United States Environmental Protection Agency

2012 GREEN INFRASTRUCTURE TECHNICAL ASSISTANCE PROGRAM
Urban Land Conservancy
Denver, Colorado

Conceptual Green Infrastructure Design for the Blake Street Transit-Oriented Development Site, City of Denver

Photo: Denver Housing Authority, Park Avenue Development

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About the Green Infrastructure Technical Assistance Program

Stormwater runoff is a major cause of water pollution in urban areas. When rain falls in undeveloped areas, the water is absorbed and filtered by soil and plants. When rain falls on our roofs, streets, and parking lots, however, the water cannot soak into the ground. In most urban areas, stormwater is drained through engineered collection systems and discharged into nearby waterbodies. The stormwater carries trash, bacteria, heavy metals, and other pollutants from the urban landscape, polluting the receiving waters. Higher flows also can cause erosion and flooding in urban streams, damaging habitat, property, and infrastructure.

Green infrastructure uses vegetation, soils, and natural processes to manage water and create healthier urban environments. At the scale of a city or county, green infrastructure refers to the patchwork of natural areas that provides habitat, flood protection, cleaner air, and cleaner water. At the scale of a neighborhood or site, green infrastructure refers to stormwater management systems that mimic nature by soaking up and storing water. These neighborhood or site-scale green infrastructure approaches are often referred to as *low impact development*.

EPA encourages the use of green infrastructure to help manage stormwater runoff. In April 2011, EPA renewed its commitment to green infrastructure with the release of the *Strategic Agenda to Protect Waters and Build More Livable Communities through Green Infrastructure*. The agenda identifies technical assistance as a key activity that EPA will pursue to accelerate the implementation of green infrastructure.

In February 2012, EPA announced the availability of $950,000 in technical assistance to communities working to overcome common barriers to green infrastructure. EPA received letters of interest from over 150 communities across the country, and selected 17 of these communities to receive technical assistance. Selected communities received assistance with a range of projects aimed at addressing common barriers to green infrastructure, including code review, green infrastructure design, and cost-benefit assessments. The Urban Land Conservancy in the City of Denver was selected to receive assistance identifying green infrastructure opportunities for a 1.44 acre transit-oriented development site.

For more information, visit http://water.epa.gov/infrastructure/greeninfrastructure/gi_support.cfm.

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Principal USEPA Staff
Stacey Eriksen, USEPA Region 8
Tamara Mittman, USEPA
Christopher Kloss, USEPA

Community Team
Debra Bustos, Urban Land Conservancy
Cindy Everett, Urban Land Conservancy

Consultant Team
Anne Thomas, Tetra Tech
Jason Wright, Tetra Tech
Erica Hanley, Tetra Tech

October 2012 Housing Colorado's Design by Community Charrette
Harsh Parikh, Parikh Stevens Arch.
Tim Van Meter, Van Meter Williams Pollack, LLC
Fonda Apostolopoulos, CDPHE
James Goodwin, Williams and Co.
Courtland Hyser, City of Denver
Mike Turner, RTD
John Hayden, UC Denver
Patrick Stanley, RTD
Ryan Sagar, UC Denver
Emily Silverman, City and County of Denver
Shannon Haydin, City and County of Denver
Yael Nyholm, Radian
Kevin Larrabee, UC Denver
Chad Holtzinger, OZ Arch
Deirdre Oss, City of Denver
Stacey Eriksen, U.S. EPA
Greg Dorolek, Wenk Associates
Trevor Toms, UC Denver
James Roy II, ULC
Joe Wynn, UC Denver
Kim Allen, UC Denver
Jim Miller, Pinkard Construction
Ken Hoagland, Community Capital
Joshua Radoff, YRNG

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Contents

Tables

Figures

1. Introduction

The Blake Street Transit-Oriented Development site, commonly referred to as the Blake TOD site, is located on the northeast fringe of the Five Points neighborhood at the intersections of 38th Street, Blake Street, Walnut Street, and Downing Street (Figure 1). The Five Points neighborhood is one of Denver's oldest neighborhoods and was once a thriving district from the 1860's through the 1950's with local business and renowned jazz venues.

Future Light Rail to Blake TOD Site.
Source: Environmental Evaluation, February 2010.

Since 2008 there has been strong neighborhood support for a revitalization effort to bring back the early spirit of the neighborhood, led by the Denver Office of Economic Development and the Five Points Business District Office. This effort led to the development of the Welton Corridor Urban Redevelopment Plan in 2012 by the Denver Urban Renewal Authority (DURA). The plan describes the vision and strategies for rebuilding and strengthening retail along Welton and Downing Streets in the heart of the neighborhood. The Blake TOD site presents a unique opportunity for two of the key strategies in the plan: "Incorporat[ing] sustainable stormwater technologies" and "Encourag[ing] Transit-Oriented Development along transit lines and near stations, in order to provide housing, services and employment opportunities."

The Blake TOD site was acquired by the Urban Land Conservancy (ULC) in 2011. The site is a 1.44-acre blighted infill site located a few miles north of downtown Denver and directly across the street from the first station along the future Denver East Corridor commuter rail line on Blake Street (inset map above). The site is also located several blocks from the South Platte River, and lies within one of five opportunity areas for redevelopment and reuse identified by the South Platte Corridor Study. The location is ideal for creating a mixed-use building site to support housing, social services, and employment opportunities. The development is envisioned as a "cross-road" between the Five Point neighborhood and access to the future commuter rail line. In addition, ULC is committed to integrating green infrastructure practices into this urban site to address stormwater quality concerns while simultaneously introducing vegetation to an otherwise paved landscape.

Urbanization and associated land cover change inhibit many of the processes that drive the natural hydrologic cycle, including infiltration, percolation to groundwater, and evapotranspiration. Traditional engineering approaches exacerbate these changes by rapidly conveying stormwater runoff into drainage systems, discharging higher flows and pollutant loads into receiving waters. As a result, stormwater runoff from urbanized areas is often a significant source of water quality impairments. In Denver, the South Platte River quickly becomes degraded as it meanders through the City and County, with large segments of the river exceeding state pathogen standards.

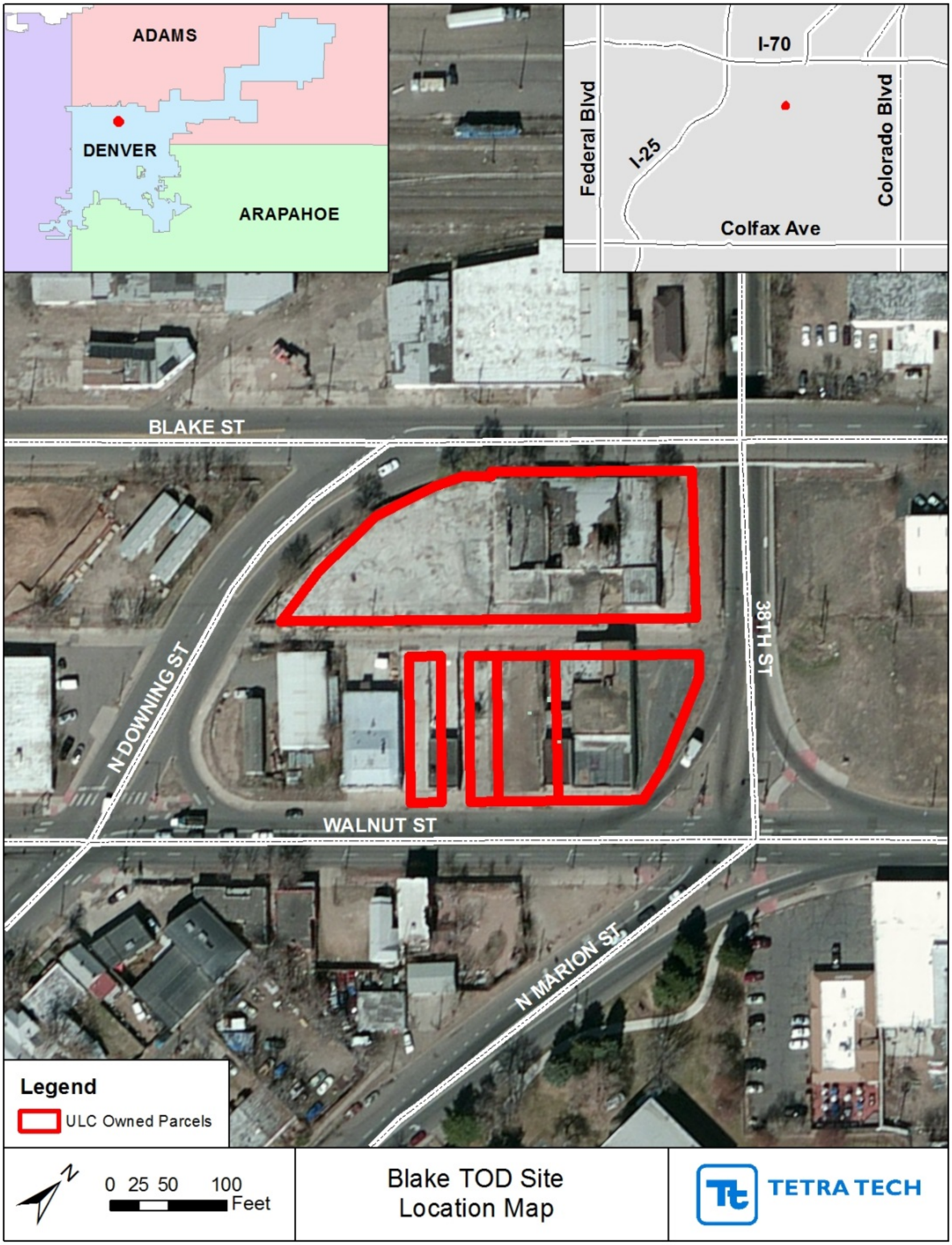

Figure 1. Site Location Map.

Green infrastructure is an important design strategy for protecting water quality that provides multiple community benefits. EPA defines green infrastructure as structural or non-structural practices that mimic or restore natural hydrologic processes within the built environment. Common green infrastructure practices include permeable pavement, bioretention facilities, and green roofs. These practices complement conventional stormwater management practices by enhancing infiltration, storage, and evapotranspiration throughout the built environment and managing runoff at its source.

Implementing green infrastructure concepts on the Blake TOD site will help improve water quality discharging to the South Platte River, approximately one half mile to the northwest. In addition, it will enhance the livability of the space by providing a "green" amenity, decreasing urban heat island effects, and providing an educational opportunity for neighborhood residents and visitors. By identifying appropriate green infrastructure techniques early in the planning process, this project sought to seamlessly integrate green infrastructure practices into the revitalization of an urban infill area with environmental contamination from historical uses. Lessons learned from this project can inform other revitalization efforts in the Denver area and nationally, demonstrating how transit-oriented infill projects on potentially contaminated sites can meet water quality and livability objectives as well as smart growth goals.

2. Report Purpose

The purpose of this report is to provide a conceptual stormwater management design and cost estimate for the proposed buildings at the Blake TOD site. The proposed buildings and site layout are part of work done previous to this report and are indicated by the plan-view rendering (Figure 6). The final stormwater management design should be completed by a stormwater management professional in conjunction with the final design of the buildings and site.

The conceptual stormwater management design presented herein includes green infrastructure practices, as much as practicable, to meet the stormwater design criteria. Underground detention/retention is proposed to supplement the green infrastructure practices in meeting the criteria.

