STORMWATER ON THE UNIVERSITY OF KANSAS MAIN CAMPUS

By

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Abstract

Beginning with a discussion of the combined acreage of the all the impervious surfaces on the main campus of the University of Kansas in Lawrence, Kansas, together with the average annual precipitation there, the HSG soil categorization of this campus, and the contours of its land, this question is asked: using stormwater best management practices, how much of the stormwater runoff can be detained or retained and cleaned before this runoff enters the stormwater drain systems of the University and the City? Considering only the two largest categories of impervious surfaces, buildings and parking lots, the study finds that more than half of the University's 216 million gallons of annual stormwater runoff can be detained or retained and cleaned by the strategic utilization of stormwater best management practices including green roofs and bioretention cells.

Stormwater on the University of Kansas Main Campus

I. Introduction

In Lawrence, Kansas, on the University of Kansas main campus, the total area of all categories of impervious surfaces combined is 9,153,898.8 square feet. That is 210 acres. How much rainwater falls on those 210 acres? One acre-foot of water means the amount of water required to cover one entire acre one foot deep in water, and since one acre-foot of water equals 325,851 gallons of water, an acre-inch of water equals 27,154 gallons of water.[1] If each of Kansas University's 210 acres of impervious surface receives 38 inches of rainwater per year, then those 210 acres receive 216,688,920 gallons of rainwater per year. It is that 216 million gallons of rainwater with which this project is concerned.

The purpose of this project is to demonstrate how, using stormwater best management practices (BMPs), a portion of the 216 million gallons can be detained or retained and cleaned, thereby both placing less demand on the University's and the City of Lawrence's storm drainage systems and also improving the quality of the water flowing to receiving waters within the campus's watersheds. The project will begin with background material concerning features of the KU main campus, the derivation of the 9,153,898.8 square foot figure, annual precipitation rates in Lawrence, and soil groups on the main campus. There will follow a description of some of the available stormwater BMPs, what they are and what some of their requirements are. Then the focus turns to KU itself, to how KU can use these BMPs to detain or retain and clean some of the 216 million gallons of rainwater that fall on its main campus annually. Next there will be

[1] *Rain: A valuable resource*. (n. d.). Retrieved February 10, 2012, from http://ga.water.usgs.gov/edu/earthrain.html.

two brief sections, one concerning other steps KU might take concerning stormwater, the second concerning what other universities have done in this regard. Lastly will be the conclusions.

Before turning to a discussion of the KU campus, however, it is appropriate to ask why it matters if stormwater is handled on campus. After all, all water returns to the streams, rivers, lakes, and oceans from whence it comes. So why does it matter if it gets there fast or slowly, if it has been detained, if it has cleaned, or not?

It matters for several reasons. The first of these is erosion. KU is a hilly campus, at some locations having a slope of "almost 17 percent."[2] Water can move fast on a slope, and as it moves it erodes the land. "If precipitation is (occasionally, regularly or irregularly) greater than evaporation and infiltration, runoff will occur, following the surface gradient. The force of gravity causes surface water to always take the shortest path downwards. It is collected in the deepest parts of valleys and flows further down the valleys in the form of small creeks or rivers."[3] On hilly lands, the less permeable the soil, the more runoff there is. And "[r]unoff carries nutrients, chemicals and soil with it, resulting in decreased soil productivity, off-site sedimentation of water bodies and diminished water quality. Sedimentation decreases storage capacity of reservoirs and streams and can lead to flooding."[4] One needs only to think of Potter Lake two years ago, before the KU community began its efforts to clean the lake, to realize what "sedimentation of a water body" and "diminished water quality" look like.

A second reason why it matters if stormwater is treated and used as much as possible where it falls concerns what soil does for stormwater. Soil acts as a filter for water. It filters out

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[2] Burns & McDonnell. (May, 1996). *Lawrence, Kansas Stormwater Management Master Plan*, at II-6.
[3] Toppe, A. (2002). River Development Planning. In S. Kunst, T. Kruse, and A. Burmester (Eds.), *Sustainable Water and Soil Management* (pp. 221-259). Berlin, Heidelberg: Springer-Verlag, at 221.
[4] USDA, NRCS. (June, 2008). *Soil Quality Indicators*. Retrieved February 10, 2012, from http://soils.usda.gov/sqi/assessment/files/infiltration_sq_physical_indicator_sheet.pdf.

debris which has accumulated on surfaces since the previous rain, such as twigs and trash; it filters out biological contaminants; it filters out chemical contaminants. To the extent that stormwater does not infiltrate or is not treated close to where it falls, to that extent the water does not get cleaned by that soil. Of course, soil is not the only cleaning mechanism for stormwater: "[t]he spinning weather machine that is Earth's climate, in which water is a full partner, does a great job of turning swamps and oceans into rushing, crystalline mountain streams."[5] But soil is the first cleaner, and because human activity has altered the natural filtration process,[6] stormwater urban runoff has been identified as a "leading source of impairment" in United States streams, in its bays and estuaries, and in its coastal resources.[7]

A third reason why it is important to treat and use stormwater where it falls whenever possible concerns plant life. Plants need water. If stormwater is running off downhill faster than it can infiltrate in the soil, then the plants lose most of it as a water source. Plant roots pull water down into the soil, making the soil healthier and the soil texture better. If they cannot get the water they need and they subsequently die, then the soil becomes less and less able to support plant life, the water which those plants used to pull down into the ground now runs off, and the groundwater supply is diminished.

A fourth reason to be concerned about stormwater is its adverse impact on groundwater level. When stormwater is conveyed through pipes and drainage channels to an outlet such as a river or a lake, it not only often arrives at the outlet in a polluted condition, but it also has left the land where it fell with no opportunity to infiltrate down to the groundwater. That is, these

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[5] Fishman, C. (2011). *The Big Thirst: The Secret Life and Turbulent Future of Water*. New York: Free Press, at 17-18. Hereinafter this work will be referred to as "Fishman."

[6] Pazwash, H. (2011). *Urban Storm Water Management.* Boca Raton, Fl: CRC Press, at 1. Hereinafter this work will be referred to as "Pazwash."

[7] EPA. *National Water Quality Inventory: Report to Congress, 2002 Reporting Cycle*, at 10, 17, and 18. Retrieved February 27, 2012, from http://water.epa.gov/owow/305b/2002report/report2002305b.pdf.

constructed drainage systems turn "overland flow to concentrated runoff."[8] Urban development alters the natural process of stormwater infiltration, and at a time when more than half of the state of Kansas is in a condition of drought,[9] replenishing the groundwater is a matter of concern.

II. Background Regarding the KU Main Campus

Three aspects of KU's main campus of particular importance to stormwater will be specified here: impervious surface acreage, average annual rainfall, and soil type. The map in Figure 1 shows the entire KU Lawrence campus divided into zones, with Iowa Street, at the west edge of Zone 3, marking the border between the main campus and the west campus. Since this project is focused on Mt. Oread, it is Zones 1 through 5, 9 through 11, and 15 through 17, which are of concern in this project. Zones 20 and 23, although east of Iowa Street, do not contain properties owned by KU and therefore are not part of this study.[10]

KU's Office of Design and Construction Management maintains figures on the square footage of the entire KU campus by category of surface and by zone. There are seven categories of impervious surfaces: buildings, sidewalks, retaining walls, exterior stairs and ramps, streets, parking areas, and outdoor recreation areas. Each building, parking lot, and so forth, in each zone is listed by name and by square footage. Adding the relevant zone totals for each of the seven categories yields the total square footage of impervious surface on the main campus.[11]

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[8] Pazwash, at 1.
[9] National Oceanic and Atmospheric Administration *U.S. Seasonal Drought Outlook, Drought Tendency During the Valid Period, Valid for February 16-May 31, 2012.* Retrieved February 27, 2012, from http://www.cpc.ncep.noaa.gov/products/expert_assessment/seasonal_drought.pdf.
[10] Email from Marion Paulette Waller, Landscape Architect, Kansas University Office of Design and Construction Management, October 20, 2011, to author.
[11] See the lists of each of the seven categories of impervious surface by zone below at Appendix A, pp. 76-87. Although "KU Campus Outdoor Recreation Area" includes outdoor fields, all of the outdoor fields are considered impervious by DCM: the football stadium and practice fields have artificial turf; the band practice field is paved; the basketball and tennis courts are paved; and, while the practice field south of Allen Fieldhouse and the baseball stadium are grass, they have drainage systems underneath, similar to the football fields and stadium.

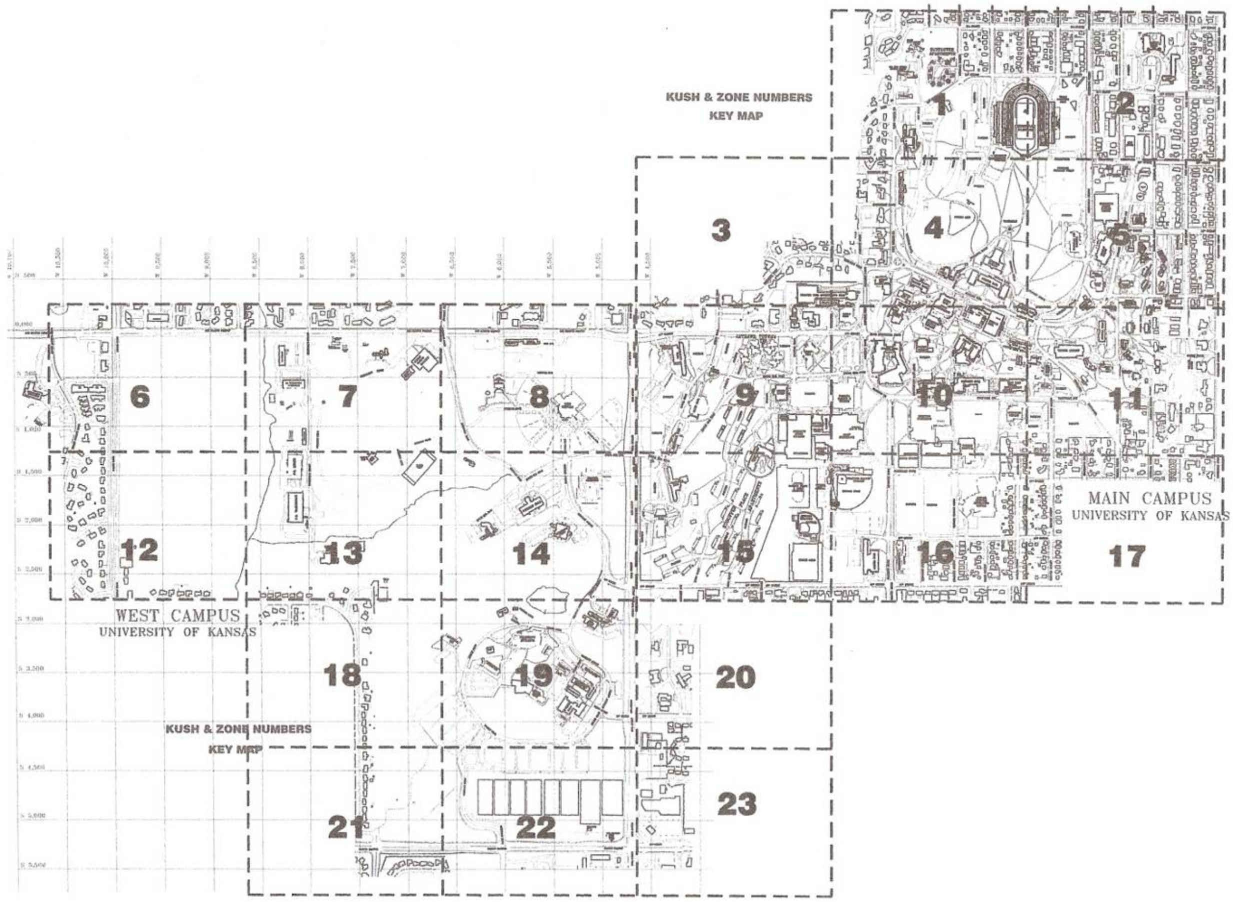

Figure 1: Zones of KU campus[12]

The totals are as follows: buildings equal 2,207,458.9 square feet of impervious surface; parking areas equal 3,506,051.0 square feet; sidewalks equal 1,086,904.1 square feet; retaining walls equal 16,418.6 square feet; exterior stairs and ramps equal 104,642.4 square feet; streets equal 1,073,988.2 square feet; and outdoor recreation areas equal 1,158,435.6077 square feet. These seven figures total 9,153,898.8 square feet of impervious surface on Mt Oread. This project is concerned with the two largest categories of impervious surfaces on KU's main campus: buildings and parking lots.

Having determined how much built surface there is on the main campus that is impervious to rainwater, it must next be determined how much rainwater falls on this surface.

