Appendix 6-4

Green Infrastructure Evaluation of Terre Haute CSO 009 Drainage Basin

Green Infrastructure Evaluation of Terre Haute CSO 009 Drainage Area

Prepared for:
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EXECUTIVE SUMMARY

LimnoTech completed an evaluation of green infrastructure retrofit potential in the CSO 009 (Chestnut CSO) drainage area, in the City of Terre Haute, on behalf of Hannum, Wagle & Cline (HWC). This work was completed to evaluate the potential for green infrastructure to reduce the size of gray infrastructure control measures for overflow reduction as part of the City of Terre Haute's long term control plan (LTCP). The goal of this evaluation was to identify potential green infrastructure retrofits in Terre Haute's CSO-009 drainage area, estimate the cost of those retrofits and assess their benefit in terms of storm water volume capture.

Based on this evaluation, it was found that there are widespread opportunities for green infrastructure implementation in the CSO 009 drainage area. These opportunities are more prominent in part of the drainage area occupied by the Indiana State University (ISU) campus, as compared to other areas occupied mainly by single family residences. On the ISU campus, the large impervious areas created by large buildings, surface parking lots, and streets present a variety of green infrastructure retrofit opportunities. Controlling stormwater runoff from these impervious areas can potentially have significant impact on reducing wet weather flows from the drainage area. In addition, large athletic fields, in combination with permeable soils, present a unique opportunity for construction of infiltration beds that can provide large stormwater storage volume without compromising the primary use of the fields.

Conceptual designs are presented in this report to illustrate several green infrastructure retrofit opportunity types. Extrapolating the storage volume and cost estimates for these conceptual designs to the overall campus area provides estimates of the total potential cost and benefit of green infrastructure in the CSO 009 drainage area. The total estimated storage volume that could potentially be provided by green infrastructure retrofits on the campus alone, assuming 100% buildout, is 6.2 million gallons, which is more than sufficient to store all runoff from the 1.0" rainfall event. The total estimated cost for complete green infrastructure buildout is $16.1 million, which yields an estimated unit storage cost of $2.60/gallon.

While it is unlikely that 100% implementation of green infrastructure retrofits can be achieved on the ISU campus, these estimates clearly show that significant stormwater storage potential exists for even partial implementation. This storage potential can be further enhanced by extending green infrastructure retrofits in other parts of the CSO 009 drainage area, including the predominantly residential area to the east. Based on these estimates, it appears possible that green infrastructure implementation in the CSO 009 drainage area can provide equivalent storage to offset the need for millions of gallons in storage tank volume.

1. BACKGROUND

CSO-009 (a.k.a. Chestnut CSO) has been identified by Hannum, Wagle & Cline (HWC) as a potential candidate for implementation of green infrastructure to reduce the size of gray infrastructure control measures for overflow reduction as part of the City of Terre Haute's long term control plan (LTCP). CSO-009 is estimated to have a "typical year" overflow volume of 74 million gallons (MG) from 30 overflow events. HWC estimates that a level of control (LOC) of four overflows per year could be achieved, in conjunction with planned gray infrastructure controls, if sufficient wet weather flow can be managed in CSO-009 through green infrastructure. Specifically, gray infrastructure controls for CSOs 009 and 010 would involve surface storage of 6 MG in a series of three tanks of 2 MG each. The storage capacity of green infrastructure in the CSO-009 drainage area should be compared to these tank volumes as a measure of the effectiveness of green infrastructure.

The goal of this evaluation was to identify potential green infrastructure retrofits in Terre Haute's CSO-009 drainage area, estimate the cost of those retrofits and assess their benefit in terms of storm water volume capture. This memo presents the findings of the CSO-009 green infrastructure evaluation, which also included development of conceptual designs to illustrate green infrastructure implementation on each of the major types of impervious surfaces in the CSO-009 drainage area. Planning-level cost estimates for these conceptual designs and estimated hydrologic benefits were also prepared. These costs and benefits were extrapolated to formulate estimates of overall benefit and cost for theoretical widespread green infrastructure implementation in the CSO-009 drainage area.

2. STUDY AREA CHARACTERISTICS

2.1 LAND USE

Land use in the CSO-009 drainage area is almost 100% developed (Figure 1), with medium intensity developed being the dominant land use at 42% of the area. Medium intensity developed is followed by low intensity developed (34%), high intensity developed (14%), open space developed (10%), and evergreen forest (less than 1%). Land use in the CSO-009 drainage area is mostly associated with the Indiana State University campus, which is highly developed and accounts for roughly 60 percent of the total area.

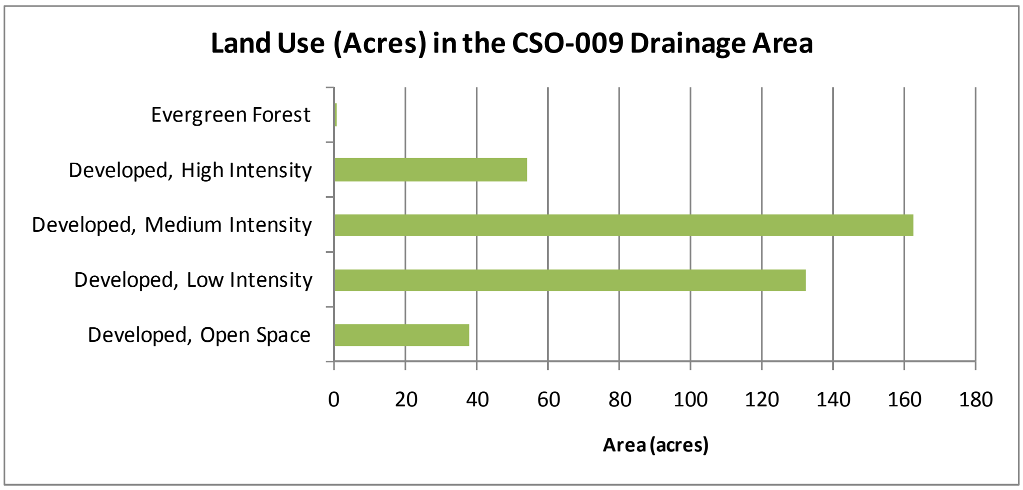

Figure 1. Summary of Land Use in the CSO-009 Drainage Area

2.2 SOILS

Over 99 percent of the soils in the CSO-009 drainage area are classified as hydrologic group A. Group A soils are classified as having low runoff potential. They typically consist of greater than 90 percent sand and/or gravel and less than 10 percent clay. These types of soils are most favorable for green infrastructure installation because they allow stormwater to infiltrate into soils instead of running off.

A very small region in the southeast corner of the CSO-009 drainage area is characterized as having group B soils. Hydrologic group B soils are classified as having moderately low runoff potential. They typically consist of between 10 and 20 percent clay and between 50 and 90 percent sand and/or loam. Group B soils are not as favorable as group A soils for stormwater infiltration, but they are certainly not unfavorable. The area of group B soils is about 2.2 acres, or only about 0.6 percent of the total CSO-009 drainage area.

2.3 IMPERVIOUSNESS

Spatial data for impervious surfaces did not exist for the CSO-009 drainage area prior to this project. Using 2010 aerial imagery, LimnoTech developed GIS layers for paved roads, paved surface parking, and building rooftops to characterize and quantify the major types of impervious surfaces.

Rooftops and paved parking account for roughly the same total area, with paved roads not far behind. Surface parking leads the impervious area total, at about 18 percent of the total drainage area. Rooftops account for 17 percent of the impervious area in the CSO-009 drainage area, and paved roads account for 13 percent (Figure 2). Together, these three categories account for 48 percent of the total CSO-009 drainage area.

It is important to note that residential driveways, paved athletic tracks, athletic fields, and sidewalks were not included here because their impervious area contributions were relatively small compared to these three categories. This observation suggests that targeting rooftops, paved roadways, and paved surface parking will provide the greatest green infrastructure opportunity.

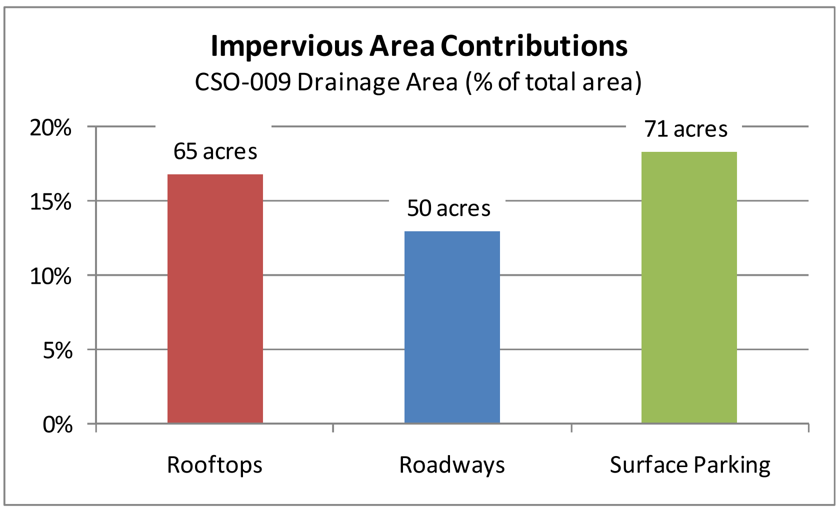

Figure 2. Impervious Area Composition in CSO-009 Drainage Area

2.4 CAMPUS VS. BUSINESS/RESIDENTIAL AREAS

The Indiana State University Campus in Terre Haute covers an area greater than 200 acres and accounts for a little over 50 percent of the total land surface in the CSO-009 drainage area. The campus area can be characterized as highly developed, with approximately 38 acres of rooftops, 43 acres of paved parking, and 25 acres of paved roads; together, these three impervious surface types account for about one-half of the total campus area. The non-campus portion of the CSO-009 drainage area accounts for about 47 percent of the land area and consists of about 30 acres each of rooftops and parking, and 25 acres of paved roads.

For design purposes, rainfall depths of 0.6 inch and 1 inch were selected (see section 5.1 for more information). During each of these storms, impervious areas on the ISU campus are estimated to generate about 1.75 million gallons and 2.84 million gallons of stormwater runoff, respectively. Impervious surfaces on the non-campus area are estimated to generate 1.4 million gallons in a 0.6-inch storm and 2.3 million gallons in a 1-inch storm. Table 1 presents a direct comparison of the campus and non-campus areas in terms of land use, imperviousness, and runoff.

Although the campus and non-campus areas of the CSO-009 drainage area are both highly impervious and both produce large runoff volumes in large rainfall events, the ISU campus is more favorable for green infrastructure installation, primarily because of the relative distribution of impervious surfaces; the ISU campus consists of many large parking lots and large rooftops, which allow for more efficient and cost-effective green infrastructure installation. In comparison, the non-campus area consists of many small, widespread impervious surfaces. Implementing green infrastructure there would not be as efficient and cost-effective, and technologies would need to be installed at many smaller sites to have the same impact as a single large site.