Stormwater management professionals charged with the stormwater management design for the site should use the proposed selection, layout, and sizing of the stormwater control measures as an initial conceptual design. The final design will need to take into account final site/building layout, soil infiltration rates, and detailed survey information, which will dictate the final layout, sizing, and outlet control of the proposed stormwater control measures.

3. Benefits of Green Infrastructure

Green infrastructure can be incorporated into redevelopment sites with relative ease and provides multiple benefits to the surrounding community. Among the environmental, social, and economic benefits that green infrastructure can provide are:

Increased enjoyment of surroundings: A large study of inner-city Chicago found that one-third of the residents surveyed said they would use their courtyard more if trees were planted (Kuo 2003). Residents living in greener, high-rise apartment buildings reported significantly more use of the area just outside their building than did residents living in buildings with less vegetation (Hastie 2003; Kuo 2003). Research has found that people in greener neighborhoods judge distances to be shorter and make more walking trips (Wolf 2008). Implementing green infrastructure practices that enhance vegetation within the neighborhood will help to create a more pedestrian-friendly environment that encourages walking and physical activity.

Increased safety and reduced crime: Researchers examined the relationship between vegetation and crime for 98 apartment buildings in an inner city neighborhood. The study found the greener a building's surroundings are, the fewer total crimes (including violent crimes and property crimes), and that levels of nearby vegetation explained 7 to 8 percent of the variance in crimes reported by building (Kuo 2001a). In investigating the link between green space and its effect on aggression and violence, 145 adult women were randomly assigned to architecturally identical apartment buildings but with differing degrees of green space. The levels of aggression and violence were significantly lower among the women who had some natural areas outside their apartments than those who lived with no green space (Kuo 2001b). The stress-reducing and traffic-calming effects of trees are also likely to reduce road rage and improve the attention of drivers. Green streets can also increase safety. Generally, if properly designed, narrower green streets decrease vehicle speeds and make neighborhoods safer for pedestrians (Wolf 1998; Kuo 2001a).

Increased sense of well-being: There is a large body of literature indicating that green space makes places more inviting and attractive and enhances people's sense of well-being. People living and working with a view of natural landscapes appreciate the various textures, colors, and shapes of native plants, and the progression of hues throughout the seasons (Northeastern Illinois Planning Commission 2004). Birds, butterflies, and other wildlife attracted to the plants add to the aesthetic beauty and appeal of green spaces and natural landscaping. "Attention restorative theory" suggests that exposure to nature reduces mental fatigue, with the rejuvenating effects coming from a variety of natural settings, including community parks and views of nature through windows. In fact, desk workers who can see nature from their desks experience 23 percent less time off sick than those who cannot see any nature, and desk workers who can see nature also report a greater job satisfaction (Wolf 1998).

Increased property values: Many aspects of green infrastructure can potentially increase property values by improving aesthetics, drainage, and recreation opportunities. These in turn can help restore, revitalize, and encourage growth in the economically distressed areas. Table 1 summarizes recent studies that have estimated the effect that green infrastructure or related practices have on property values. The majority of these studies addressed urban areas, although some suburban studies are also included. The studies used statistical methods for estimating property value trends from observed data.

Table 1. Studies Estimating Percent Increase in Property Value from Green Infrastructure

Source	Percent increase in Property Value	Notes
Ward et al. (2008)	3.5 to 5%	Estimated effect of green infrastructure on adjacent properties relative to those farther away in King County (Seattle), WA.
Shultz and Schmitz (2008)	0.7 to 2.7%	Referred to effect of clustered open spaces, greenways and similar practices in Omaha, NE.
Wachter and Wong (2006)	2%	Estimated the effect of tree plantings on property values for select neighborhoods in Philadelphia.
Anderson and Cordell (1988)	3.5 to 4.5%	Estimated value of trees on residential property (differences between houses with five or more front yard trees and those that have fewer), Athens-Clarke County (GA).
Voicu and Been (2008)	9.4%	Refers to property within 1,000 feet of a park or garden and within 5 years of park opening; effect increases over time
Espey and Owasu-Edusei (2001)	11%	Refers to small, attractive parks with playgrounds within 600 feet of houses
Pincetl et al. (2003)	1.5%	Refers to the effect of an 11% increase in the amount of greenery (equivalent to a one-third acre garden or park) within a radius of 200 to 500 feet from the house
Hobden, Laughton and Morgan (2004)	6.9%	Refers to greenway adjacent to property
New Yorkers for Parks and Ernst & Young (2003)	8 to 30%	Refers to homes within a general proximity to parks

4. Blake Transit-Oriented Development Site

The project site is located on the northeast fringe of the Five Points neighborhood (Figure 2) at the intersections of 38th Street, Blake Street, Walnut Street, and Downing Street. The neighborhood is about one mile northeast of downtown Denver. The project site is currently 1.44 acres and is owned by ULC. There is also interest in coordinating with neighboring property owners for a phased development within 4 acres of adjacent property. These additional properties extend one block southwest from the ULC-owned parcels between Downing Street and 36th Street. A conceptual green infrastructure design is presented for these properties as well.

The site is located opposite the future East Corridor rail line at 38th Street and Blake Street. The ULC-owned property is vacant property with buildings removed (Figure 3 and Figure 4). The current land use of the adjacent properties include a micro-brewery, liquor store, social club, storage lockers, a small BMX bike course, and some vacant buildings.

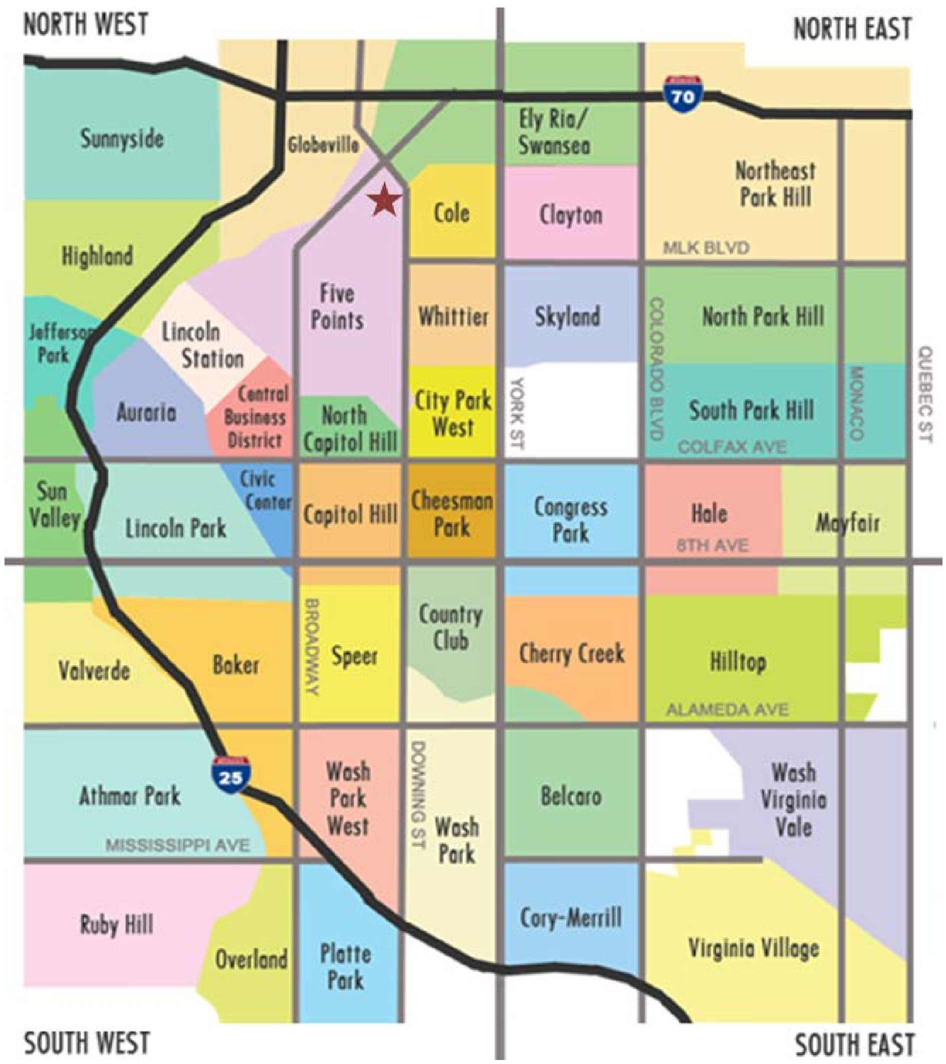

Figure 2. Denver Neighborhoods.

Source: http://extraextrahomes.com/denver-neighborhoods-property-search/

Existing Site Conditions

From 1983 until the acquisition of the parcels by the ULC, the Blake TOD site was occupied by a used truck sales operation that removed and stored truck parts and performed mechanical work on salvaged trucks. Prior to 1983, the site was used as a trucking operation and as a motor coach terminal operation. The buildings on the site were recently razed, leaving a concrete slab, asphalt pavement, and compacted bare soil. With the remaining pavement and compacted soils, the site is effectively 90 percent impervious. There are currently no stormwater control measures on the site. Runoff flows toward storm sewer inlets along Blake Street and Walnut Street, which discharge to an 81-inch brick storm sewer installed under 36th Street and discharging to the South Platte River (Figure 5).

Following acquisition of the site by the ULC, the following assessments were completed:

- Updated Phase I Environmental Site Assessment, report dated September 8, 2011
- Limited Phase II Environmental Site Assessment (LPIIESA), report dated September 18, 2011
- Supplement to the LPIIESA, report dated October 28, 2011

Although surface soil, subsurface soil, and groundwater all contain some degree of contamination including Perchloroethylene (PCE), benzo(a)pyrene, arsenic, poly-aromatic hydrocarbon (PAH), and lead (not necessarily due to contaminants from the truck parts operation), it was noted in the LPIIESA that the surface soils are manageable and could be removed or covered with pavement.

With regard to stormwater management, the main concern, not discussed in the LPIIESA, is whether infiltration to groundwater will be appropriate given the possibility of transporting contaminates in the sub-surface soils. Approval for cleanup and reuse would be based on Colorado's Voluntary Cleanup and Redevelopment program. If infiltration is appropriate, infiltration testing must be performed early in the design process at each proposed location to account for infiltration in the later design phases.

Figure 3. Blake TOD Site, east side.

Figure 4. Blake TOD Site, west side.

Figure 5. Existing Site Conditions.

Proposed Site Design

In October 2012, ULC participated in a Housing Colorado's Design by Community Charrette for the Blake TOD project. The goal of the design charrette was to develop a site plan for a mixed-use residential development. The design charrette provided the opportunity for professionals with a wide range of educational backgrounds including architects, engineers, landscape architects, city planners, and transportation experts to coordinate and cooperate on the site plan.

The vision for the development was a multi-story mixed-use building situated such that it would draw in people from the neighborhood as they commuted to the future East Corridor rail line. It was expected that the upper stories of the building would be reserved for a range of household income levels and the street-level spaces would be occupied by retail, restaurant, and social services. Green space was to be incorporated as a visual amenity and also as a place for recreation.

