Thinking Ecosystems, Providing Water: The Water Infrastructure Imperative

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Chapter 3
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As climate change impacts become more pronounced, already strained infrastructure necessary to ensure the provision of critical services will be put under additional stress. In the context of urban water supplies, climate change guarantees instability in the acquisition, transmission, provision, and disposal of water. Such challenges facing water-related services, including the provision of potable water and control of floods, pose immediate and long-term threats to health, safety, and welfare, and importantly, accompany failures in a wide array of essential public services. Nevertheless, notwithstanding widespread agreement regarding the risks, the potential for grave danger, and the high costs to improve water supplies and associated infrastructure, we have seen surprisingly little effective long-term water planning to ensure continued water-related services in the era of climate change.

Most significantly, planning for future provision of water-related services continues to focus on conventional “gray infrastructure” in which the manufactured, engineered, built environment is viewed as the primary, if not sole, means to provide essential services. Often working against natural processes, gray infrastructure—such as diversion systems, pipes, tunnels, culverts, detention basins, berms, tiling systems, and cost-intensive water treatment

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facilities—is the traditional method used to provide potable water and/or to prevent damage from unwanted water.¹

In this chapter, we look to emerging systems often called “green infrastructure” as short and long-term cost effective methods for providing services in the face of climate change impacts. Green infrastructure—such as wetlands, urban forests, bio-filtration, ponds, rain gardens and other natural-based treatments—leverages ecosystem services and capitalizes on vegetation, soils, and natural processes to provide potable water, prevent damage from flooding, lower costs, and create healthier, vibrant communities.

While we focus predominantly on threats to water systems stemming from climate change, we do so recognizing that urban water infrastructure in many locations is already greatly stressed and overtaxed by population growth, migration, and age of a neglected infrastructure. The challenges facing water-based services are amplified not only because they are related to essential human services, but also because the existing infrastructure is both vast and vulnerable. For example, each year trillions of gallons of water are lost through hundreds of thousands of miles of pipe used to transport water. Updating this infrastructure is estimated to cost hundreds of billions, if not trillions, of dollars.

In its Final Report, the Intergovernmental Panel on Climate Change (IPCC), Working Group II acknowledged the infrastructure challenges rising from climate changing conditions and the significant risks they pose to crucial services, stating:

Climate Change will have profound impacts on a broad spectrum of infrastructure systems (water and energy supply, sanitation and drainage, transport and telecommunication), services (including health care and emergency services), the built environment and ecosystem services. These interact with other social, economic, and environmental stressors exacerbating and compounding risks to individual and household well-being (medium confidence based on high agreement, medium evidence).²

For purposes of this chapter, Working Group II’s statement contains two critical observations. First, it is significant that Working Group II chose to

¹. Tiling is a sophisticated underground drainage system, designed to get water off agricultural land as quickly as possible. An example of the widespread use of tiling can be seen in the Midwest where about 48%, 48%, and 42% of Illinois’, Ohio’s, and Indiana’s cropland, respectively, is tiled. Zachary Sugg, Assessing U.S. Farm Drainage: Can GIS Lead to Better Estimates of Subsurface Drainage Extent 6 (World Resources Institute Aug. 2007), available at http://pdf.wri.org/assessing_farm_drainage.pdf.

associate climate change with stress to critical infrastructure. Second, it is equally significant that this stress will make it increasingly more difficult and expensive to provide public services. When aggregated, these two observations suggest a simple imperative: sound responses to climate change must concern securing infrastructure and ensuring the continued provision of public services.

Because many critical public services fall within the purview of local governance, communities will face the burden of providing an effective and efficient water infrastructure system. Recent water-based challenges involving the quantity and quality of water illustrate some of the service disruptions local communities face. For example, the 2015 floods in South Carolina brought *too much* water, over-taxing public service systems, resulting in local governments’ losing capacity in water treatment plants, water main breaks, boil water alerts, and thousands of citizens scrambling to find potable water.  

Meanwhile severe, extreme, and exceptional droughts throughout the West in 2015 involved *too little* water, making it difficult to provide the requisite water to citizens. In addition to quantity-based challenges, many communities are also struggling with ensuring the proper quality of potable water. The 2014 algae blooms in Lake Erie that left thousands without potable water illustrate the type of quality-based challenges cities face.

As local governments address these and other water infrastructure challenges, it is essential to consider “green infrastructure” and ecosystem services in particular. For purposes of this chapter, the divergence between gray and green infrastructure emphasizes the importance of ecosystem services. The term “ecosystem services” refers to the “measurable benefits that people receive from ecosystems. Ecosystems produce goods and services as a result of ecosystem process, function, and structure.”

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ates the manner in which ecosystems produce goods of value, the manner in which ecosystems provide services that are essential to human well-being, and the economic worth that can be attributed to functioning ecosystems as the value of the services they provide.