Attachment A presents a map of the CSO-009 drainage area, including locations of impervious areas and of the Indiana State University campus.

Table 1. Comparison of Campus vs. Non-Campus Areas in the CSO-009 Drainage Area

	Campus	**Non-Campus**
Total Area	Acres	Acres
Land Area	202.9	183.5
Land Use	Acres	Acres
Developed, Open Space	24.7	13.1
Developed, Low Intensity	70.9	61.4
Developed, Medium Intensity	89.2	73.4
Developed, High Intensity	16.0	38.3
Evergreen Forest	0.9	0.0
Imperviousness	Acres	Acres
Rooftops	37.8	30.3
Surface Parking	42.8	30.0
Streets	25.1	25.2
Total Imperviousness	105.7	85.5
Runoff Volume	MG	MG
0.6-inch rainfall	1.75	1.42
1.0-inch rainfall	2.84	2.30

3. APPLICABLE GREEN INFRASTRUCTURE TECHNOLOGIES

Based on the review and evaluation of land characteristics of the CSO-009 drainage area presented in the preceding section, a recommended list of green infrastructure technologies was developed for potential use in this evaluation. The technologies described below were determined to be the most feasible for the CSO-009 drainage area, given the land use types and composition of impervious areas.

3.1 ROOFTOP STORMWATER MANAGEMENT

Buildings account for about 17 percent of impervious surface in the CSO-009 drainage area. This high percentage suggests that targeting rooftops could potentially have a significant impact on stormwater runoff reduction.

3.1.1 Green Roofs

More than half of the rooftop area in the CSO-009 drainage area is located on the Indiana State University campus. One commonly cited technology for controlling rooftop runoff is green roofs. Where it is structurally feasible, large, relatively flat roofs can be retrofitted to accommodate growth media and vegetation to provide stormwater storage and runoff reduction benefits. This practice has been successfully implemented in many cities, although the practice is not yet widespread.

In some reported cases, green roofs were able to retain as much as 100 percent of the rainfall volume from typical storms while dramatically reducing overall site imperviousness. Other measured benefits of green roofs include increased energy efficiency, increased roof lifespan, sound insulation, reduced heat island effect in urban areas, improved air quality, improved stormwater quality, and increased habitat. Storage capacity of green roofs depends on the design of the roof and on the nature of the rainfall event.

Although proven successful on a site scale, large-scale implementation of green roofs has not been accomplished and may be impractical for several reasons including:

- Cost – Green roof retrofits can potentially be expensive design options when additional structural integrity needs to be built into existing roofs to support the weight of the roof.
- Lack of incentives – Building owners, particularly private building owners, may be reluctant to invest in retrofitting existing buildings because there are no (or insufficient) financial incentives in place.
- Structural limitations – Older buildings may be structurally insufficient to support the additional weight of a green roof and green roofs are typically not used for steep roofs. Many buildings on the ISU campus are more than 100 years old.

In spite of these limitations, the technology is rapidly becoming a proven method of controlling rooftop runoff where feasible. Although the limitations above may prevent green roofs from being the sole means of effectively controlling stormwater from building rooftops, they can be a valuable component of an overall strategy and should be considered.

The type of green roof installed will depend on the integrity of the existing roof and the desired level of both performance and maintenance. Extensive green roofs are lighter weight and feature a thinner layer (typically six inches thick or less) of growing medium than intensive green roofs. Extensive roofs are designed with the purpose of maximizing environmental benefits and are often not designed with public access in mind. Alternatively, intensive green roofs typically feature a thicker growing medium, a wider variety of plants, and are often designed as amenity spaces accessible by the public. Intensive green roofs are heavier and often require irrigation systems.

3.1.2 Cisterns

An alternative method of rooftop stormwater management is the use of cisterns, which are large storage tanks typically constructed of steel, polyethylene, fiberglass, or concrete, installed adjacent to buildings, either above or below ground. Rooftop runoff is directed into a cistern, where it is stored to be used for irrigation or other purposes, such as car washing or even toilet flushing. Cisterns can also be designed to slowly infiltrate captured water back into the soil. Cisterns are typically meant for large scale stormwater control (i.e. large buildings as opposed to individual homes) and can be designed with a capacity of thousands to hundreds of thousands of gallons. A small scale version of the cistern, the rain barrel, is discussed in section 3.5.2.

Cisterns are most effective for small storms, but can be designed to accommodate large events as well. For example, a rainfall depth of one inch falling on a one-acre roof will produce over 27,000 gallons of stormwater runoff. Multiple cisterns may be needed to completely capture events such as this or larger.

3.2 BIORETENTION

Bioretention refers to areas that are planted with vegetation and are usually excavated slightly below grade to capture and temporarily store stormwater runoff. Existing unpaved areas such as lawns, public spaces, and commercial landscaping can be retrofitted with bioretention areas, and new bioretention can also be created in currently paved areas. Where underlying soils are not suitable for completely infiltrating stormwater, the runoff can be managed through evaporation, plant transpiration, and supplemental underdrains to convey stormwater to sewers after temporary storage. This technology can, in many cases, be effectively used to manage runoff from rooftops, as well as streetscapes and parking areas.

3.2.1 Rain Gardens

Rain gardens are most commonly designed for residential use, although larger installations have been used in commercial or institutional settings. These are vegetated depressions that provide stormwater capture and temporary storage. Residential roof downspouts are often directed to this type of bioretention area.

3.2.2 Bioretention Islands and Bioswales

Bioretention islands and bioswales can be suitable retrofits in virtually any highly impervious area, depending on site conditions. The biggest consideration for employing these practices is that there is adequate space. These features are installed adjacent to buildings, parking lots, and/or roadways to collect and temporarily store runoff. Bioretention has advantages and many potential applications for urban retrofits like CSO-009 drainage area and ISU campus, including:

- Bioretention is a very scalable technology, suitable for a range of site sizes. The primary limitation on applying bioretention is the availability of adequate space.
- Bioretention can be constructed as a single area or a number of smaller areas, and can be designed to fit various shapes and contours.
- Bioretention can be implemented to capture runoff from any type of impervious surface.
- Bioretention can improve aesthetics by increasing green space.

The primary concern with retrofitting a site for bioretention, as mentioned above, is the availability of space. The bioretention retrofit must capture and temporarily store runoff from a certain storm magnitude, so the larger the site, the greater the runoff volume and the larger the required size of the bioretention.

3.3 PERMEABLE PAVEMENT

Surface parking represents the largest area of paved surface in the CSO-009 drainage area. Most of the paved parking lots are located on the ISU campus. Large parking lots such as those found on the ISU campus typically drain directly to storm sewers, contributing large volumes of runoff to the system and in turn to local waterways.

Unused or underused parking in relatively remote parts of these lots can be readily converted to bioretention. The conversion of existing parking areas to bioretention has a double benefit of reducing overall imperviousness and providing the means to manage runoff from remaining impervious areas.

A relatively new strategy for parking lot stormwater management that is seeing increasing use is the installation of permeable pavement. Permeable pavement can consist of pavers and/or porous media that allow stormwater to infiltrate into the underlying soil and be collected by an underdrain system or storage/infiltration bed, rather than running off directly to storm sewers.

Permeable pavement can be used to supplement bioretention in parking areas, provided that target areas do not experience heavy traffic volumes or that they are not used by heavy weight vehicles, as this could damage the permeable pavement structure. A common application for permeable pavement is parking stalls, which experience less use than parking lot entrances/exits and aisles.

3.4 INFILTRATION

While infiltration beds are often coupled with permeable pavement, as described in section 3.3, they also have other applications. Infiltration (or storage) beds can be installed beneath existing pervious areas to improve their infiltration capacity and reduce stormwater runoff. A common application for infiltration beds on university campuses is to install them beneath athletic fields. They consist of a coarse gravel layer overlain by a geotextile fabric and topped by either natural or artificial turf. Section 8 outlines a case study of an athletic field renovation that includes an infiltration bed at the University of North Carolina at Chapel Hill.

3.5 SMALL-SCALE GREEN INFRASTRUCTURE

Although small-scale green infrastructure technologies are typically not suitable for widespread stormwater management, they can be used in localized, highly impervious, space constrained areas to provide both local stormwater control and aesthetic benefits.

3.5.1 Tree Box Filters and Bioretention Planters

Tree box filters (Figure 3) are a means of capturing, storing, and infiltrating runoff in places that are highly impervious and where space is extremely limited. They can be used for all types of development in any soil condition. Since the filter is contained in a concrete box and completely sealed it can be built in and around roadways, sidewalks, buildings, and parking lots. A limitation of tree box filters is that they can typically only manage runoff from small areas.

Bioretention planters serve a similar function as tree boxes filters and are best suited for highly impervious areas with limited space for green infrastructure. Bioretention planters typically consist of an impervious reservoir with about 18 inches of soil and an underdrain system. As the name suggests, these small-scale stormwater management systems are planted with appropriate vegetation to assist in treatment, absorption, and evaporation of stormwater runoff.

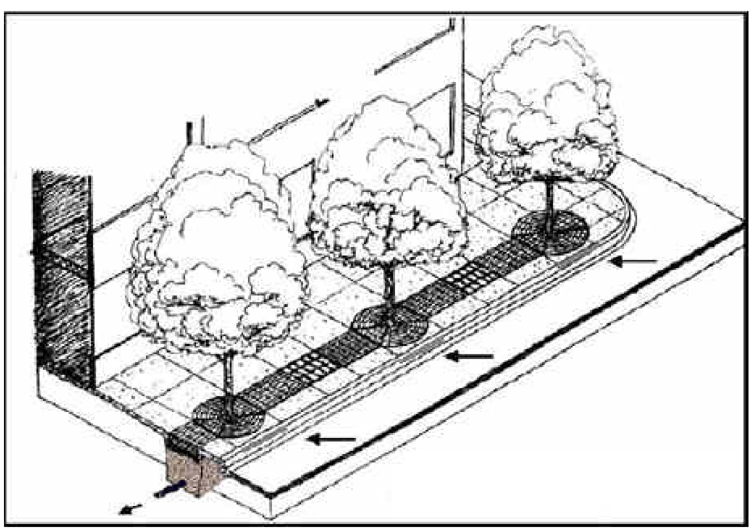

Figure 3. Tree Box Filter Schematic (Source: http://www.lid-stormwater.net)

An example bioretention application in a roadway could be vegetated curb extensions. These are features installed along the curbs of roadways that protrude outward. Gaps are created in the curbs to allow roadway runoff to enter the extensions, where a vegetated bed temporarily retains and infiltrates stormwater.