The end result of the charrette was a site development plan meeting the overall vision for the development. The site plan addressed the parcels owned by ULC as well as 4 acres of additional parcels that could potentially be developed in the future between Downing Street and 36th Street. The plan was divided into three phases with the currently-owned parcels making up Phase I and adjacent parcels making up Phase II and III. ULC would like to reach out to the adjacent parcel owners to share the conceptual vision of the catalytic development potential shared in this report.

Figure 6 is a plan view of the resulting rendering from the charrette showing buildings, sidewalks, alley, and street layout for the three phases of the proposed development. The rendering also shows green space intended to function both as landscaping and stormwater management. Green roofs, roadside bioretention, and a central green space are included in the drawing. Note the location of the future train station on Blake Street and street car (i.e. light rail) on 36th Street. More detail on stormwater management layout is provided in section "Recommended Site Layout."

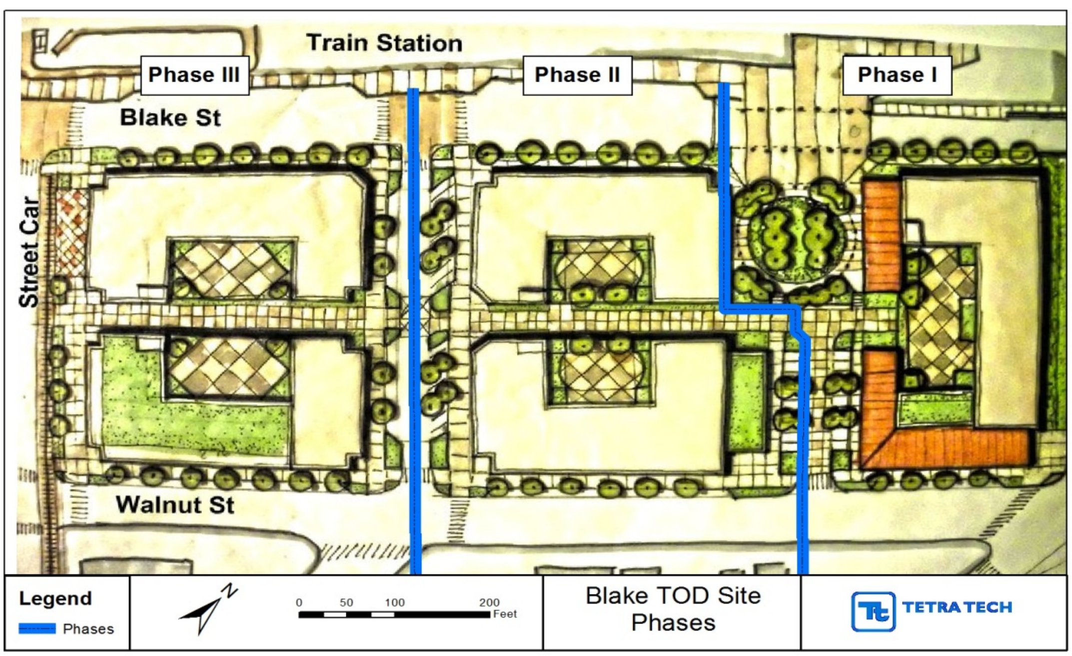

Figure 6. Blake TOD Site Phasing.

5. Goals

This project is part of a greater urban renewal effort happening around Denver. The ULC works to preserve real estate to benefit metro Denver communities. The Blake TOD site is one such site that was strategically acquired to promote a mixed-use community along a transit corridor. This also includes providing workforce housing and job opportunities within the development. To further the community benefit of the site and promote environmental stewardship, ULC is also incorporating green infrastructure.

Project Goals

The overall goal for stormwater management at the site is to restore the hydrologic conditions of the site prior to development as much as possible while allowing for full site development. The green infrastructure planned for this project is intended to assist in improving drainage and water quality in the neighborhood. Secondary goals of the project are to improve the aesthetic appeal of the neighborhood while maintaining the historic character of the area. These goals will be accomplished through implementation of permeable pavement, bioretention, and green roofs that enhance infiltration, evaporation, and detention of stormwater runoff. If infiltration is appropriate at this site based on Colorado's Voluntary Cleanup and Redevelopment program, infiltration of runoff to groundwater will be maximized.

Design Goals

Given the dense land use planned for the site, the design will include both traditional detention/retention practices and green infrastructure practices. Based on outcomes of the design charrette, the volume of runoff directed to traditional detention/retention practices should be minimized by first employing green infrastructure to meet the peak flow and water quality design criteria as much as practicable. Underground detention is strongly discouraged by the City of Denver due to its tendency to be "out of sight, out of mind" and as a result not regularly maintained.

1. Peak Flow Control

For peak flow control, the goal of this project will be to comply with the City and County of Denver Storm Drainage Design and Technical Criteria (revised January 2006). To reduce urban drainage problems and the cost of drainage facilities, the Technical Criteria require on-site detention of the 100-year storm event for all development and redevelopment projects. For watershed areas less than 10 square miles, a minimum 2-hour storm duration is suggested (UDFCD, Volume 1, RA-3). The maximum allowable unit release rate for 100-year volumes must be based on the predominant soil type at a site and ranges from 0.5 to 1.0 cfs/acre (City and County of Denver Storm Drainage Design and Technical Criteria, Section 13.2)

2. Water Quality Control

For water quality control, the goal of this project will be to provide on-site retention of the 1-year 2-hour storm event through infiltration and evapotranspiration. The water quality volume requirement is nested within the peak flow control requirement in that the water quality volume must be retained on-site while runoff exceeding this amount up to the 100-year 2-hour event must be detained or retained.

The selection of the water quality criterion was an outcome of the charrette process. The criterion is one of the options to meet the standards for Enterprise Green Communities Criteria, a program which aligns affordable housing investment strategies with environmentally responsive building practices. The water quality criterion for Enterprise Green Communities is more stringent than the City's water quality requirement. Note that the use of infiltration to meet this criterion is dependent on the infiltration capacity of the soil and the approval of the Colorado Department of Public Health and Environment to infiltrate stormwater due to the results of the Limited Phase II Environmental Site Assessment.

6. Stormwater Management Toolbox

In order to meet the project and design goals discussed above, the team identified a set of green infrastructure practices appropriate for the Blake TOD site. These practices manage stormwater at the source and provide neighborhood amenities by integrating soil and vegetation-based practices into the planned development.

In addition, the team identified a detention storage practice for project areas in which green infrastructure could not meet peak flow requirements. While green infrastructure can fulfill both water quality and peak flow requirements on sites with adequate open space, avoiding the cost of separate detention facilities, redevelopment projects often pose space constraints that limit the application of green infrastructure. For infill projects with limited open space, green infrastructure can reduce the size and cost of required detention facilities, but may not be able to eliminate the need for detention facilities entirely.

To assist ULC in incorporating green infrastructure practices into the Blake TOD site, the following discussion addresses constraints and opportunities associated with each stormwater management practice.

Green Infrastructure Practices

Multiple green infrastructure practices can be incorporated into the development of a site to complement and enhance the proposed layout while also providing water quality treatment and volume reduction. The following section describes three common green infrastructure practices that are well-suited to densely built urban areas.

1. Bioretention Facilities

Bioretention facilities are shallow, depressed areas with a fill soil and vegetation that infiltrate runoff and remove pollutants through a variety of physical, biological, and chemical treatment processes. The depressed area is planted with small to medium sized vegetation including trees, shrubs, grasses, and perennials, and may incorporate a vegetated groundcover or mulch that can withstand urban environments and tolerate periodic inundation and dry periods. Bioretention may be configured differently depending on the site context and design goals. This section summarizes general design considerations for bioretention facilities, and then describes two configurations designed for dense urban areas: planter boxes and tree boxes. Note that use of these practices within the public right-of-way will need prior approval from the City of Denver.

Bioretention is well-suited for removing stormwater pollutants from runoff, particularly for smaller (water quality) storm events, and can be used to partially or completely meet stormwater management requirements on smaller sites. Bioretention areas can be incorporated into a development site to capture roof runoff and parking lot runoff and within rights-of-way to capture sidewalk and street runoff (Figure 7 and Figure 8).

- For unlined systems, maintain a minimum of 5 feet between the facility and a building and at least 10 feet with a basement.
- A surface dewatering time of no greater than 12 hours per UDFCD, Volume 3 either through infiltration with soils of sufficient percolation capacity or with an underdrain system and outlet to a drainage system. Use of an underdrain system is very effective in areas with low infiltration capacity soils.
- Planted with native and noninvasive plant species that have tolerance for urban environments, frequent inundation, and Denver's semi-arid climate.
- Inclusion of an overflow structure with a non-erosive overflow channel to safely pass flows that exceed the capacity of the facility or design the facility as an off-line system.
- Inclusion of a pretreatment mechanism such as a grass filter strip, sediment forebay, or grass swale upstream of the practice to enhance the treatment capacity of the unit.

Figure 7. Bioretention Incorporated into a Right-of-Way.

Figure 8. Bioretention Incorporated into Traditional Parking Lot Design.

Planter Box: Planter boxes are bioretention facilities contained within a concrete box, allowing them to be incorporated into tighter areas with limited open space. Runoff from a street or parking lot typically enters a planter box through a curb cut, while runoff from a roof drain typically enters through a downspout. Planter boxes are often categorized either as flow-through planter boxes or infiltrating planter boxes. Infiltrating planter boxes have an open bottom to allow infiltration into the underlying soils. Flow-through planter boxes are completely lined and have an underdrain system to convey flow that is not taken up by plants to areas that are appropriate for drainage away from building foundations. Planter boxes are well-suited to narrow areas adjacent to streets and buildings (Figure 9 and Figure 10).

Figure 9. Planter Box within Street Right-of-Way.

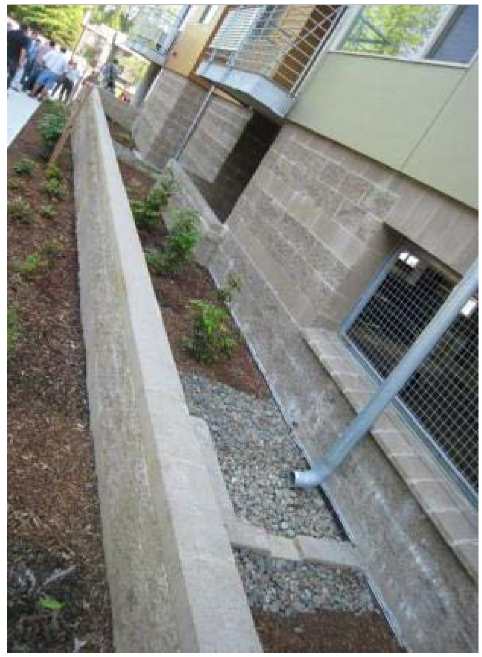

Figure 10. Flow-through Planter Box Attached to Building.

Tree Box: Tree boxes are bioretention facilities configured for dense urban areas that use the water-uptake benefits of trees. They are generally installed along street corridors with curb inlets (Figure 11). Tree boxes can be incorporated immediately adjacent to streets and sidewalks with the use of a structural soil, modular suspended pavement, or underground retaining wall to keep uncompacted soil in its place. Tree boxes typically contain a highly engineered soil media to enhance pollutant removal while retaining high infiltration rates. The uncompacted media allows urban trees to thrive, providing shade and an extensive root system for water uptake. For low to moderate flows, stormwater enters through the tree box inlet and filters through the soil. For high flows, stormwater will bypass the tree box if it is full and flow directly to the downstream curb inlet.

