Chapter 5
Roadway Infrastructure

Lisa Brothers

Abstract Roads are an integral part of everyone's daily life and have a huge economic impact. This chapter discusses how roads are designed, shares best practices for how to improve safety and reduce congestion, and reveals how engineers can work with communities to design and construct roadway projects that improve safety, protect or restore the environment, and meet the unique needs of the community. Using project case studies that range from rural municipalities to urban environments, this chapter highlights how integrating green infrastructure solutions into roadway projects allows communities to address resilience and environmental concerns while simultaneously addressing roadway safety issues and capacity deficiencies. We'll then discuss the evolution of roadway infrastructure and what communities and engineers need to consider for the future.

Keywords Roads · Infrastructure · Green infrastructure · Traffic engineering · Transportation engineering · Resilience · Roadway safety · Traffic congestion · Roadway capacity · Multimodal roads

Roads take us where we need to go: to work and home, to visit family and friends, and to see and connect with the world around us. Roads bring us the goods that we need and want to live our lives, whether via trucks that stock the shelves of our local stores or via overnight delivery vans. Roads, in short, are an integral part of everyone's daily life and have a huge economic impact.

Roads have always been important for people, but they became a bigger part of the United States in the 1950s. With President Eisenhower's signing of the Federal Aid Highway Act of 1956, the interstate highway system officially came into being. In his 1963 memoir, *Mandate for Change 1953–1956*, Eisenhower reflected on the roadway infrastructure system he fought for, saying, "More than any single action by the government since the end of the war, this one would change the face of

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America. ... Its impact on the American economy – the jobs it would produce in manufacturing and construction, the rural areas it would open up – was beyond calculation" [1].

President Eisenhower was proven correct in assessing the economic impact of a connected roadway system. The thoughtful design and construction of roadway infrastructure has proven to be an important driver for the economy. In addition to providing jobs, roads are a critical method of transport for the goods and services that contribute to our economic vitality.

5.1 What Is Roadway Infrastructure?

Roadway infrastructure encompasses all different types of roads and their related components such as sidewalks, islands, bicycle lanes, etc. Our roadway infrastructure – which includes more than four million miles of public roads [2] in the United States – is a constantly changing network that relies on studying how people use the infrastructure, planning for changes in uses, and investing in solutions that make travel safe and efficient today while preparing for the future.

There are three main types of roadways, which are defined by the U.S. Department of Transportation's Federal Highway Administration (FHWA) [3] based on how the roadway functions with respect to *access* (opportunities for entry and exit) and *mobility* (level of travel friction), as well as trip length, speed limit, average daily traffic volumes, and number of travel lanes (among other categories):

- *Arterials:* Designed and constructed with high mobility for long-distance travel. Generally have directional travel lanes that are separated by some type of physical barrier, with high speed limits and limited access and egress (on- and off-ramps). Include interstates, freeways, expressways, and highways.
- *Collectors:* Designed and constructed to balance access with mobility in higher density areas of a community. These generally mid-sized roads connect arterials to local roads and often carry public transportation bus routes.
- *Local Roads:* Designed and constructed with high access for short-distance travel. Generally have many access points, fewer travel lanes, and low speed limits to provide direct access to specific destinations (e.g., houses). Local roads make up the vast majority of roads.

Over the last two decades, travelers have become more vocal about wanting their roadways to support all of the ways that they travel. This multimodal approach to roadway design means that it has become critical to provide safe roadway space for public transportation, bicycles, and pedestrians, as well as traditional motor vehicles. This more inclusive approach to roadway design reduces emissions by encouraging alternative transportation and – when done correctly – can improve traffic operation and flow.

Once built, roads require maintenance and reinvestment to continue to operate well. With more people driving further every year – the American Society of Civil

Engineers (ASCE) notes that vehicle miles traveled jumped to 3.2 trillion in 2019 (an 18% increase over 2000) – wear and tear on existing roads has increased, leaving 43% of our public roadways in poor or mediocre condition [2]. In addition, changing expectations of roadway users – such as increased interest in bicycling (predating but reinforced by the "bicycle boom" that doubled bicycle sales during the COVID-19 pandemic in 2020 [4]), walking, and public transportation – mean that many existing roadways need to be redesigned to accommodate all roadway users.

Roadway infrastructure is designed by transportation engineers – a specialty field within civil engineering that focuses on ensuring safety and efficiency for our roadway users. Transportation engineers work closely with transportation planners, who focus on balancing the sometimes competing needs of different modes of transportation with other land uses (e.g., site development), safety, and budgets. As our communities are impacted by climate change, with more severe weather events happening regularly, transportation engineers and planners also work to address the environmental impact of roadway designs and seek to integrate sustainability and resilience into projects through the use of low-impact development and green infrastructure solutions.

5.1.1 Key Issue 1: Focusing on Safety

The highest priority for all licensed professional engineers – including those who design roadway infrastructure – is to "hold paramount the safety, health, and welfare of the public" [5]. While of course safer vehicles are a key component of roadway user safety, the design of the infrastructure can play just as important a role. As more communities (particularly those in urban areas) adopt Vision Zero policies – which aim to eliminate all traffic fatalities and severe injuries – engineers design solutions that proactively help address traffic safety concerns through smart design that takes human behavior into account.

There are a number of roadway infrastructure improvements that can improve safety and reduce traffic fatalities by providing a better experience for all roadway users – vehicular drivers, bicyclists, and pedestrians – as shown in Table 5.1.

5.1.2 Key Issue 2: Managing Roadway Capacity and Mitigating Congestion

Traffic congestion keeps getting worse – just ask any driver. Since 2008, roadway congestion has increased annually by 1–3% [2]. In urban areas, a large portion of this is due to transportation network companies (TNCs) – aka ride-sharing services – while most regions have seen an impact from increased freight movement.

Table 5.1 Roadway infrastructure safety improvement options by road type

Improvement	Arterial	Collector	Local road
Wider shoulders, travel lanes, and clearances	X	X	X
Highly visible and well-maintained signage	X	X	X
Clear lane marking	X	X	X
Longitudinal (or center line) rumble strips	X	X	X
ADA-compliant sidewalks		X	X
Mid-block crosswalks		X	X
Elevated intersections			X
Curb extensions (also called neckdowns, bulbouts, etc.)		X	X
Driveway reconfiguration		X	X
Protected bicycle lanes		X	X

On top of trying drivers' patience, congestion costs motorists money. Extra time on the road and additional fuel costs combine for a total loss of $166 billion each year – that's over $1000 annually per auto driver. And that's on top of repair costs, which poor roadway conditions can contribute to [2].

Over time, the realization has been that more and/or wider roads aren't the answer, as more roads generally result in even more cars on the road and more sprawl. Instead, roads and highways need to be smart, looking to the future, and supporting more reliable and safe multimodal opportunities. Traffic signal timing and intersection design are critical components of addressing deficiencies, helping traffic flow more smoothly and efficiently. There are a variety of tools available that transportation planners and engineers can utilize to successfully manage traffic and mitigate congestion, with the goal of either adding more roadway capacity, designing existing roadways to be more efficient, or encouraging travel and land use patterns that lessen congestion [6] as shown in Table 5.2.

5.2 What Is Green Infrastructure?

While roadway infrastructure is critical for a wide range of reasons, it has traditionally resulted in an excess of impervious surfaces (e.g., sidewalks, driveways, alleys, and roadways). These surfaces generate rapid, large volumes of stormwater runoff that overwhelm storm sewer systems, compromise the health of water bodies, and interrupt the hydrologic cycle.