3.5.2 Rain Barrels

A small-scale version of the cistern (section 3.1.2) is the rain barrel. While cisterns are typically hundreds to thousands of gallons in capacity, rain barrels typically range from 50 to 250 gallons. Rain barrel programs have been implemented in many cities to manage stormwater runoff from residential rooftops. Precipitation is temporarily stored in the barrels and released slowly to sewers, underlying soils, or used on-site for irrigation or car washing.

Rain barrels are typically used in residential areas, particularly in conjunction with disconnection of downspouts from sewers. Programs using these techniques are sometimes referred to as rain water harvesting programs. Rain barrel subsidy programs allow homeowners to purchase rain barrels at reduced cost and some programs offer sewer rate reduction incentives for homeowner participation.

Rain barrels may not be feasible for the CSO-009 drainage area; only a small portion of the area appears to have residential homes. Most of the rooftops in the area are quite large and belong to businesses or are part of the ISU campus.

4. CSO 009 GREEN INFRASTRUCTURE OPPORTUNITY IDENTIFICATION

The green infrastructure opportunity identification for the CSO-009 drainage area included identification of the types of green infrastructure that may be feasible, the extent to which green infrastructure can be implemented, and the potential benefits.

As explained in section 2.3, three types of impervious surfaces were delineated: rooftops, surface parking, and roadways. Attachment A is a map showing the locations of these three impervious surface types in the CSO-009 drainage area. For the opportunity identification, each surface type was examined in GIS using 2010 aerial imagery to identify (1) the types of green infrastructure that may be feasible for controlling runoff from the surface, and (2) potential limitations to installing green infrastructure at the target location. A wide range of spatial data supplemented the analysis, including surrounding transportation corridors, soils, and land use, for example. The green infrastructure technologies evaluated for each of the three classes of assessed impervious surfaces include:

- Rooftops:
    - green roof (intensive or extensive)
    - cistern(s) (direct roof drainage to cisterns)
    - bioretention (direct roof drainage or cisterns to bioretention)
- Surface Parking:
    - permeable pavement
    - bioretention islands
    - bioswales adjacent to parking areas
    - tree box filters
    - bioretention planters
- Roadways:
    - tree box filters
    - bioretention planters (i.e. along roadsides, vegetated curb extensions, etc.)

While completing a more detailed evaluation of the CSO-009 drainage area, an additional surface type was identified as being suitable for green infrastructure implementation: athletic fields. Athletic fields are prominent on the Indiana State University campus. Although their total imperviousness is lower than the other surface types, they should be considered because they comprise large areas, are often surrounded by impervious surfaces, and can still contribute large quantities of stormwater runoff. The following green infrastructure technologies were determined to be appropriate for athletic fields:

- Athletic fields:
    - subsurface infiltration bed
    - cisterns (above or below ground)

The specific type(s) of green infrastructure most suitable for each impervious surface type can vary greatly depending on overall site imperviousness, land use, available space, underlying soils, slope, and depth to groundwater, as well as other factors. In section 8, a green infrastructure implementation example is described for each type of impervious surface (rooftop, parking lot, roadway, and athletic field), with detailed conceptual designs presented in Attachment B.

4.1 CONTROLLING ROOFTOP RUNOFF

Stormwater runoff from rooftops can be more difficult to manage than for other impervious surface types, such as streets and parking lots. While streets and parking lots are constructed directly on top of soils, roofs do not have this advantage. Precipitation falling on rooftops must somehow be retained on site, or directed to another location for storage. For this reason, rainwater harvesting is a common green infrastructure technology applied to rooftops. Rainwater harvesting includes practices where rainfall and runoff from a surface are captured in storage (i.e. cisterns, see section 3.1.2) and then re-used later for purposes such as irrigation.

A second green practice associated with rooftops is the green roof, as described in section 3.1.1, whereby rainfall is directly infiltrated and/or retained on the roof by a soil layer and vegetation that is actually growing on the roof. A green roof alone typically does not provide sufficient storage to capture large (i.e. 10-year) rainfall events. However, installing a substrate that is at least four inches thick and properly selected vegetation can completely capture all rainfall events up to a 1-inch storm and in some cases greater.

A third green practice used to manage stormwater from roof tops is bioretention. In this case, rooftop drainage is directed to bioretention areas near the building. This is typically not a feasible application for large rooftops, where larger than typical rainfall events could easily overwhelm small bioretention areas. Instead, bioretention could be paired with another technology such as a green roof to help manage areas of the roof not served by a green roof, or to provide additional storage for larger events.

Section 5.2 presents a conceptual design for managing rooftop runoff.

4.2 CONTROLLING SURFACE PARKING RUNOFF

Surface parking lots are attractive candidates for green infrastructure implementation because they can cover large areas, contributing greatly to stormwater runoff. They may also be more favorable than streets for green practices because they typically do not experience as much loading due to lighter traffic. Two common technologies for controlling parking lot runoff include permeable pavement and various types of bioretention.

As described in section 3.3, permeable pavement is often installed in parking stalls rather than aisles due to less active traffic. Permeable (or pervious, porous) pavements come in all shapes, sizes, and materials and at a wide range of costs. Some of the more common materials include porous asphalt and concrete pavers. With favorable soils or an infiltration bed underneath, permeable pavement has been reported to infiltrate between 1-2 inches of rainfall.

A "greener" way to manage runoff from surface parking is the use of bioretention, which in this case includes bioswales, bioretention islands (rain gardens and planters), and tree box filters. All of these technologies can be applied both within and along the perimeters of parking lots, and typically provide greater storage than permeable pavement. However, bioretention requires a certain amount of space which can require parking space to be sacrificed, while permeable pavements do not decrease parking space.

Section 5.3 presents a conceptual design for managing runoff from surface parking.

4.3 CONTROLLING STREET RUNOFF

Roadways can contribute significantly to impervious surface area and consequently stormwater runoff, especially in densely developed areas like the CSO-009 drainage area. However, major roadways must often meet strict standards and specifications to allow specific traffic volumes as well as emergency vehicle passage. For this reason, arterial roads and side streets, which experience less traffic and may be subject to less stringent standards, are more attractive options for green infrastructure.

Permeable pavement is not as feasible for streets because consistent traffic can damage the pavement structure, which typically is not designed to sustain continual weight loads from vehicles. For this reason, bioretention stands out as the most practical option for green practices in streets.

In this case, bioretention can refer to both tree box filters as well as streetside bioretention planters and vegetated curb extensions. All of these practices consist of relatively minor, non-disruptive modifications to the existing roadway and landscape to create "pockets" for infiltration to occur. Roadway runoff is directed to bioretention areas where an infiltrative substrate and vegetation retain the water, remove contaminants, and release it to underlying soils.

Section 5.4 presents a conceptual design for managing street runoff.

4.4 CONTROLLING ATHLETIC FIELD RUNOFF

Athletic fields may not typically be thought of as major contributors to stormwater runoff, but their large turf areas, paved tracks and walkways, and associated parking areas can produce as much runoff as highly impervious surfaces like parking lots.

Large open turf areas in athletic fields can be used advantageously to control stormwater runoff by converting them into infiltration beds. An infiltration bed the size of an athletic field can have a very high capacity to contain large volumes of water (see section 8 for a practical example) without negatively impacting its intended use. An infiltration bed is constructed by excavating the existing field, installing a coarse (i.e. gravel) substrate coupled with a geotextile fabric, and re-installing the turf above the infiltration bed.

Section 5.5 presents a conceptual design for managing runoff from an athletic field.

5. GREEN INFRASTRUCTURE CONCEPTUAL DESIGNS

5.1 HYDROLOGIC PERFORMANCE CRITERIA

Modeling of the Terre Haute collection system suggested that during a "typical" year (1978), CSO-009 never discharges when the event rainfall depth is less than 0.3 inch and always discharges when the rainfall depth is greater than 0.6 inch.

Further, an analysis both of the "typical" year (1978) and of the rainfall record for Terre Haute (1951-2006) demonstrated that approximately 75 percent of storms in Terre Haute produce a rainfall depth of 0.6 inch or less. The analysis also indicated that 90 percent of Terre Haute's storms have a measured rainfall depth of one inch or less (Figure 4).

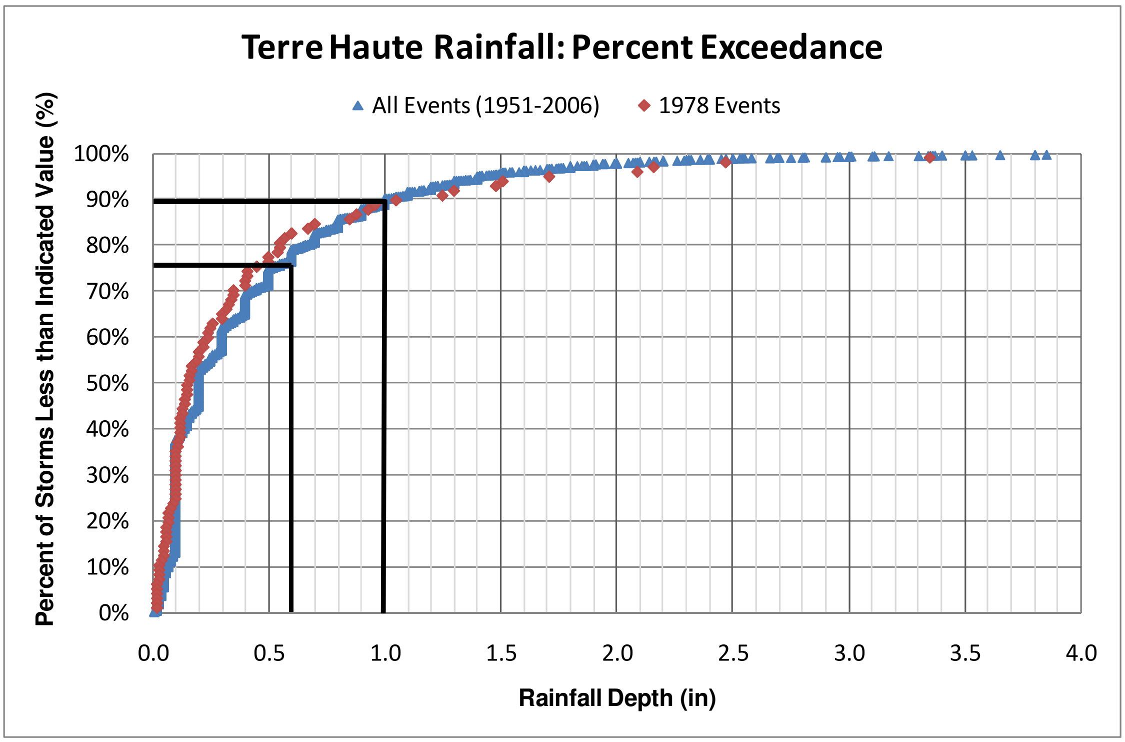

Figure 4. Percent Exceedance Plot of Terre Haute Rainfall, showing entire record (blue) and "typical" year (1978, red)

With that in mind, two rainfall depths (0.6 inch and 1 inch) were selected as appropriate rainfall amounts for the conceptual designs. They both represent events that trigger CSO-009 to overflow, as well as reasonably large events (with 25 percent and 10 percent exceedance frequencies, respectively). The conceptual design phase will involve determination of the volume retention that will be necessary for green infrastructure in order to manage these events.