Although not directly addressed in this chapter, the comparison of gray and green infrastructure also highlights different perspectives on how to fund public infrastructure. Where traditional, gray infrastructure relied predominantly on municipal bonds (and fees or assessments to make bond payments), green infrastructure makes available previously unrecognized economic benefits embedded in ecosystem services. For instance, green infrastructure programs produce water and energy efficiencies, often by capitalizing on existing natural services such as climate control (shade), storm surge (stormwater capture by root systems), and pollution control services (air and water filtering) provided by urban forests. Capturing this value can help fund green infrastructure projects. Research around funding green infrastructure is continuing to develop, but it remains a critical part of making ecosystem services a reality.7

With an eye on developing appropriate principles for implementing Working Groups II’s directive on infrastructure, this chapter explores the threats to urban water infrastructure and solutions to abate those threats based on green infrastructure. This move from gray to green infrastructure addresses the water challenge by recognizing the need to migrate away from the counterproductive assumption that nature is harmful and must be resisted, and toward the assumption that nature is helpful and must be embraced. If infrastructure and the built environment are to be sustainable and resilient in the face of climate changes—if infrastructure will have the capacity to meet the social, economic, and environmental necessities of our time and over time—an understanding of ecological services must be addressed at the local level with local land use planning tools for infrastructure and the built environment.

The first section below describes the current state of water infrastructure in the United States and its susceptibility to climate change impacts. The second section introduces ecosystem services as a method to address some of those impacts. The final section concludes with three core areas in which cities can begin to recognize and embrace opportunities in ecosystem services to implement green infrastructure projects as a means to avoid catastrophic loss as we enter a period of climate change.

7. For more information on funding local adaptation projects connected with climate change, see generally Jonathan Rosenbloom, Funding Adaptation, 47 J. Marshall L. Rev. 657 (2014).
I. Water Infrastructure and Infrastructure Accounting

We cannot ignore the anticipated problems concerning adequate water quality and quantity. Failure of a water supply, sewage disposal, or stormwater system will result in significant, unrecoverable losses. As such, it is critical to identify the challenges currently facing cities and design ways to make water infrastructure more sustainable and resilient.

To accomplish this task, it is important to recognize that water infrastructure does much more than merely provide potable water. Traditional water management is framed as an acquisition-to-disposal system: the capture of water from the surface, ground, and air; treatment of water for potable supplies; transportation of water from capture to user; wastewater disposal to prevent disease; and mitigation of unwanted water, such as from storm surges and flooding. Historically, water systems provide these services through an intentional coordination of constructed artificial and, more recently, natural systems in the form of “gray infrastructure.” These systems are designed to capture, convey, store, and treat water through complex arrangements in the built environment.

In general, the success of a water system depends upon its ability to perform the tasks associated with water. Interruptions in water provision such as breaks in water lines, emergency substitution, water quality advisories resulting from contamination, excessive and uncontrolled flooding, suggest failures. The strength of the water supply system is assessed by capacity and security—generally, miles of pipe, anticipated life span of the built infrastructure, and the ability of the system to accommodate changes in population and environmental standards.

In most typical communities in the United States, engineered solutions consisting of gray infrastructure for water services are the norm. For instance, roads are “crowned” in their center to direct the flow of water to the edges of roadways, where concrete accelerates the removal of runoff water to curbs, which capture and deliver runoff towards storm drains. Then, pipes and ditches, berms and dams, even improved riverbeds (with concrete) keep water from intruding into the ground, basements, and residential and commercial areas. They also eliminate risks to vehicle traffic by preventing ponding on road surfaces, transport water away from the built environment, and deliver water to sophisticated filtering facilities, which guarantee (in many cases) the delivery of clean, fresh water to many homes, businesses, and fields.

And, as sure as water goes in, we have designed the system for removal of waste and wastewater from human structures. The U.S. Environmental
Protection Agency (EPA) summarized conventional infrastructure planning as the following:

To date, the focus of traditional stormwater management programs has been concentrated largely on structural engineering solutions to manage the hydraulic consequences of the increased runoff that results from development. Because of this emphasis, stormwater management has been considered primarily an engineering endeavor. Economic analyses regarding the selection of solutions that are not entirely based on pipes and ponds have not been a significant factor in management decisions. Where costs have been considered, the focus has been primarily on determining capital costs for conventional infrastructure, as well as operation and maintenance costs in dollars per square foot or dollars per pound of pollutant removed.\(^8\)

Maintaining the current system of gray infrastructure is a gargantuan and costly task. At present, there are approximately 52,000 community water systems and 21,400 not-for-profit non-community water systems.\(^9\) Each system consists of miles and miles of infrastructure. For example, the provision of water in and around Chicago servicing five million people has hundreds of thousands of miles of pipes.\(^10\)