Impervious land cover and the historical and conventional stormwater management practices that focus on "end-of-pipe" solutions – gray infrastructure that is largely designed to move stormwater away from its origination point using large pipes – have the following negative consequences:

- Increased volume of runoff
- Decreased infiltration (groundwater recharge)
- Decreased evapotranspiration

Table 5.2 Roadway infrastructure congestion improvement options

Improvement	Description	Arterial	Collector	Local road
Adding more roadway capacity				
Removing physical bottlenecks	Redesigning roadways to improve physical capacity. Particularly important at highway interchanges and in areas where vehicles transition from large capacity roadways (e.g., arterials) to smaller capacity roadways (e.g., collectors)	X	X	X
Prioritizing high-occupancy vehicles (HOV)	Implementing HOV lanes provides a clear incentive for drivers to carpool	X		
Increasing transit system capacity	Providing more transit vehicles (including buses) or more frequent run times to allow more people to choose transit over individual vehicles. Could also include bus-only HOV lanes that make them more efficient than individual vehicles on the same road		X	
Designing existing roadways to be more efficient				
Implementing ramp metering	Creating regularly timed gaps between vehicles on busy on-ramps results in safer and more efficient merging conditions that can improve traffic flow for the entire corridor	X		
Optimizing traffic signal timing	Changing timing on traffic signals to support better flow and keep more vehicles moving		X	X
Improving work zone management	Scheduling and managing roadway construction to impact roadway users as little as possible	X	X	X
Integrating reversible commuter lanes	Designating a traffic lane as one on which the direction of travel can be changed based on traffic volume. Typically used on major commuter roads during peak/rush hour	X		
Restricting turns at key intersections	Prohibiting turns (typically left turns that cut across another lane of traffic) at an intersection in order to avoid disrupting traffic		X	X
Improving roadway design	Redesigning roadways with geometric improvements to better support traffic flow	X	X	X
Improving signage and lane markings	Implementing highly visible and well-maintained signage and lane markings	X	X	X
Encouraging travel and land use patterns that lessen congestion				

(continued)

Table 5.2 (continued)

Improvement	Description	Arterial	Collector	Local road
Creating programs that encourage non-vehicular transportation	Working to get vehicles off the road by promoting transit use, ridesharing, and non-motorized travel. This includes promoting land use options such as transit-oriented and high-density development that don't prioritize individual vehicles	X	X	X
Encouraging flexible work hours and telecommuting	Promoting work options that allow people to avoid traveling during peak/rush hour, thereby reducing the number of individual vehicles on the road	X	X	X
Implementing congestion pricing	Charging higher tolls during peak/rush hour incentivizes people to travel during different times, allowing vehicles to travel more efficiently	X		

- Increased peak flow of runoff
- Increased duration of discharge (detention)
- Increased pollutant loadings
- Increased temperature of runoff

These consequences have an overwhelmingly negative environmental impact that results in poor water quality in water bodies, an increased urban heat island effect, and climate change impacts. Roadway infrastructure design has been evolving to understand how these negative impacts can be prevented or mitigated within roadways; innovative design using low-impact development solutions and green infrastructure practices have emerged as best practices.

Low-Impact Development (LID) LID is a management approach and set of best management practices (BMPs) that can reduce runoff and pollutant loadings by managing runoff as close to its source as possible on a specific site. LID includes overall site design approaches and individual small-scale stormwater management practices that promote the use of natural systems for infiltration, evapotranspiration, and harvesting and reuse of rainwater. Within a roadway, this could include engineered-as-natural ecosystems such as porous pavement and curbside rain gardens that infiltrate, evapotranspirate, and/or harvest stormwater runoff, thereby reducing flows to closed drainage systems.

Green Infrastructure Green infrastructure refers to an *integrated system* of natural elements and LID practices that provide broad environmental benefits across a larger area, such as a community or watershed. By managing water in a way that respects the natural hydrologic cycle through the use of vegetation, soils, and engineered-as-natural processes – as opposed to directing water into pipes and moving it away from the location – green infrastructure provides stormwater management while also providing flood mitigation, air quality management, climate change adaptation, habitat creation, and more.

Because traditional roadway infrastructure design uses large quantities of impervious materials, roadways and streetscapes traditionally have disrupted the hydrologic cycle and required stormwater to be directed to a closed drainage system consisting of underground pipes that discharge untreated water into water bodies. By implementing green infrastructure techniques that decrease imperviousness and slow, filter, absorb, retain, evaporate, and infiltrate stormwater runoff where it falls within a roadway profile, transportation engineers have the opportunity to positively impact the environment while also improving a roadway's appearance, the pedestrian experience, and sense of place.

Some of the key green infrastructure techniques that can be used within roadways include:

- *Bioretention:* Surface feature that compounds and treats the stormwater runoff, promotes evapotranspiration, and serves as visual amenities (native plantings); promotes groundwater recharge.
  - Designed to improve water quality and not to mitigate water quantity (i.e., flooding)
  - Functions similar to a sand filter to remove contaminants
  - Requires adequate pre-treatment, such as a sediment forebay, deep sump catch basin, or grass filter strip
- *Stormwater gardens:* Slows down and filters stormwater runoff, promotes evapotranspiration, and serves as visual amenities.
- *Constructed wetlands:* Replicates benefits of natural wetlands in managing water. Generally requires larger area than bioretention or stormwater gardens. Provides primary treatment and peak rate mitigation.
- *Tree box filters:* Creates a small bioretention system that can be used within a streetscape or other urban area as a planting area for a tree. Promotes groundwater recharge and evapotranspiration and serves as visual amenity.
- *Infiltration:* Directs water into the ground using drywells and leaching catch basins to provide groundwater recharge, some peak rate mitigation, and primary water quality treatment.
- *Permeable pavement:* Directs water into the ground by reducing impervious cover, promoting infiltration, and providing primary water quality treatment, groundwater recharge, and peak rate mitigation.

- *Green streets:* Increases plantings on roadways to provide pedestrian-friendly areas, creates natural shade to reduce heat-island effect, and adds areas for water quality treatment.
- *Rainwater harvesting:* Re-purposes rainwater for applications that do not require the use of potable water, such as irrigation. Rainwater harvesting reduces the volume of stormwater discharge and helps improve water quality.

5.3 How Do Roadways and Green Infrastructure Improve Communities?

Roads take us where we need to go, and green infrastructure helps restore a natural balance. When combined, roadway infrastructure and green infrastructure provide three key community benefits:

1. Creating space for people
2. Increasing resilience
3. Supporting environmental justice

5.3.1 Creating Space for People

Integrating green infrastructure solutions such as street trees (in tree box filters) and landscaping (that also serves as bioretention) into collector and local roads invites people to participate in the streetscape. Plants help create a sense of place and, when pedestrian amenities are included, make people feel comfortable walking and sitting. Foot traffic helps bring life to a road, revitalizing a community, and helps support local businesses.

5.3.2 Increasing Resilience

The impacts of climate change – more extreme weather events, shifts in timing of seasonal activities (e.g., spring flowering happening sooner), and rising sea levels, among others – are happening now. Communities are threatened by these impacts; rising temperatures are projected to add $19 billion each year to pavement costs by 2040 [7].

Green infrastructure techniques are an integral part of addressing climate change concerns and increasing community resilience. For example, an increase in vegetation lowers urban heat island effects and increases the natural evaporative cooling abilities of plants. Further, these softscapes act as natural "sponges" to absorb increased precipitation expected in humid climates, reducing the strain on aging infrastructure caused by everyday rainfall while buffering the impacts of damaging weather to protect development and investment.

Integrating green infrastructure solutions into roadway infrastructure provides communities with the opportunity to improve the environment and increase resilience, in land that is otherwise only contributing to the problem.

5.3.3 Supporting Environmental Justice

The US Environmental Protection Agency (EPA) defines environmental justice (EJ) as “the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income, with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies” [8]. In practice, this means that each federal agency needs to pursue EJ by “identifying and addressing, as appropriate, disproportionately high and adverse human health or environmental effects of its programs, policies, and activities on minority populations and low-income populations” [9].

Integrating green infrastructure into roadway infrastructure provides a clear method for achieving environmental improvements within EJ communities. By helping improve water quality, air quality (via street trees), and climate/disaster resiliency particularly as it relates to flooding, green infrastructure can help build healthy and sustainable communities – something that is particularly important for communities that have seen historical under-investment.

5.4 Case Study: Peabody Square, Boston, MA

Located on Dorchester Avenue (a main artery to and from Boston), and adjacent to the Massachusetts Bay Transportation Authority (MBTA) Ashmont subway and bus station, Peabody Square is a principal crossroad with Talbot Avenue and Ashmont Street. Peabody Square functions as a vibrant center of the community, including a popular cluster of local businesses, public transportation access, and a public safety facility.