5.2 CONCEPTUAL GREEN INFRASTRUCTURE DESIGN FOR A ROOFTOP

5.2.1 Green Roof

The largest rooftop in the CSO-009 drainage area, at just under five acres, belongs to the Health and Human Services building. This building may be a feasible green roof candidate, provided that the roof is able to support the weight of a green roof. As described in section 3.1.1, extensive green roofs are thinner and lighter than intensive green roofs, which often permit public access and can require irrigation systems.

Green roof installation, especially for retrofits, can sometimes be cost prohibitive. One possible way to reduce costs is to install a green roof only on a portion of the roof. For example, the southernmost section of the building (next to Chestnut Street) consists of a 1-acre roof area that is of different construction that the remainder of the roof and likely is not favorable for a green roof (Figure 5). Additionally, it may be favorable to leave other roof areas uncovered to allow for both maintenance and public access. With a thick enough substrate (at least four inches), a green roof could fully capture a 0.6 to 1-inch rainfall event.

For this evaluation, green roofs were not included in the conceptual design mainly because of their relatively high unit cost (median unit cost is approximately $16/s.f. which equates to about $26/gallon for the 1.0” rainfall) and relatively low stormwater retention potential compared to other green infrastructure technologies.

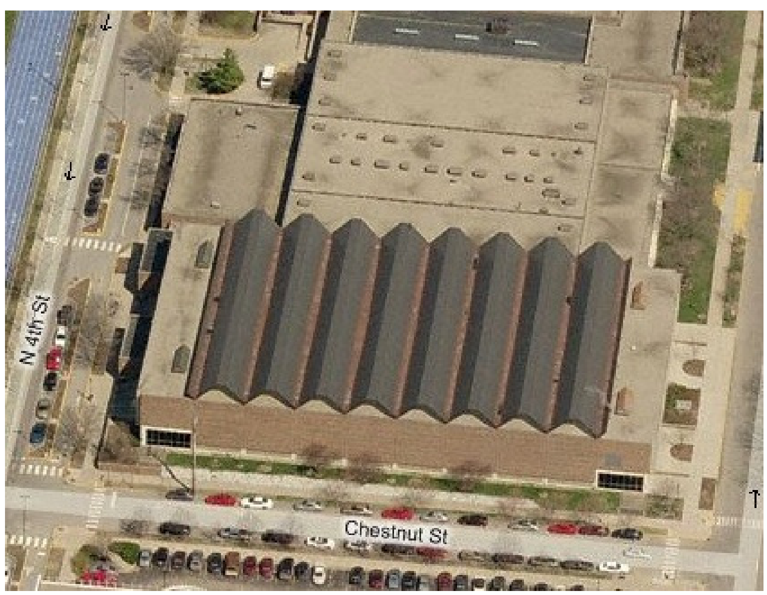

Figure 5. Southern portion of the Health and Human Services Building

Photo credit: bing.com/maps

5.2.2 Cisterns

Cisterns can be a feasible, low-complexity option for managing stormwater runoff from rooftops, and they may provide a viable control option for the Health and Human Services building. They can be installed both above and below ground, and can be used alone or in combination with other stormwater BMPs. Rooftop drainage is connected directly to the cisterns via a downspout or other stormwater channel, and harvested rainwater can be used for irrigation, greywater reuse (e.g. flushing toilets), or some other purpose. Collected rainwater can also be slowly released back into the soil.

If cisterns alone were installed to manage stormwater runoff from the Health and Human Services building's roof, about 77,000 gallons of capacity would be needed to fully capture a 0.6-inch storm, and nearly 128,500 gallons of capacity would be needed to contain a 1-inch storm. There is little space available on the Health and Human Services property for cisterns of this size, so it is recommended that several smaller systems by placed next to the building as a supplement to other methods of stormwater control (e.g green roof, bioretention). Adding cisterns could also reduce green roof installation cost, as less stormwater control would be required by the green roof.

Figure 6 shows that above-ground cisterns can be designed with aesthetics in mind. The cistern in the left image is one of four 3,000 gallon cisterns installed at the Chicago Center for Green Technology in Chicago, Illinois. The cistern on the right is a 20-foot tall cistern with a 10,000 gallon capacity owned by the University of Texas at Austin. Five cisterns on the property have a total capacity of 58,000 gallons.

The conceptual design for the Health and Human Services building proposes incorporating cisterns with enough capacity to manage runoff from a 1-inch rainfall event from 25 percent of the flat roof area plus an additional acre (the entire ridged portion of the roof, Figure 5) for a total of about two acres. In order to provide sufficient storage for a 1-inch rainfall, it is recommended that infiltration be added at Marks Field (see section 5.5 for more information on infiltration beds for athletic fields). Adding a one-acre infiltration bed will provide more than enough additional storage to retain 100% of runoff from the Health and Human Services building rooftop in a 1-inch rainfall event.

A detailed conceptual design for the Health and Human Services building is presented in Attachment B.

Figure 6. Above-ground cisterns at the Chicago Center for Green Technology (left) and University of Texas at Austin (right)

Photo credit: pedshed.net (left), Texas Commission on Environmental Quality (right)

5.3 CONCEPTUAL GREEN INFRASTRUCTURE DESIGN FOR SURFACE PARKING

5.3.1 Permeable Pavement/Subsurface Infiltration Bed

Lot A, on the north side of the ISU campus, presents a feasible opportunity for large scale permeable pavement installation. Measuring about 6.4 acres in area, Lot A is the largest parking lot on campus, and is in fact the largest continuous impervious surface on campus and in the CSO-009 drainage area (excluding roadways). Aerial imagery of the ISU campus suggests that Lot A is heavily used, such that decreasing the lot size to decrease impervious area may not be a feasible option.

Permeable pavement is ideal for parking lots because they do not experience as much active traffic as roadways. Further, it is an attractive option for highly impervious areas with space constraints, such as Lot A. Often in parking lot applications, permeable pavement is installed in parking stalls only, as they experience less frequent vehicle movement that parking lot aisles. This practice also saves on cost.

The infiltration capacity of a permeable pavement parking lot can be increased by installing an infiltration bed beneath the pavement. The bed is constructed of coarse material (e.g. gravel) and can also incorporate a drainage system. The hydrologic group A soils in the CSO-009 drainage area are well suited for a permeable pavement-infiltration bed combination.

At 6.4 impervious acres, Lot A would generate about 100,000 gallons of runoff in a 0.6-inch storm, and over 170,000 gallons in a 1-inch storm. It is unlikely that permeable pavement alone could fully contain these or larger storms unless the entire parking lot was paved with permeable pavement. However, at an average cost of $6.50/square foot, installing permeable pavement across the entire 6.4 acre lot would cost over $1.8 million. Assuming that the permeable pavement substrate has a 4" depth with a porosity of 0.3, the storage capacity is only 0.748 gal/s.f, which equates to a unit storage cost of about $8.70/gal, which is significantly higher than bioretention. For this reason, permeable pavement was not recommended for the ISU campus.

Figure 7. A permeable pavement parking lot in Denver, CO accepts stormwater runoff directly from roof downspouts

Photo credit: Colorado Association of Stormwater and Floodplain Managers (CASFM)

5.3.2 Bioretention

If there is adequate space, bioretention islands and bioswales could be installed both within and adjacent to Lot A to improve its stormwater retention, particularly during large rainfall events, and reduce some of the loading on the permeable pavement.

Bioretention islands are an attractive and cost-effective option for highly impervious areas with limited space, such as parking lots. Occasional islands installed in Lot A could capture runoff from smaller areas as well as improve parking lot aesthetics. Additionally, areas of the lot could be graded so that runoff that is not captured by the permeable pavement is directed into bioswales along the perimeter of the lot. Applying bioretention should greatly reduce stormwater runoff from Lot A but may not eliminate runoff in large events. To retain 100 percent of runoff from a 1-inch rainfall event, additional, larger bioretention areas are recommended in the vicinity of Lot A.

A detailed conceptual design for Lot A is presented in Attachment B.

Figure 8. Small Bioretention Island in Parking Lot, Dayton, Ohio

Photo credit: Dayton Bioretention Systems (daytonbioretention.com)

5.4 CONCEPTUAL GREEN INFRASTRUCTURE DESIGN FOR STREETS

Paved roadways can account for a high percentage of the total impervious surface in cities, contributing significantly to stormwater runoff. Totaling over 50 acres, paved roads cover 13 percent of the CSO-009 drainage area. Installing green infrastructure in roadways can be more difficult than in parking lots or on rooftops due to the nature of their use; paved roadways typically experience continual and heavy traffic and are subject to more stringent design standards and specifications. Main roadways must meet certain dimensions to allow predetermined traffic volumes as well as the passage of emergency vehicles such as fire trucks. There may also be requirements for street side parking. Residential streets, which experience slower and lower traffic volumes, often provide the greatest opportunity for green infrastructure.

Sixth Street north of Cherry Street has been identified as a potentially feasible site for green infrastructure implementation. Due to its dead end (cul-de-sac) near Dede Plaza, this segment of Sixth Street experiences less traffic than many other areas of campus. There are also two large looped driveways, one on the north side of the Technology Building and the other immediately in front of Burford Hall, which could provide some stormwater management opportunity. These two areas already have "green" islands at their centers (Figure 9) which could be retrofitted and converted into bioretention islands.

As shown in Figure 9, North Sixth Street is also constructed with 8-10 foot wide strips of land between the curbs and sidewalks. These small areas could be converted to long strips of bioretention planters, requiring little new construction. From aerial imagery, it also appears that there are numerous existing trees along North Sixth Street. To increase stormwater management potential, these trees could be modified into tree box filters to accept runoff from adjacent sidewalks. Each square foot of surface area in a tree box filter is estimated to provide nine gallons of storage, or more than twice as much water as an equivalent area of bioretention.

The total paved roadway area on North Sixth Street is approximately one acre, but this does not include adjacent driveways, sidewalks, and curbs. In a 0.6-inch storm, the roadway area alone would contribute over 16,000 gallons of stormwater runoff. In a 1-inch storm this volume would increase to over 27,000 gallons. It is feasible that the entire volume from small, typical storms could be fully controlled using bioretention on Sixth Street north of Cherry Street. An example "green street" is illustrated in Figure 10.