[12] Kansas University Office of Design and Construction Management. *University of Kansas KUSH and Zone Map.*

Several different figures are available for this determination. Figure 2, a precipitation map developed by The United States Department of Agriculture's Natural Resources Conservation

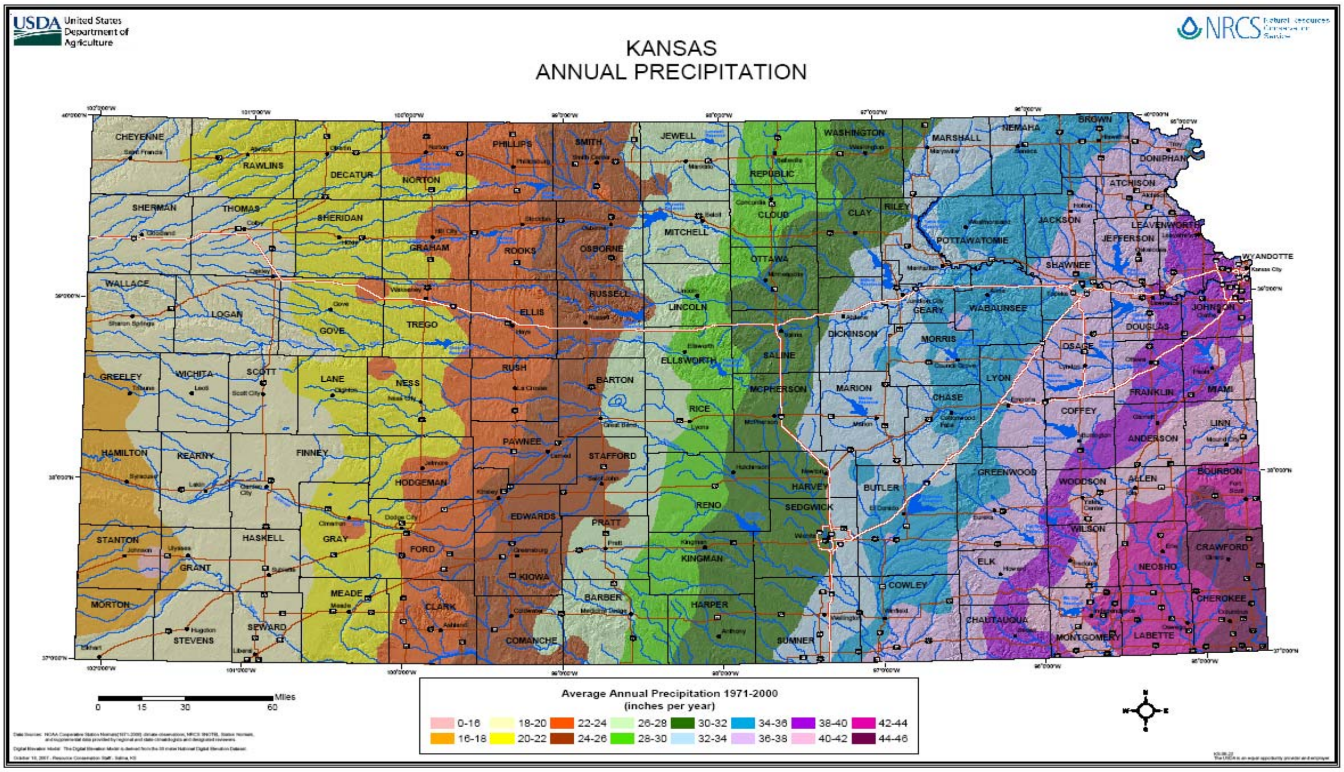

Figure 2: NRCS: Annual precipitation in Kansas

Service (NRCS) for the entire state of Kansas, shows Lawrence receiving, during the years 1971 through 2000, between 38 and 40 inches of rain annually.[13] Data collected from 1981 to 2010 for the National Oceanic and Atmospheric Administration (NOAA) shows that Lawrence annually received an average of 39.9 inches of rain during those years.[14] The Kansas State Research and Extension web site shows that, from 1890 through 2009, Kansas received an average annual rainfall of 37.43 inches; from 2000 through 2009, an average of 36.03 inches;

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[13]USDA, NRCS. (n. d.). *Kansas Annual Precipitation*. Retrieved February 16, 2012, from ftp://ftp-fc.sc.egov.usda.gov/KS/Outgoing/Web_Files/Technical_Resources/Maps/ks_08_22.pdf.
[14] *Current Results: Research news and science facts.* (n. d.). Retrieved February 16, 2012, from http://www.currentresults.com/Weather/Kansas/average-yearly-precipitation.php#a.

and for 2008 through 2009, an average of 42.95 inches.[15] Thirty-eight inches, the low end of NRCS's assessment, then, seems a close approximation of the average annual rainfall in Lawrence and will be the figure used throughout this project.

The third aspect of KU's main campus of significance here concerns soil group. The NRCS classifies soil into four main hydrologic soil groups (HSG): A, B, C, and D. HSG A is the soil which will infiltrate the most water. It has the "lowest runoff potential when thoroughly wet," and it typically has "less than 10 percent clay and more than 90 percent sand or gravel."[16] HSG B soils have "moderately low runoff potential when thoroughly wet," and typically "have between 10 percent and 20 percent clay and 50 percent to 90 percent sand."[17] HSG C soils have "moderately high runoff potential when thoroughly wet" and "typically have between 20 percent and 40 percent clay and less than 50 percent sand."[18] Lastly, HSG D soils "have high runoff potential when thoroughly wet" and "[w]ater movement through the soil is restricted or very restricted."[19] Usually, HSG D soils "have greater than 40 percent clay, [and] less than 50 percent sand," or are less than 20 inches to the water impermeable layer.[20] Group A soils are the most permeable; Group D soils are the least permeable. It is possible for HSG A, B, C, or D soils to be found in any other HSG group; the designation simply means that the predominant soil type in the particular area is the HSG designation.

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[15] K-State Research and Extension. *Weather Data Library: Kansas Climate Collection*. Retrieved February 16, 2012, from http://www.ksre.ksu.edu/wdl/. Click "Kansas Climate Collection" (next to a picture of a sheaf of wheat), click "Kansas weather records, historical to recent data files;" scroll to "Comma separated ASCII" and click "Lawrence."
[16] USDA NRCS. (2007). Part 630 Hydrology, *National Engineering Handbook*, §630.0701, at 7-2. Retrieved February 16, 2012, from http://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba.
[17] *Id*.
[18] *Id*.
[19] *Id*.
[20] *Id*., at 7-2, 7-4.

Figure 3[21] shows NRCS's hydrologic map of the KU campus and surrounding area, with the campus showing in color. The numbers on the map refer to the type of soil found in that colored area of the map. As shown in Table 1, NRCS has categorized those areas colored yellow as HSG C soils. Those areas colored purple are categorized as HSG D soils. The numbers or "map unit symbols" in each colored segment refer to the type of soil prevalent in that particular

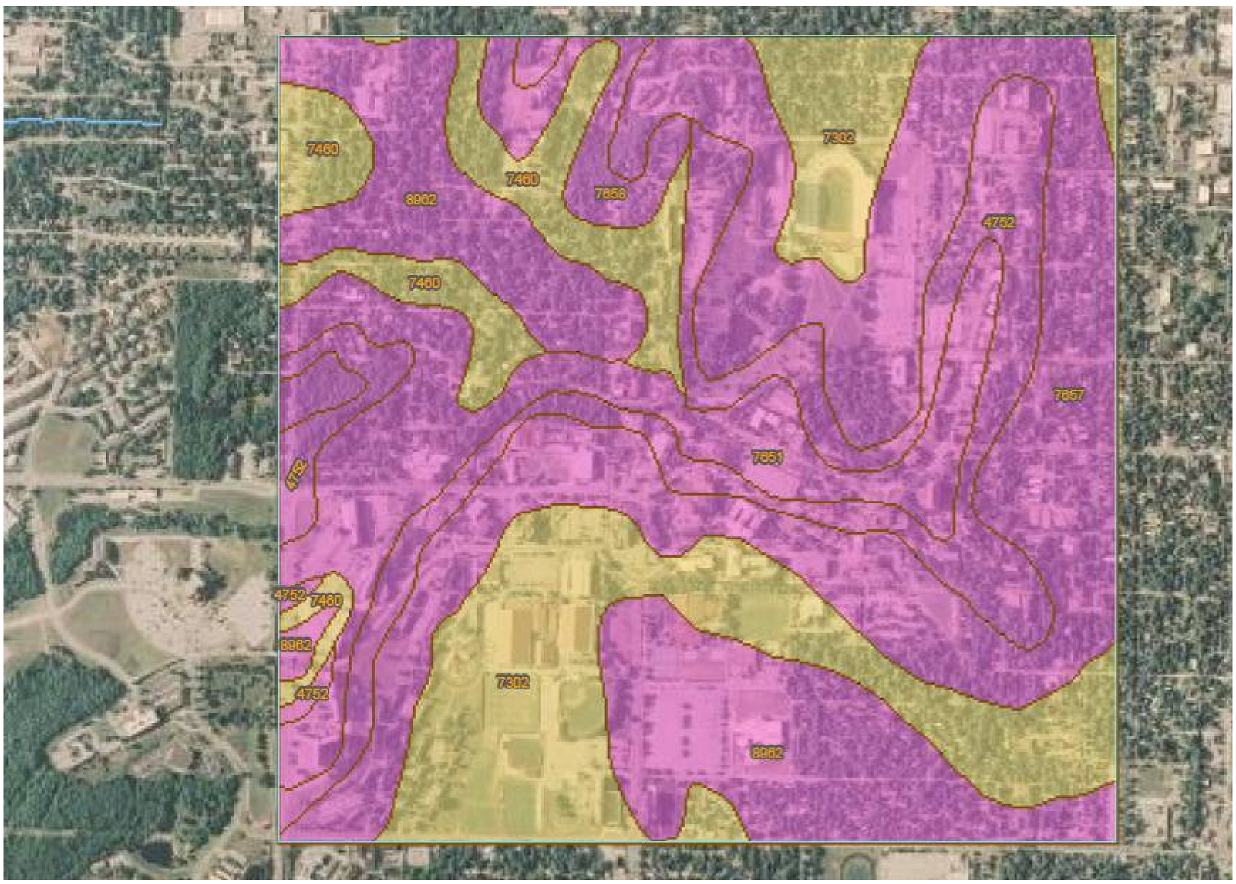

Figure 3: NRCS map of KU main campus by HSG soils

segment. These are specified in Table 2. As Table 2 shows, 27.3 percent of the KU main campus is HSG C, while the remaining 72.7 percent is HSG D, the soil most resistant to infiltration. Mt. Oread is very clayey, and getting stormwater to infiltrate into the ground will be difficult. BMPs must be chosen that accommodate this fact. That is why the focus of this

[21] Email from Cleveland Watts, Kansas USDA, with Map and Tables 1 and 2, October 7, 2011, to author.

project will be on determining how to detain, retain and clean the storm water that flows on KU's main campus. Some of the stormwater will infiltrate on its own as it always does; some will be captured in a BMP to be recommended for the roofs of some of KU's buildings; but regarding the water that reaches the ground, the focus in this project will be on detaining, retaining, and cleaning it before it enters the KU's and the City of Lawrence's drainage systems, or is reused.

MAP LEGEND

Area of Interest (AOI)
- Area of Interest (AOI)

Soils
- Soil Map Units

Soil Ratings
- A
- A/D
- B
- B/D
- C
- C/D
- D
- Not rated or not available

Political Features

Water Features
- Streams and Canals

MAP INFORMATION

Map Scale: 1:15,800 if printed on A size (8.5" X 11") sheet.

The soil surveys that comprise your AOI were mapped at 1:24,000.

Please rely on the bar scale on each map sheet for accurate map measurements.

Source of Map: Natural Resources Conservation Service
Web Soil Survey URL: http://websoilsurvey.nrcs.usda.gov
Coordinate System: UTM Zone 15N NAD83

This product is generated from the USDA-NRCS certified data as of the version date(s) listed below.

Soil Survey Area: Douglas County, Kansas
Survey Area Data: Version 8, Nov 30, 2010

Date(s) aerial images were photographed: 6/15/2006

The orthophoto or other base map on which the soil lines were compiled and digitized probably differs from the background imagery displayed on these maps. As a result, some minor shifting of map unit boundaries may be evident.

Table 1: NRCS hydrologic soil groups

Table 2: HSG summary by map unit symbol

Hydrologic Soil Group— Summary by Map Unit — Douglas County, Kansas (KS045)				
Map unit symbol	Map unit name	Rating	Acres in AOI	Percent of AOI
4752	Sogn-Vinland complex, 3 to 25 percent slopes	D	112.1	13.3%
7302	Martin silty clay loam, 3 to 7 percent slopes	C	164.6	19.5%
7460	Oska silty clay loam, 3 to 6 percent slopes	C	65.7	7.8%
7651	Vinland complex, 3 to 7 percent slopes	D	95.0	11.3%
7657	Vinland-Martin complex, 7 to 15 percent slopes	D	240.2	28.5%
7658	Vinland-Rock outcrop complex, 15 to 45 percent slopes	D	22.1	2.6%
8962	Woodson silt loam, 1 to 3 percent slopes	D	143.6	17.0%
Totals for Area of Interest			843.4	100.0%

II. Varieties of Best Management Practices

Having seen aspects of the KU campus that will determine what sort of BMPs can be used in order to detain, retain, and clean stormwater, the BMPs themselves will be briefly discussed here. There are a variety of them. Not all are feasible for a given site, though, and that may be the most important point to make about them: BMPs are site-specific. Their tributary areas, slopes, surrounding soil types, and stormwater sources, among many other factors, must all be considered in choosing the most appropriate BMP for a given site. Some BMPs are better at cleaning a specific type of pollutant out of the water. Others work well handling the first flush of a storm, the first half-inch or so of rain, considered the most polluted water of a rainfall. What works well in one location may not work at all in another location only several yards away. Among the various kinds of BMPs, basins, trenches, swales, filters, and proprietary devices will be described here.