The revitalization of Peabody Square began in 2006 as part of the larger Dorchester Avenue improvement project that focused on improving pedestrian and vehicle safety, expanding multimodal transportation opportunities, enhancing green space, and addressing stormwater management. As the project entered the 75% design phase in 2007, the Massachusetts Department of Environmental Protection through the Charles River Watershed Association (CRWA) funded a grant to integrate LID techniques into the redesign of Peabody Square as a Green Street Pilot Demonstration Project.

The intent of the pilot project – the first of its kind in the City of Boston and early in the movement toward more "green streets" – was to examine how green infrastructure could be implemented into an urban street without sacrificing safety or creating long-term maintenance issues, with the goal of replicating successes throughout the City.

The key stakeholders for the project included the Boston Public Works Department (BPWD) as the owner, the Boston Transportation Department (BTD), and the St. Mark's Area Main Street non-profit group (who had been actively involved in initiating the project).

Key Project Milestones

Design start: 2006
Grant received to integrate green infrastructure: 2007
Construction start: Spring 2010
Peabody Square construction completion: Winter 2011
Dorchester Avenue construction completion: Summer 2012

5.4.1 Collaborating with the Community

Peabody Square was a highly trafficked area with an unnecessarily complex multi-legged configuration and all impervious hardscape that was uninviting to the pedestrian. Peabody Square had many channelizing islands and numerous signal phases, resulting in 13 crossings that created an unfriendly and unsafe environment for pedestrians, and congestion and long delays for motorists. At the initiation of the project, the accident rate was higher than the Massachusetts Department of Transportation's (MassDOT) Statewide and District averages. The safety improvement project was formulated with the goal of improving conditions by reducing the number of crossings significantly and improving the number of pedestrian walkways – with a seamless incorporation of green infrastructure.

The process began by dedicating time to collecting traffic data and other physical data from visiting the site and observing challenging areas. The design team recognized the excessive number of intersections and identified cut throughs used to access the many local businesses. A land survey resulted in base plans that the design team used to prepare concepts for five intersection redesign alternatives that would simplify and improve roadway layout, reduce points of conflict, create a safe environment for vehicles and pedestrians, provide for public plazas and area gateways, and revitalize the aesthetic appeal of the Square to promote commercial and community activity. The design team determined how to best incorporate sustainable design elements without compromising the safety and accessibility of the plaza.

After working with the BPWD and BTD to refine the concept designs, the design team managed a series of three public meetings where five alternative concepts for the Square were presented to the public. These meetings were approached with a goal of fact finding to pinpoint the issues that pedestrians had with the existing conditions. With this collected data, the design team phased out any options that immediately didn't meet the needs of the public and then modified the remaining designs to reflect the input from the community. The process of feedback and revisions continued, including on-site meetings with neighborhood associations, with input from each meeting used to better support the community desires for the area.

Through this in-depth community process, the five options were narrowed down to two options. The community and design team then unanimously agreed on one design alternative (Fig. 5.1) that eliminated the channelizing islands and long pedestrian crossings; discontinued Bushnell Street across the Square; realigned Talbot Avenue; reduced residential neighborhood cut-through traffic; added bicycle lanes; decreased traffic queuing (reducing air pollution); provided fire station signal preemption; addressed parking issues; created a socially inviting park and plaza that retained the area's historic clock tower and water trough; and added a variety of perennials, grasses, shrubs, and tree plantings.

5.4.2 Green Infrastructure Solutions

The design team collaborated with CRWA to implement sustainable design techniques to reduce stormwater runoff volume into the closed drainage system and remove pollutants from waterways. These LID techniques included integrating a bioretention basin, porous plaza pavers/pavement, and an infiltration trench within the planned plaza areas. The bioretention basin collects and treats stormwater runoff

Fig. 5.1 Existing conditions (on left) vs. selected alternative. (Courtesy of Nitsch Engineering)

via engineered layers of mulch, soil, and plant root systems. The porous paver/pavement provides infiltration with an overflow protection connection to the storm drain system. The infiltration trench recharges and treats stormwater runoff from the adjacent parking lot.

Along with the goal of balancing safety improvements with sustainable design, the design team was charged by the City to make apparent the benefits that green infrastructure could have beyond its impact on the City's infrastructure. The vision of the Peabody Square pilot project was to create a socially inviting park and plaza that offered aesthetic benefits to the community all while managing the stormwater runoff using low-impact development designs. With this community-centric vision in mind, the design team maintained a line of open communication with the local public throughout the process. This was done through an interwoven community outreach approach throughout the design and construction administration processes.

On every project within the City of Boston, designs must be coordinated with the Boston Water and Sewer Commission (BWSC) which operates the drainage system. The Peabody Square project benefitted from the BWSC being open to establishing green infrastructure because of its benefits as an alternate water treatment method. The low-impact BMPs that were selected for the project provide numerous stormwater benefits, including runoff volume and rate reduction, groundwater recharge, natural treatment of stormwater runoff, and runoff temperature reduction. These benefits are particularly important because the stormwater runoff that discharges from the site into the City's storm drain system eventually makes its way to the Neponset River, which is on the Massachusetts list of impaired waters. The river is identified as impaired for organics, pathogens, and turbidity, all common pollutants in stormwater runoff. By treating the stormwater on-site using sustainable design components — including the bioretention basin shown in Fig. 5.2, porous pavers/

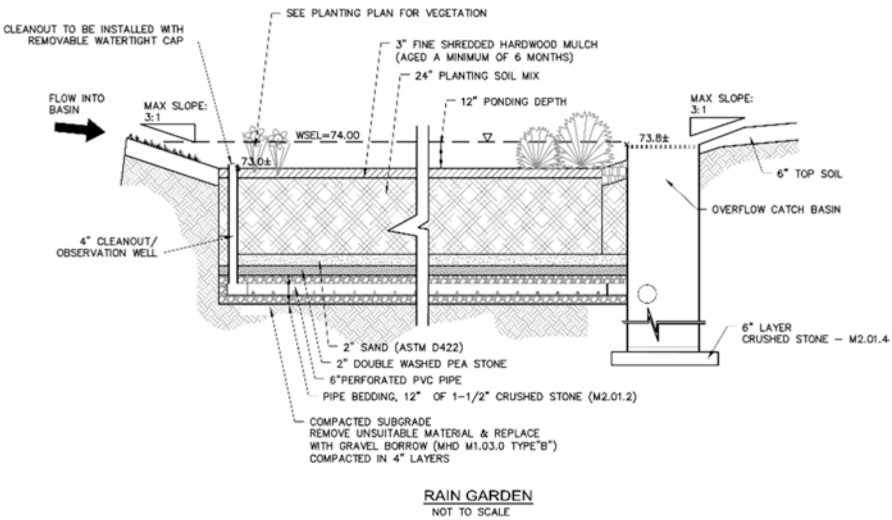

Fig. 5.2 Bioretention basin cross section. (Courtesy of Nitsch Engineering)

pavement, infiltration trench, and greening of the intersection — the project is doing its part to improve the water quality of the Neponset River.

Out of an abundance of caution on this pilot project, the BWSC requested that the design team also install a "traditional" closed drainage system as a secondary back-up in case the green infrastructure system failed.

The green infrastructure improvements are connected to the city system, so that any excess stormwater from heavy storms (e.g., 100-year, 50-year) can be sent into those connections to prevent area flooding.

5.4.3 Establishing Confidence in the New Peabody Square

A number of constraints and requirements contributed to the complexity of the Peabody Square project, including building over the subway tunnel cutting diagonally across the Square and within 3 feet of the surface in some areas; allowing for fire station operations including providing a location for the testing of the ladder truck at every shift change; working around the historic clock and water trough to lay out the new intersection; overcoming the reluctance to use sustainable design techniques; and establishing a public/private partnership for maintenance responsibilities.

5.4.3.1 Addressing Structural Support Concerns

The design team focused on maintaining the integrity of the subway tunnel. This included ensuring that the tunnel could withstand the weight of the fire station's equipment where the tunnel crossed under the station's parking lot that was regularly used for maintenance and cleaning of the station's equipment.

5.4.3.2 Maintaining Movement

During construction, the design team was continuously challenged by the many different movements that required continued access to Peabody Square, including coordinating with the fire station to avoid impacts to their services, accommodating neighborhood traffic that continued throughout the entirety of the project, and providing access to the surrounding businesses including curb cuts while still eliminating dangerous existing cut throughs. The design team was able to mitigate these challenges by working closely with members of the community and anticipating the needs of pedestrians through initial traffic studies and community outreach.