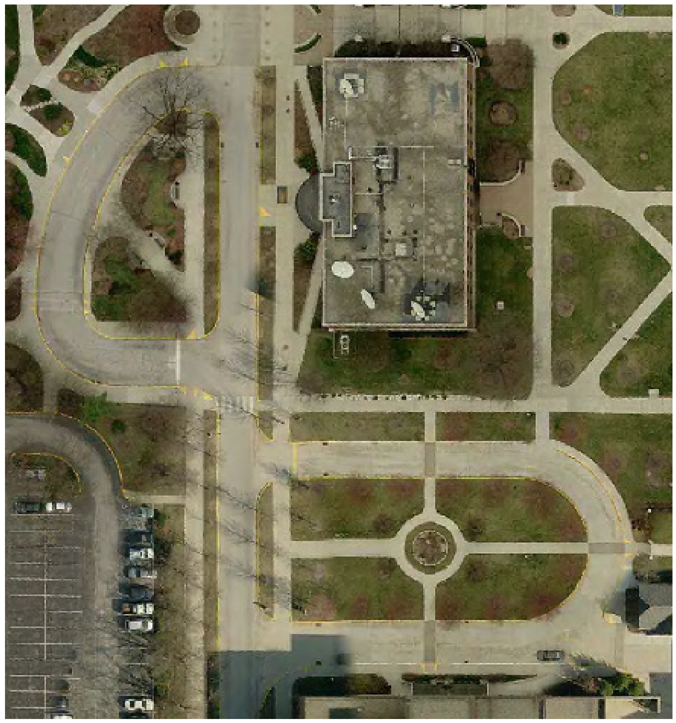

Figure 9. Area of Sixth Street north of Cherry Street showing looped driveways (potential bioretention opportunity)

(Source: bing.com/maps)

Figure 10. 12th Avenue Green Street featuring bioretention planters, Portland, Oregon

Photo credit: City of Portland, Environmental Services

5.5 CONCEPTUAL GREEN INFRASTRUCTURE DESIGN FOR AN ATHLETIC FIELD

Athletic fields represent important opportunities for stormwater infiltration, especially on university campuses that are highly developed like the ISU campus, where impervious surfaces prevent rainwater from reaching soils and replenishing the water table.

Instead of directing stormwater runoff away from athletic fields, water can be directed to them if they are designed to maximize infiltration. This can be accomplished through a subsurface infiltration bed, which is installed below the field with a layer of geotextile fabric on top. The turf is installed on top of the infiltration bed. The bed's storage capacity can be increased using a cistern or multiple cisterns, which can capture excess runoff from the field and from nearby impervious areas (e.g. roads, building rooftops).

The field at Simmons Student Activity Center/Recreation East is an ideal candidate for a subsurface infiltration bed. The field consists of a semicircular paved track with a large turf area on the infield. There are also large impervious surfaces on the west side (Lot Q, Ninth Street), south side (Lot 15, Sycamore Street, Facilities Management buildings and parking lots), and east side (Lots J and B).

The total area of the turf infield at the Simmons Student Activity Center is about four acres, and the area of the paved track is about one acre. With 0.6 inch of rainfall, the turf area is estimated to generate about 65,000 gallons of runoff, while the paved area would generate about 16,000 gallons. In a 1-inch storm, the turf and paved areas would generate approximately 109,000 gallons and 27,000 gallons, respectively.

Another benefit would come from the field's ability to manage runoff from nearby impervious areas. For example, if an infiltration bed at the field is designed to receive stormwater runoff from Lot Q on its west side, which measures about three impervious acres, this would account for nearly 50,000 gallons of stormwater in a 0.6-inch storm and over 81,000 gallons in a 1-inch storm. Runoff from Lot 15, which also measures three acres, could be directed to the infiltration bed as well.

Section 8.0 presents a case study of an athletic field at the University of North Carolina at Chapel Hill that recently underwent renovation and is now able to hold 500,000 gallons of stormwater runoff.

A detailed conceptual design for the Simmons Student Activity Center is presented in Attachment B.

6. OVERALL GREEN INFRASTRUCTURE PERFORMANCE POTENTIAL

The potential for green infrastructure to provide significant storage volume for stormwater is evaluated in this section.

6.1 STORMWATER STORAGE POTENTIAL FOR DESIGN RAINFALLS

Although it may not be feasible to install green infrastructure throughout the entire CSO-009 drainage area, it is worthwhile to estimate the potential benefit that can theoretically be realized from widespread implementation; in this case, the entire ISU campus. "Benefit" refers to the volume of stormwater that can be captured by applying the types of stormwater green infrastructure practices described in section 3. Capturing or retaining stormwater will reduce or at least have a delayed effect on the combined collection system and ultimately reduce the volume of water that CSO-009 discharges to the Wabash River.

To estimate the overall performance potential of the proposed green infrastructure technologies, the conceptual designs provided in section 5 were applied to the entire ISU campus area (based on impervious surface type), and their estimated hydrologic benefits extrapolated. For a 0.6-inch storm, the estimated total volume captured is 2 million gallons, and for a 1-inch storm, the estimated total volume captured is 3.4 million gallons. These estimates assume that 100% of the runoff for both of these rainfall events for each respective impervious surface type can be captured using green infrastructure. Further, many of the proposed green infrastructure technologies are capable of capturing greater than a 1-inch rainfall event.

Table 2 summarizes the potential stormwater retention benefit of the conceptual designs provided in section 5 and of widespread green infrastructure implementation on the ISU campus area. These estimates illustrate the potential for green infrastructure on the ISU campus to control stormwater from the 0.6" and 1.0" design rainfall events. As presented in Table 2, 100% buildout with green infrastructure can provide approximately 2 MG storage for the 0.6' rainfall and about 3.4 MG storage for the 1.0" rainfall. In some cases, the storage capacity of the green infrastructure will exceed these volumes. The total storage potential is discussed below.

Table 2. Estimated Impervious Surface Area Totals (Acres) and Runoff Volume Captured (Gallons) by Green Infrastructure on the ISU Campus Area

CONCEPTUAL DESIGNS					
Surface Type	Rooftop	Street	Surface Parking	Athletic Field	**TOTALS**
Total area (acres)	4.7	1.0	6.4	7.5	**19.6**
Estimated volume captured (gallons)					
0.6-inch rainfall	76,600	16,300	104,300	122,200	**319,400**
1.0-inch rainfall	127,600	27,200	173,800	203,700	**532,300**

FULL-SCALE IMPLEMENTATION (ISU CAMPUS)					
Surface Type	Rooftop	Street	Surface Parking	Athletic Field	**TOTALS**
Total area (acres)	37.8	25.1	42.8	19.3	**125.0**
Estimated volume captured (gallons)					
0.6-inch rainfall	615,400	696,700	409,700	314,500	**2,036,300**
1.0-inch rainfall	1,025,700	1,161,100	682,800	524,100	**3,393,700**

6.2 TOTAL STORMWATER STORAGE POTENTIAL

As mentioned above, some of the green infrastructure technologies considered in this study were sized to control the design rainfall events (e.g., cisterns), while others provide storage capacity in excess of the design rainfall (e.g., bioretention). The total storage potential for green infrastructure can be estimated by extrapolating the unit storage capacity (e.g., gal/s.f.) for a given technology to the total quantity of that technology required for complete buildout on the ISU campus.

Table 3. Total Estimated Storage Potential for Green Infrastructure on the ISU Campus

Rooftop Green Infrastructure				
Technology	**Unit Storage Capacity (gallons/sq. ft.)**	**Total Quantity (acres)**	**Total Quantity (sq. ft.)**	**Total Storage (gallons)**
Bioretention	3.74	1.6	69,700	260,700
Cisterns*	0.623	16.0	697,000	434,200
Street Green Infrastructure				
Bioretention	3.74	17.5	762,300	2,851,000
Tree Box	17.45	0.3	13,100	228,600
Surface Parking Green Infrastructure				
Bioretention	3.74	7.4	322,300	1,205,400
Athletic Field Green Infrastructure				
Infiltration	3.74	7.7	335,400	1,254,400
Total Storage Capacity on ISU Campus (gallons)				**6,234,000**

*Assume cistern captures 1" of rainfall from roof

6.3 ANCILLARY BENEFITS OF GREEN INFRASTRUCTURE

Aside from the apparent hydrologic benefits that green infrastructure can provide, there are numerous other benefits, some of which are difficult to measure. Green infrastructure technologies that incorporate trees and other vegetation improve the quality of life in the developed environment by introducing green spaces that improve aesthetics, provide habitat, and reduce the urban heat island effect. Trees and plants absorb and store carbon dioxide and other air pollutants, improving air quality. Vegetation employed in green infrastructure technologies captures and cleanses stormwater runoff before it enters local waterways, improving water quality. Further, bioretention, infiltration, and other green practices allow stormwater to infiltrate, enabling replenishment of groundwater supplies.

In some cases, green infrastructure can also reduce energy costs. For example, installing a green roof on a building can reduce heating costs in winter and cooling costs in summer due to its insulating properties, all while extending the life of the roof. Rainwater harvesting (i.e. cisterns) can dramatically reduce irrigation costs; in some cases, reclaimed stormwater has been used to flush toilets or wash cars, reducing consumption of drinking water sources even further.

Extensive implementation of green infrastructure on a university campus has a precedent at the University of North Carolina (UNC). A brief description of the UNC green infrastructure retrofit is presented in Attachment C.

7. COST ESTIMATES FOR GREEN INFRASTRUCTURE

Unit costs to install green infrastructure can vary greatly depending on a wide range of factors, from suitability of existing soils to local availability of materials and many sources of information exist for unit cost estimation. The Center for Neighborhood Technology (CNT) has developed a "Green Values Calculator"[1] that uses unit costs developed from review of nationwide data on green infrastructure costs and is regarded as a good representation of median unit costs for most green infrastructure project types. The median unit costs developed by the CNT were used in this study, where available. For technologies that are not included in the CNT database, other sources were sought and are cited below. It is worth noting that the CNT database also provides estimates of maintenance costs and expected lifespan for green infrastructure technologies, as well as construction costs.

7.1 CONCEPTUAL DESIGN COST ESTIMATES

7.1.1 Rooftop Green Infrastructure Cost Estimate

The CNT database estimates cisterns to cost between about $0.60 and $3/gallon, with a median cost of $1.50/gallon. Cistern cost is mostly dependant on the material, which can be anything from galvanized steel (least expensive) to fiberglass (most expensive), including various plastics (i.e. polyethylene) and concrete.

Bioretention (rain gardens) are estimated to cost between about $5 and $16/square foot, with a median cost of $7/square foot. Cost is primarily determined by the character of existing soils and the vegetation selection.

The CNT database does not provide unit costs for infiltration beds, so unit costs presented in the Pennsylvania Stormwater Best Management Practices Manual (Pennsylvania Department of Environmental Protection, 2006) were used here. According to the Pennsylvania Stormwater BMP Manual, construction of an infiltration bed typically costs about $6/square foot, which includes excavation, a 2-foot deep aggregate, geotextile, drainage pipes, and plantings. Replanting the field with natural or artificial turf could increase costs.

