In this case, the main actor, the Northeast Ohio Regional Sewer District, is a regional utility that must target its interventions principally within city boundaries. While it may be able to meet its own goals without cooperation, through direct acquisition of property, the creation of multiple benefits or the addition of multiple functions into its infrastructure projects requires cooperation and coordination with city agencies and organizations.

The Sewer District is in a unique position to not only repurpose vacant land, but to do so in such a way that it encourages or generates investment and development. Partnership and coordination can provide useful expertise and vision for how to design specific green infrastructure improvements or incorporate them into larger development efforts for maximum benefit and transformation of affected communities. The short timeline, other requirements of the consent decree, and financial limitations have motivated the Sewer District to identify what efforts can produce the most reductions in CSO volumes at the most economical price.[22] Based on the Sewer District's 20 potential project areas, this could result in five large detention basins that produce little benefit aside from CSO reduction and possibly the use of vacant land. However, the inclusion of vacant land, development plans and opportunities, and public parks or greenways in its selection criteria demonstrate initial efforts to create multipurpose infrastructure to the extent possible. The ability of the Sewer District to effectively coordinate with partners through the next phases of planning and design as well as their capacity to create projects that meet multiple needs will determine the success of multipurpose infrastructure implementation in Cleveland.

While it seems advantageous to work with organizations that have already given thought about how to strategically reuse or repurpose vacant properties, it remains to be seen if the involvement of various entities through advisory and steering committees will facilitate the development of multipurpose infrastructure. Will they become the proverbial 'too many cooks in the kitchen' or provide sound guidance to create multipurpose infrastructure as intended? It will also remain to be seen if partners can leverage funding and planning processes to support the addition of other amenities to green infrastructure projects on a short timeline. At the very least, the Sewer District could grade or design projects so that they can be enhanced by other parties in the future.

The planning and implementation of green infrastructure projects for compliance with the consent decree will also provide a foundation for the development of partnerships and longer project planning process in the future. If the Sewer District demonstrates the effectiveness of green infrastructure measures it could choose to trade grey for green investments to make progress towards its core CSO volume reduction effort.[23] This means that the implementation of additional green infrastructure projects could occur after the initial eight-year timeline. In the future, it is also likely that environmental regulations will require continued reduction of CSOs. This will prompt further green infrastructure investment since compliance with the consent decree would leave 456 million gallons of CSOs each year that cannot be reduced with grey infrastructure investment. Furthermore, the

Sewer District could consider how to integrate its stormwater management program in the rest of its service area with the CSO reduction program.[24] All of these factors indicate that it is likely that the Sewer District would continue to be a driver of multipurpose infrastructure development in the future. This also indicates that its efforts could contribute to the emerald fibers concept and reincorporate both site specific and linear environmental systems back into the city.

While it has sought to coordinate with committees and city officials on a planning level, the Sewer District has also shown a preference to work with single landowners for project implementation. One of its main selection criteria targeted large parcels and many of its potential project areas lie in commercial or industrial areas revealing a large patch strategy. It will be interesting to see how and if this strategy evolves through the next phases of planning and design. It will also be interesting to see if the steering committee, advisory committee, and community members share this preference.

Finally, the current method of cost evaluation seeks to produce the largest volume reduction for the lowest cost. However, triple bottom line analysis could provide a different prioritization of projects as it incorporates the added value of other community or ecological benefits into the analysis as apposed to an add on benefit after the fact. If a triple bottom line analysis were to be conducted resulting in different prioritization or sizing of projects, it would indicate that the financial evaluation of investments for multipurpose infrastructure should be different to capture the range of values it produces.

ENDNOTES

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3 Victoria McCauley, "Personal Communication", April 23, 2012.

4 Northeast Ohio Regional Sewer District, "Project Clean Lake", n.d., http://www.neorsd.org/projectcleanlake.php.

5 McCauley, "Personal Communication."

6 Northeast Ohio Regional Sewer District, Project Clean Lake: Green Infrastructure Plan (Cleveland, OH: Northeast Ohio Regional Sewer District, n.d.), 3.12, www.neorsd.org/images/703/NEORSD_GI_Plan_12282011_project-clean-lake.pdf.

7 Ibid., G.1–G.20.

8 McCauley, "Personal Communication."

9 Ibid.

10 Ibid.

11 Northeast Ohio Regional Sewer District, Project Clean Lake: Green Infrastructure Plan, 5.6; McCauley, "Personal Communication."