Figure 11. Tree Box Using Grate Inlets in Street.

2. Permeable Pavement

Conventional pavement results in increased surface runoff rates and volumes. Permeable pavements, in contrast, allow streets, parking lots, sidewalks, and other impervious surfaces to retain the underlying soil's natural infiltration capacity while maintaining the structural and functional features of the materials they replace. Permeable pavements contain small voids that allow water to drain through the pavement to an aggregate reservoir and then infiltrate into the soil. If the native soils below the permeable pavements do not have enough percolation capacity, underdrains can be included to direct the stormwater to other downstream stormwater control systems. Permeable pavement can be developed using modular paving systems (e.g., concrete pavers, grass-pave, or gravel-pave) or pour-in-place solutions (e.g., pervious concrete or permeable asphalt).

Permeable pavement reduces the volume of stormwater runoff by converting an impervious area to a treatment unit. The aggregate sub-base can provide water quality improvements through filtering and enhance additional chemical and biological processes. The volume reduction and water treatment capabilities of permeable pavements are effective at reducing stormwater pollutant loads.

Permeable pavement can be used to replace traditional impervious pavement for most pedestrian and vehicular applications. Composite designs that use conventional asphalt or concrete in high-traffic areas adjacent to permeable pavements along shoulders or in parking areas can be implemented to meet both transportation and stormwater management needs more cost effectively. Permeable pavements are most often used in constructing pedestrian walkways, sidewalks, driveways, low-volume roadways, and parking areas of office buildings, recreational facilities, and shopping centers (Figure 12 and Figure 13).

General guidelines for applying permeable pavement are as follows:

- Permeable pavements can be substituted for conventional pavements in parking areas, low-volume/low-speed roadways, pedestrian areas, and driveways if the grades, native soils, drainage characteristics, and groundwater conditions of the paved areas are suitable.
- Permeable pavement is not appropriate for stormwater hotspots where hazardous materials are loaded, unloaded, or stored unless the sub-base layers are completely enclosed by an impermeable liner.
- The granular capping and sub-base layers should provide adequate construction platform and base for the overlying pavement layers.
- If permeable pavement is installed over low-permeability soils or temporary surface flooding is a concern, an underdrain should be installed to ensure water removal from the sub-base reservoir and pavement.
- The infiltration rate of the soils or an installed underdrain should drain the sub-base in 24 to 48 hours.
- An impermeable liner can be installed between the sub-base and the native soil to prevent water infiltration when clay soils have a high shrink-swell potential or if a high water table or bedrock layer exists.
- Measures should be taken to protect permeable pavements from high sediment loads, particularly fine sediment, to reduce maintenance. Typical maintenance includes removing sediment with a vacuum truck.

Figure 12. Pervious Concrete Parking Stalls.

Figure 13. Permeable Interlocking Concrete Paver Parking Stalls.

3. Green Roofs

Green roofs introduce vegetation and soil media onto sections of roof tops to reduce imperviousness and absorb and filter rainfall. At a minimum, a green roof consists of a waterproof membrane and root barrier system to protect the roof structure, a drainage layer, filter fabric, a lightweight soil media, and vegetation that filter, absorb, and retain/detain the rainfall. Rainfall that infiltrates into the green roof is lost to evaporation or transpiration by plants, or, once the soil has become saturated, percolates through to the drainage layer and is discharged through the roof downspouts. Typically, a green roof is part of a treatment train with the green roof draining to another stormwater control measure such as a bioretention cell, bioswale, or cistern. Compared to other green infrastructure practices, they are fairly expensive, but may be a worthwhile asset if designed to allow human access.

Green roofs may cover large sections of a roof while maintaining access for utilities, maintenance, or recreation. The green roof design is dictated by the intended use for the space which can range from serving solely a water quality treatment mechanism, i.e. extensive green roof, to serving as a recreational space for building tenants, (Figure 14, Figure 15, and Figure 16). The soil media of extensive green roof systems is typically shallow (i.e. 2 to 6 inches) while the soil media for intensive systems is deep (i.e. > 6 inches). Green roofs are most often applied to buildings with flat roofs, but can be installed on roofs with slopes with the use of mesh, stabilization panels, fully contained trays, or battens. Alternatively, detention on roofs without vegetation (i.e. blue roofs) may be an option as long as the water drains through a biological filter, such as at ground level.

General guidelines for applying green roofs are as follows:

- The building roof must be designed to safely support the saturated weight of the green roof, which varies depending on the green roof design and manufacturer.
- Extensive green roofs, with soil depths of 2 to 6 inches, are most commonly used for stormwater management.
- The soil media for green roofs should be light-weight and largely inorganic.
- Plants selected for green roofs should be hardy, self-sustaining, drought-resistant plants able to withstand daily and seasonal variations in temperature and moisture on rooftops. Typical plants used for extensive roofs are from the genera Sedum and Delosperma.
- At a minimum, a temporary irrigation system should be used to establish plants and ensure success during drought. This is particularly important in the semi-arid climate of Denver.
- A drainage layer installed beneath the green roof routes excess runoff from the roof to the downspouts.
- A root barrier installed below the drainage layer prevents plant roots from damaging structural roof membranes.
- A waterproof membrane is used to prevent transmission of moisture from the green roof to the structural roof.
- An insulation layer between the green roof and structural roof can improve the thermal qualities of the system.
- An optional leak detection membrane can be used to assess the integrity of the waterproof membranes.

- Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West by Leila Tolderlund is a local reference for green roofs. http://www2.epa.gov/sites/production/files/documents/GreenRoofsSemiAridAridWest.pdf

Figure 14. Extensive Green Roof at EPA Region 8 Headquarters.
(Photo courtesy of Western Solutions.)

Figure 15. Intensive Green Roof at the Denver Botanic Gardens.
(Photo courtesy of Leila Tolderlund.)

Figure 16. Green Roof with Fully Contained Trays on a Highly Sloped Roof.

Gray Infrastructure Practices

The Blake TOD site incorporated green infrastructure in all available areas to meet the design criteria before supplementing with gray infrastructure (in this case underground detention storage) to meet the peak flow requirements. While underground detention facilities are often more costly on a unit basis (cost per gallon) than green infrastructure practices, these facilities can save valuable space in space-limited urban areas. This section discusses design considerations for underground detention/retention facilities in general and describes the type of detention facility selected for this study.

1. Underground Detention/Retention

Underground detention/retention facilities achieve the capture and temporary storage of stormwater collected from the tributary drainage area. Curb inlets, surface drains, or overflow from upstream practices lead stormwater to underground tanks/vaults or systems of large diameter subsurface storage pipes. The stormwater is then released directly through an outlet pipe back into a stormwater drainage system or allowed to infiltrate to the groundwater table. The outlet system is designed to meet the allowable release rates.

Underground detention/retention should not be expected to substantially improve water quality unless preceded by a pretreatment practice such as a planter box. Underground detention/retention may be useful for developments where land availability and land costs preclude the development of surface stormwater control measures and in retrofit and redevelopment settings. Pretreatment is crucial for minimizing maintenance of the storage unit and should be designed to remove sediment, floatables, and oils if prevalent in the drainage area. Note that entry into an underground unit typically requires confined space procedures.

For this conceptual design, large diameter subsurface storage pipes were selected as the detention storage method. Note that many developments in Denver install more costly underground concrete tanks/vaults to provide detention storage (Figure 17). The cost savings achieved by implementing green infrastructure would therefore be greater for a typical design using underground vaults than for the design described in this study.

Interlocking Plastic Block

Subsurface Pipe Storage

Precast Concrete Vault

Cast-in-place Concrete Tank

Figure 17. Examples of Underground Detention Units.

7. Green and Gray Infrastructure Conceptual Design

This section addresses the selection, layout, and design of the stormwater control measures within the three phases of development of the Blake TOD site. Green infrastructure practices were incorporated into the proposed site design as much as practicable before supplementing with underground detention/retention to meet peak flow requirements. While the October charrette provided an initial proposed layout, the detailed considerations that informed the final design are described in the sections below.

Design Elements

The selection of green infrastructure practices for the Blake TOD site was guided both by the project goals and by the physical constraints posed by existing and future conditions. Because this site has limited available space for stormwater control measures, green infrastructure practices that use vertical retaining walls rather than gradual side slopes are more applicable in most areas, such as sidewalks and lanes. Practices with vertical retaining walls include planter boxes, tree boxes, and permeable pavement.

Of the three options, planter boxes and tree boxes were preferred because they include vegetation. In comparing a planter box and a tree box on the basis of cost per volume of storage, a planter box is more cost-effective than a tree box, so planter boxes were placed throughout the site to meet the goals of greening the urban environment while allowing for full site development. Traditional bioretention with side slopes was used where space allowed.

Where vegetated options were either maximized or not appropriate, permeable pavement was used. Permeable pavement is easily integrated into paved areas such as parking, sidewalks, or streets without affecting their use for pedestrian or auto traffic. Visitors would experience no difference between permeable and conventional pavement, except maybe to see fewer puddles when it rained. On the basis of cost per volume of storage, permeable pavement is twice the cost of a planter box but still significantly less than a tree box (Table 2).

Several green roofs were also incorporated in the design during the charrette to aid in improving water quality and reducing runoff volume and as an amenity to the housing units. In all cases it was assumed that the green roof would overflow to another stormwater control measure to aid in meeting the design goals. On the basis of cost per volume of storage, the cost of a green roof is ten times more than that of permeable pavement (Table 2).

Because of the space constraints of the site, underground detention/retention was also incorporated into the design to meet peak flow requirements. Although the unit construction cost per volume of water stored for underground detention/retention is comparable to the unit cost for the planter box, improving water quality and aesthetic appeal are important project goals that are not achieved by this stormwater control. Underground detention/retention was therefore placed and sized only after green infrastructure practices were examined. As there are many types of underground detention/retention systems, Table 2 provides unit costs of several types for comparison. Large subsurface pipe storage was the technology envisioned for this conceptual design.

Table 2. Comparative Volumetric Unit Costs of Stormwater Control Measures.

Stormwater Control Measures	Construction Cost per Volume of Water Stored within Cross-Section of Practice ($/CF)
Green Infrastructure	
Bioretention	$7
Planter Box	$9
Permeable Pavement	$22
Green Roof	$200
Tree Box	$67
Gray Infrastructure	
Underground Detention/Retention	
Subsurface Pipe Storage (Triton Stormwater Solutions)	$9
Interlocking Plastic Blocks (Cudo cube)	$15
Cast-in-Place Concrete Tank[1]	$26
Precast Concrete Vault[1]	$28

[1] The cast-in-place concrete tank cost and the precast concrete vault cost are based on engineering estimates for construction of a 6,400 cubic foot storage unit. Note that the unit cost of a precast unit is variable depending on how closely the storage capacity of the manufactured product matches the storage need.

Analytical Methods

A simple volumetric calculation was used to size the green infrastructure practices for each phase of development. The goal for the sizing of each proposed green infrastructure practice was to contain the 100-year 2-hour storm runoff volume from its tributary drainage area. In some cases, underground detention/retention was used to supplement the green infrastructure to meet the peak flow requirement, but the water quality volume from the 1-year 2-hour storm event was, at a minimum, able to be retained within the green infrastructure practice. During final design, it will be necessary to design the outlet control such that the 1-year 2-hour storm event, at a minimum, is retained within the practice.