By applying the median unit costs reported by CNT to the volumes and areas of green infrastructure recommended for the conceptual rooftop design (section 5.2), the total cost of this conceptual design is estimated to be about $0.4 million, as outlined in Table 4. Note that areas and volumes required represent the storage necessary to capture, at minimum, a 1-inch rainfall event.

[1] http://greenvalues.cnt.org

Table 4. Cost Estimate for Conceptual Rooftop Green Infrastructure Design

	Cistern	Bioretention	Infiltration
Area needed (acres)	--	0.20	1.00
Area needed (sq. ft.)	--	8,700	43,560
Volume needed (gallons)	54,000	--	--
Unit cost applied	$1.50/gallon	$7/sq. ft.	$6/sq. ft.
Cost per category	$81,000	$60,900	$261,360
TOTAL COST	**$403,300**		

7.1.2 Surface Parking Green Infrastructure Cost Estimate

The conceptual design for a surface parking lot (section 5.3) included only one component: bioretention. As described in section 7.1.1, bioretention typically costs between $5-$16 per square foot, with a median cost of $7/square foot. The greatest cost will likely be associated with converting existing islands in the parking lot into bioretention islands.

By applying median unit costs to the areas of green infrastructure recommended for the conceptual parking lot design (section 5.3), the total cost of this conceptual design is estimated to be around $336,000, as outlined in Table 5. Note that areas required represent the storage necessary to capture, at minimum, a 1-inch rainfall event.

Table 5. Cost Estimate for Conceptual Surface Parking Green Infrastructure Design

	Bioretention
Area needed (acres)	1.1
Area needed (sq. ft.)	48,000
Unit cost applied	$7/sq. ft.
Cost per category	$336,000
TOTAL COST	**$336,000**

7.1.3 Street Green Infrastructure Cost Estimate

The conceptual design for a street (section 5.4) included two components: bioretention (both rain gardens and planters) and tree box filters. As described above, bioretention (rain gardens) typically costs between $5-$16 per square foot, with a median cost of $7/square foot. Bioretention planters have a slightly higher estimated cost than rain gardens: between $0.50 and $24.50/square foot, with a median unit cost of $8/square foot.

Tree box filters come at a much higher cost due to their structural components and the relatively high cost of mature trees (which can range from $175-$400 each). These practices should be limited to a small but effective area, such as in or along sidewalks. The unit cost for tree box filters is estimated to range from $69 to $600/square foot, with a median cost of $222/square foot. Each square foot of surface area in a tree box filter is estimated to provide nine gallons of storage, or more than twice as much as an equivalent area of bioretention.

By applying median unit costs to the areas of green infrastructure recommended for the conceptual street design (section 5.4), the total cost of this conceptual design is estimated to be approximately $342,000, as outlined in Table 6. Note that areas required represent the storage necessary to capture a 1-inch rainfall event.

Table 6. Cost Estimate for Conceptual Street Green Infrastructure Design

	Tree Box Filters	Bioretention	
		Rain Gardens	Planters
Area needed (acres)	--	0.30	0.40
Area needed (sq. ft.)	500	13,100	17,400
Unit cost applied	$222/sq. ft.	$7/sq. ft.	$8/sq. ft.
Cost per category	$111,000	$91,700	$139,200
TOTAL COST	**$341,900**		

7.1.4 Athletic Field Green Infrastructure Cost Estimate

A stormwater infiltration/storage bed was recommended for the athletic field conceptual green infrastructure design (section 5.5). According to the Pennsylvania Stormwater Best Management Practices Manual (Pennsylvania Department of Environmental Protection, 2006), construction of an infiltration bed typically costs about $6/square foot, which includes excavation, a 2-foot deep aggregate, geotextile, drainage pipes, and plantings. Replanting the field with natural or artificial turf could increase costs.

By applying median unit costs to the areas of green infrastructure recommended for the conceptual athletic field design (section 5.5), the total cost of this conceptual design is estimated to be approximately $784,000, as outlined in Table 7, excluding any additional costs that may be incurred for replanting of turf on the field. Note that areas required represent the storage necessary to capture, at minimum, a 1-inch rainfall event.

Table 7. Cost Estimate for Conceptual Athletic Field Green Infrastructure Design

	Infiltration Bed
Area needed (acres)	3.0
Area needed (sq. ft.)	130,680
Unit cost applied	$6/sq. ft.
Cost per category	$784,080
TOTAL COST	**$784,000**

7.2 OVERALL COST ESTIMATE FOR CSO 009 DRAINAGE AREA

To estimate the cost of implementing green infrastructure throughout the CSO-009 drainage area, the green infrastructure conceptual designs provided in section 5 were applied to the entire drainage area (based on impervious surface type). These costs represent a proposed level of implementation that would be necessary in order to capture a 1-inch rainfall event. Cost estimates for each conceptual design (rooftop, street, surface parking, and athletic field) were extrapolated across the entire drainage area based on surface area to provide a rough estimate of costs for widespread implementation.

As shown in Table 8, implementation of the four conceptual designs is estimated to cost about $1.9 million, while complete green infrastructure implementation across the ISU campus area could cost approximately $16 million.

Table 8. Estimated Cost to Construct Conceptual Green Infrastructure Designs (Top) and to Implement Green Infrastructure on the ISU Campus (Bottom)

CONCEPTUAL DESIGNS					
Surface Type	Rooftop	Street	Surface Parking	Athletic Field	TOTALS
Total area (acres)	4.7	1.0	6.4	7.5	19.6
Estimated construction cost to control the 1-inch storm ($)					
Estimated cost	$403,300	$341,900	$336,000	$784,080	$1,865,000

FULL-SCALE IMPLEMENTATION (ISU CAMPUS)					
Surface Type	Rooftop	Street	Surface Parking	Athletic Field	TOTALS
Total area (acres)	37.8	25.1	42.8	19.3	125.0
Estimated construction cost to control the 1-inch storm ($)					
Estimated cost	$3,241,200	$8,597,800	$2,244,900	$2,017,800	$16,102,000

An overall estimate of the unit cost/gallon for stormwater runoff control by green infrastructure on the Indiana State University campus can be provided by dividing the total estimated cost (Table 8) by the estimated total storage (Table 3). The total estimated cost to install the proposed green infrastructure technologies across the ISU campus is $16.1 million, and the estimated total storage provided by the proposed technologies is 6.2 million gallons, for an overall unit cost of about $2.60 per gallon of storage provided. It is important to note that in many cases, the green infrastructure technologies used in this evaluation will provide capacity in excess of that which is needed to control the 1.0" rainfall.

It should be noted that the areas and costs presented in Table 8 represent 100% implementation of green infrastructure for each category of impervious surface shown. In reality it is unlikely that an implementation rate of 100% is feasible because of limitations associated existing structures and infrastructure, available space, and competing needs for project areas. For preliminary planning purposes, the overall storage potential presented here can be scaled by an assumed implementation rate. For example, if the assumed implementation rate for green infrastructure on the ISU campus is only 50%, then the storage volume can estimated at 3.1 million gallons.

These estimates clearly indicate that significant potential exists in the CSO 009 drainage area for stormwater capture and storage using green infrastructure. By implementing green infrastructure retrofits on the ISU campus alone, the potetnial exists to provide stormwater storage in excess of the storage provided by a 2 million gallon storage tank.

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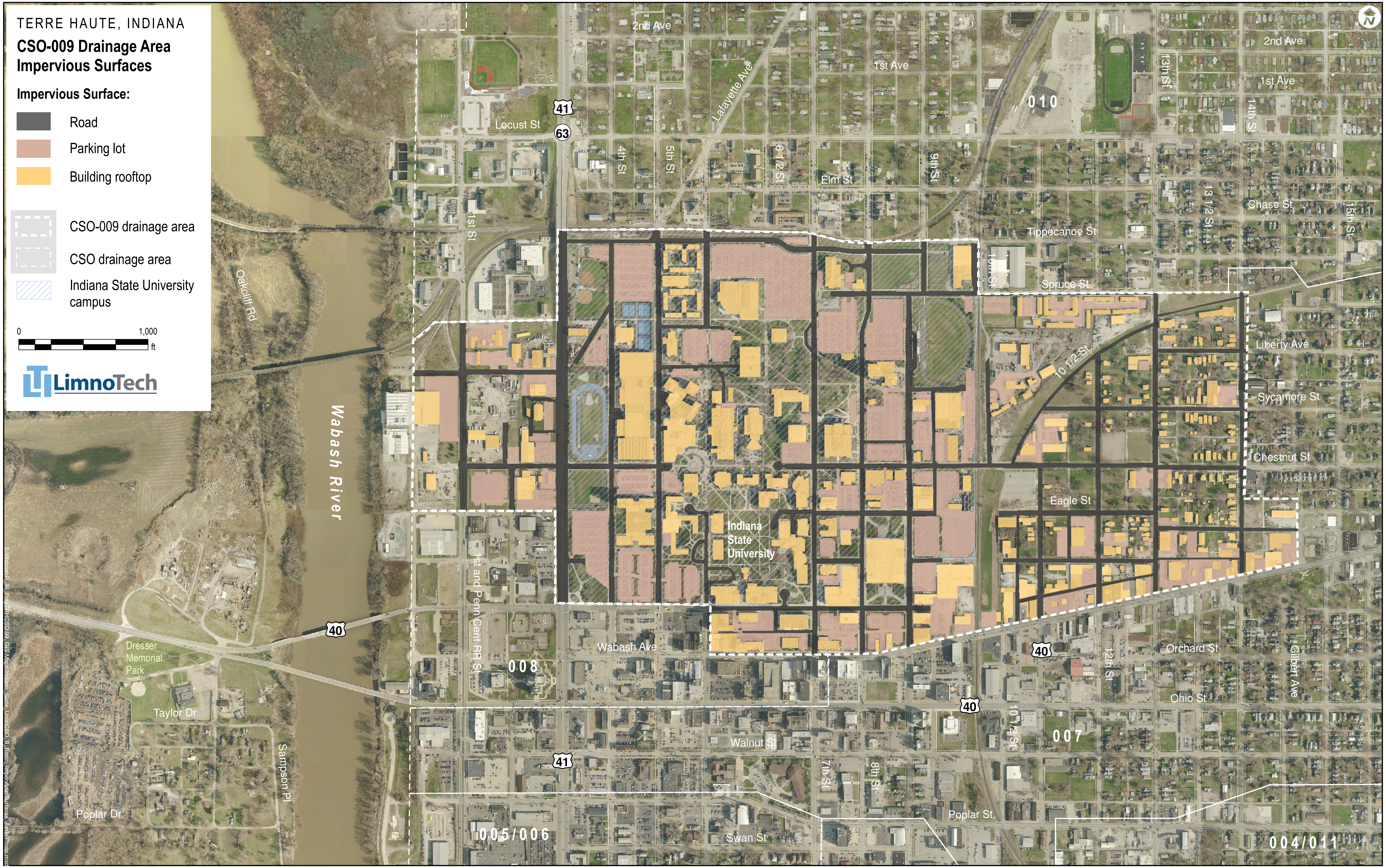
http://www.epa.gov/owow/nps/lid/lid.pdf