Many water infrastructure systems across the United States are currently strained by two forces: age of the system and added burdens levied by climate change. As to the age and deterioration of the system:

\[\text{[T]he task of providing an adequate supply of clean water and sufficient wastewater and storm water treatment capacity in the U.S. is more challenging now than ever before. Some of the country’s water, wastewater and storm water systems were constructed over 100 years ago. Most were built during the last 50 years with the spread of suburbanization, largely unrestrained by concerns for sustainability. Many of these facilities are at the end of their useful life and need to be either renewed or replaced. Meanwhile, changes in federal clean water and drinking water programs require upgrades in plants, technology and practices that require various forms of investment. In addition, periods of economic distress, taxpayer or ratepayer revolt, rapid increases or decreases in service population, and instability in municipal bond markets have left many}\]


communities struggling to fund the maintenance and replacement of their water infrastructure. . . . 11

As the infrastructure ages, it deteriorates. A 2015 report estimated that 2.1 trillion gallons of water are lost yearly to leaky pipes. That number amounts to almost six billion gallons of lost water per day. Chicago is estimated to lose 22 billion gallons of water per year, enough to service 700,000 people. 12 Importantly, water loss at this scale suggests economic hardships in addition to environmental and social impacts. The water lost through leakage has often already been treated for water quality purposes. Once the water is lost, the water authority is unable to recover its investment as the water does not reach the paying customer.

In addition to its diminishing status, existing water infrastructure is burdened by the consequences of climate change. Climate change makes an already difficult and costly situation more complex and unpredictable, adding risk that will threaten the physical constitution of water infrastructure. Floods, landslides, avalanches, mudslides, forest fires from hotter, drier summers, and loss of snowpack will disrupt water flow expectations. 13 Storms will impact infrastructure as a result of their frequency, intensity, and predictability. Sea-level rise will have a direct effect on the location of population and infrastructure. Changing precipitation patterns, especially combined with temperature changes, will make it difficult to plan for disease control, water availability and quality, and pest control.

These climate change impacts can be expected to have associated costs. When local communities aim to resist climate impacts by widening pipes, building more dams, dikes, and berms, building more treatment capacity, and converting salt water in yet-to-be-built in a cost effective way desalination plants, there is an associated cost. And that cost is daunting. With respect to water supply, EPA observes that:

> Without global GHG mitigation, damages associated with the supply and demand of water across the U.S. are estimated to range from approximately $7.7-190 billion in 2100. The spread of this range indicates that the effect of climate change on water supply and demand is highly sensitive to projected


Similarly,

In 2009, the National Association of Clean Water Agencies (NACWA) estimated the cost of adapting water utilities to climate change in the U.S. to be between $448 billion and $944 billion. The report states that NACWA based its estimates on the IPCC's 2007 report and expects changes upon a review of the now released IPCC 2013 report, which shows significantly more severe climate changing impacts. NACWA's report is nonetheless telling, as it provides a uniquely comprehensive estimate of the costs to adapt a single local government service.\footnote{Rosenbloom, supra note 7, at 669.}

According to one estimate, the average cost of drinking water infrastructure replacement will range from $550-$2,300 per household to $6,300 per household for smaller systems, but up to $10,000 per household if treatment plants and pumps need replacement.\footnote{Wastewater infrastructure suffers similar liability. EPA reported as follows in 2008: The needs for Wastewater Treatment, Pipe Repairs, and New Pipes are $187.9 billion, an increase of $28.6 billion (18 percent) since 2004. Of this increase, $16.3 billion is for Advanced Wastewater Treatment (Category II) needs, $7.0 billion is for Secondary Wastewater Treatment (Category I) needs, and $4.8 billion is for Pipe Repair (Category III) needs. These needs increases are mainly for improvements to rehabilitate aging infrastructure, to meet more protective water quality standards, and to respond to and prepare for population growth. New York ($17.0 billion), California ($16.3 billion), Florida ($9.4 billion), and New Jersey ($6.3 billion) reported almost half (47 percent) of the Secondary Treatment (Category I) and Advanced Treatment (Category II) needs. Similarly, nearly half (47 percent) of the Pipe Repair (Category III) and New Pipe (Category IV) needs were reported by California ($7.9 billion), Florida ($6.5 billion), New York ($5.0 billion), Ohio ($4.4 billion), Texas ($4.2 billion), Puerto Rico ($3.7 billion), North Carolina ($3.7 billion), and Massachusetts ($3.6 billion). U.S. Envtl. Prot. Agency, Clean Watersheds Needs Survey, 2008 Report to Congress vi (EPA 832-R-10-002) (2008).} In the meantime, the useful life of water infrastructure has declined: the average life expectancy for gray infrastructure has decreased from 120 years (for systems features installed in the
late 1800s) down to 75 years for post-WWII infrastructure. The staggered life expectancies of water infrastructure components makes financing infrastructure more complicated, including equitably allocating scarce resources to the replacement where and when systems come to the end of their useful life.¹⁸

In all, the cost of sustaining the built infrastructure to ensure the provision of potable water in the climate change era will be profound.¹⁹ Given that water is an imperative, communities must struggle with these infrastructure questions, costs, and risks. No local government may opt out or race to the bottom of water. Hence, the question arises of whether it is time to adjust infrastructure thinking to leverage ecosystem services.