First, the site was divided into small subcatchments tributary to one or more proposed green infrastructure practices (Figure 18, Figure 19, and Figure 20). The subcatchment delineation was based on current architectural renderings (Figure 3-4) and need to be updated as part of the final design. Rainfall depth was calculated for the 100-year 2-hour storm event (2.98 inches) based on the methods from the Urban Storm Drainage Criteria Manual, Volume 1, while rainfall depth for the 1-year 2-hour storm (1.02 inches) was extrapolated from the 2, 5, 10, 25, 50, and 100 year 2-hour rainfall depths.

Runoff coefficients were used to estimate initial abstraction from the subcatchment drainage areas, most of which consisted of impervious surfaces. Runoff volume from the 100-year 2-hour event for each subcatchment area was calculated as follows:

Runoff Volume = Subcatchment Area x 100-year Rainfall Depth x Composite Runoff Coefficient

The runoff volume and available physical space were then used to determine surface area and cross-section of each practice. The storage volume within the bioretention practices took into account surface storage depth, planting soil depth, aggregate storage depth, and void space ratios of the soil and aggregate. Permeable pavement storage volume parameters included aggregate storage depth and the void space ratio.

During final design, stormwater control measure sizes may be reduced by accounting for stormwater discharging from each practice at the maximum allowable release rate to the City's storm drainage network along Blake Street and Walnut Street. These storm sewers discharge to the 80-inch brick storm sewer on 36th Street. The maximum allowable release rate is dependent on the site-specific hydrologic soil group and is found in Table 13.2 of the City and County of Denver Storm Drainage Design and Technical Criteria (Revised January 2006). A hydrologic soil analysis will be necessary to determine the soil characteristics at the proposed stormwater control measure locations.

Table 3, Table 4, and Table 5 include the subcatchment drainage areas, composite runoff coefficients, and runoff volumes. More detailed information regarding the conceptual sizes of the stormwater control measures is included in section "Recommended Sizing and Layout".

Table 3. Phase I Subcatchment Delineations and Runoff Volumes.

Subcatchment	Subcatchment Drainage Area (sq ft)	$C_{composite}$	Required Storage Volume for 1-year, 2-hour Storm (cu ft)	Required Storage Volume for 100-year, 2-hour Storm (cu ft)
01	7,990	0.90	610	1,790
02	13,650	0.85	990	2,880
03	18,900	0.66	1,070	3,120
04	7,170	0.85	520	1,510
05	8,000	0.85	580	1,680
06	25,000	0.66	1,400	4,080

Table 4. Phase II Subcatchment Delineations and Runoff Volumes.

Subcatchment	Subcatchment Drainage Area (sq ft)	$C_{composite}$	Required Storage Volume for 1-year, 2-hour Storm (cu ft)	Required Storage Volume for 100-year, 2-hour Storm (cu ft)
01	11,950	0.89	910	2,650
02	6,340	0.87	470	1,370
03	6,920	0.88	520	1,520
04	10,240	0.89	760	2,210
05	17,610	0.85	1,280	3,720
06	4,980	0.85	360	1,050
07	18,830	0.85	360	3,980
08	4,930	0.85	360	1,040
09	8,160	0.85	590	1,720
10	9,110	0.85	660	1,930

Table 5. Phase III Subcatchment Delineations and Runoff Volumes.

Subcatchment	Subcatchment Drainage Area (sq ft)	$C_{composite}$	Required Storage Volume for 1-year, 2-hour Storm (cu ft)	Required Storage Volume for 100-year, 2-hour Storm (cu ft)
01	13,460	0.90	1,030	3,000
02	6,150	0.85	450	1,300
03	5,000	0.85	360	1,050
04	11,650	0.89	880	2,590
05	5,200	0.88	390	1,140
06	5,250	0.87	390	1,140
07	18,800	0.85	1,360	3,970
08	6,000	0.85	430	1,260
09	19,350	0.85	1,400	4,080
10	5,450	0.85	390	1,150
11	9,300	0.85	670	1,970

Recommended Sizing and Layout

The conceptual layout and sizing of the green and gray infrastructure practices for each of the project phases are discussed in this section. Most green infrastructure practices were sized to meet both the water quality and peak flow criteria described in section “Design Goals” by retaining the 100-year 2-hour storm event. For some portions of the site, however, retention of the 100-year storm event with green infrastructure was not feasible given the space constraints, and green infrastructure practices were designed to retain the water quality storm and overflow to underground detention storage. The cross-section designs used for the sizing of the green infrastructure practices are in the section on “Stormwater Control Measure Technical Specifications.”

Within the discussion below, note that the water storage volume is the product of the surface area of the practice and the equivalent storage depth. Equivalent storage depth is the sum of the surface ponding depth and the product of the void space and applicable underlying layers. The soil layer, bedding layer, and aggregate storage layer void space are 20 percent, 30 percent, and 40 percent, respectively. Storage volume indicates the stormwater control measure volume, discounting the underlying soil infiltration rate, required to meet the design criteria. The cross-section of the final design can vary from the conceptual design cross-section as long as the water storage volume capacity is maintained.

The placement of the stormwater control measures across the development is based on the following routing objectives:

1. Capture adjacent street runoff along the sidewalk, essentially treating right-of-way runoff within the right-of-way. Outlet to the storm sewer on Walnut Street, Blake Street, and 36th Street.
2. Direct private development runoff including roofs, drives, and walkways to green infrastructure practices within the development property. For green infrastructure practices able to handle the 100-year storm event volume from the tributary area, discharge the treated runoff to the storm

sewers on Walnut Street, Blake Street, and 36th Street. For green infrastructure practices not able to capture the 100-year storm event volume, due to lack of available space, capture the water quality volume and discharge the overflow to an underground detention system beneath the building parking lots running under the building terraces.

3. For Phases II and III, construct a storm sewer beneath the lane running parallel to and between Blake Street and Walnut Street to collect the discharge from the green and gray infrastructure practices. This storm sewer would discharge to the large 81-inch storm sewer under 36th Street.

It should be recognized that future discussions between stakeholders may result in changes to the preferred location and sizing of green infrastructure practices based on aesthetics, safety concerns, constructability, or construction cost.

1. Phase I

Proposed green infrastructure practices for Phase I include a combination of planter boxes, traditional bioretention, and green roof, providing storage capacity as well as aesthetically-pleasing vegetation. The runoff from the 100-year 2-hour storm event is able to be stored entirely within these green infrastructure practices.

Planter boxes are used along Walnut Street and along the entry driveway to the development to capture road and roof runoff (Subcatchments 01 and 02). They are also used to capture roof runoff between the building and Blake Street on the northwest side of the building (Subcatchment 04) and terrace runoff adjacent to the terrace near the driveway (Subcatchment 05).

Traditional bioretention is used around the perimeter of the circular park area and behind the building along 38th Street where there is more available space. The park area bioretention captures runoff from the park and surrounding walkway (Subcatchment 03). The bioretention along 38th Street captures predominately roof runoff and is preceded by a green roof for a portion of the total roof drainage area (Subcatchment 06).

Refer to Table 6 and Figure 18 for available water storage volume and placement of the green infrastructure practices, respectively. Table 7 includes the cross-section design for each of the practices.

Table 6. Phase I Green Infrastructure Practice Proposed Location and Sizing.

Subcatchment	Green Infrastructure Practice Type	Location	Width (ft)	Length (ft)	Surface Area (sq ft)	Available Water Storage Volume (cu ft)	Overflow Volume to Under-ground Detention (cu ft)
01	Planter Box[1]	Sidewalk	4.5	189	851	1,800	0
02	Planter Box	Sidewalk	5	95	452 212 264 475	2,896	0
03	Bioretention	Perimeter of circular park	11	261	2,871	3,184	0
04	Planter Box	Sidewalk	4.5 4.5	81 81	729	1,543	0
05	Planter Box	Adjacent to driveway	16	50.4	806	1,707	0
06	Green Roof[2], Bioretention	Open area behind building	17	167	2,839	4,081	0
				Total	9,499	15,211	0

[1] If curbside parking is allowed on this block, pedestrian "bridges" will be needed to cross from the curbside parking to the sidewalk.
[2]Subcatchment 06 is partially treated by a green roof draining to the bioretention area.

Table 7. Phase I Green Infrastructure Practice Cross-Sections

Subcatchment	Green Infrastructure Practice Type	Location	Ponding Depth (inch)	Engineered Soil Depth (inch)	Aggregate Storage Depth (inch)
01	Planter Box	Sidewalk	8	18	30
02	Planter Box	Sidewalk	8	18	30
03	Bioretention	Perimeter of circular park	8	18	30
04	Planter Box	Sidewalk	8	18	30
05	Planter Box	Adjacent to driveway	8	18	30
06	Bioretention	Open area behind building	8	18	30

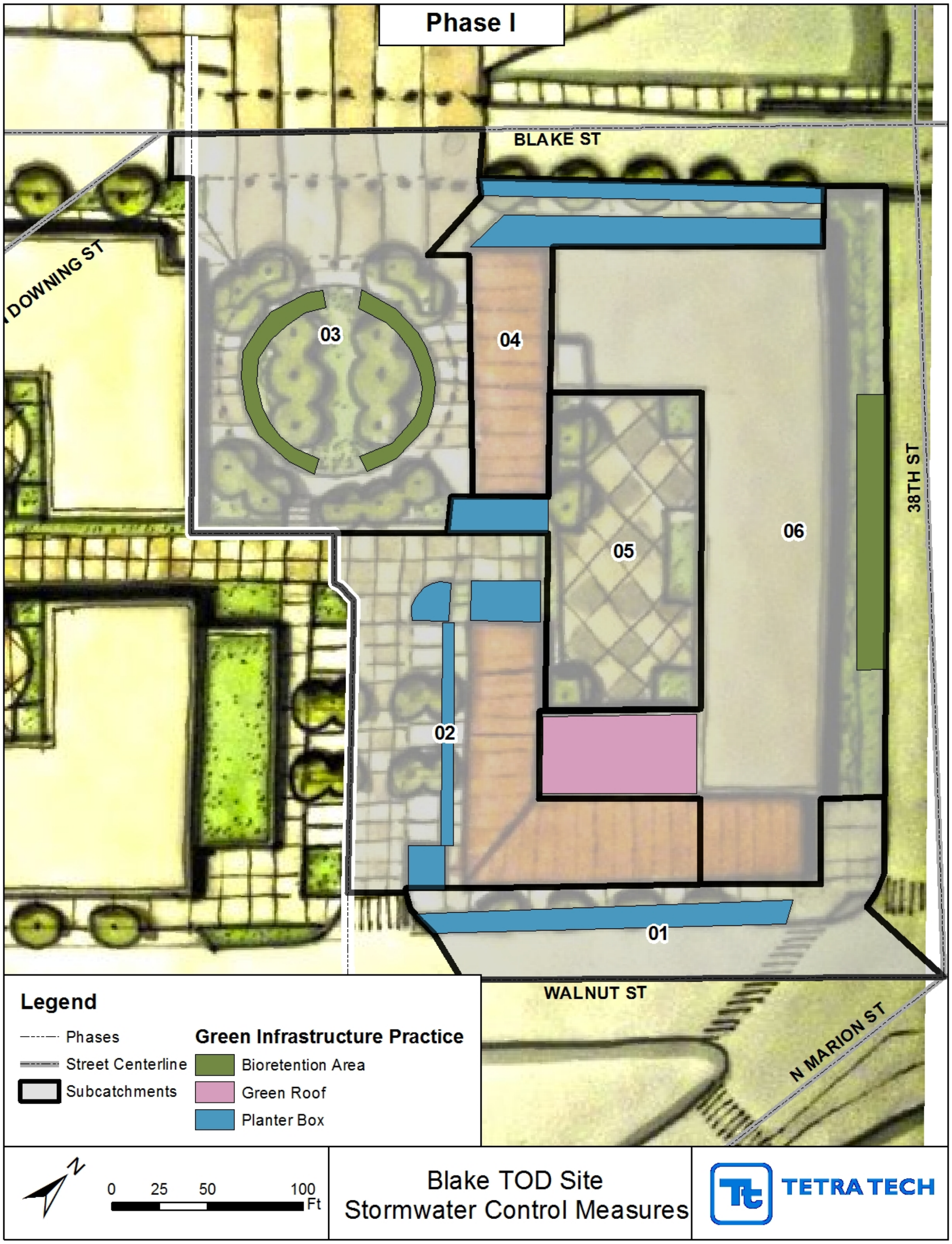

Figure 18. Phase I Stormwater Control Measure Layout.