Rain gardens may be the BMP with which the KU community is most familiar. These are small basins, excavated areas covered with a mulch layer and planted with a diversity of woody and herbaceous vegetation.[22] KU students and faculty have already built a rain garden on KU's main campus. It is situated just in front of the Ambler Student Recreation Center. Rainwater is collected at the point of runoff from the building's downspouts and directed into the rain garden. Indeed, this is one of the most important features of rain gardens: they can be used to capture a storm's first flush.[23]

[22] *MARC/APWA Manual of Best Management Practices for Stormwater Quality.* (August, 2009, 2nd ed.), at 8-1. This can be accessed at http://www.marc.org/Environment/Water/bmp_manual.htm. In some instances, the author has had access to and used copies of several revisions to the *Manual* that are not yet on the web site. Hereinafter, this work will be referred to as "*MARC Manual*."
[23] *BNIM/USGBC*. (March, 2011). *Multi-Variate Study of Stormwater BMPs*, *Final Report*, at 77. Hereinafter this work will be referred to as "*BNIM*."

Care must be taken in selecting the plants to be planted in a rain garden, as it was in KU's rain garden. KU selected plants which are native species, species which in Lawrence can survive cold, snow, heavy rainfalls, and drought. All plantings can slow down the speed of stormwater runoff, but native species, once well established, can do more than that. Native species can develop amazingly deep root systems. In regard to native prairie species, for example, "about 65 percent of the prairie species extend their roots beyond five feet. In some cases maximum depths of eighteen to twenty-four feet are attained."[24] One benefit to the earth regarding these deep root systems is that they can draw water down to themselves and absorb it into themselves: they can retain stormwater into the soil where it can be cleaned, and they can infiltrate it.

Other types of basins are the infiltration basin, the bioretention cell, the Extended Detention Wetland (EDW), the Extended Wet Detention Basin (EWDB), and the Extended Dry Detention Basin (EDDB). Basins in general are "stormwater ponds typically designed to protect against flooding and downstream erosion by storing water for a limited period of time."[25]

The infiltration basin temporarily stores stormwater and allows infiltration. Its depth is no more than two feet, and its ponding time no more than 72 hours.[26] The bioretention cell, another form of basin, is a small vegetated landscaped basin which cleans and infiltrates stormwater close to the source of the water, and which serves a tributary area usually less than

[24] Abbott, F.D. (October 3, 1966). *Kansas Range Technical Note KS-3: Subject: Root Systems of Prairie Plants*. USDA NRCS. Retrieved February 16, 2012, from http://www.ks.nrcs.usda.gov/technical/tech_notes/ran3.html. See the extraordinary five-page pen-and-ink renderings of the root systems of various prairie plants in the attachment to this Technical Note. A pen-and-ink drawing of the Little Bluestem root system appears on p. 3 of the attachment, grown to a depth of seven feet; and a drawing of the Side-Oats Grama root system, grown to a depth of five feet, appears on p. 2. Both of these perennials are planted in the rain garden in front of Ambler.
[25] *BNIM*, at 77.
[26] *MARC Manual*, §8.2.5.

four acres.[27] A bioretention cell "has one of the highest nutrient and pollutant removal efficiencies of any BMP."[28]

Both the Extended Detention Wetland (EDW) and the Extended Wet Detention Basin (EWDB) are constructed to detain water in a permanent pool throughout the growing season, and both can function as BMPs for tributary areas between two and 1000 acres, but whatever their size, they must be large enough to maintain water in these permanent pools. The main difference between these two types of basins is their ponding depths: the maximum depth of the EWD is about 18 inches, while that of the EWDB is optimally "from 4 to 6 feet, and shall be no greater than 12 feet."[29]

Another type of basin is the Extended Dry Detention Basin, similar to the EWDB except that it does not have a permanent pool.[30] The KU community will be familiar with this type of stormwater BMP also: there is an EWDB just alongside and adjoining the Ambler rain garden. The stormwater which is not retained and infiltrated by the rain garden flows through a level spreader into the detention basin, a large, shallow basin which is dry except during and after a rain event. Some rainwater can infiltrate here, but this BMP serves mainly to detain the water runoff so that less peak demand is placed on the stormwater drainage system since the water from Ambler's roof drains more slowly into and through this BMP than water flowing directly from the control segment of the roof and into the storm drain. And this EDDB does work; it does detain stormwater runoff. BNIM's study of the combined rain garden/detention basin concluded the following: "[w]hen the rain gardens were dry, there was a lag time of about an hour and twenty minutes between the start of rainfall and the time water discharged from the rain

[27] *Id*., at §§8.4.1-4, unnumbered page.
[28] *Id*., at §8.4.3, unnumbered page.
[29] *Id.*, at §8.6.1 and §8.10.5.
[30] *Id.*, at §8.12.1.

garden. When there had been an inch or more of precipitation the prior day and site soils were wet, the time to runoff was 50 to 70% shorter."[31]

A second type of stormwater BMP is called an infiltration trench. This is an excavated trench filled with coarse, granular material. Because it can capture only a small amount of runoff, an infiltration trench, like a rain garden, can be designed to capture a storm's first flush. This BMP can detain runoff and infiltrate some of it, but is not suitable where the soil has a low permeability rate. Therefore, their use on Mt. Oread could be problematic. Their tributary area is less than or equal to two acres. "Filtration strips" have been installed on the west campus, at Park and Ride, and they "collect stormwater runoff and filter it to a bioretention basin."[32]

Swales constitute another type of stormwater BMP, and, like basins, there are a variety of these: bioswales, wetland swales, native vegetated swales, and turf swales. The KU community has an example of a rain garden plus a bioswale on the west campus near the Pharmacy Building. Swales in general can be natural or constructed, and are broad, shallow channels with dense stands of vegetation. Bioswales have prepared soil filter beds and an underdrain system for drainage. They "promote infiltration" and they filter "pollutants through an engineered media and through plant biological uptake."[33] However, they are "only effective conveying shallow concentrated flow."[34]

Wetland swales, on the other hand, do not include a prepared soil filter bed or an underdrain system. These wetland swales "slowly convey stormwater runoff," "promote

[31] *BNIM*, at 81. BNIM's drawings on pp. 80 and 81 demonstrate that both the rain garden and the detention basin are included in determining the amount of time of runoff delay.
[32] Kansas University. (2011). *Building Sustainable Traditions: University of Kansas Campus Sustainability Plan,* at 34. Hereinafter this document will be referred to as "*KU CSP*."
[33] *MARC Manual*, §8.9.2.
[34] *Id*.

infiltration, plant transpiration, adsorption, settling of suspended solids, and microbial breakdown of pollutants," and can "replace curbs, gutters, and storm sewer systems."[35]

The remaining two types of swales, the native vegetation swale and the turf swale, are distinguished from the wetland swale and the bioswale mainly by the type of vegetation which covers their side slopes and their channel bottoms. Their names identify their vegetation: native grasses for the native vegetation swale and turf grasses for the turf swale. Both are effective only in conveying shallow concentrated water flows; both have relatively small tributary areas (less than two acres for the native vegetation swale; less than five acres for the turf swale); and both can function as a substitute for traditional pipe systems to treat and convey roadway drainage.[36]

Two examples of a further kind of stormwater BMP can be found on the KU campus. This BMP is the green roof, and the two examples are the roof of the Anderson Family Football Complex just to the southwest of Memorial Stadium, and the Center for Design Research on the west campus. A green roof is "an extension of the existing roof which involves a high quality water proofing and root repellant system, a drainage system, a filter cloth, a lightweight growing medium, and plants."[37] If the growing medium is two to four or so inches deep, "with plant communities adaptable [to] shallow soil systems, then the green roof is called "extensive;" if the growing medium is about eight inches deep and therefore allows for a wider selection of plants and some small trees, then the green roof is called "intensive."[38]

Green roofs can reduce stormwater runoff since they capture stormwater and use it themselves. They improve the water quality of the runoff that does occur, since they themselves capture and keep the first flush (which on roofs is much cleaner than on streets). They can also

[35] *Id.*, at §8.8.1-2.
[36] *Id.*, at §§8.11 and 8.13.
[37] *Id.*, at §8.19.
[38] *Id.*, at §8.19.3.

reduce utility bills because they serve as insulators as well as stormwater collectors: they prevent some heat from entering the building in the hot months, and they reduce heat loss in the cold months. When the green roof was installed on the Anderson Family Football Complex, the University architect estimated that it would save the University $20,000 per year in utility bills because the weight room, the room under the green roof, would not have to be heated or cooled to the degree that other buildings require.[39]

Because KU's soil is HSG C and D, and will not allow for much infiltration of water, green roofs will play an important role in the detention and retention of stormwater on the main campus. Before any green roof is added to any KU building, however, an engineer for the University must certify that the structures of the buildings considered for green roofs are sufficiently strong to support the additional weight of the green roof system when at maximum water-holding capacity.

A further type of stormwater BMP whose name might be familiar to many is pervious pavement. This pavement can be made of pervious concrete, that is, concrete without the fines, or can be made of porous asphalt, with little or no sand.[40] There are proprietary forms of permeable pavement such as modular pavers, pre-cast concrete grids, and cellular confinement systems.

Filters are another kind of stormwater BMP to be described here, and these include both sand filters and proprietary media filters. Sand filters are self-contained beds of sand into which "runoff is diverted, . . . collected in underground pipes, and discharged into a stream, channel, or sewer system."[41] Sand filters function "primarily for water quality enhancement;" they can

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[39] Keefer, C. (2008). Football complex goes green with grass roof. *The University Daily Kansan*. Retrieved February 18, 2012, from http://www.kansan.com/news/2008/jul/08/roof.
[40] *MARC Manual*, §8.5.1.
[41] *Id*., §8.7.1.

"collect, treat, and release runoff either to a storm drainage system or directly to surface water;" they typically handle runoff from "completely impervious drainage areas of 1 acre or less;" they "can accept the first 0.5 inch of runoff;" and they "are only feasible for highly impervious stabilized areas such as parking lots and rooftops."[42]

Proprietary media filters vary in design, but "all remove pollutants from stormwater by directing the runoff flow through a bed of media."[43] There are chemically inert media which filter sediment and other pollutants, or media which "utilize ion exchange or other sorption processes to remove dissolved pollutant constituents."[44]

Last among the BMPs to be described here are manufactured devices that function as stormwater BMPs. These include hydrodynamic separation devices, most of which "utilize vortex-enhanced sedimentation;"[45] baffle boxes, which "typically target coarse solids and large oil droplets" and can treat the first flush;[46] and catch basin inserts. These inserts are "manufactured filters or fabrics designed to remove trash, debris, and coarse sediment from stormwater runoff directly at the storm drain inlet structure." They are installed under the stormwater grate, either by "mounting directly to the structure wall or by suspension from the lip of the inlet."[47]

In 2011, KU developed its *Campus Sustainability Plan*, which includes a section addressing campus grounds. Goal 4 of KU's Campus Grounds Vision is "Reduce stormwater runoff." Objective 4.1 recognizes that "[a]n increase in the volume and rate of storm water runoff leads to more frequent and severe flooding, stream bank erosion, and poor water quality."

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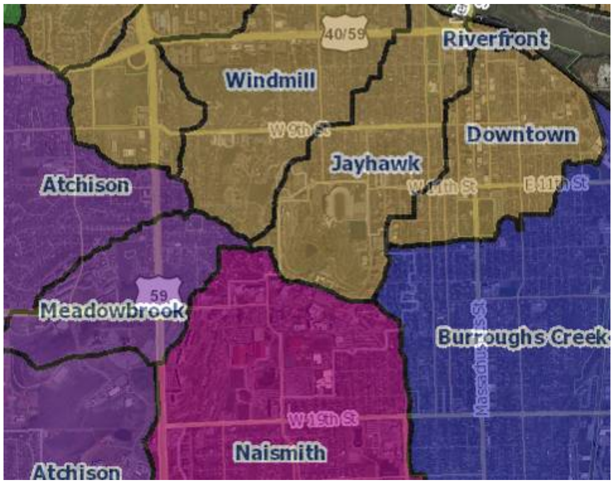
[42] *Id*., §8.7.1-2.
[43] *Id*., §8.14.1.
[44] *Id*.
[45] *Id*., §8.15.1.
[46] *Id*., §8.17.1.
[47] *Id*., §8.16.1.

To address these problems, Strategy 4.1.2 states: "Increase the square footage of rain gardens, bioswales and climate adapted plantings on Main Campus." Strategy 4.1.3 states: "Reduce the square footage of non-permeable pavements on campus by converting pavements to permeable surfaces. Strategy 4.1.4 states: "Develop building standards that encourage or require green roofs."[48] This project will proceed with those directives in mind.



III. BMPs for KU's Main Campus

As can be seen in Figure 4,[49] KU's main campus sits in parts of six different watersheds: the Meadowbrook watershed, the Windmill watershed, the Jayhawk watershed, a sliver of the Downtown watershed, the Burroughs Creek watershed, and the Naismith watershed, with this last watershed constituting, geographically, the largest part of the main campus. Each of these watersheds will be examined in turn, in regard to the two largest categories of impermeable surface whose square footages were stated earlier, that is, buildings and parking lots. The goal is to determine which BMPs might be used to detain or retain this runoff; to slow down the runoff; to improve its quality by taking out some of the total suspended solids (TSS) and some of the pollutants; where possible, to reduce the volume of the runoff; and to quantify in gallons the amount of runoff so handled.