5.4.3.3 Leveraging the Landscape

To overcome hesitations the community had about changes to the plaza, the design team and the City focused on creating a stronger sense of place through creative landscape design that combined form with function.

The design team overcame some hesitations about green infrastructure by displaying the aesthetic benefits of the design. The selected green infrastructure components, such as the porous pavers, not only provided a cost-effective way to treat stormwater but also enhanced the beauty of Peabody Square by incorporating stormwater into landscape-based systems and aesthetic patterns. Bioretention basins with resilient perennials were used not only because of their ability to collect water but also because they provide a better aesthetic by creating additional green space. The design team incorporated the existing historic elements (i.e., the clock and water trough) that had been fenced off and inaccessible by installing the green infrastructure around these existing elements to create a cohesive landscape. The green infrastructure was used to re-imagine Peabody Square to provide a higher-quality environment that is accessible to the community, provides opportunities for pedestrian gathering, and is used for community events.

5.4.3.4 Planning for Operation and Maintenance

As one of the first implementations of green infrastructure elements owned by the City, developing an operation and maintenance (O&M) plan was critical to the success of the project. The design team conducted initial research and made recommendations, but the success of the project relied on a collaborative process between stakeholders and the design team to resolve construction and maintenance concerns. The public/private partnership between the BPWD, BTD, and the St. Mark's Area Main Street non-profit group helped address this challenge.

A key component of a successful O&M plan is the education of those who are responsible for long-term O&M. The design team educated the many project stakeholders (e.g., BPWD, BWSC, CRWA, the St. Mark's Area Main Street non-profit group, and the community) about how the innovative sustainable design techniques worked and should be maintained.

One key O&M challenge for the project involved how to care for porous pavers. While the technology existed, it had not been implemented much (if at all) in the City of Boston and presented a challenge for long-term maintenance. Porous pavers being applied to a project in the City required research into how to best care for them. The design team attended training at the University of New Hampshire, a national leader in pavement research, and used the information gained from the training to create a set of guidelines that established how to properly vacuum the porous pavers. Originally, the City anticipated having to contract out this work, but thanks to these guidelines, they instead discovered that they were able to adapt existing equipment to adequately perform this maintenance. This was a step in the direction of the City's long-term goal of integrating green infrastructure into future roadway infrastructure.

5.4.4 *Impact*

The Peabody Square project established a model for future green infrastructure projects in the City of Boston. The project highlighted how success can be achieved when there is investment from multiple entities (e.g., City of Boston, CRWA, BWSC, etc.). The vision and innovation of the project stakeholders and design team, combined with an iterative community engagement process, resulted in a project that could best meet the needs of its community, as shown in Fig. 5.3.

As the pilot project for the implementation of green infrastructure in the City, the project established a framework of integrating green infrastructure into complete streets that was able to be replicated repeatedly throughout the City and was used as a case study to illustrate the City of Boston's Complete Streets Guidelines.

Project Team

Transportation and Civil Engineer: Nitsch Engineering
Landscape Architect: IBI Placemaking
Structural Engineer: Lin Associates
Contractor: McCourt Construction

Fig. 5.3 Peabody Square landscaping includes bioretention, rain gardens, pervious pavers, and aesthetic improvements. (Courtesy of Nitsch Engineering)

5.5 Case Study: Kennedy Street Green Infrastructure Challenge, Washington, D.C.

The District of Columbia Water and Sewer Authority (DC Water) owns and operates a combined sewer system that serves more than 672,000 residents and 17.8 million annual visitors in the District of Columbia. As part of a 2005 consent decree from the EPA, DC Water began planning three storage tunnels under the DC Clean Rivers Project to minimize combined sewer overflows (CSOs) to District waterways, including the Anacostia River, the Potomac River, and Rock Creek (and ultimately the Chesapeake Bay watershed). By 2010, DC Water began investigating the application of green infrastructure as another tool for controlling CSOs, as they understood that the additional social and economic benefits associated with these techniques are much broader than the benefits associated with traditional "gray" infrastructure. After proposing to modify the consent decree to include green infrastructure in 2011, DC Water launched an international design competition in April 2013 that sought innovative green practices focused on capturing and absorbing stormwater to meet DC Water's goals of reducing CSOs.

The Kennedy Street Green Infrastructure Challenge Streetscape project began with this design competition. DC Water hoped to amend their consent decree obligations by accounting for the use of green infrastructure but had already begun building large sewer tunnels to store the overflow during large storm events. They aimed to target areas where tunnels had yet to be built and assess if widespread green infrastructure could reduce the size of the tunnels, or eliminate the need for them altogether, in order to fulfill their obligation to form a mitigation plan.

The Potomac and Rock Creek watersheds presented an opportunity for a hybrid approach incorporating smaller sewer tunnels with green infrastructure within an urban environment. DC Water also saw an opportunity to re-direct funds spent on the large infrastructure of the tunnels by reducing or eliminating the need to build the future tunnels that would otherwise store combined sewer overflow.

Key Project Milestones

Design competition: 2013
Design start: March 2015
Construction completion: September 2018

5.5.1 Competing for a More Sustainable City

As a design competition finalist, the design team proposed a streetscape design that integrated porous pavements, bioretention bump-outs and planters, infiltration opportunities, pedestrian boardwalks, and an engaging proposal for environmental art. The location for the improvements was in a commercial section of Kennedy Street NW, a 1.14-acre site located approximately four miles north of Capitol Hill in the Rock Creek watershed that had been pre-selected by the DC Water Clean Rivers staff. The street, which is located within an EJ community, had a redevelopment plan on the horizon and was a priority area in need of revitalization with large under-utilized sidewalks.

The design team began working with DC Water to advance the pilot project in March 2015, with the goal of designing improvements that could serve as a model for larger green infrastructure projects throughout the District. The pilot project was intended to allow DC Water and local permitting agencies to become more familiar with the intricacies of designing and building green infrastructure facilities in the District's urban environment.

DC Water and the EPA came to an agreement in 2015 to modify the 2005 consent decree to include green infrastructure strategies that could eliminate a large percentage of the CSOs in each of the three watersheds. If deemed practicable after the first large-scale projects, the green infrastructure facilities would reduce the size (and therefore the cost) of the tunnel needed in the Rock Creek and Potomac River watersheds.

5.5.2 Using Green Infrastructure as a Solution

The Kennedy Street pilot project was designed to provide clear and measurable environmental benefits that would ultimately reduce CSO discharges. The sustainable design included:

- 40 trees (5 existing; 35 new)
- 580 linear feet of infiltrative parking lanes
- 15 bioretention curb extensions
- 240 linear feet of landscape infiltration gaps
- 520 linear feet of recessed landscape infiltration
- 4 dry wells

By installing (and connecting) 5 technologies in 33 locations on 1 urban city block, the overall green infrastructure system design results in the reduction of 9000 square feet of impervious surface over the 1.14-acre site and the retention of 59,941 gallons of stormwater. The goal for the green infrastructure design was to retain the stormwater from a 1.2″ rainfall event over the project area. When it rained 1.2" before, 28,000 gallons of stormwater drained to the combined sewer in 5 minutes. When it rains 1.2" now, zero gallons drain to the combined sewer – in fact, the new green infrastructure facilities retain enough stormwater to mitigate a 2.1″ rainfall event. The travel time for water flowing from one end of the block to the other also slows to 20 minutes.

Although the Kennedy Street project was driven by the need to reduce CSO discharges, it became much more than a stormwater mitigation project. The seat walls, grates, and additional trees were intentionally included to activate the pedestrian streetscape and encourage people to socialize on the street while also providing education about stormwater management. The additional trees provide climate change adaptation benefits by reducing heat island impacts on the streetscape.

The team designed the facilities in a way that avoided the underground utilities (i.e., water, sewer, stormwater, gas, electric, and telecommunications) and preserved well-established street trees. This allowed DC Water to spend their money on green infrastructure interventions instead of utility relocations. However, it also required the team to design on the fly when unknown conditions were found underground – for example, when they found an electric vault that was much larger than anticipated and had to redesign a bioretention basin and seat wall to accommodate it.