II. Recognizing Ecosystem Services as a Preparedness Necessity

Having established the dire need for effective water infrastructure planning and the gargantuan cost associated with ensuring the provision water-related services, this chapter now addresses the benefits of integrating ecological economics into infrastructure planning. In the past, this integration was absent from infrastructure planning. Nevertheless, against the challenges set forth in Part I, local governments need better options to develop water infrastructure that demonstrates “the ability of a system and its component parts to

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¹⁸. The costs of built infrastructure maintenance and replacement have associated benefits that do not have a corresponding counterpart in maintenance of natural capital. As stated in a recent report by the U.S. Conference of Mayors:

The estimates exhibit a wide range, but the consensus is that public infrastructure investment yields positive returns, and investment in water and sewer infrastructure has greater returns than most other types of public infrastructure.
- A recent study estimates that one dollar of water and sewer infrastructure investment increases private output (Gross Domestic Product, GDP) in the long-term by $6.35.
- With respect to annual general revenue and spending on operating and maintaining water and sewer systems, the US Department of Commerce’s Bureau of Economic Analysis estimates that for each additional dollar of revenue (or the economic value of the output) of the water and sewer industry, the increase in revenue (economic output) that occurs in all industries is $2.62 in that year.
- The same analysis estimates that adding 1 job in water and sewer creates 3.68 jobs in the national economy to support that job.


¹⁹. David Monsma et al., Sustainable Water Systems: Redefining the Nation’s Infrastructure Challenge 10 (The Aspen Institute 2009) (“Greatly adding to these challenges are the far-reaching impacts of climate change, which, through changing precipitation patterns, more intense storms, and warmer temperatures that increase snowpack melt and add to droughts, pose a number of new and uncertain challenges for our water supply and management.”).
anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner.”

When we observe the long-term costs and ecological destruction associated with gray infrastructure, consideration of ecologically based solutions to infrastructure needs presents an opportunity. Of course, from the engineering perspective, ecological solutions to infrastructure challenges may seem like a foreign language because they challenge the idea that built infrastructure should determine the direction of infrastructure solutions. Nevertheless, ecosystem concepts may provide an advantage over a gray infrastructure approach because ecosystem planning requires an accounting of needs that are local, contextual, and environmentally situated. In comparison, gray infrastructure planning is typically based on more universal criteria that relate to manufactured elements such as roads and dams, to the exclusion of local ecological assets and needs.

By appreciating ecosystem functionality, ecosystem services analyses reveal aspects of ecosystems that are important to human well-being, even though such features are otherwise invisible in the market. As noted by the

20. Intergovernmental Panel on Climate Change, Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation 561 (2012).

21. Incorporation of conventional stormwater treatment, end-of-pipe solutions, into development has resulted in improvements to how stormwater runoff is released from a development. Primarily these improvements are in the form of reduced localized flooding directly downstream of the development but this improvement is often negated over time due to lack of maintenance of the facilities. Research has shown that ponds at the end of a developed site will never adequately achieve the goal of maintaining pre-developed runoff conditions. Severe changes in the landscape upstream of the pond just cannot adequately be addressed by the pond. The lack of ability to meet this difficult goal is apparent in the ever increasing requirements for sizing conventional stormwater ponds and may eventually be recognized as an unachievable goal through conventional stormwater treatments.


22. Green infrastructure design and performance is generally more context-specific then gray infrastructure. Because these types of controls must be designed and built to suit the soil, terrain and hydrologic conditions of each individual site. As a result, however, they can be designed and implemented to address local concerns and values.


Often invisible, ecosystem services and their value to society are frequently ignored when determining the allocation of water to instream flows. If included, ecosystem services would further underline the importance of dedicating water to instream flows beyond just the
National Research Council, “The value of capital is defined by flows of useful services. Defining ecosystems as natural capital that yields useful services is the first step toward quantifying the value of ecosystems.” 24 Ecosystem services analysis identifies the manner in which ecosystems produce goods (such as marketable products, including food, medicines, building materials and other goods), regulate climatic and ecosystem conditions (such as climate and air and water quality), provide important spiritual and cultural services (such as recreational, aesthetic, and spiritual opportunities), and support other processes and physical structure (such as soil formation, geological structure, and nutrient cycling). 25

Ecosystem services thinking demands a break from commodity-based valuation. By focusing attention on the market values of goods that can be taken from ecosystems, without also accounting for the methods of sustaining the production of those goods or the loss of production in the future, we have expedited the decline of functionality throughout the natural system. Both consumption and the corresponding inattention to ecosystem functions that occurs in the commodification of nature have limited the ability of ecosystems to regenerate and sustain themselves, requiring the production of substitutes.