The impermeable surfaces in the Naismith watershed will be studied first. This watershed extends across the entire southern boundary of the main campus, and receives all the stormwater

[48] *KU CSP*, at 34-35.
[49] City of Lawrence, Kansas interactive map, at http://lawrenceks.org/city_maps. Hereinafter this resource will be cited as "Lawrence interactive map." This interactive map was an invaluable resource in this project. The main campus is faintly outlined in Figure 4.

runoff from this entire southern portion. Notably, this southern end KU's main campus lies approximately two blocks north of the Naismith flood zone.[50]

Comparing Figure 1, the campus zones, with Figure 4, the watershed map, one can see that the zones and the watersheds do not share the same boundaries. That is, a zone may be partly in one watershed and partly in another. Likewise, a watershed may include more than one zone. This is because the zone map was not developed from the watershed map, nor is it based on the watershed map. What watershed a given building or a parking lot is in will determine where the property is studied in this project. The Naismith watershed therefore will be seen to include most of zone 9, and zones 10, 15, 16, and 17, but also some of the land in zone 11. The Meadowbrook watershed includes a part of zone 9, that part being a small triangular section of Daisy Hill between Engel Road, Iowa, and 15th Street. The Windmill watershed includes a tiny portion of zone 1 just to the west of the Sunflower Apartments. The Jayhawk watershed includes most of zone 1, all of zone 2, and some of zones 3, 4, and 5. The Downtown watershed includes only a tiny strip of the KU main campus, just two parking lots in zone 5. The Burroughs Creek watershed includes most of zones 5 and 11.

A. Naismith Watershed:

<u>1. Naismith Watershed Buildings:</u>

"Buildings" comprise the second-largest impervious square footage on the KU main campus. Controlling the rain water that falls on the building roofs, therefore, can have a substantial impact on the quantity of the rain water flowing into the storm drainage system. One of the ways to control this rain water is through vegetated roofs, or roof "greening." "The

[50] Lawrence interactive map. Information on the Naismith flood-zone location comes from the City of Lawrence's web site, where one can click on "Resources" and then "Interactive Map," and go to "Aerials 2009 labels." One can overlay on the City map such options as flood zones, watersheds, and land contours, and can use a drawing tool to measure the size of any chosen space in linear feet, square feet, or acres.

essential effects of roof-green are: a reduction of drainage water from precipitation, the retention of raw water to meet the water needs of the roof vegetation and the delay in the runoff water into the drains. These features are of economic, ecological and technical significance."[51]

Green roofs can be applied to steeply sloping roofs as well as to flat roofs.[52] Typically, however, "[r]ooftop runoff management BMPs are. . .applied on flat or gently sloping roofs." Further, the green roof BMP "can be retrofitted to many conventionally constructed buildings."[53] Because green roof installation and maintenance are simpler and safer than the same for sloped roofs, the recommendation in this project is that green roof installation be made only for flat or nearly flat roofs. A different treatment will be recommended for KU's sloped-roof buildings.

If the Stouffer Place Apartments (25 different buildings) and the Jayhawk Towers Complex (5 different buildings) are each considered to be a single unit, then there are 47 KU buildings in the Naismith watershed.[54] Among these 47 are some of the largest buildings on campus. Of these 47 buildings, 24 have completely or almost completely flat roofs. The 24 buildings are Nunemaker, Lewis, Hashinger, Jayhawk Towers, Burge Union, Green, Anderson, Eaton, Art and Design, Dole, Computer Services, Haworth, Wescoe, Murphy, Summerfield,

[51] Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau. (2008). *Guidelines for the Planning, Construction and Maintenance of Green Roofing: Green Roofing Guideline.* Bonn, Germany. The April, 2011, *Stormwater Management Guidance Manual for the City of Philadelphia*, at 7-4, states the following: "Presently, the most complete established standards for green roof construction are those developed in Germany by Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL)." Hereinafter, the German work will be referred to as "*FLL*." The Philadelphia work will be referred to as "*Philadelphia Manual*."

[52] *FLL* says that for "roofs with a gradient in excess of 45° greening should not be considered." At 22.

[53] North Carolina Department of Environment and Natural Resources. (Rev. 2007). *NCDENR Stormwater BMP Manual*, at 19-2. Hereinafter, this work will be referred to as "NCDENR."

[54] This count is based on the "KU Campus Building Area" at Appendix A, pp.77-78. If a building has been added to the campus since this list was compiled, it is not included in this work here. Additionally, Watkins Memorial Health Center is listed twice: once in zone 10 and again in combined zones 15, 16, and 17. Here it is counted only once, however. Stouffer Place Apartments are also listed twice, once in zone 9 and again in the combined zones 15, 16, and 17, but that is because some of the units are in one zone and some are in another zone. The count of 47 includes six buildings in zone 11. Marvin Hall is divided by the Jayhawk and the Naismith watersheds. It is counted here in the Naismith watershed.

Robinson, Malott, Watkins Memorial Health Center, Blake, Ellsworth, McCollum, Hilltop, Oliver, and Ambler.

Four of these 24 buildings, Jayhawk Towers, Art and Design, Haworth, and Malott, appear to have such a significant quantity of pipes, tubes, vents and other openings on their roofs that they will be included with sloped-roof buildings instead of here with completely or almost completely flat roofs. The recommendation from this project for all of the remaining 24 flat-roofed buildings is that they be greened. This recommendation is in keeping with KU's *Campus Sustainability Plan* which, at its Campus Grounds Vision Objective 2.2, Strategy 2.2.2, states this: "Use high albedo surfaces such as light colored pavements and green roofs where feasible."[55]

According to the *MARC Manual*, the rainwater retention standard for a green roof is that "70% of 1.37" rain event (or 0.96 cubic inches of rain per square inch of surface) must be held within the green roof system."[56] The "1.37 inches" is an important concept to understand: it is the "design storm" for the Kansas City region. That means that it is the "water quality storm," or the "storm event that produces less than or equal to 90 percent stormwater runoff volume of all 24-hour storms on an annual basis. In the Kansas City metropolitan area this is the 1.37" storm."[57] Since 70 percent of 1.37 inches equals 0.959 inches, that figure times the number of square inches in the given surface equals the number of cubic inches of rain water that an extensive green roof with a recommended average soil depth of four inches must be able to contain per rain event.

[55] At 35.
[56] *MARC Manual*, unnumbered page following 8.19-4, titled "Design Procedure Form: Green Roof Main Worksheet."
[57] *Id*., at 2-4. Note here that 1.37 inches is the water quality storm for the Kansas City, Missouri region, and while that includes Johnson County, Kansas, it does not include Douglas County, Kansas. However, Mr. Matt Bond, the Stormwater Engineer for the City of Lawrence, Kansas, in an interview with the author on February 17, 2012, indicated that the design storm for Lawrence is probably 1.38 inches, but he thought that using the 1.37inch-figure, and the tables associated with that figure, would make sense for this project.

Holding 70 percent of the design storm volume on the roof does not limit green-roof runoff to zero, of course. But it does limit runoff significantly:

> Although rooftop runoff management is generally more effective in controlling small storms, since the vast majority of rain events are in this category, rooftop runoff management can be important in planning for comprehensive stormwater management. By retaining this rainfall for evaporation or plant transpiration, some rooftop runoff management measures, such as vegetated roof covers, can achieve significant reductions in total annual runoff.[58]

To determine how many rain storms in Lawrence could be completely handled annually by shallow, extensive green roofs on each of the 20 buildings under consideration now, the Kansas State University web site mentioned earlier was consulted.[59] The number of days during which precipitation in Lawrence occurred was hand-counted, as was the number of times this precipitation amount exceeded 0.96 inches.[60] This was done for each of the years 2000 through 2009.

As Table 3 illustrates, the number of times in each of these 10 years when the one-day rainfall exceeded 0.96 inches per square inch of surface ranged from 5 times to 15 times. Annually, the total amount of rainfall in inches by which all of these large one-day rainfalls exceeded 0.96 inches ranged from 1.61 inches in 2002 to 9.90 inches in 2004, for an average

Year	Total number of rainfall events	Number of rainfall events exceeding 0.96 inches	Annual average amount of rain which would run off green roof (with 38" = average annual rainfall)	Annual average amount of rain which green roof could handle (with 38" = average annual rainfall)
2000	67	10	5.47	32.53
2001	84	15	5.96	32.04
2002	74	8	1.61	36.39
2003	67	5	4.30	33.70
2004	94	12	9.90	28.10

[58] NCDENR, at 19-2.
[59] Footnote 15 and text associated therewith.
[60] Snow storm events were not considered because snow does not melt all at once and continue without interruption to run off until gone.

2005	87	13	8.75	29.25
2006	90	11	3.81	34.19
2007	93	9	6.64	31.36
2008	108	15	6.36	31.64
2009	104	11	9.41	28.59
			10-year average: 6.22	10-year average: 31.78

Table 3: Lawrence, Kansas, annual rainfall events, 2000-2009

during these 10 years of 6.22 inches. The 10-year average by which the rain events exceed 0.96 inches is 6.22 inches.

Returning now to the 20 buildings in the Naismith watershed with completely or almost completely flat roofs, and adding their roof surface, the total square footage of these 20 roofs equals 719,395.07 square feet. From that total square footage, an arbitrary 10 percent will be subtracted to allow for areas on any building which for some reason, such as existing pipes, ducts, and vents, cannot have a green roof on them. This leaves 647,455.56 square feet of roof space available for greening, or 93,233,600.64 square inches. Multiplying that number of square inches by 6.22 inches, which is the number of inches of average annual rainfall which the 23 green roofs cannot contain, yields 579,912,996 cubic inches, which converts to 335,597.80 cubic feet. This figure, multiplied by 7.48, the number of gallons per cubic foot, equals 2,510,271.54 gallons of uncontained runoff per year from the 20 greened roofs.

How many gallons of rain water can the green roofs hold in an average year? If the figure 38 inches constitutes the average annual rainfall in Lawrence, and the 20 roofs cannot contain 6.22 inches of that, then they can contain 31.78 inches. Multiplying the same 93,233,600.64 square inches by 31.78 inches yields 2,962,963,828 cubic inches, which converts to 1,714,678.14 cubic feet, and to 12,825,792.49 gallons of water. This is almost 13 million gallons of water per year that would not run off the green roofs and straight into the storm drain.

It is water that would be held on the roofs, available for the plants on the roofs and for evaporation and evapotranspiration.

But green roofs not only retain rain water; they also delay the timing of the runoff that they cannot contain, and they have been shown to neutralize acid rain and to reduce the particulates in the portion of stormwater that does runoff.[61] Furthermore, green roofs mitigate the heat island effect. "On hot summer days, the surface temperature of a green roof can be cooler than the air temperature whereas the surface of a conventional rooftop can be up to 90° F (50° C) warmer."[62] This is one reason why KU's *Campus Sustainability Plan* urges their use.

Green roofs do not come cheaply, however. The EPA estimates that the "costs of installing a green roof start at $10 per square foot for the simpler extensive roofing, and $25 per square foot for intensive roofs."[63] A University of Michigan cost study estimated that a green roof on a 21,000 square foot building "would cost $464,000 to install versus $335,000 for a conventional roof in 2006 dollars." But over its lifetime this "green roof would save about $200,000. . . .[and n]early two-thirds of these savings would come from reduced energy needs" for the green-roof building.[64] More savings would come from the utility needing less megawatt capacity to heat and cool the building and from the extended life of the roof itself.

Even before considering the cost to retrofit the green roof, a structural engineer must be consulted to determine whether the existing structure is sufficiently strong to support a green roof. "The load capacity of a roof structure must be taken into account when considering the installation of a green roof. Extensive green roofs typically weigh between 15 and 30 lbs. per

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[61] Buranen, M. (2008). *University Roofs Go Green*. Retrieved March 17, 2012, from http://www.stormh2o.com/SW/Editorial/University_Roofs_Go_Green_2194.aspx.
[62] *Green Roofs*. (n. d.). Retrieved March 17, 2012, from http://www.epa.gov/heatisland/mitigation/greenroofs.htm.
[63] *Id*.
[64] *Id*.

square foot and are compatible with wood or steel decks."[65] If the existing structure needs to be strengthened, then the cost of the roof increases, and the cost to be considered here includes not just the dollar cost of the strengthening, but also the environmental cost of the use of more resources to do the strengthening.

A second option which KU might consider for managing the stormwater runoff from the roofs of the Naismith watershed buildings is that of a treatment train, a series of BMPs instead of just one BMP. Here the treatment train could be a filter and then a storage tank. This option could be used both for flat-roofed buildings and for sloping-roofed buildings as well. The storage tanks could be above ground or underground. How big the tanks would need to be depends on the square footage of the roof. If Robinson's square footage of 107,359.37 were to receive 2 inches of rain in one day,[66] a storage tank with a capacity of 133,850.6431 gallons would be sufficient. That would be a big tank, but bigger tanks are already underground on the KU main campus.

How could KU use this stormwater? If KU so determined, it could install a second system of plumbing and pumps for each building, and dedicate all of the water harvested from each of the 51 roofs, flat and sloped, for irrigation and for the operation of the toilets in each of the 51 buildings. The filter would be needed at the head of the treatment train in order to keep the rain event's first flush debris, such as twigs, leaves, plastic bags, and so forth, from entering the storage tank, but with it in place, KU would be in a position to eliminate the unnecessary use of resources which are now expended in bringing irrigation and toilet water to potable standards.