12 McCauley, "Personal Communication."

13 Northeast Ohio Regional Sewer District, "Project Clean Lake."

14 Ibid.

15 Northeast Ohio Regional Sewer District, Project Clean Lake: Green Infrastructure Plan, 5.8–5.9.

16 McCauley, "Personal Communication."

17 Ibid.

18 Northeast Ohio Regional Sewer District, Project Clean Lake: Green Infrastructure Plan, 2.6–2.8; McCauley, "Personal Communication."

19 Schwarz, "Personal Communication."

20 Gauri Torgalker and Terry Schwarz, eds., Water Craft, vol. 3, Urban INFILL (Cleveland, OH: Kent State University, Cleveland Urban Design Collaborative, 2010), 56–59; Re-Imagining a Greater Cleveland, "Re-Imagining a [Greater] Cleveland"; Schwarz, "Personal Communication."

21 Schwarz, "Personal Communication."

22 McCauley, "Personal Communication."

23 Schwarz, "Personal Communication."

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CONCLUSIONS

These cases demonstrate a variety of lessons for future practitioners as they implement stormwater management programs and strive to develop multipurpose infrastructure to meet the diverse needs of their communities.

A review of the cases and the exploration of possibilities within each type of urban environment reveal both a set of common themes and particular differences.

ADDITIONAL BENEFITS AND MULTIPURPOSE INFRASTRUCTURE

All three entities responsible for stormwater management seek to use green infrastructure approaches in order to meet water management goals and provide additional benefits. While they may not explicitly refer to the creation of multipurpose infrastructure, they recognize that an ecologically based approach, or at least a more ecological approach that mimics natural processes, can be leveraged to create additional community benefits. However, the combination of functions they each bundle together also makes clear that multipurpose infrastructure can take on different meaning in different places. While each case builds upon the same fundamental component of stormwater management, the specific additional purposes or functions it includes or seeks to address are influenced by its physical and social characteristics.

The San Francisco Public Utilities Commission principally identified the value that green infrastructure could add to the sewer system for added capacity and flood control. In addition, it explicitly anticipates aesthetic, pedestrian safety, recreation, open space, and water supply benefits. The case also reveals the potential to strategically locate or coordinate projects in order to accomplish other citywide goals related to livability and connectivity. Coordination between city agencies allows for the addition of more functions to a single project, supports efficiency gains, and adds to the more effective provision of services from multiple city agencies. The development multipurpose infrastructure in San Francisco facilitates the implementation of multiple city agendas to make a dense urban environment more livable.

The City of Lincoln seeks to disperse BMPs throughout neighborhoods for aesthetic benefit, to add value to new development, and allow for the recreational use of detention basins. While the principle function of green infrastructure systems is to manage flooding and water quality, the development of new subdivisions based on natural drainage also addresses population growth in a manner that is beneficial for both the city and developers. The added benefit to the city by eliminating the need to construct and maintain grey storm sewer infrastructure, the benefit to developers by increasing home prices and the speed of sales, and the benefit to homeowners of added aesthetic and recreational value address the principal issues associated with growth. The addition of riparian and aquatic habitat is an additional environmental benefit integrated into the multipurpose infrastructure system that serves the above purposes.

The Northeast Ohio Regional Sewer District aims to use vacant land and contribute to economic and community development efforts identified by the City of Cleveland or other organizations. The Sewer District notes that this approach could lower the cost of implementation of its green infrastructure program required by the EPA and allow it to contribute to larger city development efforts.

The concept of multipurpose infrastructure is evident all cases as actors in each city seek to plan projects and advocate for their multiple benefits. Planning and design can add complexity or functions and allow municipalities and communities to leverage stormwater management investments to meet their larger goals. However, these specific goals shift in each case.

SPATIAL STRATEGY

As is expected, each case reveals a different spatial strategy. Project descriptions in the Sewer System Improvement Program reports and earlier watershed charrettes indicate that the San Francisco Public Utilities Commission (SFPUC) will pursue a small surface strategy linked to potential medium or large projects. Although it is in the process of reassessing opportunities and its spatial strategy may evolve, streetscape designs, other actions in the right-of-way, and incentivizing downspout disconnection are the principal small surface approaches that are likely to come to fruition in this dense environment. These small surfaces will also be highly designed to fit into existing streets and sidewalks and to provide the desired additional benefits of street calming or pedestrian enhancement. Even daylit portions of streams will likely be channelized and wetland areas will likely have park like features to provide open space amenities and connect with regional trails.