2. Phase II

Proposed green infrastructure practices for Phase II include a combination of planter boxes, permeable pavement, and green roof. A portion of these practices are not able to contain the full 100-year 2-hour event from each drainage area so underground detention is also provided to supplement these green infrastructure practices.

Planter boxes are used behind the curb along Walnut Street, a proposed "37th Street", Blake Street, and the entry driveway to capture primarily road and sidewalk runoff (Subcatchments 01, 02, 03, 04, and 09). The planter boxes along the entry driveway in Subcatchment 09 also capture discharge from a green roof. These practices are sized to capture the 100-year 2-hour storm event with discharge to the nearest storm sewers.

Planter boxes are also used to capture just the water quality volume, due to space constraints, from roof and terrace drainage (Subcatchments 05, 06, 07, and 08). Runoff beyond the 1-year 2-hour volume will be directed to underground detention located beneath the parking areas, which are beneath the second floor terraces (Subcatchments 06 and 08). These planter boxes are located adjoined to the building walls, which means that the building walls will need to be waterproofed. As this water is required to be retained on-site, the water will need to infiltrate or evapotranspire. Because of its close proximity to the building, it may be necessary to disperse this water through the aggregate layer beneath the permeable lane or create an additional subsurface infiltration gallery.

Permeable pavement with subsurface aggregate storage is proposed for the lane (Subcatchment 10). There is plenty of subsurface storage within the practice to capture the 100-year 2-hour runoff volume from the lane. The aggregate storage layer depth could be increased to handle discharge from the planter boxes.

Refer to Table 8 and Figure 19 for available water storage volume and placement of the green infrastructure practices, respectively. Table 9 includes the cross-section design for each of the practices.

Table 8. Phase II Green Infrastructure Practice Proposed Location and Sizing.

Subcatch-ment	Green Infrastructure Practice Type	Location	Width (ft)	Length (ft)	Surface Area (sq ft)	Available Water Storage Volume (cu ft)	Overflow Volume to Under-ground Detention (cu ft)
01	Planter Box[1]	Sidewalk	5.5	225	1,238	2,650	0
02	Planter Box[1]	Sidewalk	5	130	650	1,370	0
03	Planter Box[1]	Sidewalk	5	135	675	1,435	0
04	Planter Box[1]	Sidewalk	5	215	1,075	2,265	0
05	Planter Box[2]	Along building wall	3	200	600	1,270	2,440
06	Planter Box[2]	Along building wall	3	57	171	362	690
07	Planter Box[2]	Along building wall	3	215	645	1,370	2,600

Subcatch-ment	Green Infrastructure Practice Type	Location	Width (ft)	Length (ft)	Surface Area (sq ft)	Available Water Storage Volume (cu ft)	Overflow Volume to Under-ground Detention (cu ft)
08	Planter Box[2]	Along building wall	3	57	171	362	680
09	Green Roof, Planter Box	Green roof drains to planter boxes in sidewalk	10 10 10	42 20 20	420 200 200	815	0
10	Permeable Pavement	Lane	12	300	3,600	2,160	0
				Total	9,645	14,060	6,410

[1] If curbside parking is allowed on this block, pedestrian "bridges" will be needed to cross from the curbside parking to the sidewalk.
[2] The green infrastructure practice treats the 1-yr, 2-hr storm only.

Table 9. Phase II Green Infrastructure Practice Cross-Sections

Subcatch-ment	Green Infrastructure Practice Type	Location	Ponding Depth (inch)	Engineered Soil Depth (inch)	Aggregate Storage Depth (inch)
01	Planter Box	Sidewalk	8	18	30
02	Planter Box	Sidewalk	8	18	30
03	Planter Box	Sidewalk	8	18	30
04	Planter Box	Sidewalk	8	18	30
05	Planter Box	Along building wall	8	18	30
06	Planter Box	Along building wall	8	18	30
07	Planter Box	Along building wall	8	18	30
08	Planter Box	Along building wall	8	18	30
09	Planter Box	Green roof drains to planter boxes in sidewalk	8	18	30
10	Permeable Pavement	Lane	0	0	18

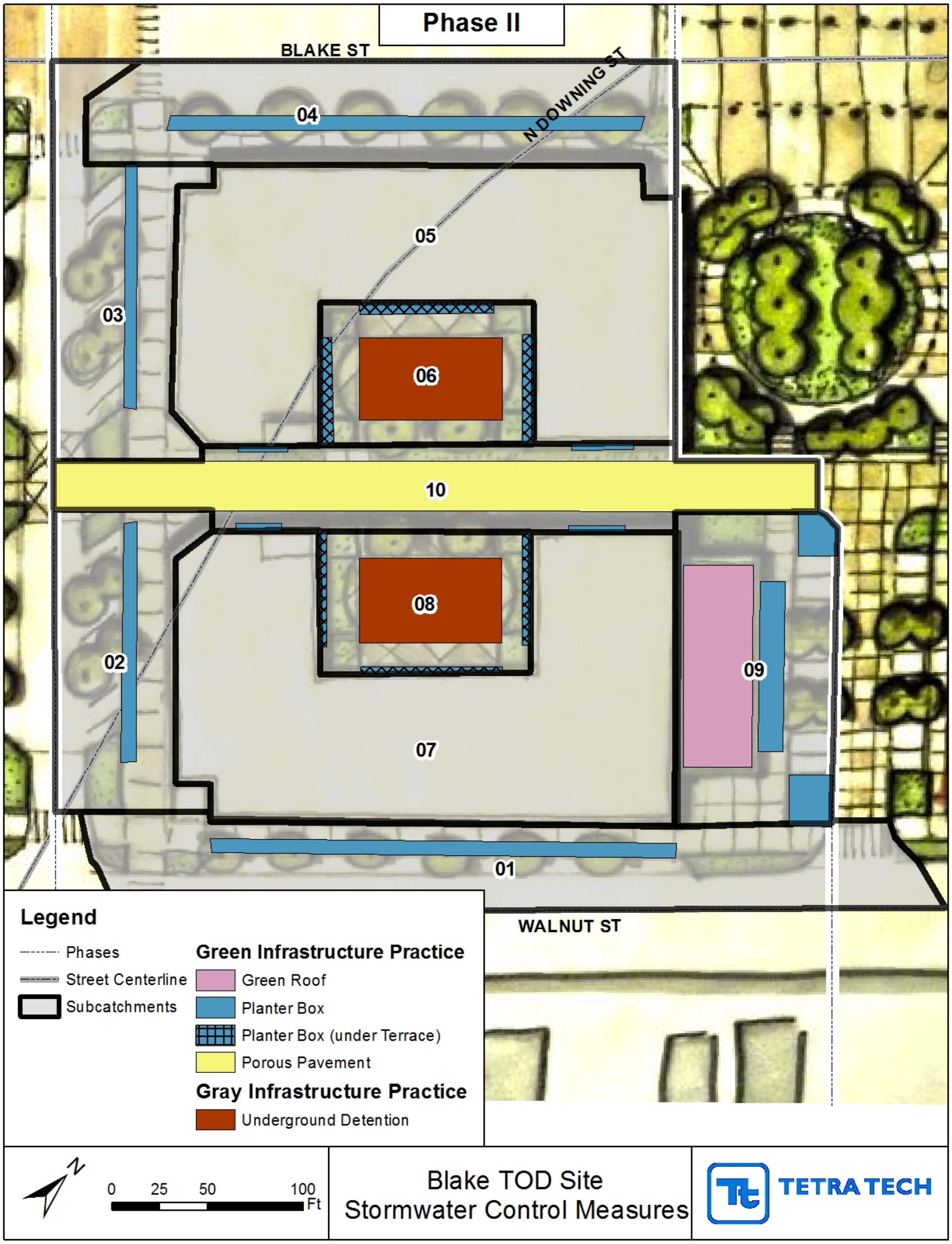

Figure 19. Phase II Stormwater Control Measure Layout.

3. Phase III

Proposed green infrastructure practices for Phase III are similar to Phase II and include a combination of planter boxes, permeable pavement, and green roof. A portion of these practices are not able to contain the full 100-year 2-hour event from each drainage area so underground detention is also provided to supplement these green infrastructure practices.

Planter boxes are used behind the curb along Walnut Street, 36th Street, Blake Street, and the proposed "37th Street" to capture road and sidewalk runoff (Subcatchments 01, 02, 04, 05, and 06). These practices are sized to capture the 100-year 2-hour storm event with discharge to the nearest storm sewers.

Planter boxes are also used to capture just the water quality volume, due to space constraints, from roof and terrace drainage (Subcatchments 07, 08, 09, and 10). Runoff beyond the 1-year 2-hour volume will be directed to underground detention located beneath the parking areas, which are beneath the second floor terraces (Subcatchments 10 and 08). These planter boxes are located adjoined to the building walls, which means that the building walls will need to be waterproofed. As this water is required to be retained on-site, the water will need to infiltrate or evapotranspire. Because of its close proximity to the building, it may be necessary to disperse this water through the aggregate layer beneath the permeable lane or create an additional subsurface infiltration gallery.

Permeable pavement with subsurface aggregate storage is proposed for the lane (Subcatchment 11). There is plenty of subsurface storage within the practice to capture the 100-year 2-hour runoff volume from the lane. The aggregate storage layer depth could be increased to handle discharge from the planter boxes.

Refer to Table 10 and Figure 20 for available water storage volume and placement of the green infrastructure practices, respectively. Table 11 includes the cross-section design for each of the practices.

Table 10. Phase III Green Infrastructure Practice Proposed Location and Sizing.