5.5.3 Establishing Lines of Defense

As a pilot project for DC Water, the Kennedy Street green infrastructure project was primarily focused on developing unique and innovative green infrastructure applications that could serve the District. To capture the largest quantity of stormwater – and therefore provide the most benefit to the District – the engineers designed a unique interconnected system that provides multiple lines of defense.

The green infrastructure BMPs used on site provide three lines of defense: above-ground rainfall capture through the enhanced tree canopy, street-level capture through a combination of landscape-based strategies and permeable parking, and below-grade infiltration using drywells for stormwater traveling down the existing alleys between the buildings. This detailed design of multiple lines of defense allowed for flexibility when challenges arose.

By designing the 33 green infrastructure BMPs to connect in a series, as shown in Fig. 5.4, the system provides enhanced treatment and infiltration of stormwater. In this system, any water that cannot be infiltrated in a green infrastructure BMP will flow into the next BMP, with water flowing from east to west. Along the sidewalk, a trench drain is innovatively used to capture surface water and convey it to a series of recessed planters – which, in turn, overflow to the bioretention curb extensions. The goal was both to provide volume and to slow down the travel of water.

Another unique application of existing technologies can be found along the northern side of the streetscape: landscape infiltration gap facilities (LIGs). These facilities include the first known implementation of LIGs in public space in the District (and possibly the United States, as the design team could only find prior information on the practice from European installations). LIGs are small strips of grass that break up a paved area, allowing smaller quantities of stormwater to directly infiltrate into the ground. The LIGs created a perception of more green and open space than a standard permeable paver that has only sand. By breaking up pavement areas, they also help mitigate the heat island effect. The design team installed six LIG facilities on the north side of the street to test out this practice in the District, as shown in Fig. 5.5.

Each system was designed to be fully dedicated to collecting rainwater from only a small area. Rainwater from the backside of the sidewalk was captured with LIGs

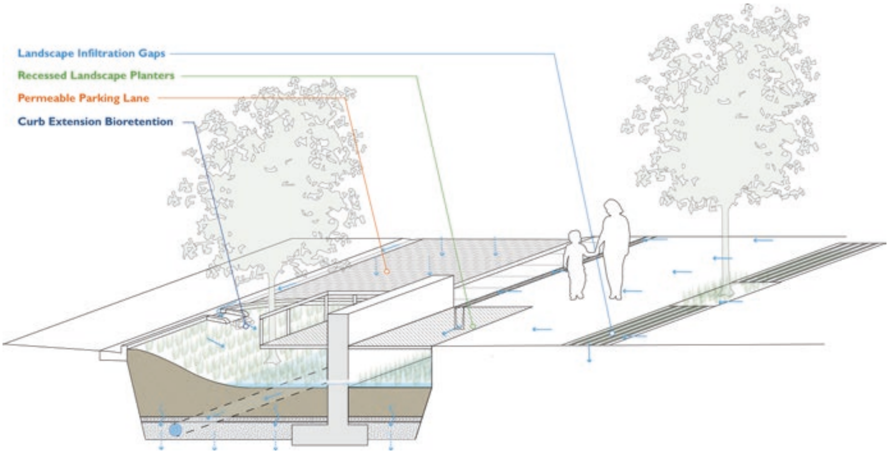

Fig. 5.4 Cross section showing how four BMPs connect on Kennedy Street. (Courtesy of Nitsch Engineering)

Fig. 5.5 Landscape infiltration gaps on Kennedy Street. (Courtesy of Nitsch Engineering)

on one side of the street and a sidewalk planter on the other side of the street. Rainwater from the parking lane gets absorbed by permeable paving. Water from the roadway runs into the gutter and into the bioretention area. The design team broke the streetscape down to interconnected, micro-managed pieces rather than allowing everything to run to the end of the street and one large piece of infrastructure. As a result, the design optimizes the performance of every green infrastructure facility.

Multiple regulatory agencies had jurisdiction over the project, including the District Department of Transportation (DDOT), the District Department of Energy and the Environment (DOEE), DC Water, and the local utilities. Permitting the project was a significant challenge, as the unique interconnected nature of the BMPs did not fit within the authorities' existing standards. Furthermore, because LIGs had not been used in the District, there was no specific permitting process in DOEE's online permitting database. To address these complexities, the design team worked closely with DOEE staff to show how the interconnected system met the functionality requirements and to develop an approach to receiving permits for these facilities.

5.5.4 *Creating Place*

As climate change reshapes communities, those in the engineering profession continue to work on practical solutions to mitigate or prevent damage. Green infrastructure is an integral tool. The unique way that green infrastructure BMPs are connected on Kennedy Street, and the first application of LIGs in the District, serves as implementable inspiration to other engineers as they also seek to reduce the strain on aging infrastructure while buffering the impacts of damaging weather to protect development and investment. In addition, the success of these BMPs provides a critical example of how these practices can be successful in highly urbanized areas.

Engineering success is reliant on public acceptance: the very best idea would exist only on paper if the community didn't support it. It was important not only to gain acceptance of the project from the Kennedy Street neighborhood but also to demonstrate to ratepayers located throughout the watershed and DC area the importance of the project for its long-term impacts all over. The goal was to display how this demonstration project could be replicated in the future to positively benefit the watershed in its entirety. Through two public engagement meetings, residents learned about the design and how stormwater moves through an urban environment. The process allowed the design team the opportunity to educate the public about the existing issue of CSOs and high-cost infrastructure and to bring awareness about the ability of green infrastructure to store water and address the CSO problem while benefiting the neighborhood with beautification, heat island mitigation, and solutions to other urban environmental issues. Many residents left the meetings excited about the positive impact these improvements would have on their community.

5.5.5 *Telling the Story of Water*

Although the project was conceived as part of a larger strategy to use green infrastructure techniques to address CSOs, it became much more than a stormwater management project. Along Kennedy Street, the design team sought opportunities to include education and placemaking elements that also met other community needs.

To highlight the movement of stormwater, while still providing wide sidewalks, the team designed steel grating above some bioretention basins. This design retains an ADA-accessible walking area – a particular concern of the DDOT – while also using the space to provide more green infrastructure facilities. Although not part of the stormwater functionality of the project, the grates over the bioretention areas allow pedestrians to experience the movement of stormwater as they walk above it.

A seat wall integrated a public art element: an engraving of a map of Washington, D.C., highlighting the water bodies of the watershed the project was designed to protect. This was incorporated to enhance the streetscape, draw people to the sidewalk, and provide public education through the engravings. The design also intentionally sought to improve pedestrian safety on the block; the bioretention curb extensions narrowed the roadway, which reduced traffic speeds and provided shorter crosswalks. Thirty-five additional street trees were incorporated to improve stormwater functionality but also provide shading to reduce heat island impacts.

Great care was taken to intentionally incorporate design elements into the project that would enhance the streetscape and create a more sustainable, resilient, and walkable place. The public can then begin to understand why money is being spent on green infrastructure and how it can provide ample benefits to their local communities. The aim with including additional education and placemaking elements was to create an experience that told the story of the water as people utilized the roadway. These educational and experiential details – and the care taken to ensure their incorporation into the project – are unique when compared with other CSO mitigation projects.

5.5.6 Planning for the Future

The success of the Kennedy Street pilot project was critical for the future of DC Water's green infrastructure program and for compliance with the consent decree: if the project had not been successful, DC Water's plans for large-scale green infrastructure implementation would have needed to be revised. The success of this project has also paved the way with other regulatory authorities for future green infrastructure implementation in the District, providing direct value to engineers working within the District.

The Kennedy Street pilot project has provided DC Water with a test run for the design, permitting, and maintenance of green infrastructure facilities in a densely urbanized environment. DC Water had signed an agreement with DDOT to do the long-term O&M. Still, DC Water was challenged with training their staff in green infrastructure maintenance, so they signed a contract with a maintenance company for coverage while working on a framework for creating new "green" jobs.

DC Water has been demonstrably happy with the project process, speaking at many conferences about the project, and sending out regular updates via social media channels.