In Nebraska, the City of Lincoln will promote dispersed stormwater BMPs that could become a large system strategy (in comparison to the large point strategy of a single detention pond) through the use of natural drainage systems and dispersed detention or retention ponds.

In Cleveland, the Northeast Ohio Regional Sewer District has identified large sites to treat large volumes as part of a large target strategy. These efforts could eventually build to a large system strategy as the Sewer District continues to implement projects into the future.

For each case, the physical context of each city and the desire to address other goals shape their spatial strategies and additional goals.

RESPONSIBLE ENTITIES AND COORDINATION

These cases highlight the need for coordination between multiple entities. In San Francisco, interagency coordination is necessary to implement multipurpose projects. Because land acquisition for all projects would be cost prohibitive, coordination is necessary to find available space in the public right-of-way. Since multiple agencies also seek to use the same space for their projects, coordination is also necessary for each agency to fulfill its mission effectively. Coordination will also allow for agencies to take advantage of project efficiencies through the coordination of planning processes and construction timelines.

Lincoln is a distinct case in that coordination is not required for implementation in new growth areas to the same extent as the other cases. Consultation with natural resource agencies or developers may be helpful for writing regulations and city ordinance that governs new building and development requirements. However, once written, planning, design, and implementation become the principal responsibility of developers, a private entity.

Cleveland presents a case of multi-scalar coordination where a regional entity must act within a local jurisdiction. While interagency coordination may not be technically necessary given that the Northeast Ohio Regional Sewer District could acquire property on its own, consultation and coordination is essential to incorporate the expertise of organizations focused on the use of vacant land and economic and community development.

COST EVALUATION AND PROJECT PRIORITIZATION

The comparison of cost evaluation and project selection processes between cases could reveal the impact of cost evaluation methods on project selection outcomes. In Cleveland, the technique to reduce CSO volumes at the lowest cost is a rational decision making process that does not evaluate additional benefits of using vacant land (other than a potential reduction in the cost to implement the project) or community development benefits. This differs from San Francisco's triple bottom line analysis that includes economic costs as well as environmental and social costs and benefits for each set of project alternatives. While it is too early to know what specific projects will be implemented, a comparison of outcomes generated by both cost evaluation methods would be useful to understand how financial analysis impacts the development of multipurpose infrastructure. It is likely that a new form of evaluation that considers the range of benefits generated from a project, like triple bottom line analysis, will be necessary to better understand and justify multipurpose projects.

ECOLOGY

Since the cases mention improvements to habitat as an additional benefit of green infrastructure for stormwater management it is also useful to evaluate the environmental benefit these projects would produce beyond water quality.

San Francisco represents a case where green infrastructure could contribute to a patchwork of green spaces and habitat areas with new plantings and possible connections through streets, tree canopy, small patches, or green roofs. If these green infrastructure measures provide small stepping-stones or improve connectively between other patches in the city, the effort would improve the landscape of habitat within the city. However, it would remain highly fragmented and disturbed. While green infrastructure efforts would not generate a fully functioning ecological system, as compared to other 'natural' areas, it would be an incremental increase over existing conditions, the quality of which depends upon the location, size, and arrangement of project components. Given the constraints of the urban environment, it is unlikely that projects would create significant habitat areas. Even daylighting would entail vegetated, channelized approach in lieu of a full ecological restoration.

In Lincoln, the development of new subdivisions based on natural drainage systems and dispersed water management measures has the potential to preserve and enhance existing corridors. This would serve to maintain large ecological systems and expand habitat. The addition of BMPs throughout the neighborhood would also add new patches or stepping-stones as compared to current agricultural uses today.

In Cleveland, the large target approach could add natural systems back into the city through the construction of wetlands or reforested areas in specific locations. The likelihood of additional green infrastructure development also creates the long-term possibility to reinsert natural systems along stream corridors or to link large patch projects together.

FACTORS AFFECTING MULTIPURPOSE INFRASTRUCTURE

Available surface area, the number of actors involved in project development, and project economics contribute to different rates of success in the design and implementation of multipurpose infrastructure.