Again, KU's *Campus Sustainability Plan* speaks in favor of this option: Goal 3 of its Campus Grounds Vision is this: "Reduce the use of potable water in preserving the landscape."

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[65] *Philadelphia Manual*, at 7-3.
[66] As Table 3 illustrated, from 2000 through 2009, of the 868 rain events, only 18 were 2 inches or more.

The *Plan* recognizes that “[w]ater is a finite resource and treated water consumes energy.” Strategy 3.1.1 states: “Determine opportunities and limitations for using non-potable [water] for campus landscaping.” Strategy 3.1.2 states: “Use existing underground tanks to collect stormwater runoff for irrigation.”[67]

Using stormwater in this manner would also answer the problem of what to do when a second big storm came just after the first one ended. Some of the stormwater in the storage tank could be used before the second storm arrived. Since KU’s HSG designations are C and D, getting the storage-tank quantity of water to infiltrate overnight from a storage tank could be problematic. Of course, the second-day excess stormwater could simply bypass the storage tanks and go directly to the stormwater drainage system as it now does. Both KU’s and the City’s stormwater drain systems would still be benefitted by having the timing of the volume of water flowing into it postponed or extended, thereby placing less demand on the stormwater drain systems.

2. Naismith Watershed Parking Lots:

At 3,506,051 square feet, parking lots constitute by far the largest category of impervious surfaces on the KU main campus. Twenty-four of these parking lots lie in the Naismith watershed in whole or in major part, and they will now be examined, beginning with one of the lots for a dorm on Daisy Hill.

[67] *KU CSP*, at 35.

Figure 5: McCollum parking lot with area, contours, and elevations

(a.) McCollum Parking Lot:

DCM gives a combined total figure for the parking lots at McCollum and Ellsworth of 176,183.83 square feet. Figure 5[68] shows the McCollum lot with an approximate size of 55,800 square feet.[69] It also shows the elevations of the McCollum lot, a most important consideration because water flows as elevations change. BMPs should work with this flow, not against it, so the direction of the flow must be considered in the shape and the location of the BMP.

One can see in Figure 5 that the elevation of the north end of the McCollum lot is approximately 1004 feet and that, moving south, the elevation decreases to approximately 990 feet. One can also see, near the north boundary of this lot, a small wedge of grass that goes from north to south between the two interior rows of parked cars.

How does one calculate the amount of stormwater runoff from a parking lot? There are several runoff formulas. There is the peak runoff formula, which tells the user what the peak runoff rate is in cubic feet per second. There is the “Small Storm Hydrology Method,” which can be used when the tributary area is comprised of various uses and therefore various

[68] Lawrence interactive map.
[69] *Id*.

coefficients of runoff, for example, a parcel of land which includes a building, a parking lot, and a two-acre garden. Then there is the "Simple Method," the method used to estimate the Water Quality volume "for sites with one predominant type of cover and a drainage area less than 10 acres."[70] The McCollum parking lot is such a site: it is all impervious surface and it is a little larger than one acre.

Again the HSG C and D soils play a role here. Because of them, the recommendation here is that KU select BMPs that are designed to detain and retain the stormwater as opposed to selecting those BMPs which function to infiltrate the runoff. This is not to say that no stormwater can infiltrate into KU's soils, because some can and does. It is only to say that without percolation tests infiltration is not an identifiable quantity in this project, and therefore it is not one on which BMP recommendations made here rely.

So to calculate the runoff from the McCollum lot, the formula is the following:

$$V = 3630 \text{ times } R_D \text{ times } R_V \text{ times } A,$$

where:

V = Volume of runoff that must be controlled for the design storm (ft^3)

R_D = Design storm rainfall depth (in) (here this will be 1.37 inches)

R_V = Runoff coefficient (storm runoff (in)/storm rainfall (in)), unitless;

$R_V = 0.05 + 0.9$ times I_A

I_A = Impervious fraction (impervious portion of drainage area (ac)/ drainage area (ac)), unitless.

A = Watershed area (ac).[71]

[70] *MARC Manual*, 6-1. "Water Quality Volume" is defined as the "storage needed to capture and treat 90 percent of the average annual stormwater runoff volume. It is calculated by multiplying the Water Quality Storm times the volumetric runoff coefficient and site area." At 2-4.
[71] *NCDENR*, 3-3.

For purposes of this project, the small wedge of concrete and grass in the parking lot will be ignored, and therefore the value of I_A will be considered to be 1.00. That is, the entire parking lot is considered impervious. Therefore, R_V = 0.05 + (0.9 times 1.00), or 0.95. McCollum parking lot's required BMP volume retention ability for the design storm is as follows: 3630 times 1.37 inches times 0.95 times 1.281 acres (which is the 55,800 square feet), or 6047.30 cubic feet.

Mr. Frank Hahne, with Sustainable Design Consultants in Lexington, South Carolina, has developed an Excel spread sheet program which, with few inputs required of the user, calculates the cubic feet requirement for a rain garden/bioretention cell BMP. He modified his program for the Kansas City design storm of 1.37 inches, as can be seen at Appendix B below. His Excel program also arrives at a figure of 6047 cubic feet as the required capacity size for the McCollum BMP.[72] His program then calculates other values, including the length and width dimensions required for this capacity or for any other capacity as determined from the size of a given tributary area. For the McCollum parking lot, the BMP required size is approximately 54 feet by 34 feet, or approximately 1836 square feet. The shape can be free-form.

To construct BMPs in McCollum's parking lot probably means that some parking spaces will be lost. KU has several options here, but what must always be kept in mind is the direction of the flow of the water. In this lot, it flows mainly from north to south, from the 1004-foot elevation to the 990-foot elevation. This explains why the narrow wedge of grass does not provide much benefit relative to stormwater detention. The wedge, too, runs from north to south,

[72]Hahne's program (see Appendix B, pp. 88-91 below) includes aspects specific to the soil in his area. This does not affect the calculations for runoff volume or for sizing of the BMP. He said that KU would need to test its media mix "to find the actual infiltration rate, then use a factor of safety." The engineer would determine the necessary media mix. The *MARC Manual* notes that the "soil characteristics are critical for the proper operation of the bioretention facility" (at §8.4.5.6, unnumbered page), and also gives specifications as to the proper mix at Appendix, A-4-6.) Hahne's program also includes speed-of-drainage requirements which may be more strict than KU would require. If so, the size of the BMP could be modified. The *MARC Manual* also includes, in §8.4, four unnumbered pages of worksheets to assist in properly sizing a bioretention cell.

so it could catch only the stormwater which flows to its north end. It could catch this small amount, that is, if its north end did not have a curb which prevents the stormwater from entering the grassy area.

One option for KU is to construct two small and one larger rain garden or bioretention cells. The main difference between these two BMPs is size: the bioretention cell is generally somewhat larger than a rain garden. But both are small basins with relatively small tributary areas; both are quite effective at improving water quality, targeting sediment (in the case of rain gardens) and nutrients (one of the highest nutrient-removal rates of all BMPs in the case of bioretention cells), and trash, metals, bacteria, oil and grease, and organics (both).[73] Both require an amended soil mix, and both control runoff close to the source. A difference between the two is that bioretention cells are frequently designed with an underdrain; however, this is not required.[74] The bioretention cell must not be constructed closer than two feet to bedrock, but if an underdrain is included in its design, then it can be somewhat closer to bedrock than the two-foot minimum. An engineer would have to make this determination for KU.

If KU constructed two smaller cells and one larger cell, each of the two smaller cells could be about 25 feet by 20 feet. The first one could be located about one-third of the way south of the north boundary of the lot; the second could be located about two-thirds of the way south of the north boundary. The larger cell could be triangular in shape, and located at the southwest corner of the lot. Its dimensions could be a base of approximately 56 feet and a height of approximately 30 feet. There would either be no curbs located at the northern edge of either of the two smaller cells, or if there were curbs, they would each have a sufficient number and size of cutouts in them to receive the sheet of water flowing from the northern elevation of the

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[73] *MARC Manual*, pp.8-1—8-2, and §§8.4.1-8.4.3, unnumbered pages.
[74] *Id.*, at pp. 8-1—8-4, and §§8.4.1-8.4.5.8, unnumbered pages.

lot. The larger cell could not have curbing at its triangular base, and would receive the largest volume of stormwater runoff, runoff from any overflow of the first two cells as well as from the rest of the parking lot. The dimensions of these three cells would constitute a total of 1840 square feet, the amount required for a tributary area of McCollum's parking-lot size.

Alternatively, KU could choose to construct one large bioretention cell in the south portion of the lot. It could be triangular, in the southwest corner of the lot, with a base of 88 feet and a height of 42 feet. A bioretention cell of this size, 1848 square feet, would be sufficient to retain and clean all of the runoff from a Lawrence design storm, since a cell of 1836 square feet is the required size. KU's choice of options might be determined by the number of parking spaces each option takes. Figure 6[75] shows how this larger triangular bioretention cell might be placed so that the number of parking spaces lost would be about 18.

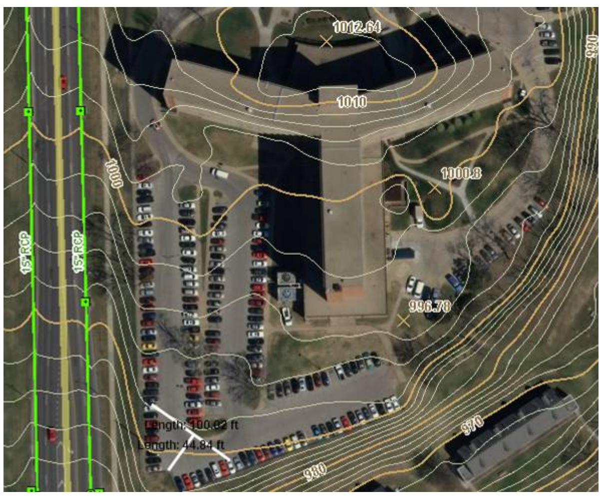

Figure 6: McCollum parking lot with location of possible bioretention cell shown in white lines

KU might also decide to handle the runoff in the McCollum parking lot by locating the bioretention cell on the grassy slope just beyond the apex of the white triangle in Figure 6. Figure 7 shows how the runoff now curves right around the top of this slope, because the curb prevents water from entering onto the slope. If KU were to choose this option, the velocity of the water entering the cell could be problematic, but this velocity could be reduced by placing a filtration strip before the bioretention cell. The *MARC Manual* specifies that if "the 1 percent

[75] Lawrence interactive map with white lines added.

event is to pass through the facility, the maximum velocity shall be kept below 3 feet per second to avoid erosion of the soil matrix."[76] If it were to be possible for KU to locate the bioretention cell on this slope, though, fewer parking spaces, if any, would be taken.

Figure 7: Grassy slope at southwest corner of McCollum parking lot

KU could also utilize the concrete and grass wedge between the two interior rows of parked cars. Now there is a small segment of grass surrounded on either side by sidewalk and enclosed in curbing. At the southern tip of the grass, which is about half-way down the row of cars, the two sidewalks merge into one smaller sidewalk and there is no more grass. KU could remove all of this concrete, widen the southern half of the wedge, extend the grassy area throughout the entire wedge, plant the area with native species instead of grass, and provide curb cutouts on the north edge of the wedge and all along its east edge, so that at least some of the water in the east half of the lot could be captured and slowed before it flows into the bioretention cell.

A final step the KU could take in this parking lot concerns the area at the southern tip of the parking row closest to the dorm. This area has a "ballooned" area with a tree and grass. On this area, too, curb cutouts could be provided in order to capture some of the stormwater flowing from the east leg of the lot.

[76] At §8.4.5.3, unnumbered page.

Of course, should KU decide to install a double plumbing system and the necessary pumps, then all of this water, properly filtered, could be saved in underground storage tanks and used for the flushing of toilets and for any irrigation needs KU may have.

The bright green vertical lines in Figure 6 show a portion of the City's stormdrain system. KU's DCM has a large map showing of KU's entire stormdrain system. KU's map shows a 15-inch RCP stormdrain running from in or close to the white triangle drawn in Figure 6. Wherever KU would choose to locate the bioretention cell, the water flowing from its underdrain, if one is used, and any excess amount of runoff beyond the design storm, could still be directed into this storm drain and then into the City's drains.

As has already been calculated, the bioretention cell(s) in the McCollum parking lot must be designed to capture 6047 cubic feet of water in any given rain event. What will that volume total on an annual basis? The cell is designed to capture 90 percent of the average annual rainfall; that is 0.90 of 38 inches, or 34.2 inches. So: 34.2 times 6047 cubic feet equals 206,807.4 cubic feet of captured stormwater annually. Since there are 7.48 gallons per cubic foot, a properly sized bioretention cell(s) for this parking lot would result in 1,546,919.35 gallons of stormwater per year that would not flow directly into the City's stormdrain system, but instead would be detained, retained, slowed down, and cleaned before entering the system; and some of the gallons, though how many cannot be calculated without on-site percolation tests, would be infiltrated.[77]

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[77] It might be helpful also to calculate this figure using the actual number of inches constituting 90% of average annual rainfall amounts as stated above in Table 3. For those years the average number of inches constituting the 90% is 31.78 inches instead of 34.2. The calculation would then be: 31.78 times 6047 times 7.48 = 1,437,458.98 gallons. In both calculations, the final figure is somewhat lower than it actually would be, though, because even in the storms occurring after the 90 percent level, the bioretention cell would still capture the first 1.37 inches of runoff.