The ecosystem services approach suggests that water infrastructure planning should associate—instead of separate—infrastructure services with ecosystem services. An ecosystem services approach to infrastructure planning will require us to contextualize the costs of built infrastructure in relation to the costs of losing natural capital in the construction process and the benefits of including natural capital in infrastructure planning. As shown in the examples below, by incorporating ecosystem services into the planning process, we benefit from a collaboration of ecology and economics: an understanding of how natural processes and functions produce services that have real, measurable economic worth. 26 Because ecosystem service value is based on the worth of natural capital to human needs, an ecosystem services accounting is always measuring the value of ecosystems to human

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26. See Earth Econ., supra note 6, at 54.
well-being, where humans are the beneficiaries of this form of wealth. As a result, green infrastructure approaches tend to outperform in costs pertaining to built capital, repair and maintenance, mitigation of external impacts, and structural replacement.

Moreover, the change in thinking toward ecosystem services is a monumental move toward resiliency. Consider two realizations that come with ecosystem services thinking: (1) we have typically displaced and interrupted ecosystems to build infrastructure systems and the built environment, and (2) built infrastructure has a relatively short lifespan. A resilient water infrastructure system leverages the role that natural systems play in producing clean and sufficient water (rivers, lakes, streams, groundwater aquifers, floodplains, floodways, wetlands, and the watersheds) and integrates those processes in formulating the means to capture, treat, store, and deliver water to places it is needed. Attentiveness to environmental quality in general will tend to promote resiliency in at least three ways: strengthen ecosystems and their resiliency to change; reduce the risks of pollution resulting from climate events; and reduce the negative impacts of adaptation measures implemented to protect the built, human environment.

For purposes of this chapter, a final important characteristic of ecosystem services and water infrastructure is the relative importance of local governments. Elsewhere, we have argued that local governments are critical participants for the effective design and execution of climate change preparedness. Although it is not the intention to reargue the point here, it is worth mentioning the advantages that local governments offer in this...

27. See Kai M.A. Chan et al., Conservation Planning for Ecosystem Services, 4 PLoS Biology 2138, 2138-39 (2006), available at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1629036/. See also EARTH ECON., supra note 6, at 18-21 ("Ecosystems are assets, a form of wealth.").

28. Built infrastructure typically displaces and eliminates natural areas and ecosystems, interrupting or interfering with habitat, hydrology and other ecosystem feature. In some cases, the elimination of natural systems is intended to facilitate a value or amenity that is entirely different than the displaced ecosystem. In this case, we discuss trade offs. As a simple matter of space, every built infrastructure choice entails a replacement of some natural feature or amenity with a built one. Yet, trade offs often prioritize the provision of built infrastructure. For example, we fill coastal wetlands to capture the market value of a view and more convenient access to water. In the process, we may lose the ability of the land to mitigate storm surges. In others, however, infrastructure replaces an ecosystem process with built infrastructure that provides essentially the same service. This notion that the loss of ecosystem features is an unaccounted cost is a critical question for climate change preparedness.

29. See Jonathan Verschuuren, Climate Change Adaptation and Environmental and Pollution Control Law, in RESEARCH HANDBOOK ON CLIMATE ADAPTATION LAW 383 (Jonathan Verschuuren ed., 2013).

regard and how these advantages are emphasized in light of ecosystem services valuation. First, the benefits stemming from ecosystem services are partially felt locally, both as to matter of scale and gratification. Communities—much more than state or federal governments—identify specifically with local ecosystem processes, features, and their benefits. Second, the loss of such services is disproportionately appreciated across levels of government. The loss of productive soils can be crushing to an agricultural community, the loss of trees or logging rights can crush a logging community, and the depletion of fisheries can wreak havoc on coastal communities. Because such losses are felt so acutely at the local level, their value is most accurately identified at the local level. Third, water infrastructure has traditionally and historically been a matter for local concern and responsibility. At least, these points demand careful consideration of the role that local governments might play in climate change preparedness. In all likelihood, these points suggest we look to local innovation to understand how infrastructure needs can be met effectively by integrating ecosystem concepts into infrastructure planning.

III. Greening the Gray: Climate Preparedness Through Ecosystem Services Implementation

In this final part, we begin what we hope is a sustained dialog about where and how ecosystem services can be implemented at the local level to help provide water-based services. The areas of focus and the examples below are meant to illustrate the benefits of ecosystem services planning. They also showcase opportunities where cities and communities are investing in ecosystem functionality to ensure that ecosystems performing at a fraction of the cost of built infrastructure while illustrating that implementing ecosystem services at the local level can occur in many ways, from broad-based approaches (such as “low impact development” practices described in Section A) to specific ordinances (such as mitigation of urban forest losses set forth in Section B). In addition, ecosystem services may apply to diverse and core local legal instruments, including comprehensive plans, zoning and building codes, and water distribution regulations.