5.5.7 *Impact*

The Kennedy Street Improvement Project was an opportunity to experiment with communicating the value of sustainable design in the face of concerns over spending and investment. Project Manager Nicole Holmes, licensed professional engineer (PE), noted, "It is challenging to validate the cost of green infrastructure for stormwater mitigation if you're comparing it to gray infrastructure alone. Green infrastructure will cost more to manage the same amount of water, so it's extremely important to validate the many other benefits of green infrastructure through a long-term life cycle cost benefit analysis. You're saving so much in all of these other ways: energy, property values, standard of living, and other environmental benefits. It requires a close partnership to let everyone account for and contribute to the benefits that everyone could receive long-term from choosing green infrastructure."

In the case of the Kennedy Street project, shown in Fig. 5.6, there was a challenge when interacting with public agencies who were tasked with working with ratepayers and stakeholders and explaining the benefits of spending more money for what at first was seen as the "same outcome." DC Water successfully established a

Fig. 5.6 Kennedy Street. (Courtesy of Nitsch Engineering)

partnership of trust and understanding with all of the agencies that would benefit from this project, making it possible to explain the many additional benefits of choosing green infrastructure.

Project Team

Civil Engineer: Nitsch Engineering
Landscape Architect: Urban Rain|Design and Warner Larson Inc.
Land Surveyor and Geotechnical Engineer: EBA Engineering, Inc.
Permitting: McKissack & McKissack
Community Engagement: Tina Boyd & Associates
Contractor: Capitol Paving

5.6 Case Study: Roadway Improvements, Buckland, MA

Hurricane Irene brought devastation to western Massachusetts in the summer of 2011 – including the Town of Buckland, which borders the Deerfield River. The river and its connecting streams flow through Buckland and into the neighboring tourist town of Shelburne Falls. In Shelburne Falls, the river passes beneath the Bridge of Flowers, which attracts visitors in the spring who are delighted to walk across admiring the variety and abundance of blooms, and highlights the Glacial Potholes, which usually show smoothed rock surfaces with the anomalies of deep eroded craters and a backdrop of water piling over the man-made dam. Hurricane Irene raised water levels to the bottom of the Bridge of Flowers, submerged the glacial potholes, and caused the roadways of Conway Street, Summer Street, South Street, and Shelburne Falls Road to flood over. This storm event created a debt of damage that left elements of the roadways in disrepair, disconnecting the community.

Covering 1.7 +/− miles of roadway, the Buckland Roadway Improvements project includes the reconstruction and widening of Conway Street, South Street, and Conway Road from Bridge Street to the Conway Town Line. These roadways were in dire need of improvement due to the damage and devastation from Hurricane Irene. A MassDOT Transportation Improvement Program (TIP) funding grant made improvements possible. Otherwise, the rural nature and low population of the Town and a corresponding lack of budget for repairs would have precluded the project from moving forward. The improvements were designed to meet MassDOT's Complete Streets standards, which focus on encouraging safer multimodal transportation while integrating LID elements that result in a greener street.

Key Project Milestones

Design start: January 2016
Construction start: Fall 2021 (estimated)
Construction completion: September 2023 (estimated)

5.6.1 Re-building and Growing the Town Center

The main economic driver in the Town of Buckland is the tens of thousands of visitors travelling to Shelburne Falls each year. The downtown area, collectively called Shelburne Falls with part of Shelburne, is a major tourist and shopping area that includes the historic manufacturing plant and shop of Lamson and Goodnow. The Town's economic development and local employment base depend on its ability to present a vibrant and attractive gateway to the "Shelburne Falls" village community.

The Buckland Roadway Improvements project is focused on supporting the economic growth of the center of Buckland through three interconnected goals: repairing damage done to existing infrastructure by Hurricane Irene; improving access to the business district through reconstruction of the roadway and sidewalk; and encouraging safer multimodal travel through Complete Streets design.

5.6.1.1 Repairing After Hurricane Irene

After Hurricane Irene, the essential infrastructure of Conway Street, South Street, and Conway Road was in need of repair. The many culverts that supply passages for the Deerfield River tributaries along the roadways overtopped, the roadway was washed away, and 1104 feet of sidewalk were damaged by the flooding of the road. There were tripping hazards where the roadway connected to the existing sections of sidewalk, and road edges were rough, uneven, undefined, and dangerous for both pedestrians and bicyclists, as shown in Fig. 5.7. This lack of defined road edge, sidewalks, and curbing made for inconsistent and dangerous parking for local homeowners and businesses, as well as for pedestrians.

The repair and improvement project prioritizes creating a smoother, more consistent riding surface on the roadway and establishing defined shoulders. The project design includes 1104 feet of sidewalks in highly trafficked areas along portions of Conway, Summer, and South Streets and makes the existing sidewalks ADA-compliant. The improvements benefit motorists, pedestrians, and bicyclists alike by encouraging safer multimodal transportation and improving pedestrian connectivity and accessibility through the Town of Buckland to Shelburne Falls.

The project also replaces two existing culverts with larger culverts to help prevent future roadway overtopping and redesigns the roadway infrastructure by replacing drainage lines, sewer lines, and water piping to bring everything up to MassDOT standards. One concrete culvert with scour will be repaired, as identified by the bridge inspection team.

5.6.1.2 Improving Pedestrian Access

Within the Town of Buckland's center are community amenities that drive both pedestrian and vehicle use. A community ball field is accessed from South Street, and the back of the field runs along Summer Street; bicyclists and joggers use this

Fig. 5.7 Edge of road and sidewalk connectivity issues. (Courtesy of Nitsch Engineering)

route daily. A school bus route for the elementary school, high school, and Franklin County Technical School means that students walk along the poor sidewalks or road edge where the sidewalk is either poor or missing completely. The Police Station and the Highway Department are located on Conway Street, and the Wastewater Treatment Facility is located just off Summer Street; all these Town departments would benefit from improved road and drainage conditions improving their response times. This route is also a major connection from Routes 2 and 112 to Route 116 in Conway, and many Conway residents and Southern Ashfield residents use this route daily.

The existing sidewalk – where it exists – offers little safety as there is no definition from the road edge on much of it and it is flush with the lane of travel. Much of the sidewalk is severely cracked and heaving and contains trip hazards, and there are sections that are impassable to wheelchairs. Wheelchair ramps are nonexistent or in poor shape along most of the route. These issues had resulted in concern for bicyclist and pedestrian safety in this area for some time.

The roadway improvement project will either improve, upgrade, or install new roadside appurtenances including signs, curbs, sidewalks, pavement markings, drainage facilities, barriers, and guardrails. Outdated, inappropriate, and missing signage will be removed, replaced, and installed in accordance with the FHWA's Manual on Uniform Traffic Control Devices (MUTCD) standards. Damaged and non-functional guardrails will be replaced along Conway Road. Drainage will be updated and improved along the entire project, including replacement of some "fabricated" structures.

Pedestrian and bicyclist safety were a priority for the design team. Road edge and pavement markings will be installed, allowing for lane markings. Wheelchair ramps will be installed to meet ADA standards. New curbing and sidewalks where there currently are none will tie the area to the downtown business district.

Several businesses along the corridor will benefit from enhanced definition of curb cuts from both safety and aesthetic perspectives. Sidewalk improvements and expansion create a more walkable community, business, and tourist district and are expected to help revitalize this edge of Shelburne Falls where there are several shops and offices as well as a small park and observation deck over the Deerfield River to view Salmon Falls (a traditional Native American fishing site that the town was built around). Increased pedestrian and bicycle activities are also expected from the improvements to road edges.

5.6.1.3 Creating a Complete Street

The priority of the project was to design both a Complete Street and a Green Street, focusing on safe multimodal travel, including bikeways and sidewalks; drainage improvements including new catch basins and stormwater design to meet MassDOT standards; and culvert outfall improvement with stone riprap to help prevent erosion.

At project initiation, traffic count data from the Franklin Regional Council of Governments showed that from 2005 to 2010 there was an increase from 1750 cars to 1980 cars tracked by their Average Annual Daily Traffic Count data on Conway Street. The data also showed that there were seven crashes on this route, with the majority having taken place on Conway Road. Most accidents were reported to have happened when the road was described as "wet, icy, sandy, or slushy" due to poor drainage that caused pooling and freezing.