Cleveland has the surface and space available, which should facilitate the implementation of multipurpose infrastructure based on stormwater management. However, there are many actors involved at different scales with limited financial resources. Although it may be "easier" to implement in a place with vacancy, the speed at which projects may develop and the quality of their design remains to be seen, as does the extent to which the Northeast Ohio Regional Sewer District can incorporate and address the concerns of partner organizations.

This concern indicates that the number of actors involved would also affect project outcomes. In Lincoln, it would seem that fewer actors would facilitate project implementation. However, the outcome of projects in Lincoln will depend upon the effectiveness of regulations and ability of developers to design and incorporate multipurpose infrastructure in their new subdivisions. Politics and political culture will influence the ability of the City to effectively regulate and incentivize new development.

In the end, ability to pay and project economics will also affect outcomes. Even in physical conditions conducive to multipurpose infrastructure development, like Cleveland, limited funds could compromise the ability to provide multiple benefits to the extent desired. Since the Sewer District cannot pay for items aside from green infrastructure measures for stormwater management, for example, they may be forced to implement a minimal design if partners cannot leverage sufficient resources to include additional functions in the project. In contrast, San Francisco has dedicated substantial resources to its Sewer System Improvement Program and has begun to develop systems for coordination. However, if current efforts to model and evaluate project alternatives show that the effectiveness and costs of green infrastructure projects and daylighting are, respectively, less and higher than expected, the SFPUC may not be able to implement green infrastructure measures to the extent anticipated.

Because each municipality will have a combination of available surface area, actors, and financial resources the development of multipurpose infrastructure networks will depend upon policy entrepreneurs as well as planners and designers versed in overcoming barriers to the development of multipurpose infrastructure.[1] As these projects unfold it will be possible to evaluate the role of different factors and how they affect outcomes.

A METHODOLOGY FOR MOVING FORWARD

The characteristics of these three cases also provide a framework for moving forward. While hybrid situations exist within each city, they principally represent a retrofitting, preemptive, or repurposing approach that planners and designers can use to guide their efforts to produce the most value with multipurpose infrastructure.

In the retrofitting city, the creation of multipurpose infrastructure is an exercise in finding space. This involves subtracting development or built areas, identifying underutilized areas, or places 'in between' to insert green infrastructure. It involves the creation of connections or linkages between them or the strategic placement of projects to create larger connected systems. It involves creative design to ensure that each intervention functions for water management, but also addresses other city goals to the maximum extent possible. Given the dense urban environment, the public right-of-way is a significant surface for action. This entails the need for coordination to act and maximize value in this shared space. The identification of overlapping capital improvement projects and community plans is essential to identify layers of functionality that can be added to a project, as is public participation.

In the preemptive city, the task is to proactively blend development and natural systems. It entails a combination of systems that work both environmentally and programmatically to produce productive and enjoyable landscapes. The use of natural drainage and ecosystem services should be designed in such a way as to avoid the construction of grey infrastructure systems and to avoid the need for costly retrofitting in the future. Instead of allowing the use of single detention basins, the planner and designer should actively integrate dispersed green infrastructure systems to manage stormwater, enhance habitat, and create value for developers and residents within communities.

In the repurposing city the goal is to capitalize upon the opportunity to reintroduce natural systems and work at larger scales. It involves targeting the use of vacant land to both remove the burden of underutilized space and contribute to economic and community development. It also involves the use of design to move beyond the detention basin to include other environmental or community uses. The approach uses the lack of development to create a new combination of development and natural systems.

INFRASTRUCTURE AND ITS MULTIPLE FUNCTIONS

Intrinsically, green infrastructure is more multipurpose than grey infrastructure due to its use of vegetation. However, simply adding vegetation is not enough. Each case demonstrates how stormwater management using a green infrastructure approach could be designed beyond the isolated, individual BMP. To truly create multipurpose infrastructure, planners and designers must leverage environmental systems and initiatives to address additional issues. They must actively identify larger goals and incorporate them into planning and design efforts to create multifunctional and multipurpose infrastructure networks. In this sense, multipurpose infrastructure should not just have many functions, but bundle them in a manner that addresses broader issues and contributes to the achievement of other city goals at a range of scales.

Borrowing from the literature on green infrastructure, the desired outcome for multipurpose infrastructure is a network that functions as a whole and is a strategic connection of system components.[2] It should be designed to link elements into a system that functionsas a whole, rather than as separate, unrelated parts. It should be laid out strategically and include ecological, social, and economic benefits, functions and values.[3]

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