A. Low Impact Development

One example of green infrastructure for reducing stormwater impacts has been “low impact development” (LID) practices. LID generally refers to con-
servation-based land use strategies that minimize impervious surfaces and emphasize the use of natural features and native vegetation as stormwater control tools. Common implementation programs include reduction of lot sizes and parking lot sizes while maintaining overall density (and preserving open space), rooftop capture of stormwater, downspout disconnection, adjusting curb design to capture instead of transport stormwater in vegetated swales, replacing impervious surfaces with permeable surfaces, and increasing vegetation on development sites. Common targets for these practices are parking lots, roads and driveways, street curbs, rooftops and residential and commercial developments. In recent decades, many communities and municipalities have implemented LID practices to control stormwater flows and improve water quality, especially in communities suffering the challenges of combined sewer overflows (CSO).

A study commissioned by Pierce County, Washington, illustrates some potential LID practices in local residential subdivisions. The consultant was directed to evaluate the costs and benefits of implementing green infrastructure solutions to the stormwater impacts caused by new development. The report analyzed a typical lot size, but on atypical developments that incorporated LID practices. The report described the following:

[T]he LID design attempts to reduce the severity of the changes in the landscape thereby reducing the change in the hydrology from the predeveloped state. Mitigation for changes in the landscape are completed as close to the source of runoff as possible with nonstructural [best management practices] such as swales, bioretention areas, and open spaces. If designed correctly and allowed to function without encroachment from incompatible uses these stormwater treatments should function much more like natural systems thereby meeting the goal of maintaining the predeveloped hydrology of the site.31

The report identified significant benefits from the use of green infrastructure techniques and provided support for the notion that green infrastructure can facilitate stormwater infiltration at volumes closer to natural and background levels of stormwater control. These designs also incorporate air and water filtration through the protection of vegetation and wetlands, reductions to habitat impacts, and reduced peak flows through groundwater infiltration. Interestingly, the report also identified “non-quantified benefits,” which included a reduction in automobile traffic as a result of the creation of

a more walkable neighborhood, as well as environmental literacy benefits by
including residents in the water quality process.\footnote{Id. at 39.}

The approach set forth in the Pierce County Report exemplifies the initia-
tives taken by local governments across the nation to infuse infrastructure
planning with ecosystem concepts. New York City, for example, has com-
mitted roughly $2.4 billion to green infrastructure practices over the next 18
years to integrate green roofs and streets, bioswales, and other natural sys-
tems to manage stormwater. This approach is intended to reduce the amount
of “contaminant-latent water” flowing into the waterways. The city of Phila-
delphia has committed $1.2 billion to green infrastructure over the next 25
years to manage stormwater, including the conversion of 9,600 impervious
acres into permeable surfaces. Washington, D.C., has proposed nearly $60
million in green infrastructure along its Rock Creek waterway and another
$30 million along the Potomac River. These projects will capture pollutants
and retain stormwater to prevent flooding, while providing green space and
recreational opportunities. Portland, Oregon, has launched a campaign to
promote rooftop rainwater capture, downspout disconnection, curb cuts to
feed runoff water into bioswales, and permeable road surfaces to complement
Oregon’s smart growth system.

These examples of LID practices implement an ecosystem services
approach by using natural processes to control and mitigate stormwater
flows. As a component of the local land use regulatory process, LID practices
integrate resiliency by improving the natural environment and the depen-
dency on gray, temporary solutions.

\section*{B. Urban Forests as Water Infrastructure}

In addition to LID practices, cities are looking to forests to help ensure the
provision of water-based services. From the forestry perspective, urban forests
are relevant to an ecosystem services analysis because urban trees are engaged
where people live, work, and play. From the infrastructure perspective, urban
forests are relevant because of the critical and essential services they pro-
vide.\footnote{Trees in urban areas “soothe eyes and spirits, they shade, they form special places for
recreation or relaxation, they provide habitat for birds and other wildlife, they purify the air, and they increase
37 \textit{Forest \& Conservation Hist.} 26, 35 (1993).} The shade offered by urban trees results in lower climate control costs.
Trees capture air pollutants, provide shelter and food for urban critters, and
even contribute community assets such as neighborhood attractiveness and
property values. For our purposes here, urban forests also provide substantial stormwater control services by retaining soils and by capturing and filtering stormwater, resulting in cleaner water and reducing flood flows. Urban forests illustrate the importance of ecosystem function and transform our understanding of nature “from amenity to living technology.”