(b.) The South Robinson Parking Lot:

The name given to the single largest area of impervious surface on KU's main campus is the "South Robinson Parking Lot." This lot is bounded by Naismith Drive, Schwegler Drive, Watkins Center Drive, with 18th Street as its southern boundary. DCM's "Parking Area Calculation" sheet lists this parking lot as Lot Number 90, and gives a combined square footage for this lot and Lot Number 117, a lot near Watkins Health Center. DCM does not separate the square footages of the two lots. Therefore, the square footage used here has been derived from the City of Lawrence's interactive map and its "draw" tool which calculates the square footage of any parcel in question. As can be seen in Figure 8,[78] the square footage of this one parking lot is 406,231.01 square feet. The contour lines in Figure 8 show that the lot slopes from northwest to southeast, from approximately 896 feet to 880 feet. This slope leads most of the stormwater runoff into one of three different large stormwater drain inlets: one at approximately the southern tip of the center island of the lot, another at the southern tip of the two easternmost rows of cars, and the third in the southeast corner of the lot.[79] How much stormwater flows across this 407,000 square foot lot? This square footage equals 9.34 acres. Again the entire lot will be considered to be

Figure 8: South Robinson parking lot

[78] Lawrence interactive map.
[79] Standing here during the rainstorm on March 19, 2012, one could hear the stormwater literally roar into the storm drain.

impervious, including the relatively small center island with trees. The same formula is used here as was used to calculate the cubic feet flowing in the McCollum lot: $V = 3630$ times R_D times R_V times A. Substituting, V = 3630 times 1.37 inches times 0.95 times 9.34 acres, or 44,126.36 cubic feet of runoff during the design storm for this lot. That cubic footage times 34.2 equals 1,509,121.51 cubic feet of stormwater flowing into the stormdrain system from the South Robinson lot annually. That figure, times 7.48, yields 11,288,228.89 gallons of stormwater flowing from this lot and into the stormdrain.[80] That is 11 million gallons of water that do not get detained, slowed down, or cleaned.

What sort of BMPs can handle such a large quantity of water, how many of them must there be, and where should they be? Again, the soil groups and the slope of the land are key factors in making these decisions.

Could pervious pavement be used on this parking lot? The lot does not appear to be used for heavy equipment which could crush pervious pavement, but instead appears to be used only for the parking of cars, so in that sense pervious pavement might be an answer to the volume of runoff. However, besides usage, soil group must be considered. If the soil under the pavement is HSG C and D, and it is, then the stormwater getting through the pervious pavement would have no greater likelihood of infiltrating into the soil than it would on the rest of the main campus. That would mean that the unabsorbed stormwater would just pond on the parking lot surface, and run off as it now does. It could also mean that, to the extent that the water was held

[80] Again, if the calculation is performed using 90 percent of the actual rainfall during the ten years from 2000 through 2009, then the annual number of gallons of stormwater runoff from this parking lot is as follows: 31.78 times 44,126.36 times 7.48 equals 10,489,461.57 gallons annually.

in the pavers, the pavers would be subjected during the cold season to damaging freeze-thaw cycles.[81] Pervious pavers do not seem to be a good solution.

Nor do bioswales or detention basins. BMPs need to work with the land. Here, there is only a narrow strip of land on 18th Street all along the south boundary of the parking lot which might be used for a swale. However, the stormwater is not flowing due south; rather, it flows to the southeast. Furthermore, the shape of this southern-boundary strip is not conducive to a swale: it is a shoulder instead of a trench. A significant amount of excavation would be necessary to turn this strip into a swale, and even then, because the strip is relatively narrow, it is hard to see that it could hold 330,065 gallons of stormwater. Of course, these gallons could run directly into the storm drain at the southeastern corner of the parking lot. But that would defeat the purpose of the swale. And if the water were held in the swale, again because it would abut 18th Street, there could be danger both to drivers, to pedestrians, and to children.

Detention basins pose the same problems. Dry detention basins would have to infiltrate 330,065 gallons of water within 40 hours.[82] But KU has HSG C and D soils. To the extent that such a basin in this location would not so infiltrate, the water would sit in the basin or flow to the southeastern corner and down the drain. If it sat in the basin so close to the road, it poses safety problems and perhaps liability problems. If it flowed into the stormwater drainage system, it perhaps would have benefited that system by retarding the time of peak flow, but in terms of cleaning the water, it would not have contributed significantly, if at all.

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[81]One author, however, states: "A general misconception exists in the industry about functionality of porous asphalt (and porous concrete, as well) in cold-weather environments. Based on field observations…, freeze-thaw action and freezing of filter material is not an issue in the porous asphalt. By allowing the runoff to infiltrate, pervious asphalt has less icing conditions and there is less need to snow plow." Pazwash, at 400. Infiltration is key. This same author also notes: "In low permeability soils, a sub-drain pipe may be installed in the sub-base." At 402.

[82] *MARC Manual*, §8.12.1 at 8-108.

KU does have options here, however, and again these involve bioretention cells. Because of the size of the South Robinson parking lot, a single bioretention cell would not be feasible. "The use of small drainage areas and microscale BMPs which can be integrated into a site's landscape elements is a fundamental concept of distributed storm-water management technology."[83] The *MARC Manual* specifies that "[b]ioretention is most effective for tributary areas of less than 4 acres."[84] So here, in this parking lot of 9.34 acres, more than one cell is necessary. How many are needed can be determined, as was done with the McCollum parking lot, by the use of the Excel program found at Appendix B, and this will be done shortly.

If the parking lot is divided into halves, as indeed the center island strip so does, then one can estimate that the west half is 4.34 acres, and the east half is 5 acres, both of which are larger than the 4 acres recommended in the *MARC Manual*. The center island is useful here. It is a strip that runs from the north end to the south end of the parking lot, and is comprised of several mature trees, river rock, and curbing. There is no grass in this island. KU could change this island, marked in a vertical white line in Figure 9,[85] into a treatment train of bioretention cells. KU could widen the entire center island, remove the river rock, plant native species in the areas that are not now completely shaded by trees,[86] and provide curb cutouts so that some of the stormwater flowing from the west half of this lot could be detained in the island. KU might choose to break this approximately 470-foot-long island into four or so smaller islands. Doing so would subtract from the total square footage of the islands available for stormwater detention and

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[83] Davis, A., Hunt, W., Traver, R., & Clar, M. (2009). Bioretention Technology: Overview of Current Practice and Future Needs. *Journal of Environmental Engineering, 135, No. 3,* 109-117, at 114.
[84] At §8.4.4, unnumbered page.
[85] Lawrence interactive map.
[86] The *MARC Manual,* in Appendix A, §9004, unnumbered page, states that its Table 4 "includes native species commonly found within a 50-mile radius of the general Kansas City metro area." "Fifty miles" includes Lawrence, Kansas. The Table consists of nine pages of lists of plants, and their requirements for sun, shade, moisture, and so forth, for different BMPs. It also indicates seasonal colors of various plants.

Figure 9: Locations of South Robinson proposed bioretention cells marked in white lines

retention, but it could also reduce the velocity of the stormwater entering the smaller islands by providing more cutouts for entry along the northern and western boundaries of each smaller island.

KU would still need to provide for the large amount of stormwater which would not flow into the center islands from the west half of the parking lot, and also for all of the stormwater flowing across the east half of the lot. One way KU could do so would be by adding, along the south boundary of the parking lot, sand filters or bioretention cells. The pocket sand filter, also called the "Delaware sand filter," "can handle runoff from drainage areas of 5 acres or less," but this filter does require that the stormwater be "pretreated by a sediment basin, filter strip, or other means" before it enters the sand filter.[87]

Another way KU could choose to handle most of the stormwater runoff from South Robinson would be to add two more bioretention cells, these to be located as shown in Figure 9,

[87] *Id*., at 8-61.

in two locations in the southern portion of the lot. To size these, the Excel program can be used. Splitting the parking lot into two segments, the one to the west of the center island being less than 4.34 acres, and the one to the east being less than 5.0 acres ("less" in each case because the cells in the center island would take some of the flow from the tributary area in the western half of the lot, and that would leave less for the eastern half to capture), the Excel program yields the following results: the cell for the 4.34-acre segment needs to be able to contain 20,504 cubic feet of stormwater in the design storm, so its dimensions would be approximately 62 feet wide by 100 feet long. The cell for the 5.0-acre segment needs to be able to contain 23,622 cubic feet of stormwater, so its dimensions would be approximately 66 feet wide by 107 feet long.

Figure 9 shows their possible locations and their sizes relative to the entire lot. The smaller cell could be located alongside and to the west of the lot entrance off 18th Street. The other cell could be located so as to include the area of the two storm drains in the southeast corner of the lot. KU would lose some parking spaces, but that might not be a problem since it often appears that this lot is far from full.[88] These strategically placed bioretention cells could minimize or eliminate the runoff, shown in Figure 10, which flows out into 18th Street and pools there. This could be a welcome

Figure 10: South Robinson at 18th and Arkansas from South Robinson entrance

[88] Basketball season may present its own parking problems, but there are solutions such as off-site park and ride locations and carpooling.

relief to the City and its stormwater drain system, which collects runoff just at the southeast corner of the lot, at Watkins Center Drive and 18th Street, as can be seen in Figure 9 where again the bright green lines represent the City's stormwater drainage system.

Figure 11[89] shows the same view of the South Robinson lot as does Figure 9, but on a larger scale. This scale allows the viewer to see both the 18th Street and Arkansas entrance to the South Robinson lot, and, just to the south of KU's southern boundary of 19th Street, the green-highlighted Lawrence flood zone which begins at approximately Naismith Drive and West 20th Terrace.

Figure 11: Naismith Drive flood zone

(c.) The Remaining Parking Lots in the Naismith Watershed:

Twenty-two parking lots in the Naismith watershed, plus the Ellsworth portion of the Ellsworth-McCollum lot, remain to be discussed here. They will not be discussed in the detail that McCollum and South Robinson have been. What sort of BMPs should be chosen for each site and where, based on the contours of the land, these BMPs should be located, will not be examined here. Instead, both because the same HSG C and D soil groups comprise all of the ground of the KU main campus and also because of the sloping character of Mt. Oread, the recommendation of this project is that bioretention cells should be used in each of these remaining lots. The size these cells will need to be will be calculated using the Excel program found in Appendix B. The

[89] Lawrence interactive map.

volume of the stormwater runoff expected to occur and to be captured by the properly sized cells, both on a single design-storm basis and also on an annual basis, will also be calculated.

Once again, the formula to be used to calculate the volume of runoff in cubic feet is this: V = 3630 times R_D times R_V times A. R_D is still 1.37 inches; R_V is still 0.95 (again, each entire lot is assumed to be impervious); and A will, with one exception, be the square footage assigned to each lot by DCM. The exception is in combined zones 15, 16, and 17, where DCM combines the West Oliver and the Horejsi lots into a total of 294,103.11 square feet. Here that total figure will be separated into two subtotals, each 147,000 square feet. This is done so that, when calculating the required size of the bioretention cell, no calculation is based on a tributary area larger than five acres. A further note is that DCM has totaled all of the parking lots for the Stouffer Place units into one figure, 167,672.83 square feet. Since this total does not exceed the five-acre maximum for calculating dimensions of a bioretention cell, DCM's number will be used here and not a smaller number for each small lot for the various Stouffer Place units. An engineer, of course, must accurately and carefully size each of these smaller lots before designing a BMP for each one, and cannot estimate. However, here in this project the purpose is different from an engineer's: here it is to see how much stormwater runoff there is to be handled from the total square footage, and not necessarily how much there is from each separate part.