ATTACHMENT A

MAP SHOWING LOCATIONS OF IMPERVIOUS SURFACES IN THE CSO 009 DRAINAGE AREA


TERRE HAUTE, INDIANA
CSO-009 Drainage Area
Impervious Surfaces
Impervious Surface:
Road
Parking lot
Building rooftop
CSO-009 drainage area
CSO drainage area
Indiana State University campus
0
1,000
ft
LimnoTech
Wabash River
Indiana State University
Locust St
2nd Ave
1st Ave
Lafayette Ave
Elm St
Chase St
Tippecanoe St
Spruce St
Liberty Ave
Sycamore St
Chestnut St
Eagle St
10 1/2 St
Wabash Ave
Orchard St
Ohio St
Walnut St
Poplar St
Swan St
Poplar Dr
Taylor Dr
Sampson Pl
Oakcliff Rd
Dresser Memorial Park
1st St
4th St
5th St
6 1/2 St
9th St
10th St
13th St
13 1/2 St
14th St
15th St
1st and Penn Cent RR St
7th St
8th St
10 1/2 St
12th St
Gilbert Ave
41
63
40
010
008
007
005/006
004/011

ATTACHMENT B

GREEN INFRASTRUCTURE CONCEPTUAL DESIGNS

TERRE HAUTE, INDIANA

Green Infrastructure Conceptual Design

Parking Lot Stormwater Management

Indiana State University
Simmons Student Activity
Center/Recreation East

Infiltration 1 2

Site Description

- 7.5 acre complex includes 1 acre paved track, 0.7 acres of paved walkways and parking, 4 acre turf infield, and 1.8 acres of additional turf
- Estimated total runoff from 0.6" and 1" events is 122,000 and 203,700 gallons, respectively
- Nearby parking lots 15 and Q: 6 total acres. Runoff from both lots is 98,000 gal and 163,000 gal

Concept

- Retrofit site with 3-acre subsurface infiltration bed in center of track (similar to depicted)
- Bed designed to infiltrate up to 6" depth of water (489,000 gallons)
- Bed has more than enough capacity to capture runoff from entire complex and from Lots Q and 15

Benefit

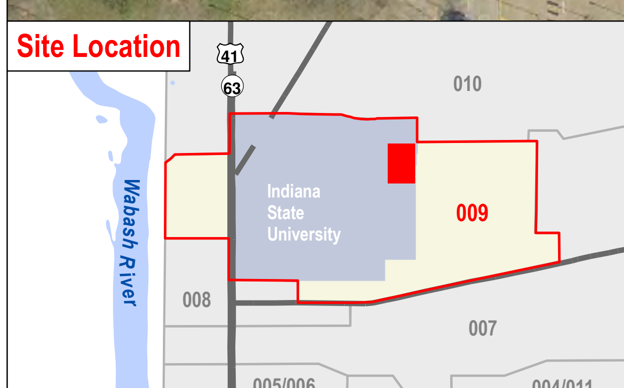
- Infiltration bed at Simmons Student Activity Center will completely capture a 1" rainfall event. This includes runoff from all paved and turf areas
- Bed can also fully capture runoff in 1" rainfall from Lot Q and Lot 15 (6 acres, about 163,000 gallons)

Cost

- Total estimated cost: $784,000
- Weighted average cost/gallon: $1.60/gallon

0 150 ft

LimnoTech



TERRE HAUTE, INDIANA

Green Infrastructure Conceptual Design

Parking Lot Stormwater Management
Indiana State University
North Campus Parking Lot A

Bioretention 1 2

Site Description

- 6.4 acre asphalt paved parking lot
- Estimated runoff from 0.6" and 1" events is 104,300 and 173,800 gallons, respectively

Concept

- Retrofit existing parking lot islands with bioretention
- Install long, narrow bioretention areas along perimeter of parking lot
- Install large bioretention areas (rain gardens) on Student Activity Center property and on open land on south side of Lot A to help manage runoff

Benefit

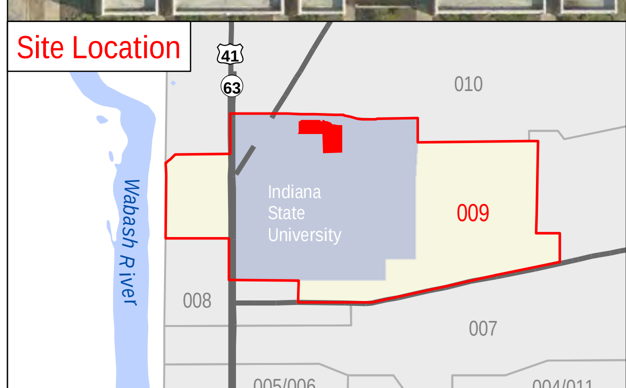
- 1.1 acres of bioretention (as shown) designed to retain up to 6" depth of water (179,000 gallons)
- With these measures in place, 100% of runoff from Lot A will be retained in a 1" storm
- Bioretention areas will improve aesthetics
- No loss of existing parking spaces

Cost

- Total estimated cost: $336,000
- Weighted average cost/gallon: $1.90/gallon

0 150 ft

LimnoTech



TERRE HAUTE, INDIANA

Green Infrastructure Conceptual Design

Rooftop Stormwater Management

Indiana State University Health and Human Services Building

- Cistern — 1
- Bioretention — 2
- Infiltration

Site Description

- 4.7 acre rooftop of which 1 acre is not flat
- Estimated runoff from 0.6" and 1" events is 77,000 and 128,500 gallons, respectively

Concept

- Install cisterns adjacent to building to provide storage for 25% of flat roof plus 1 acre of non-flat roof (about 2 acres total)
- Water collected in cisterns directed to bioretention on sides of buildings (0.2 acres) and to Marks Field
- Install 1 acre infiltration bed (similar to depicted) in Marks Field that can retain 6" of rainfall

Benefit

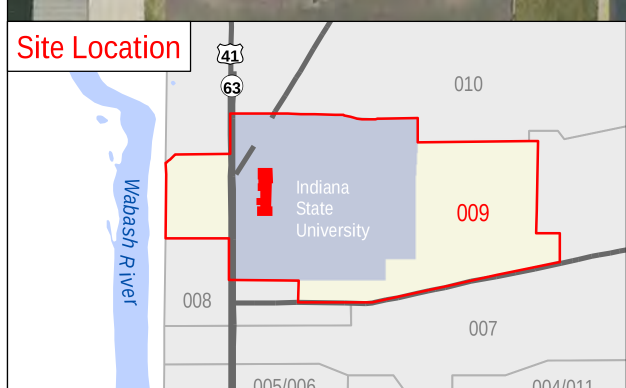
- Cisterns will store at least 54,000 gal in 1" storm
- Bioretention areas have 32,500 gallon capacity
- Infiltration bed has 163,000 gallon capacity
- Total storage capacity including cisterns is nearly 250,000 gallons

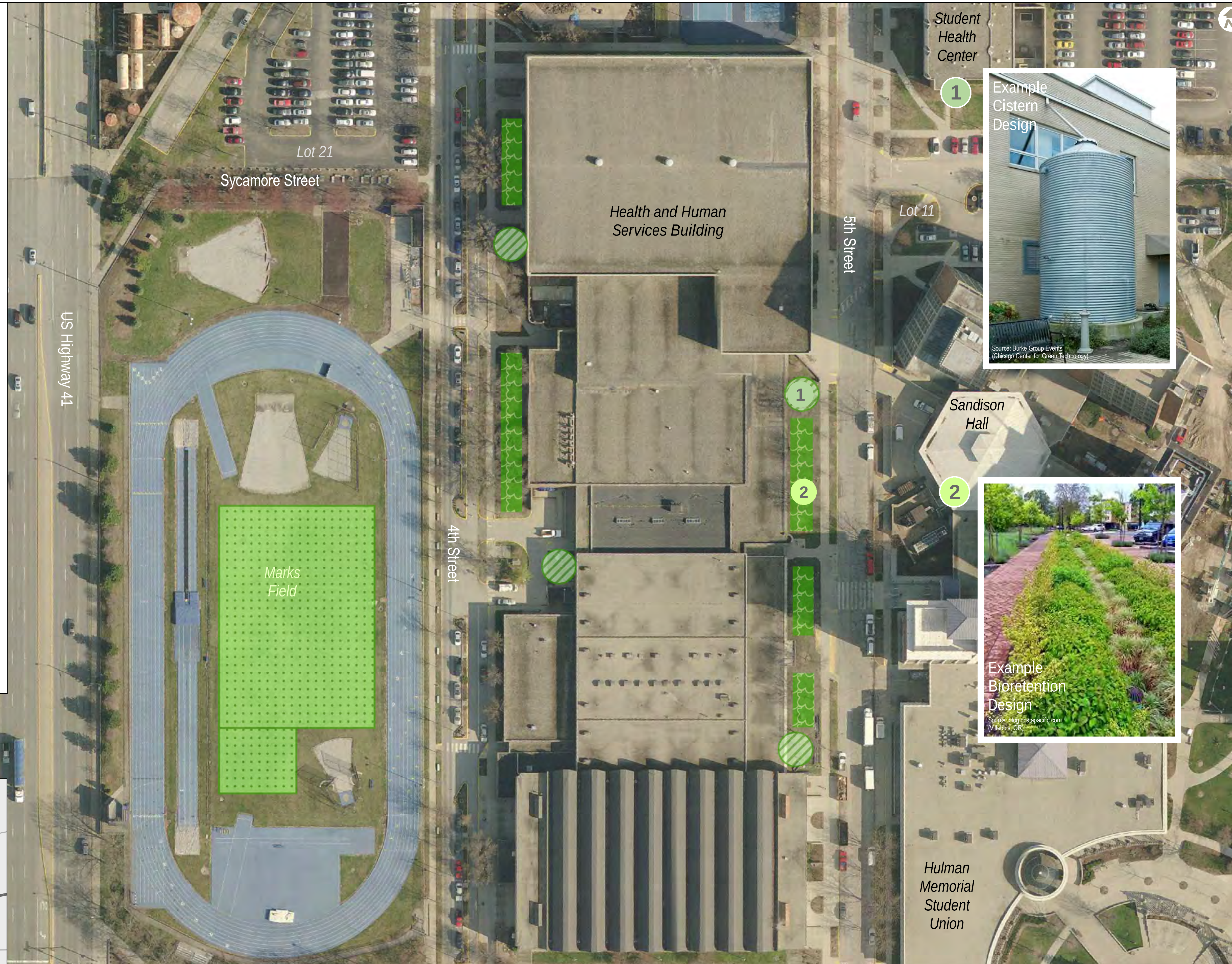
Cost

- Total estimated cost: $403,300
- Weighted average cost/gallon: $1.60/gallon

0 150 ft

LimnoTech





TERRE HAUTE, INDIANA

Green Infrastructure Conceptual Design

Street Stormwater Management
Indiana State University
Sixth Street North of Cherry Street