Some local governments protect these values by requiring tree removal applications, imposing stringent tree replacement requirements, and mandating the planting of native species. Other cities incorporate urban forest resources throughout their land use planning scheme because of the significant economic benefits they accrue as infrastructure. For instance, the city of Vancouver, Washington, has noted in its comprehensive plan that, “unlike traditional grey infrastructure capital improvements, such as transportation and water systems, which begin to depreciate as soon as they are installed, green infrastructure accrues value and provides greater services as time passes.” As part of its comprehensive plan, the city of Vancouver has been active in protecting its urban forest resources for some time. Currently, urban forestry is included as part of the city’s compliance with state stormwater control requirements. To protect the benefits of urban trees, the city of Vancouver has created an urban forestry commission, adopted regulations to protect street trees, and regulated clearing in priority habitat areas to maintain “habitat function and value.” In its tree conservation ordinance, Vancouver also regulates the destruction or removal of “any tree” without an approved tree plan. Development applicants under this program are

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35. For instance, the Township of Jackson, New Jersey, has declared that its trees are “important cultural, ecological, scenic and economic resources” and regulates land uses to preserve tree canopy, biomass production, air filtering and oxygen production. J ACKSON, N.J., ADMIN. CODE §100:A (2003). Applications must be accompanied by a reforestation plan and may be denied where the proposed activity indicates “any negative effect upon ground and surface water quality, specimen trees, soil erosion, dust, reusability of land, and impact on adjacent properties.” Id.; see also New Jersey Shore Builders Association v. Township of Jackson, 970 A.2d 992 (N.J. 2009) (in which the New Jersey Supreme Court upheld the Jackson Ordinance).
37. The purpose of the Urban Forestry Commission for “managing, conserving and enhancing the existing trees located in the parks and public areas owned by the city of Vancouver and in public right-of-way, and thereby enhancing the appearance of the city and protecting an important environmental and economic resource. . . .” VANCOUVER, WASH. MUN. CODE 12.02.010 (2009).
required to preserve any tree that could be protected by selection of a “feasible and prudent location alternatives on-site” for the project.\textsuperscript{41} Development applicants must also demonstrate meeting the minimum 30 tree units per acre for most projects.\textsuperscript{42}

Vancouver estimates that its tree canopy captures enough stormwater to save $12.9 million in avoided construction costs for stormwater retention structures and $78.3 million in air pollutant removal services. Vancouver estimates an annual net benefit per tree of $1 to $8 for small trees, $19 to $25 for medium-sized trees, and $48 to $53 for large trees. Vancouver has stated:

Improving aesthetics of our community has tangible economic benefits. Systems of open space and bike trails give a community a reputation for being a good place to live and visit. Increased recreational and community activity attracts new businesses and stimulates tourism. Well-maintained trees improve residential “curb appeal” and increase potential buyers’ willingness to pay a 3-7% premium for property. Trees in retail settings increase shoppers’ willingness to pay for goods and services by 12%.\textsuperscript{43}

Tree protection programs similar to Vancouver’s stand apart from conventional water infrastructure wisdom. Without pipes and dams to measure, urban forestry programs break free of preferences for the built environment. Yet, tree protection programs typically provide added societal benefits and critical functions needed in water infrastructure at a substantially decreased cost and with a longer lifespan.

\textbf{C. City Creation and Infrastructure Planning}

A third example of innovative, ecosystem-based infrastructure planning is illustrated in the city of Damascus, Oregon. When Damascus was drawn into the Portland Urban Growth Boundary in 2002, public infrastructure

\textsuperscript{43} City of Vancouver, supra note 36, at 9. In the Vancouver Municipal Code, the city declares that trees are protecting and valuable for the following functions: 1. Increasing the air quality with the absorption of air pollutants, assimilation of carbon dioxide and generation of oxygen, and with the reduction of excessive noise and mental and physical damage related to noise pollution; 2. Minimizing the adverse impacts of land disturbing activities and impervious surfaces on runoff, soil erosion, land instability, sedimentation and pollution of waterways, thus, minimizing the public and private costs for stormwater control/treatment and utility maintenance; 3. Cost-effective protection against severe weather conditions with cooling effects in the summer months and insulating effects in winter; 4. Providing habitat, cover, food supply and corridors for a diversity of fish and wildlife; and 5. Economic support of local property values and contribution to the region’s natural beauty and enhancing the aesthetic character of the community. Vancouver, Wash. Mun. Code 20.770.010 (2004).
served only 10% of its area. Damascus subsequently incorporated and took on significant infrastructure responsibilities. The cost for constructing built infrastructure and public services was estimated at $3 to $4 billion. In the process of developing a comprehensive land use plan and an ecosystem services master plan, the city prioritized ecosystem services as a component of its utility infrastructure and stormwater management “to forestall increased costs to the citizens of Damascus. These increased costs take the form of built infrastructure to replace the service (as in stormwater management), increased regulatory compliance hurdles (as in Clean Water Act and Endangered Species Act compliance), and loss of quality of life.” The city prepared a public facilities plan that mapped the existing ecosystem services to develop “relative level of service (LOS)” that incorporated the location and quality of the ecosystem services. With input from service providers and the public, Damascus developed an Integrated Water Resource Management Plan (IWRMP) “to establish an integrated, cost-effective, and sustainable approach for providing water, wastewater, reclaimed water, and stormwater services to new and existing development in the city.”