The repairs and improvements meet MassDOT Complete Streets design criteria by implementing roadside stormwater improvements. In the more rural portion of the project, the design team maintained and enhanced roadside vegetated swales – one of the first LID solutions – along Conway Road. These swales enter drop inlets and then are piped to the other (down grade) side of the road. They are designed with vegetation and check dams to slow water, reduce pollutants, and convey runoff from the road to periodically spaced drain inlets. In other parts of the project – more residential areas with limited right-of-way space, presence of ledge, and steep topography – the design team updated the closed drainage system with deep sump and hooded catch basins that captures runoff from about 3450 feet of roadway.

The upgrades to the closed drainage system and road runoff along the entire route improve the quality of the stormwater discharged into the Deerfield River and

Salmon Falls. This has a lasting impact of reducing damage done to the road and will extend the life of the infrastructure. The project design improves drainage and lessens the probability of pooling water and icing, thereby reducing the frequency and potential for accidents.

5.6.2 Redesigning Culverts to Prevent Flooding and Support Coldwater Fish

One of the streams carried by the roadway's culverts is classified as a Coldwater Fish Resource (CFR). The Massachusetts Division of Fisheries and Wildlife notes, "A CFR is a waterbody (stream, river, or tributary thereto) used by reproducing coldwater fish to meet one or more of their life history requirements. CFRs are particularly sensitive habitats. Changes in land and water use can reduce the ability of these waters to support trout and other kinds of coldwater fish" [14].

The goals of the culvert replacement were to alleviate the flooding condition by meeting MassDOT criteria for hydraulic design while also improving fish and wildlife passage in a sensitive habitat. To achieve these goals, two culverts were redesigned as a part of this project.

The original two culverts, shown in Fig. 5.8, were 4 to 4.5 feet wide, and the replacement culverts are more than 10 feet wide, which classifies them as bridges. Analysis of hydraulics, performed in accordance with the MassDOT LRFD (Load and Resistance Factor Design) Bridge Manual, showed that the dimensions of both culverts needed to be larger to increase the flow capacity, reduce flood risk over the roadway, and align with the Massachusetts Stream Crossing Standards (which provide guidelines for specific culvert dimensional requirements to enhance fish and wildlife passage). The increased size of the culverts met both design goals of reducing the risk of overtopping the roadway and improving fish passage.

Designing for fish habitat in CFR also requires considering the materials within the culvert. The design team sought to re-create the riverbed within the replacement culvert to encourage the transient wildlife to utilize the pass-through in a way that the previous culvert hadn't done. Additionally, the culvert along the CFR was originally in a perched condition – meaning the culvert was 4 feet higher at its outlet – and so fish were unable to move back upstream. The design team redesigned the replacement culvert to remove the perch and create a stream bed within the culvert, thereby reconnecting the stream to the downstream Deerfield River. Because of the velocity of the water through the culvert, multiple large boulders are included as eddies to act as resting areas for fish traveling upstream.

In order to build this new connection, the design team proposed a three-sided culvert, shown in Fig. 5.9, to allow for the most accurate imitation of the riverbed by allowing adjustments and observation before the top is then enclosed. A full culvert would have limited this re-creation of the natural stream bed.

Fig. 5.8 Existing roadside culverts. (Courtesy of Nitsch Engineering)

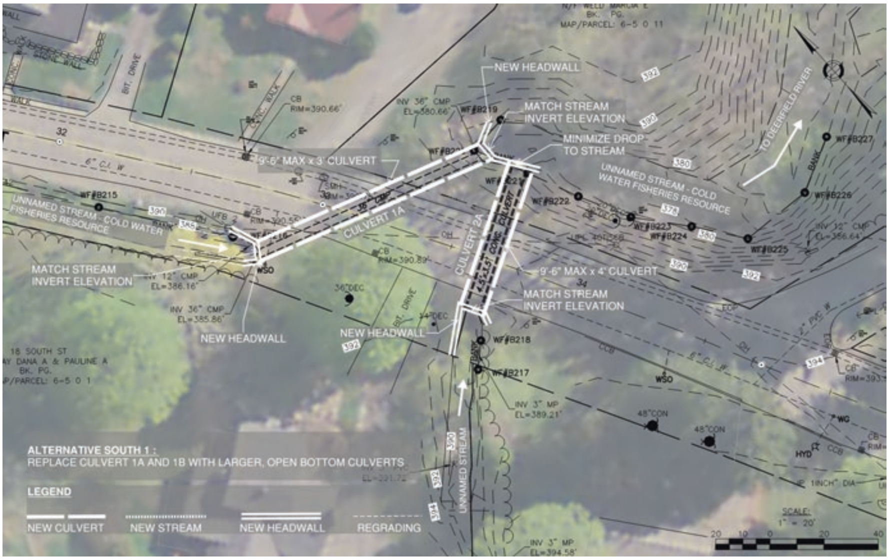

Fig. 5.9 Design plan of culvert. (Courtesy of Nitsch Engineering)

This project is the first example of a stream reconnection of a culvert on a MassDOT project. This project results in a new connection between a regularly stocked upstream pond and the Deerfield River, allowing the fish that travel downstream at maturity to return upstream to again spawn, creating a more abundant cycle of wildlife in the area.

5.6.3 Impact

The Buckland Roadway Improvements project highlighted the importance of and benefits of collaboration. The design team worked closely with the Town and MassDOT to improve the resilience through Complete Streets design goals.

The Buckland Roadway Improvements project improves accessibility while protecting environmental sensitivities. The project allowed a Town that lacked funding due to a small population and limited tax base to bring a roadway that was in disrepair to MassDOT Complete Streets standards, improving the standard of living in the neighborhood. New benefits such as bike lanes, improved geometry with widening of the road, and improved drainage encourage community activity and growth.

Project Team

Civil, Transportation, and Structural Engineer; Land Surveyor: Nitsch Engineering
Environmental Engineer: LEC Environmental Consultants
Geotechnical Engineer: Lahlaf Geotechnical Consulting

5.7 Conclusion

5.7.1 Keys to Successful Implementation

Selecting appropriate green infrastructure solutions for integration into roadway infrastructure projects requires engineers and owners to consider a few things:

1. *Designing flexible, context-sensitive solutions:* Each community that is threatened by climate change faces a unique situation that requires tailored solutions: one-size-fits-all solutions are not an option.
2. *Choosing the right tool from the toolkit:* Many communities have benefited from working with an engineer to develop a toolkit of solutions that could work for their specific issues and needs and then choosing the right BMP for the specific project.
3. *Considering long-term operations and maintenance:* Like anything else, appropriate operations and maintenance is key to making green infrastructure last for the long term. Roadway infrastructure owners need to have a clear asset management plan that helps them effectively operate, maintain, and improve their assets. Generally speaking, a structured schedule helps accomplish this.

5.7.2 Future of Roadway Infrastructure

Roadway infrastructure is a long-term commitment, with roads generally designed to last around 20 years [10]. Because of that long lifespan, every roadway design project needs to anticipate and consider the future, so that roadway profiles and layouts, as well as how they impact and protect the environment, are ready to support the altering climate future. Some of the key trends that will impact roadway infrastructure design in the future are as follows.

5.7.2.1 Emphasizing Sustainability and Resilience

The rise in severe weather events that result from climate change have impacted roads and added increased costs. Today, FHWA requires state DOTs to consider resilience in their roadway design. Because what is required and gets funded gets built, public policy is trending toward regulations that support green infrastructure at the local, state, and federal levels. Similarly, there are now many different grant programs that provide states and municipalities with money dedicated to making roadway improvements that prioritize sustainability and resilience.

The Institute for Sustainable Infrastructure (ISI) developed the Envision rating system: "a consistent, consensus-based framework for assessing sustainability, resiliency, and equity in civil infrastructure" [11]. Created in 2010 by the American Public Works Association (APWA), ASCE, the American Council of Engineering Companies (ACEC), and the Zofnass Program for Sustainable Infrastructure at the Harvard University Graduate School of Design, ISI's Envision system pull the best practices for green infrastructure into one cohesive system. Like the LEED certification system for buildings, Envision seeks to create a clear standard for what sustainability and resilience mean within the roadway. With the focus on sustainability and resilience on the rise, rating systems like Envision will continue to grow in prominence as long as costs for registration can be managed.