Subcatch-ment	Green Infrastructure Practice Type	Location	Width (ft)	Length (ft)	Surface Area (sq ft)	Available Water Storage Volume (cu ft)	Overflow Volume to Under-ground Detention (cu ft)
01	Planter Box[1]	Sidewalk	5	286	1,430	3,022	0
02	Planter Box[1]	Sidewalk	4.5	136	612	1,299	0
03	Permeable Pavement	Sidewalk	30	60	1,800	1,080	0
04	Planter Box[1]	Sidewalk	4.5	271	1,220	2,585	0
05	Planter Box[1]	Sidewalk	6	90	540	1,136	0
06	Planter Box[1]	Sidewalk	6	90	540	1,143	0
07[2]	Green Roof, Planter Box[3]	Along building wall	3	215	645	1,362	2,607

Subcatch-ment	Green Infrastructure Practice Type	Location	Width (ft)	Length (ft)	Surface Area (sq ft)	Available Water Storage Volume (cu ft)	Overflow Volume to Under-ground Detention (cu ft)
08	Planter Box[3]	Along building wall	3 3 20	35 35 20	105 105 400	1,276	822
09	Planter Box[3]	Along building wall	3	222	666	1,410	2,670
10	Planter Box[3]	Along building wall	3 3	60 54	180 162	95 95	744
11	Permeable Pavement	Lane	12	375	4,500	2,700	0
				Total	12,900	17,200	6,840

[1] If curbside parking is allowed on this block, pedestrian "bridges" will be needed to cross from the curbside parking to the sidewalk.
[2] The green roof and planter box in Subcatchment 07 treat the water quality volume in parallel prior to draining to the underground detention.
[3] The Green Infrastructure practice treats the 1-yr, 2-hr storm only.

Table 11. Phase III Green Infrastructure Practice Cross-Sections.

Subcatch-ment	Green Infrastructure Practice Type	Location	Ponding Depth (inch)	Engineered Soil Depth (inch)	Aggregate Storage Depth (inch)
01	Planter Box	Sidewalk	8	18	30
02	Planter Box	Sidewalk	8	18	30
03	Permeable Pavement	Sidewalk	0	0	18
04	Planter Box	Sidewalk	8	18	30
05	Planter Box	Sidewalk	8	18	30
06	Planter Box	Sidewalk	8	18	30
07	Planter Box	Along building wall	8	18	30
08	Planter Box	Along building wall	8	18	30
09	Planter Box	Along building wall	8	18	30
10	Planter Box	Along building wall	8	18	30
11	Permeable Pavement	Lane	0	0	18

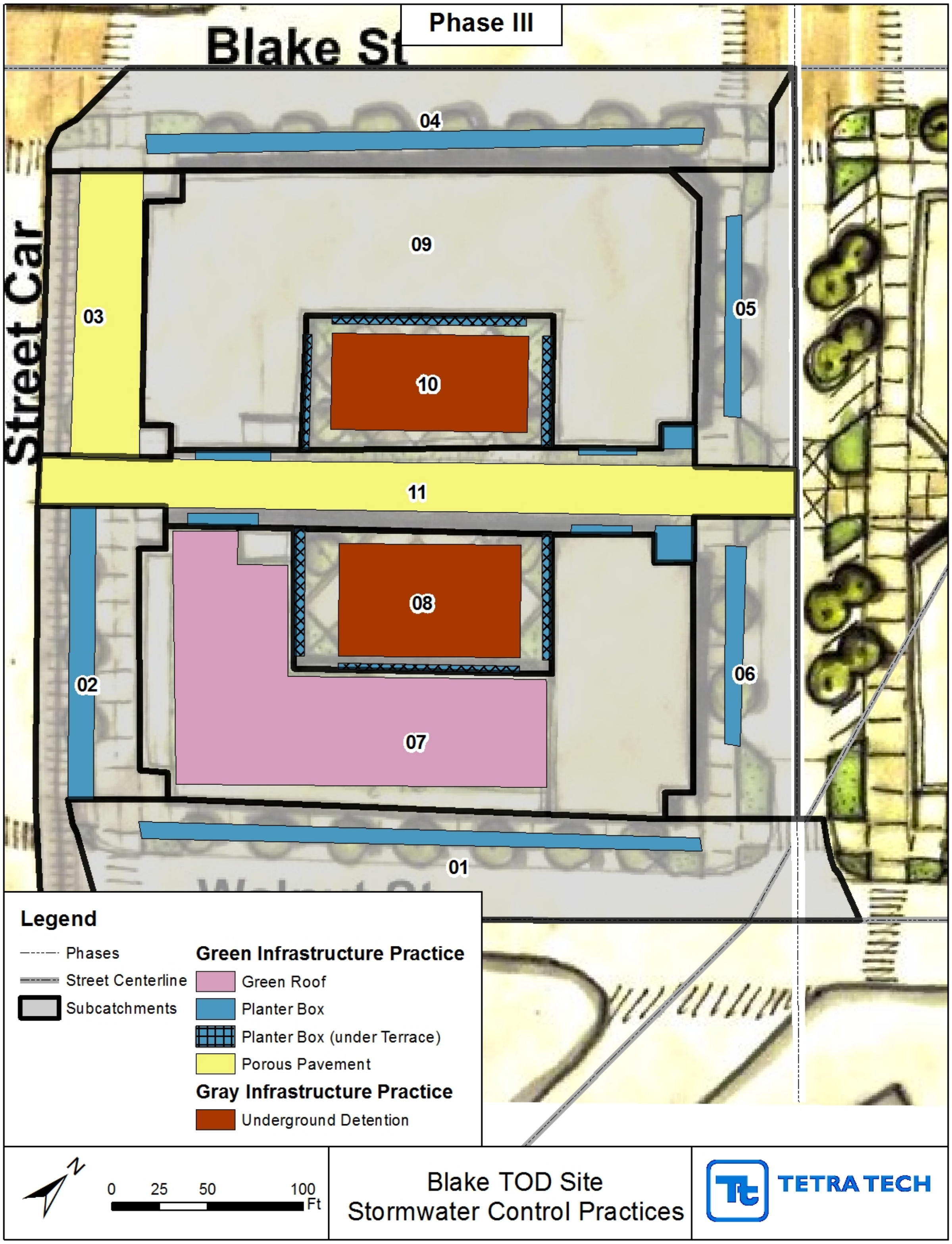

Figure 20. Phase III Stormwater Control Measure Layout.

8. Stormwater Control Measure Technical Specifications

As the Denver Urban Drainage and Flood Control District (UDFCD) Urban Storm Drainage Criteria Manual, Volume 3 contains extensive design information on bioretention practices, permeable pavement, green roofs, and underground best management practices, guidance on these practices is not further addressed in this report.

9. Operations and Maintenance

This section provides recommendations for the maintenance of green and gray infrastructure practices applicable to the conceptual design at the Blake TOD site. Maintenance tasks and the associated frequency of the tasks are included for bioretention, green roof, permeable pavement, and underground detention/retention.

Bioretention

Maintenance activities for bioretention are generally similar to maintenance activities for any garden (Table 12). The focus is to remove trash and monitor the health of the plants, replacing or thinning plants as needed. Over time, a natural soil horizon should develop which will assist in plant and root growth. An established plant and soil system will help in improving water quality and keeping the practice drained. The biological and physical processes over time will lengthen the facility's life span and reduce the need for extensive maintenance. Irrigation for the landscaped practices may be needed, especially during plant establishment periods or in periods of extended drought. Irrigation frequency will depend on the season and type of vegetation. Native plants often require less irrigation than non-native plants.

Table 12. Bioretention Operations and Maintenance Considerations.

Task	Frequency	Maintenance notes
Monitor infiltration and drainage	1 time/year	Inspect drainage time (12 hours). Might have to determine infiltration rate (every 2–3 years). Turning over or replacing the media (top 2–3 inches) might be necessary to improve infiltration (at least 0.5 in/hr).
Pruning	1–2 times/year	Nutrients in runoff often cause bioretention vegetation to flourish.
Mowing	2–12 times/year	Frequency depends on the location, plant selection and desired aesthetic appeal.
Mulching	1–2 times/ year	Recommend maintaining 1”–3” uniform mulch layer.
Mulch removal	1 time/2–3 years	Mulch accumulation reduces available water storage volume. Removal of mulch also increases surface infiltration rate of fill soil.

Task	Frequency	Maintenance notes
Watering	1 time/2–3 days for first 1–2 months; sporadically after establishment	If drought conditions exist, watering after the initial year might be required.
Fertilization	1 time initially	One-time spot fertilization for first year vegetation.
Remove and replace dead plants	1 time/year	Within the first year, 10% of plants can die. Survival rates increase with time.
Inlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow into the retention area is as designed. Remove any accumulated sediment.
Outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for erosion at the outlet and remove any accumulated mulch or sediment.
Underdrain inspection	Once after first rain of the season, then yearly during the rainy season	Check for accumulated mulch or sediment. Flush if water is ponded in the bioretention area for more than 12 hours.
Miscellaneous upkeep	12 times/year	Tasks include trash collection, plant health, spot weeding, and removing mulch from the overflow device.

Green Roof

Similar to bioretention maintenance tasks, monitoring the health of the plants is necessary (Table 13). In areas having a semi-arid climate, such as Denver, it is recommended to install a rooftop irrigation system to use for plant establishment and in times of drought. Green roofs must also be inspected regularly for signs of leaks. The proactive removal of roots, leaves, rocks, and debris from features that penetrate the roof is essential.

Table 13. Green Roof Operations and Maintenance Considerations.

Task	Frequency	Maintenance notes
Inspection of features penetrating roof	3 times per year	Inspect all joints, borders, abutting vertical walls, roof vent pipes, outlets, air conditioning units and perimeter areas. Remove roots, leaves, rocks and debris.
Inspection of drains and rooftop structures	3 times per year and after major storm events	Remove vegetation and debris. Ensure drainage pathways are clear.
Vegetation upkeep	Twice per year in spring and fall	Weed vegetation and remove and replace unsuccessful or diseased plants. Replant bare spots in the soil. Fertilization may also be required.
Irrigation	As needed	Water vegetation as necessary during establishment and drought. Flush out irrigation system before the first winter freeze.

Permeable Pavement

The primary maintenance requirement for permeable pavement consists of regular inspection for clogging and sweeping with a vacuum-powered street sweeper (Table 14). If interlocking concrete permeable pavers are installed, the small aggregate used to fill the void between pavers must be replaced following vacuum sweeping.

Table 14. Permeable Pavement Operations and Maintenance Considerations.

Task	Frequency	Maintenance notes
Impervious to Pervious interface	Once after first rain of the season, then monthly during the rainy season	Check for sediment accumulation to ensure that flow onto the permeable pavement is not restricted. Remove any accumulated sediment. Stabilize any exposed soil.
Vacuum street sweeper	Twice per year as needed	Portions of pavement should be swept with a vacuum street sweeper at least twice per year or as needed to maintain infiltration rates.
Replace fill materials (applies to pervious pavers only)	1-2 times per year (and after any vacuum truck sweeping)	Fill materials will need to be replaced after each sweeping and as needed to keep voids with the paver surface.
Miscellaneous upkeep	4 times per year or as needed for aesthetics	Tasks include trash collection, sweeping, and spot weeding.

Underground Detention/Retention

As underground facilities are out of sight, it is critical to establish regularly scheduled maintenance of these facilities to ensure proper functioning (Table 15). Key maintenance tasks include regular inspection of the inlet and outlet and removal of sediment and debris. Other maintenance tasks may be necessary according to the manufacturer's recommendation.

Table 15. Underground Detention/Retention Operations and Maintenance Considerations.

Task	Frequency	Maintenance notes
Inlet and outlet inspection	Once after first rain of the season, then monthly during the rainy season	Check for debris and sediment accumulation to ensure that flow into and out of the detention/retention facility is as designed. Remove any accumulated debris and sediment using catch basin cleaning equipment (vacuum pumps).
Manufacturer's recommended maintenance.	Variable	Other maintenance duties may be necessary depending on the type and manufacturer of the underground detention/retention system.