The city of Damascus has not completed its infrastructure, and in likelihood, the road ahead will be complicated. In the summer of 2015, the city was presented with an infrastructure white paper that detailed an accounting of the needs and assets required to maintain an effective water infrastructure. The white paper referred to the city’s ecosystem services obligations in its capital facilities plan. It relied on the capital facilities plan map previously produced that located gray infrastructure based in part on minimizing interruption of ecosystem services. On the other hand, the city has not yet adopted the LID concepts that were intended to govern new development and integrate ecosystem services ideas. Even worse, the white paper does not illustrate the importance of ecosystem services in the accounting for infra-

44. Anita Yap et al., Ecosystem Services & City Planning: The City of Damascus Develops a Model Approach to Public Facilities Planning, Or. Insider 1, 4 (Aug. 2009), on file with the authors.
45. Id. at 1.
46. Id.
47. Id. at 3, 9.
48. Work Session, City of Damascus City Council, Ecosystem Services—Executive Summary From the Tier II Ecosystem Services Report ES-1 (2010), on file with the authors.
49. Id.
51. The white paper notes, “In addition to the traditional public facilities, the plan also took into consideration ecosystem services, which are the unique and irreplaceable service provided by the existing natural resources such as air and water quality, stormwater management, erosion control, and fish and wildlife habitat.” Infrastructure White Paper, City of Damascus 3-4 (June 22, 2015), http://www.damascusoregon.gov/AgendaCenter/ViewFile/Agenda/06252015-397.
structure needs. Rather, the white paper provides a needs assessment for new pipes and culverts, roads, and treatment facilities.\textsuperscript{52}

The example of Damascus is interesting from a resiliency planning standpoint because of the breadth of the challenge: because Damascus’ water infrastructure was, in a sense, starting “from scratch,” it was not bound to conventional formulae and engineering preferences. Under these circumstances, the idea of accounting for ecosystem services and ecosystem vulnerabilities as a launching point for infrastructure planning is a great experiment. In the climate change era, many, if not most, cities will undergo transformation and will bear the burden of reinvention as climatic changes are more extreme and vulnerabilities become more pronounced. Cities will have opportunities to rebuild.

\textbf{IV. Conclusion}

The objective of this chapter is to promote fluency in ecosystem service vocabulary so that we are able to recognize infrastructure opportunities that exist in the natural environment. Ecosystem services will improve water infrastructure planning because it is contextual, builds in resilience and provides services at a lower cost than the built environment. Such an approach will have continuing importance as we address the challenges of the climate change era.

That water infrastructure is addressed by the IPCC as a climate change planning mandate is no small thing: without an effective infrastructure, individuals may be unable to obtain basic needs and the consequences will be catastrophic. Of course, clean, dependable water is often difficult to guarantee. As such, the IPCC statement acknowledges the immense cost of infrastructure maintenance and replacement into the next century, as well as the “profound” importance that civil society effectively plan for scarcity and challenges to the provision of basic human needs.

Confronting the challenges of climate change requires a more accurate accounting of infrastructure needs and resources. Our water infrastructure must be designed with resiliency in mind to meet the challenge. Some opportunities are relatively unobjectionable and proven: protecting wetland functions along riparian areas provides protection from floods during storm events, increases resiliency in coastal and riparian communities, filters water, and provides biomass and habitats; and retaining trees at building sites provides shade, reducing energy costs to cool buildings, captures stormwater,

\textsuperscript{52.} \textit{Id. at} 6-11.
and facilitates community building. Other ecosystem investments may be more controversial: ecosystem restoration often disrupts historical land uses, such as agricultural uses benefitting from diking floodplains; and conservation decisions in times of water shortage may disrupt industrial and agricultural needs, such as shutting off irrigation pumps to maintain minimum river flows.

The cities discussed above have realized that the built or gray infrastructure that comprises the water system is designed to deliver services that are already provided by natural systems, including water and sewer, storm and flood protection, temperature control and climate stabilization, waste cycling and assimilation, and other natural services. As an additional benefit, natural systems provide these services effectively and efficiently, while also securing other foundational goods and services including oxygen, water, land, recreational opportunities, aesthetic value, and spiritual attachment and energy. Although ecosystem services planning does not benefit from a long history, it is essential that water managers incorporate ecosystem services concepts into the decisionmaking process. The result of an integration will be to capture the benefits of functioning ecosystems, while protecting the valuable assets of natural capital. Ecosystem services thinking connects ecosystem function with basic human needs—not merely as a means to protect the environment, but as a means to assure human well-being.

In large part, the shift to a more resilient infrastructure will be a project of environmental literacy. Ecosystem services may be accounted for as opportunities when the services provided by ecosystems are understood. Unfortunately, communities often must suffer ecosystem loss and disruption to grasp the value of the loss of ecosystem functionality. As such, resiliency may also demand that local governments experiment with a wide variety of literacy projects, such as participating in and facilitating markets in ecosystem services to raise awareness and establish the economic worth of ecosystem processes. Infrastructure, which historically has comprised the local government’s obligation to insure the delivery of services for human needs, is a good place to start.