Table 4 shows the calculations for each of the remaining lots in Naismith. As can be seen, the numbers of gallons of stormwater runoff per year from the individual parking lots is significant. Looking just at the Ellsworth lot on Daisy Hill, the number of gallons running off annually totals 3,251,106.68. If McCollum lot's annual total of 1,546,919.35 is added to this figure, then the annual total for these two Daisy Hill lots alone becomes 4,798,026.03 gallons. It is no wonder that, as shown on DCM's stormwater drain-system map, KU needs two stormwater drains running from these two dorms and lots to the east, ultimately to Naismith Drive, and two more such lines running from these two dorms and lots to Iowa Street on the west.[90]

Table 4: Gallons of stormwater to be captured annually in 23 parking lots in the Naismith watershed

Parking lot	Square footage of tributary area; then acreage	Required size of bioretention cell (in feet)	Number of cubic feet of stormwater captured per design storm	Number of cubic feet of stormwater captured annually	Number of gallons of stormwater captured annually
W. Learned	33,561.37; 0.77	26 x 42	3637.83	124,413.79	930,615.15
S. Lindley	41,283.77; 0.95	29 x 47	4488.23	153,497.47	1,148,161.08
S. Marvin, Budig	28,412.40; 0.65	24 x 39	3070.89	105,024.44	785,582.81
E. Jayhawk Tower	30,041.92; 0.69	25 x 40	3259.87	111,487.55	833,926.87
E. Burge Union	103,056.04; 2.37	46 x 74	11,196.95	382,935.69	2,864,358.96
S. Jayhawk Tower	23,658.77; 0.54	22 x 35	2551.20	87,251.04	652,637.78
Hilltop	55,203.84; 1.27	33 x 54	6000.05	205,201.71	1,534,908.79
W. Jayhawk Tower	69,035.28; 1.58	37 x 60	7464.63	255,290.35	1,909,571.82
E. Learned/ Eaton	9895.24; 0.23	14 x 23	1086.62	37,162.40	277,924.75
E. Green Hall	63,742.52; 1.46	36 x 58	6897.70	235,901.34	1,764,542.02
Allen Field Parking	62,256.85; 1.43	35 x 57	6755.96	231,053.83	1,728,282.65
S. Wescoe Hall	27,712.67; 0.64	24 x 38	3023.65	103,408.83	773,498.05

[90] Kansas University Office of Design and Construction Management. *Storm Sewer Map: University of Kansas Campus.*

N. Summerfield	36,730.92; 0.84	27 x 44	3968.54	135,724.07	1,015,216.04
N. Haworth	50,755.85; 1.17	32 x 52	5527.61	189,044.26	1,414,051.06
Ellsworth	117,183.83; 2.69	49 x 79	12,708.77	434,639.93	3,251,106.68
Stouffer Place	167,672.83; 3.85	58 x 94	18,189.13	622,068.25	4,653,070.51
West Oliver and Horejsi	2 lots, each: 147,052; 3.38	25 x 40 25 x 40	15,968.64 15,968.64	546,127.49 546,127.49	4,085,033.63 4,085,033.63
E. Computer Services	79,932.82; 1.84	40 x 65	8692.99	297,300.26	2,223,805.95
Sunnyside and Illinois	121,670.26; 2.79	43 x 80	13,181.22	450,797.72	3,371,966.95
E. Hall Center	9966.97; 0.23	14 x 23	1086.62	37,162.40	277,974.75
S. Watson Library	16,262.09; 0.37	18 x 29	1748.05	59,783.31	447,179.16
E. Blake Hall	16,849.12; 0.39	19 x 30	1842.54	63,014.87	471,351.23
Facilities Operations	30,364.18; 0.70	25 x 40	3307.12	113,103.50	846,014.18
Total gallons captured annually					41,635,926.57

The total number of gallons of stormwater flowing annually from all of the lots listed in Table 4 is an eye opener: 41,635,926.57 gallons. When the runoffs from McCollum and South Robinson are added to Table 4's total, this figure climbs to 54,471,074.81 gallons of stormwater runoff annually from the Naismith watershed parking lots.

If KU installs BMPs on each of these lots, then some of these 54 million gallons of stormwater would be able to infiltrate into the ground as they did before the impervious surfaces were laid. How much could infiltrate depends, of course on the soil, the slope, and the plants chosen for the BMP. If in any particular location the soil tested more infiltratable than HSG C or D, then perhaps infiltration BMPs—such as infiltration trenches, or bioretention cells designed to infiltrate as well as to detain, retain, and clean, or even pervious pavement—could be used. It all depends on the soil and the slope. But all of the gallons from design storms could be detained or retained, slowed, and cleaned with bioretention cells.

Of course, if KU chooses to install double plumbing and any necessary pumps, and therefore BMPs such as sand filters and storage tanks, then KU would have an annual 54-million-gallon supply of water available at its fingertips at no cost for the water itself, and this, just from the Naismith watershed parking lots. Adding Naismith watershed's green roof total gallons increases this amount to 67,296,867.30 gallons of water which would be available to KU annually, at no cost for the water, and this is without considering the water that could be captured from the sloping-roofed buildings in the Naismith watershed. Sixty-seven million gallons.

Figure 12: Portion of Daisy Hill in Meadowbrook watershed

B. Meadowbrook Watershed: Only a relatively small section of KU's main campus lies in the Meadowbrook watershed, the next watershed proceeding clockwise from the

Naismith watershed. That entire section of the main campus can be seen above in Figure 12.[91] It includes two buildings and parts or all of four parking lots. In Figure 12, the Meadowbrook watershed is the darker purple on the left.

Figure 13: Visitor Center and Templin Hall.

1. Meadowbrook Watershed Buildings:

The Visitor Center and Templin Hall lie in the Meadowbrook watershed. DCM lists the square footage for Visitor Center and Templin Hall combined as 24,401.32 square feet. Since the roof of the Visitor Center is not flat, however, only the square footage of Templin, found with the assistance of the Lawrence interactive map, will be used here. Figure 13[92] shows that figure to be approximately 13,715 square feet.

As was done with the buildings in the Naismith watershed, so here, too, the recommendation being made in this project is that all flat roofs be greened. The same standard is used here as was used for the Naismith watershed buildings, that is, the green roof must be able to contain 70 percent of the 1.37-inch design storm. Subtracting an arbitrary 10 percent to allow for any roof areas on Templin which for some reason cannot be greened leaves 12,343.5 square feet available for a green roof. How much stormwater can this roof contain? Referring back to Table 3, the average amount of rainfall in inches by which all of these large one-day rainfalls exceeded 0.96 inches was 6.22 inches. If the green roof is not able to contain 6.22 inches of the design storm on an annual basis, then it can contain 31.78 inches. Therefore, greening Templin's

[91] Lawrence interactive map.
[92] *Id*.

roof would mean that annually 56,487,805.92 cubic inches, which converts to 32,689.7 cubic feet, or 244,518.97 gallons of stormwater could be captured by this roof and used for the plants there, for evapotranspiration, for delaying any runoff that may occur, and for reduction of the heat island effect, among other benefits.

2. Meadowbrook Watershed Parking Lots:

(a.) The West Visitor Center Parking Lot:

Figure 12 shows the parking lots which lie partially or completely in the Meadowbrook watershed. DCM lists 42,852.74 as the square footage for the "W. Visitor Center Parking," and Figure 12 shows that all of this lot is in Meadowbrook. DCM does not separate the square footages for the other lots in this watershed, but instead lists "Hashinger, Lewis, Templin, Nunemaker Lot" as having a combined total square footage of 269,353.64. Looking at Figure 12, one can see that, while all of the Lewis parking lot lies in Meadowbrook, only parts of the lot east of Templin and west of Hashinger do so. Nonetheless, all of the square footage of these parking lots will be treated as though the entire lot lies in the Meadowbrook watershed. It should be noted, though, that for those lots which lie part in one watershed and part in another, the stormwater will flow in two different directions, and so at least two BMPs must be used in each lot and sited to accommodate this fact.

The west Visitor Center lot is, according to DCM measurements, 0.983763545 acres, close enough to be considered to be one acre in size. Using the Excel program from Appendix B, a bioretention cell properly sized for a one acre-parcel should be

Figure 14: Visitor Center parking lot, white lines marking 2 possible bioretention cells

30 by 48 feet, shown in Figure 14,[93] at the southwestern tip of the lot. A second such cell could, if KU so chose, be placed just near the north entrance to the lot from 15th Street. If KU chose to place two such cells, then the dimensions of each could be approximately 37 feet by 20 feet.

Given the slope of this parking lot toward Iowa Street, and given that this land area between the lot and Iowa Street is not one typically used by pedestrians, and given also that this is a generous amount of land, it might be practical for KU to install sand filters and a bioswale here in this grassy area instead of bioretention cells. "Sand filters take up little space and can be used on highly developed sites and sites with steep slopes. They can be added to retrofit existing sites….[and] they are only feasible for highly impervious stabilized areas such as parking lots and rooftops."[94] For a Delaware sand filter, the recommended tributary-area size of five acres or less would not be exceeded here. The Delaware filter has "the potential to remove 85 percent of suspended solids, 55 percent of phosphorous, 35 percent of nitrogen, and between 35 and 90 percent of metals from the stormwater."[95]

If the soil would allow it, KU could then construct bioswales at the foot of the sand filters, running parallel to Iowa Street. The bioswale is supposed to be designed such that it can store and infiltrate the design storm "with a maximum ponding depth of 12 inches and maximum ponding time of 40 hours."[96] The sand filter preceding the bioswale would capture the stormwater first, and delay its entry into the bioswale, much as the rain garden does for the bioswale in front of Ambler, so even if the soil on this incline is all HSG C and D, a bioswale may still prove feasible. If so, it could provide added beauty to the entrance to KU and the Visitor Center from Iowa Street.

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[93] Lawrence interactive map.
[94] *MARC Manual*, 8-60.
[95] *Id*., at 8-61.
[96] *Id*., at 8-75.

Besides beauty, though, the question that remains to be answered for this parking lot is this: much stormwater can be captured from the west Visitor Center parking lot, assuming that the BMP ultimately chosen is the bioretention cell? To answer this question, the same formula is used as was used in the Naismith parking lots: V = 3630 times R_D times R_V times A. That is, V = 3630 times 1.37 inches times 0.95 times 1 acre, or 4724.45 cubic feet per design storm. That figure times 34.2 equals 161,576.19 cubic feet annually, or 1,208,589.90 gallons of stormwater annually captured.

(b.) Nunemaker, Templin, Lewis, and Hashinger Parking Lots:

The combined square footage for these lots is given by DCM as 269,353.64. In this project, the Nunemaker lot will be considered to be 28,000 square feet, the Lewis lot to be 110,000 square feet, the Templin lot to be 43,000 square feet, and the Hashinger lot to be 88,000 square feet, for a total of 269,000 square feet.[97] The detail provided in the discussion of the Visitor Center lot will not be provided here. Instead, calculations will be made simply to determine how much storm water the recommended bioretention cells in each lot can capture, and what the dimensions of the cells must be in order to capture this volume. Table 5 shows these calculations.

Table 5: Gallons of stormwater to be captured annually in 4 parking lots in the Meadowbrook watershed

Parking lot	Square footage of tributary area; then acreage	Required size of bioretention cell (in feet)	Number of cubic feet of stormwater captured per design storm	Number of cubic feet of stormwater captured annually	Number of gallons of stormwater captured annually
Nunemaker	28,000; 0.64	24 x 38	3023.65	103,408.83	773,498.05

[97] These figures are approximately proportionate to those determined by drawing and measuring the three large lots on the Lawrence interactive map. They are approximate because they need to total the figure which DCM maintains.

Templin	43,000; 0.99	29 x 48*	4677.21	159,960.58	1,196,505.14
Lewis	110,000; 2.53	47 x 76	11,952.86	408,787.81	3,057,732.82
Hashinger	88,000; 2.02	42 x 68*	9543.39	326,383.94	2,441,351.87
Total gallons captured annually					**7,469,087.88**

*Both Templin and Hashinger will actually need two bioretention cells because each lot lies in two watersheds. The two combined must equal the size required here.

If KU chooses to install bioretention cells in these four parking lots, KU can detain, retain, slow down, and clean a total of 7,469,087.88 gallons of stormwater per year. If to that sum is added the figure of 1,208,589.90 gallons for the west Visitor Center parking lot, then KU could capture, detain, retain, slow down, and treat 8,677,677.78 gallons of stormwater annually from the five Meadowbrook watershed parking lots.

If instead of bioretention cells, KU chooses to install double plumbing and the requisite pumps, then for the Meadowbrook watershed buildings and parking lots combined, KU would have 8,922,196.75 million gallons of water annually at no cost for the water itself, and not taking into account any water that could be captured through filters into storage tanks from the non-greened roof.

C. Windmill Watershed:

Two buildings and one parking lot lie in whole or in part in the Windmill watershed, all of which are in KU's zone 1 and are located a little west and north of the Sunflower Apartments.

1. <u>Windmill Watershed Buildings:</u>

The KPR and Baehr Audio-Reader Center building and the Max Kade Center are the only KU buildings in the Windmill watershed. Figure 15[98] shows these buildings, with KPR and the Audio-Reader Center at the top of the Figure being divided between the two watersheds, and the Max Kade Center and Sudler annex being so divided near the bottom of the Figure. None of the Sudler annex lies in the Windmill watershed, and therefore it will not be considered here, but all of KPR/Baehr Audio-Reader Center and Max Kade will be.

Figure 15: Part of KU in Windmill Watershed

Neither of the KU buildings in this watershed have flat roofs. KU could install small rain gardens and small detention basins at downspout locations for each of the buildings, as KU has done at Ambler. As at Ambler, "the outlet structure [should be] located at least 10 feet away from building foundations, shredded hardwood mulch (not pine or woodchips) [should be] applied at installation, and native plants [should be] selected for drought and wet conditions."[99] The Ambler rain garden plus detention basin drain a roof area of 44,000 square feet, and themselves constitute an infiltration area of 4980 square feet, for a ratio 11.3 percent, which BNIM notes is "a good ratio for pollutant removal."[100]

KPR/Baehr has a square footage of 5666.50, and Max Kade's is 2147.02. Properly sized rain gardens and detention basins could detain, retain, and clean all of the stormwater runoff

98 Lawrence interactive map.
99 *BNIM* at 77.
100 *Id.*, at 91.

from these two roofs just as they do at Ambler. At Ambler, the stormwater runoff time was delayed by one hour and twenty minutes when the soil was dry, and by 50 to 70 percent less time than that when the soil was wet.[101] If KPR/Baehr's rain garden and detention basin were a combined size of 11.3 percent of the building's square footage, then they would need to be approximately 640.31 square feet, or about 28 feet by 24 feet. Similarly, if Max Kade's rain garden and detention basin were a combined size of 11.3 percent of the building's square footage, then they would need to be approximately 242.62 square feet, or about 19 feet by 13 feet.