Bioretention (1)
Tree Box Filter (2)

Site Description

- 1 acre of paved roadway, not including sidewalks
- Estimated runoff from road in 0.6" and 1" events is 16,300 and 27,200 gallons, respectively

Concept

- Retrofit site with 0.7 acre of bioretention (similar to depicted) to manage runoff from all of roadway
- Install tree box filters along select sidewalk areas

Benefit

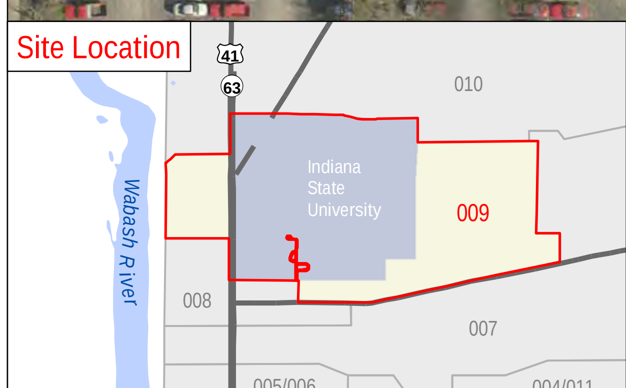
- 0.7 acres of bioretention can store water up to 6" deep (114,000 gallons total) and can completely capture the 1-inch rainfall event
- Retention capacity is great enough to handle runoff from Lot 5 as well (41,000 gallons in 1-inch rainfall)
- Tree boxes can store 4,500 gallons in only 500 sq ft of area, and also improve aesthetics

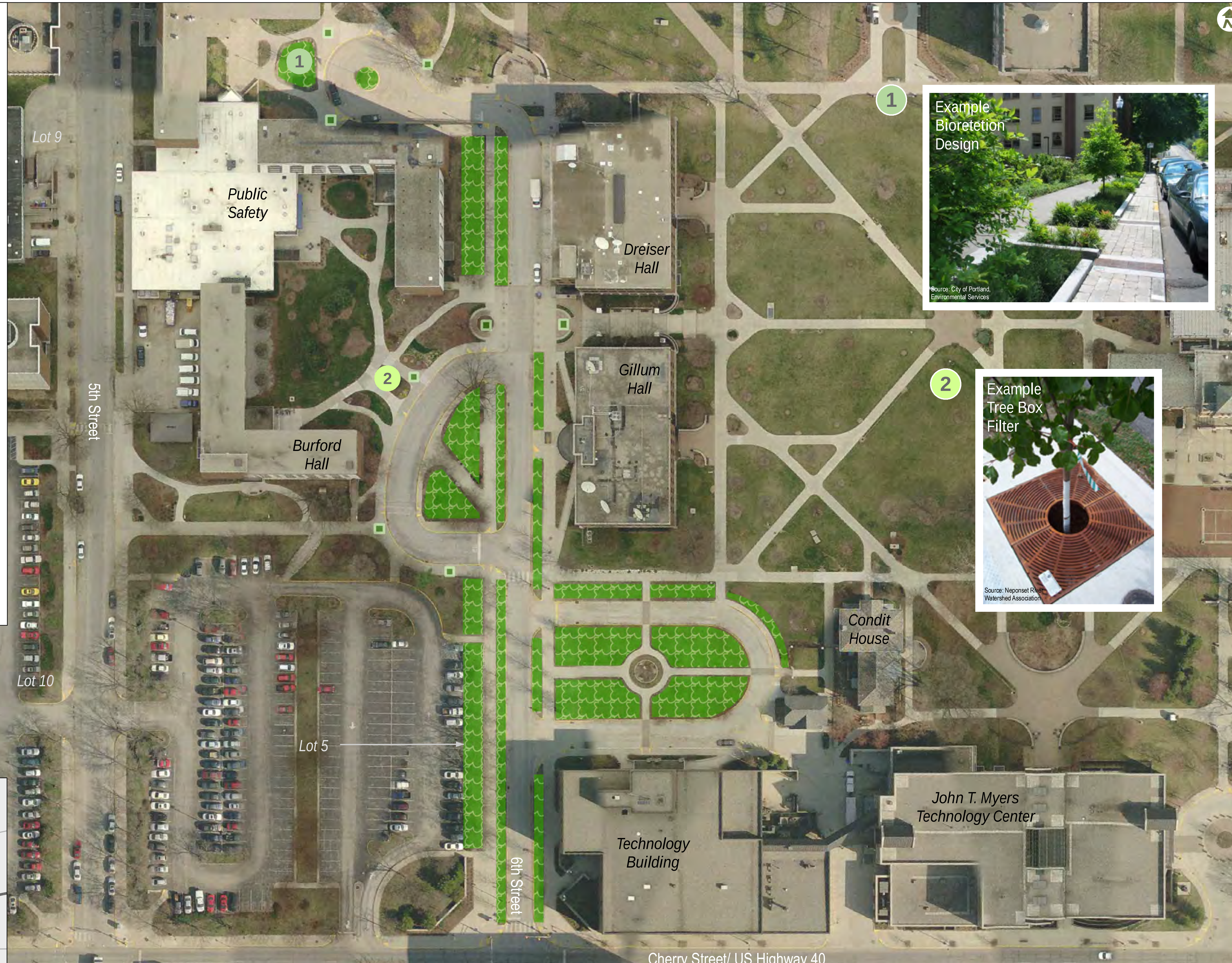
Cost

- Total estimated cost: $341,900
- Weighted average cost/gallon: $2.90/gallon

0 120 ft

LimnoTech





ATTACHMENT C

UNIVERSITY CAMPUS GREEN INFRASTRUCTURE EXAMPLE

Since 2001, the University of North Carolina has incorporated numerous green infrastructure practices on its campus at Chapel Hill (notably the oldest public university in the United States). The University negotiated with the town of Chapel Hill to incorporate green infrastructure techniques in new development, which assists the town in complying with regulatory requirements as part of their Phase II stormwater permit. Green infrastructure designs and specifications are now included in new building projects. Adopted technologies include porous pavement, stormwater plantings, green roofs, infiltration beds, cisterns, and bioswales.

Porous pavement has been installed in four parking lots on campus totaling 3-4 acres, with infiltration/storage beds beneath the pavement. Paved and turf areas across campus have been converted to perennial beds and trees (stormwater plantings).

The University has installed three green roofs totaling one acre; one green roof atop the University's Rams Head Plaza has a soil layer thick enough to support trees that will grow up to 60 feet tall. Cisterns have also been installed adjacent to these buildings to collect excess runoff not managed by their green roofs.

Two athletic fields on campus were converted to stormwater BMPs by first installing a gravel infiltration bed, covering it with a geotextile fabric, and then installing artificial turf on top of the infiltration bed. An infiltration/storage bed at the University's Hooker Field can hold up to 500,000 gallons of water. Retained water is able to infiltrate into the ground or can even be pumped out for irrigation.

The renovated Hooker Field also incorporates an underground cistern with a capacity of 500,000 gallons that collects excess runoff from the field as well as from nearby buildings. Collected water is used to irrigate other nearby athletic fields. Two other buildings on campus incorporate cisterns; water collected in a cistern from the Rams Head Plaza roof is used to irrigate trees and lawns, and a cistern at the FedEx Global Education Center building collects rainwater from the roof and uses it to flush toilets. A vegetated swale (bioswale) has also been installed at the Rams Head Plaza. Runoff that is not captured by the green roof and cistern overflows into the swale for retention and treatment. More information on green infrastructure at the University of North Carolina at Chapel Hill is available at these websites:

http://cfpub.epa.gov/npdes/greeninfrastructure/gicasestudies_specific.cfm?case_id=72

http://ehs.unc.edu/environmental/stormwater/innovative.shtml

Sustainability Walking Tour of UNC - Chapel Hill

The University of North Carolina at Chapel Hill has worked hard to implement policies, practices, and curricula that support sustainability throughout the campus community. This 2.3-mile walking tour is designed to provide you with a glimpse of some of the many sustainability features of UNC's campus. By following this tour, you will visit different types of buildings across campus that demonstrate a wide variety of sustainable features. If you would like to learn more about UNC's sustainability initiatives not featured on this tour, visit our website at **http://sustainability.unc.edu.**

① **Rams Head Center** - This plaza sits on the roof of a parking deck and features a green roof designed to absorb and reuse rainwater. The dining hall offers a range of vegetarian options and uses a composting system for food waste. The firm that composts the food also collects and uses the waste cooking oil for fuel.

② **Morrison Residence Hall** - The building's 2007 renovation included local and recycled building materials as well as a monitoring system to educate residents about their energy and water use. Its solar thermal panels are the first renewable energy technology at UNC and provide up to 60% of the building's hot water.

③ **Carrington Hall** - The building's addition, completed in 2005, was the first in the UNC system to receive LEED certification from the U.S. Green Building Council. It features a green roof (on the 4th floor); water efficient fixtures; a carbon dioxide sensor for bringing in fresh air when needed; paneling and cabinets constructed using wheatboard, a renewable resource; and recycled content featured in at least 5% of the materials used.

④ **FedEx Global Education Center** - Completed in 2007, this building has a long list of sustainable features, including a 3-story atrium that provides day lighting for much of the building, 2 green roofs that collect stormwater, bathrooms which reuse rainwater to flush toilets, and local buiding materials such as slate, maple, and cherry wood.

⑤ **UNC Institute for the Environment** - This building is the center for environmental research and outreach at UNC. Inside there is information about the environmental curriculum, as well as elective and extracurricular opportunities in environmental stewardship.

⑥ **Frank Porter Graham Student Union** - This building is the hub of student life at Carolina. The roof was constructed out of zinc, which is 100% recyclable, and lasts 50-100 years. Inside, you can get a cup of fair trade organic coffee from Alpine Bagel Cafe.

⑦ **School of Government** - Look for the distinctive "SOGreen" stickers located throughout the building to see the variety of features that have made this a more sustainable building. These features include low-flush toilets, light sensors, recycling, and low-E film that blocks the sun's heat.

⑧ **Hooker Field #3** - This turf field covers a cistern and infiltration bed that collect rainwater from the neighboring School of Government and Field House buildings. The water in the cistern is used for irrigation, while the water collected in the infiltration bed replenishes groundwater sources.

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http://sustainability.unc.edu