10. Stormwater Control Measure Cost Estimates

Estimated costs for green and gray infrastructure proposed at the Blake TOD site are included in the tables in this section. Table 16, Table 17, and Table 18 include costs for green and gray infrastructure for Phase I, Phase II, and Phase II, respectively. The costs are for the construction of stormwater control measures and do not account for site preparation, mobilization, utility removal/rerouting, soil erosion control measures during construction, or any costs that would be part of the overall site development. It is also assumed that all construction is new and not retrofit.

When considering the cost of green infrastructure practices using the totals below, note that the costs for some of the materials would, to a certain extent, be incurred regardless of whether the practice were installed or not. For example, in locations where permeable pavement is installed, such as in the sidewalk and lane, a pavement type would have had to be installed if the permeable pavement were not. Because of this and because the many indirect monetary benefits often associated with green infrastructure were not included in the cost estimate, these costs should not be used to directly compare green and gray infrastructure costs. Indirect monetary benefits may include a decrease in energy use due to a green roof or shade tree, reduction of air pollution due to trees, and increase in the value of real estate due to aesthetics. Refer to "The Value of Green Infrastructure" developed by the Center for Neighborhood Technology and American Rivers for more information regarding the indirect benefits of green infrastructure (CNT, 2010).

Table 16. Phase I Cost Estimate.

Item No	Description	Quantity	Unit	Unit Cost	Total
GREEN INFRASTRUCTURE					
	Traditional Bioretention				
1	Fine Grading	5710	SF	$0.72	$4,111
2	Excavation (includes hauling)	540	CY	$10	$5,405
3	Soil Media	180	CY	$40	$7,205
4	Filter Layer (sand and No. 8 stone)	48	CY	$45	$2,177
5	Drainage Layer (Open graded aggregate)	242	CY	$50	$12,111
6	Underdrains (4" perforated PVC pipe)	600	LF	$5.50	$3,300
7	Outlet Control Structure (24-inch catch basin)	5	EA	$1,000	$5,000
8	Cored opening, 4-inch	2	EA	$500	$1,000
9	Native Seed	5710	SF	$1.11	$6,338
10	Mulch	53	CY	$45	$2,379
11	Cleanout, PVC	5	EA	$70	$350
	SCM Sub-Total Cost				$49,377
	Planter Box				
12	Fine Grading	3754	SF	$0.72	$2,703
13	Excavation (includes hauling)	649	CY	$10	$6,488
14	Vertical Concrete Curb1	1253	LF	$15	$18,792
15	Soil Media	209	CY	$40	$8,342
16	Filter Layer (sand and No. 8 stone)	46	CY	$45	$2,085

Item No	Description	Quantity	Unit	Unit Cost	Total
17	Drainage Layer (Open graded aggregate)	348	CY	$50	$17,379
18	Underdrains (4" perforated PVC pipe)	750	LF	$5.50	$4,125
19	Outlet Control Structure (24-inch catch basin)	8	EA	$1,000	$8,000
20	Cored opening, 4-inch	4	EA	$500	$2,000
21	Native Seed	3754	SF	$1.11	$4,167
22	Mulch	35	CY	$45	$1,564
23	Cleanout, PVC	8	EA	$70	$560
	SCM Sub-Total Cost				$76,206
	Green Roof				
24	Green Roof (extensive) (includes waterproofing, modular system, irrigation, and 2 years of maintenance)	2358	SF	$20	$47,160
Sub-total Cost					**$172,742**
	Construction contingency (20% of subtotal)				$34,548
Total Cost					**$208,000**

[1] When planter boxes are installed adjacent to infrastructure such as roads and buildings, it is necessary to provide separation between the road or building subsoils and the planter box soils. Use of a 2-foot deep vertical concrete curb is common, but a geotechnical investigation is necessary in the planter box locations to determine if expansive soils exist. If expansive soils exist, an impermeable barrier to the bottom of the planter box facility may be warranted.

Table 17. Phase II Cost Estimate.

Item No	Description	Quantity	Unit	Unit Cost	Total
GREEN INFRASTRUCTURE					
	Planter Box				
1	Fine Grading	4,804	SF	$0.72	$3,459
2	Excavation (includes hauling)	830	CY	$10	$8,304
3	Vertical Concrete Curb[1]	2,023	LF	$15	$30,351
4	Soil Media	267	CY	$40	$10,676
5	Filter Layer (sand and No. 8 stone)	59	CY	$45	$2,669
6	Drainage Layer (Open graded aggregate)	445	CY	$50	$22,242
7	Underdrains (4" perforated PVC pipe)	1,300	LF	$5.50	$7,150
8	Outlet Control Structure (24-inch catch basin)	4	EA	$1,000	$4,000
9	Cored opening, 4-inch	5	EA	$500	$2,500
10	Native Seed	4,804	SF	$1.11	$5,333
11	Mulch	44	CY	$45	$2,002
12	Cleanout, PVC	9	EA	$70	$630
	SCM Sub-Total Cost				$99,316
	Permeable Pavement				
13	Permeable Pavement	3,600	SF	$12	$43,200
14	Excavation (includes hauling)	200	CY	$10	$2,000

Item No	Description	Quantity	Unit	Unit Cost	Total
15	Bedding Layer (washed No. 8 stone, 3 inches)	33	CY	$40	$1,333
16	Base Layer (washed No. 56 aggregate)	200	CY	$50	$10,000
17	Concrete Transition	624	LF	$4	$2,496
18	Underdrains (4" perforated PVC pipe)	314	LF	$5	$1,570
19	Cored opening, 4-inch	1	EA	$500	$500
20	Cleanout, PVC	3	EA	$70	$210
	SCM Sub-Total Cost				$61,309
	Green Roof				
21	Green Roof (extensive) (includes waterproofing, modular system, irrigation, and 2 years of maintenance)	3,133	SF	$20	$62,660
GRAY INFRASTRUCTURE					
	Underground Detention/Retention				
22	Triton Stormwater Solutions Chambers (includes labor and material costs)	8,400	CF	$9	$75,600
	New Storm Sewer in Lane				
23	12-inch RC Pipe (includes Exc. and backfill)	314	LF	$65	$20,410
24	48-inch Manholes (includes Exc. and backfill)	3	EA	$2,600	$7,800
	SCM Sub-Total Cost				$28,210
	Sub-total Cost				**$327,096**
	Construction contingency (20% of subtotal)				$65,419
	Total Cost				**$393,000**

[1] When planter boxes are installed adjacent to infrastructure such as roads and buildings, it is necessary to provide separation between the road or building subsoils and the planter box soils. Use of a 2-foot deep vertical concrete curb is common, but a geotechnical investigation is necessary in the planter box locations to determine if expansive soils exist. If expansive soils exist, an impermeable barrier to the bottom of the planter box facility may be warranted.

Table 18. Phase III Cost Estimate.

Item No	Description	Quantity	Unit	Unit Cost	Total
GREEN INFRASTRUCTURE					
	Planter Box				
1	Fine Grading	4,735	SF	$0.72	$3,409
2	Excavation (includes hauling)	818	CY	$10	$8,184
3	Vertical Concrete Curb1	2,201	LF	$15	$33,020
4	Soil Media	263	CY	$40	$10,522
5	Filter Layer (sand and No. 8 stone)	58	CY	$45	$2,630
6	Drainage Layer (Open graded aggregate)	438	CY	$50	$21,921
7	Underdrains (4" perforated PVC pipe)	1,300	LF	$5.50	$7,150
8	Outlet Control Structure (24-inch catch basin)	4	EA	$1,000	$4,000
9	Cored opening, 4-inch	5	EA	$500	$2,500

Item No	Description	Quantity	Unit	Unit Cost	Total
10	Native Seed	4,735	SF	$1.11	$5,256
11	Mulch	44	CY	$45	$1,973
12	Cleanout, PVC	9	EA	$70	$630
	SCM Sub-Total Cost				$101,195
	Permeable Pavement				
13	Permeable Pavement	5,510	SF	$12	$66,120
14	Excavation (includes hauling)	350	CY	$10	$3,500
15	Bedding Layer (washed No. 8 stone, 3 inches)	51	CY	$40	$2,041
16	Base Layer (washed No. 56 aggregate)	306	CY	$50	$15,306
17	Concrete Transition	1,022	LF	$4	$4,088
18	Underdrains (4" perforated PVC pipe)	504	LF	$5	$2,520
19	Cored opening, 4-inch	2	EA	$500	$1,000
20	Cleanout, PVC	3	EA	$70	$210
	SCM Sub-Total Cost				$94,784
	Green Roof				
21	Green Roof (extensive) (includes waterproofing, modular system, irrigation, and 2 years of maintenance)	14,900	SF	$20	$298,000
GRAY INFRASTRUCTURE					
	Underground Detention/Retention				
22	Triton Stormwater Solutions Chambers (includes labor and material costs)	8,050	CF	$9	$72,446
	New Storm Sewer in Lane				
23	12-inch RC Pipe (includes Exc. and backfill)	384	LF	$65	$24,960
24	48-inch Manholes (includes Exc. and backfill)	3	EA	$2,600	$7,800
	SCM Sub-Total Cost				$32,760
Sub-total Cost					**$599,185**
	Construction contingency (20% of subtotal)				$119,837
Total Cost					**$720,000**

[1] When planter boxes are installed adjacent to infrastructure such as roads and buildings, it is necessary to provide separation between the road or building subsoils and the planter box soils. Use of a 2-foot deep vertical concrete curb is common, but a geotechnical investigation is necessary in the planter box locations to determine if expansive soils exist. If expansive soils exist, an impermeable barrier to the bottom of the planter box facility may be warranted.

11. Conclusions

The conceptual stormwater management design developed for the Blake Transit Oriented Development site demonstrates how green infrastructure approaches can complement smart growth principles - providing innovative stormwater management while accommodating infill, transit oriented development.

The Blake TOD site is an assemblage of six properties in Denver's Five Points neighborhood acquired by the Urban Land Conservancy with the goal of providing affordable homes close to a major transit line. The site is several blocks from the South Platte River, and less than one block from the first station along the planned East Corridor Commuter Rail Line. Recognizing the opportunity to achieve multiple environmental and livability goals by addressing green infrastructure early in the planning process, the Urban Land Conservancy sought technical assistance from EPA. Based on the project and design goals, an EPA team developed a conceptual stormwater management design that would complement and enhance the planned transit-oriented development.

The final conceptual design achieved the project goals of improving drainage, water quality, and aesthetic appeal with a combination of bioretention, permeable pavement, green roofs, and detention storage. In conventional redevelopment projects, peak flow requirements are met by installing single-purpose gray infrastructure controls (typically underground detention vaults). The conceptual design developed for this project, in contrast, used multi-functional green infrastructure techniques to provide some peak flow control, improve water quality, and add amenities to the site. The conceptual design includes:

- Bioretention practices on the private site as well as within the public right-of-way
- Permeable pavement in the "lane" between buildings and within the sidewalk
- Green roofs to capture and treat stormwater in locations accessible to residents

As cities and towns seek to revitalize historic neighborhoods and redirect growth into existing urban areas, green infrastructure can complement redevelopment efforts. In addition to meeting stormwater management goals, this conceptual design illustrates how green infrastructure can help create a more attractive and livable landscape that weaves functional natural elements into the built environment.

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