Innovative materials and technologies could make a huge impact on the sustainability and resilience of roadway infrastructure. Increased use of permeable paving materials will reduce storm runoff by recharging water to the ground below and could help prevent flooding. Advanced pavement monitoring systems, which embed sensors into the pavement to measure moisture and temperature, allow owners to understand pavement conditions more efficiently and help prioritize maintenance and improvements that help roads last longer. More research and development of innovative paving materials could provide even greater impacts, and moving toward sustainable pavement solutions that achieve engineering goals while using resources effectively and preserving the environment should be the goal [12].

5.7.2.2 Designing for Vehicles of the Future

Transportation remains the largest contributor to greenhouse gas (GHG) emissions in the United States. As costs drop, electric vehicles will become a larger economic driver. Automobile manufacturers, looking to the future, are ramping up the production of electric vehicles. For example, in January 2021, General Motors announced that they would exclusively produce electric vehicles by 2035. The US federal government has begun to replace their fleet of vehicles with electric ones, including Postal Service vehicles.

As electric cars become more popular, there will be a necessary shift in infrastructure support. The United States will require a much more reliable electric grid and more charging stations. Some companies are looking into ways to charge electric vehicles as they are driven, which would require integrating wireless charging capabilities into roadway surfaces.

As electric vehicles move more into the mainstream, so too do autonomous vehicles. If these vehicles are implemented correctly, they have the potential to have hugely positive impacts on roadway safety and mobility, reducing congestion and improving the environment [2]. From a roadway infrastructure perspective, designing roads for autonomous vehicles involves integrating new materials (e.g., special paint for lane stripes to help the vehicle's computer determine location) and/or technologies (e.g., wireless signals in overhead lights and traffic signals to connect cars). There may also be maintenance implications from autonomous vehicles, which may require roads to be in better condition than many owners currently deliver to operate safely, thereby requiring more maintenance.

5.7.2.3 Addressing Congestion

Traffic congestion is everyone's least favorite thing. While it's too early to understand whether the rise in remote work (working from home) during the COVID-19 pandemic will permanently impact traffic patterns, the importance of mitigating congestion will remain high. Engineers and roadway infrastructure owners will continue to drive best practices for managing traffic forward. For example, ASCE reports that decentralized traffic lights promote traffic flow [2], and studies by FHWA show that practices like congestion pricing can help address peak hour traffic congestion.

In addition, non-vehicular travel continues to rise in popularity, as communities find that if safe and comfortable non-car options are provided, more people will use them. More roadway infrastructure will need to be dedicated to bicycle lanes, sidewalks, and bus lanes.

5.7.2.4 Leveraging Technology

Technology advances at an ever-increasing rate, and transportation engineers will continue to leverage these advancements to drive progress for the future. New technologies can help address each of the trends for the future already identified: new climate models and interfaces, such as the Massachusetts Climate Resilience Design Standards Tool, make it easier for owners to see how climate change may impact a specific site; smart roads technologies that support electric and/or autonomous vehicles will continue to grow in importance; and traffic simulation modeling tools such as PTV Vissim make complex traffic simulations more realistic and intuitive to understand for lay audiences.

5.7.2.5 Funding Maintenance and Improvements

Roadway infrastructure, in spite of bipartisan support from both the public and the largest political parties, is consistently underfunded, which has resulted in 40% of the system being in poor or mediocre condition [2]. Right now, spending is focused on system preservation (roadway repairs and maintenance), which has been underfunded to the point that ASCE estimates a $786 billion backlog of road and bridge capital needs [2]. ASCE further estimates that current spending levels must be increased by 29% to address the current and anticipated backlogs [2].

The Highway Trust Fund (HTF) funds federal roadway investment using user fees from the federal gas tax, which has not been raised since 1993, even as inflation has cut its purchasing power by 40%. At the same time, increased vehicle fuel efficiency has resulted in drivers buying less gas. The Congressional Budget Office estimates that the HTF will have a $15B deficit by 2022 as current spending levels exceed user-fee revenues [2]. While some states have worked to increase their portion of funding through raising and/or reforming gas taxes, and exploring new revenue sources such as mileage-based user fees, not enough has been done to even maintain the US current roadway infrastructure – let alone make improvements.

Underfunding infrastructure (including roadway infrastructure) has a negative impact on both the US economy and its citizens' lives. From a purely economic perspective, ASCE projects that if the funding gap is not addressed, the US economy will lose more than $10.3 trillion in GDP by 2039 – and each household will lose more than $3300 per year in disposable income [13].

There are many ideas for how to address the funding gap. No matter which solutions are chosen, the end result must be the development of public policy – at the municipal, state, and federal levels – that provides the required funding to maintain existing roadway infrastructure, make improvements that better support environmental goals, and prepare for the future.

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Lisa Brothers, PE, ENV SP, LEED AP BD+C, was first introduced to the idea of a career in engineering by her high school business teacher. While she was not yet familiar with what a profession in the engineering industry entailed, Lisa chose to apply to the University of Massachusetts Lowell's College of Engineering. She ultimately gravitated toward the field of civil engineering based on her interest in being outside and observing the building process. She graduated from UMass Lowell with a BS in Civil Engineering in 1984.

Upon graduating, Lisa began working for the Massachusetts Department of Public Works (now MassDOT) as an Assistant Roadway Engineer and Bridge Engineer for a $30-million highway construction project. In this role she was the first female engineer assigned to construction at the District. After 3 years working in the public sector, Lisa chose to move into the private sector where she could better pursue her entrepreneurial interests. In the spring of 1986, Lisa enrolled in the part-time MBA program at Northeastern University, earning that degree in 1991 while continuing to work full-time.

After working as a design engineer for a couple different firms, Lisa found her calling when her colleague announced that she was going to start her own firm in 1989. She has long been an advocate for women to create their own opportunities and knew immediately that this was hers. Lisa followed her colleague out of the room saying, "Not without me!" Her MBA definitely helped position the new company for success.

Lisa now has more than 35 years of experience in the design, construction, and management of roadway, site development, sustainable design, and infrastructure-related projects. As President and CEO of Nitsch Engineering since 2011, Lisa is responsible for the vision, growth strategy, strategic direction, and overall performance of the firm. She also serves as Principal-in-Charge for many of the firm's design projects.

The love for the outdoors that initially drew Lisa to civil engineering extends beyond her work life. She enjoys staying active as much as possible through a variety of outdoor activities such as hiking, biking, and kayaking – particularly alongside her husband and two adult children.

Lisa is dedicated to supporting UMass Lowell; she recognizes that she would not be in the position she is today without the affordable, exemplary engineering education she received and continues to give back to the University. She currently sits on the Chancellor's Advisory Council, is a founding member of the Center for Women and Work Advisory Board, and is a past Chair of the College of Engineering/Industrial Advisory Board.

Raising awareness about and making progress on issues of equity, diversity, and inclusion within the engineering industry is a passion of Lisa's. She serves on the Boston Women's Workforce Council, which is working to close the gender and racial wage gap, and is Chair of the American Council of Engineering Companies' (ACEC's) National Diversity, Equity, Inclusion, and Belonging Committee.

A registered professional engineer in Massachusetts and 11 other states, Lisa is involved in a wide range of professional activities. She has been actively involved in the American Council of Engineering Companies/Massachusetts (ACEC/MA) for more than 25 years; Lisa currently serves on the ACEC/MA Board as National Director, as the PAC Committee Chair, and on the Government Affairs Committee, and she is a past President of the Member Organization. She is a member of the Environmental Business Council of New England Board of Directors. Lisa also served as President of the Women's Transportation Seminar-Boston (WTS-Boston) Chapter.

Lisa's contributions to her community have been well recognized by a range of organizations. She was named a 2015 Woman of Influence by the Boston Business Journal and received the EY Entrepreneur of the Year™ 2014 Award in the New England region's services category. She also received the 2017 Leadership Award and was named the 2008 Woman of the Year by WTS-

Boston; received the 2004 Citizen Engineer Award from the Boston Society of Civil Engineers; received the 2018 University Alumni Award and 2003 Francis Academy Distinguished Engineering Alumni Award from UMass-Lowell; was honored with a 2002 Pinnacle Award as an Emerging Executive from the Greater Boston Chamber of Commerce; and received the BSCES Lester Gaynor Award in recognition of her exemplary service as a public official in Wilmington, Massachusetts, in 2001.