How much stormwater each building's BMP could detain, retain, and clean can be determined by the same formula as has been used for green roofs: the total square footage of the roofs times 31.78 inches times 7.48 gallons. The result is 154,782.22 gallons of stormwater detained, retained, and cleaned, annually, just from these two buildings.

<u>2. Windmill Watershed Parking Lot:</u>

Although the only parking lot in the Windmill watershed does not lie entirely in this watershed, it will be treated here as though it does. It must be remembered, though, that BMPs must be provided to handle the flow of stormwater moving in each watershed.

Figure 16[102] shows the parking lot in question, the square footage of which DCM lists

Figure 16: Windmill watershed with contours

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[101] *BNIM*, 86, 91.
[102] Lawrence interactive map.

as 35,913.88, or 0.82 acres. The green contour line that seems to wiggle through most of the lot marks an elevation of 988 feet. The gold contour line that curves right around the top of the lot marks an elevation of 980 feet. The stormwater in this lot flows from an elevation of 988 in the approximate middle of the lot down to the 980 on either side. However, for purposes of this project, a single bioretention cell sized to serve, hypothetically, the entire lot will allow one to determine how much stormwater is involved here. Using the Excel Program to size the cell, and the same formula as has been used for all the previously studied parking lots, one can see that such a cell would be approximately 27 feet by 43 feet, and could retain and clean 991,043.97 gallons of stormwater annually. Cells for each watershed would of course be smaller than this, and would be sized to match the area of the watershed they would serve, but combined they could retain and clean the same total number of gallons of stormwater runoff per year.

D. Jayhawk Watershed:

In clockwise progression from the Windmill watershed lies the Jayhawk watershed, the next watershed to be considered here. KU zones 1, 2, 3, and 4 comprise part of this watershed.

1. Jayhawk Watershed Buildings:

KU buildings in the Jayhawk watershed include most of the properties which KU lists in zones 1, 2, 3, and 4. This includes all of the property from Memorial Stadium to the north, some of the property along Memorial Drive, and all of the property along West Campus Road. Eighteen buildings are included in these zones, and of these eighteen, nine have flat or almost completely flat roofs. These are the Anderson Family Football Complex, the Joseph R. Pearson Hall, the Gertrude Sellards Pearson Residence Hall, Carruth-O'Leary Hall, Spencer Research Library, Strong Hall, the Spencer Museum of Art, the Kansas Union, and Sabatini Multicultural

Resource Center. One of these nine buildings, Strong Hall, has so many panels and vents on its roof that it will not be considered here as available for greening.

Of the remaining eight buildings in the Jayhawk watershed, one, the Anderson Family Football Complex, already has one-third of its roof green. Therefore, only two-thirds of its DCM-ascribed square footage will be considered here. With this one condition, the roofs of the buildings under consideration total 183,971.62 square feet. Subtracting, as was done with the buildings in the other watersheds, an arbitrary 10 percent of the square footage to allow for vents, tubes, pipes and other structures on the roofs, leaves 165,574.46 square feet. Again it is recommended here that these roofs all be greened.

How much stormwater can these greened roofs capture? The 165,574.46 square feet equal 23,842,722.24 square inches. Referring again to Table 3, if the green roof cannot contain 6.22 inches of the design storm on an annual basis, then it can contain 31.78 inches of Lawrence's annual precipitation. So, 23,842,722.24 square inches times 31.78 inches equals 757,721,712.8 cubic inches, which converts to 438,496.36 cubic feet, and to 3,279,952.79 gallons of stormwater. That is, these eight flat roofs in the Jayhawk watershed could capture more than three million gallons of stormwater annually. This would be water that would not enter KU's or the City's stormdrain system, but would instead be used by the plants on the roof, for evaporation and evapotranspiration. It is also water that would reduce utility costs incurred in heating and cooling the buildings and would also reduce the heat island effect to which the buildings themselves contribute. Further, any water that the roofs could not contain would be cleaned by the green roofs before it ran off, and its runoff time would be delayed, thereby putting even less demand on the stormdrain systems.

Here too, as with buildings in the other watersheds, KU could choose to double-plumb its buildings, and provide the pumping system necessary to cycle the stormwater back into the buildings off which it flowed. If KU were to choose to do this, then KU would have, from these eight buildings, three million gallons of stormwater at its disposal every year, at no cost for the water itself. And if KU chose to do this, it could do so for all of the buildings, not just the flat-roofed buildings. All of its buildings could receive free water.

2. Jayhawk Watershed Parking Lots:

(a.) The Carruth-O'Leary Parking Lot:

DCM lists 19 parking lots in the Jayhawk watershed with a total of 931,060.63 square feet. Several of these lots have trees planted in them here and there, but, as has been done throughout this project, all of the square feet of surface will be considered to be impervious. As an example of what KU could do concerning the stormwater runoff from these lots, one of the Carruth-O'Leary lots can be used. Figure 17[103] shows this lot with a square footage assigned by DCM as 29,451.88. As the Figure shows, West Campus Road has an elevation of 1030 feet; just east of Carruth-O'Leary is an elevation of 1020 feet, and east of the lot itself is an elevation of 1010 feet.

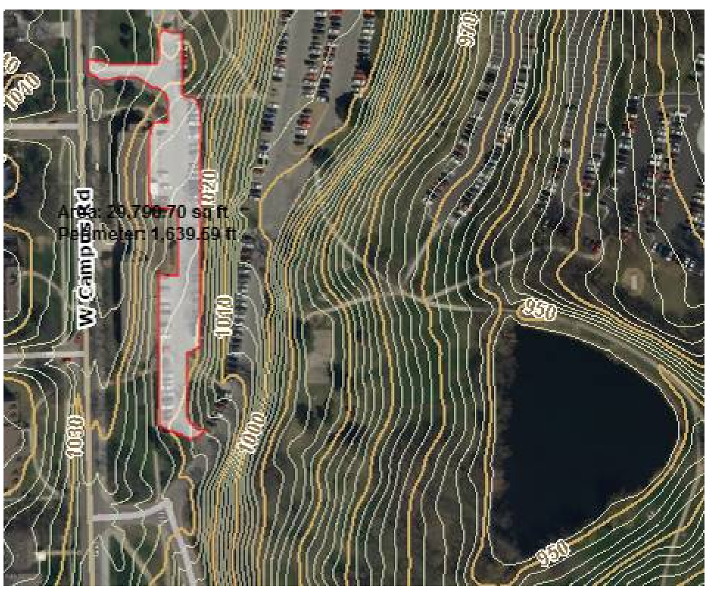

Figure 17: Carruth-O'Leary with area and contours

[103] Lawrence interactive map. The large dark area is Potter Lake.

Figure 18: Carruth O'Leary parking lot with white lines indicating possible bioswale locations

As the nearly vertical lines through the parking lot indicate, the stormwater from this lot flows almost directly east.

With the contour lines removed in Figure 18,[104] one can more clearly see that to the east of the lot and running its entire length is a green area larger than the lot itself. This area slopes 10 feet from its west side to its east. KU could use this area to install a treatment train of filters and three long, shallow bioswales. The bioswales could be located at the west edge of the green space, as shown in Figure 18. They would require some excavation, but they could capture, detain, retain, and clean most or all of the runoff from the lot, just as the west campus bioswale near the Pharmacy Building does. How much water that would be can be determined by using the same volume-formula as has been used throughout this project. If it is assumed that the bioswales could capture only the design storm volume, that volume annually would equal 821,842.19 gallons.

As an alternative, KU might want to consider perimeter sand filters. A typical application for these sand filters "is along the perimeter of a parking lot."[105] This type of sand filter uses a two-chamber vault: "the first chamber of the vault is used for pretreatment that settles out coarse sediments. Stormwater flows over a weir into the second chamber that contains an 18-inch layer of sand. An underdrain system collects the filtered stormwater and conveys it to the stream or channel downstream."[106] Given the dedicated work that the KU community has put into cleaning Potter Lake, cleaning the water that flows into it makes

[104] *Id.*
[105] *MARC Manual*, 8-61.
[106] *Id.*

sense.[107] If KU were to use the green space, then none of the existing parking spaces would need to be taken.

Bioretention cells could also be used here, but they would need to be sized much larger than would be necessary for the size of the parking lot. This is because the stormwater flows almost due east the entire length of the lot. A bioretention cell anywhere along the length of the lot could capture the sheetflow of stormwater flowing directly toward it, but it could not capture the water flowing across the rest of the lot. Assuming the northern portion of the lot and the southern portion are about equal, then each is approximately 0.35 acres. A properly sized bioretention cell for that tributary area, per the Excel Program, is approximately 28 feet by 18 feet. As can be seen in Figure 18, however, the lot is closer to 300 feet in length than to 56 feet, so the bioretention cells would either be larger than needed or they would miss much of the stormwater flowing from the lot.

(b.) The Remaining Parking Lots in the Jayhawk Watershed:

As has been done in the previously discussed watersheds, the remaining parking lots in this watershed will not be discussed in the detail with which the Carruth-O'Leary lot was. Instead, on the assumption that bioretention cells or rain gardens will be the BMPs selected for the parking lots here, calculations will be presented in Table 6 to show what size they should be and how many gallons of stormwater each can retain and clean on an annual basis.

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[107] KU's Department of Environment, Health, and Safety on January 13, 2012, released its study of Potter Lake, *Potter Lake: University of Kansas Lawrence Campus, Douglas County, Kansas, Water Quality Evaluation 2011*. It states: "Ongoing efforts by the University of Kansas have been undertaken to improve the water quality of Potter Lake. These efforts have significantly improved the lake's water quality and the results of an eight-month monitoring program are presented in this report. Based on the findings of the water quality monitoring program, it is believed that Potter Lake should be delisted from the Kansas list of impaired waters 303(d) list."

Table 6: Gallons of stormwater to be captured annually in 18 parking lots in the Jayhawk watershed

Parking lot	Square footage of tributary area; then acreage	Required size of bioretention cell (in feet)	Number of cubic feet of stormwater captured per design storm	Number of cubic feet of stormwater captured annually	Number of gallons of stormwater captured annually
Sunflower Apartments	15,162.77; 0.35	18 x 28	1653.56	56,551.75	423,007.09
East of JRP	79,357.72; 1.82	40 x 65	8598.50	294,068.70	2,199,633.88
North of JRP	15,680.31; 0.36	18 x 29	1700.80	58,167.36	435,091.85
West Football Stadium	81,686.08; 1.88	41 x 66	8881.97	303,763.37	2,272,150.01
West Football Stadium (different lots)	123,320.57; 2.83	50 x 81	13,370.19	457,260.50	3,420,308.54
East of Stadium Parking	96,194.17; 2.21	44 x 71	10,441.03	357,083.23	2,670,982.56
Mississippi Street Parking	19,444.97; 0.45	20 x 32	2126.00	72,709.2	543,864.82
GSP and Corbin Halls Parking	179,883.02; 4.13	60 x 97	19,511.98	667,309.72	4,991,476.71
South Stadium Parking	89,268.42; 2.05	42 x 63	9685.12	331,231.10	2,477,608.63

W. GSP and Corbin Halls Parking	8676.80; 0.20	13 x 21	944.89	32,315.24	241,718.00
E. Carruth-O'Leary (second lot)	31,357.95; 0.72	25 x 41	3401.60	116,334.72	870,183.71
N. Snow Hall	13,757.21; 0.32	17 x 27	1511.82	51,704.24	386,747.72
Jayhawk Blvd/Snow Hall	2601.34; 0.06	7 x 12*	283.47	9694.67	72,516.13
North Strong Hall	51,108.51; 1.17	32 x 52	5527.61	189,044.26	1,414,051.07
Jayhawk Blvd/Strong Hall	3593.90; 0.08	8 x 14*	377.96	12,926.23	96,688.20
W. Memorial Drive	9316.29; 0.21	14 x 22	992.13	33,930.85	253,802.76
Mississippi Street Parking Garage	6627.39; 0.15	11 x 19*	708.67	24,236.51	181,289.09
N. Spencer Museum	74,571.33; 1.71	39 x 63	8078.81	276,295.30	2,066,688.84
Total gallons captured annually					Including the 3 small lots: 25,017,809.61 excluding the 3 small lots: 24,667,316.19

*The minimum required size for a bioretention cell is 10 x 20.

That is, in the parking areas listed in Table 6, a total of 25,017,809.61 gallons of stormwater annually could be detained or retained and cleaned if KU were to invest in constructing bioretention cells in the lots of sufficient size, and rain gardens or curb cutouts in the three small parking areas, Jayhawk Boulevard in front of Snow, Jayhawk Boulevard in front of Strong, and the Mississippi Street Parking Garage. If the total number of gallons which could be captured by bioswales at the Carruth-O'Leary parking lot were added to Table 6's total, the figure would be 25,839,651.8 gallons of water. That is 25 million gallons of water annually that would be slowed down and cleaned before entry into KU's and the City's stormdrain systems.

Or, it could be free water to KU to use for toilet flushing or for irrigation, if KU chooses to double-plumb its buildings and provide the pumps necessary to distribute the collected stormwater from filtered storage tanks to locations where it would be put to use.

E. Downtown Watershed:

Figure 19[108] shows the sliver of KU property which lies in the Downtown watershed, the watershed colored in brown and lying to the right of the vertical black line. The parking lot to the left of the line, in the Jayhawk watershed, is the Mississippi Street Parking Garage, the garage just north of the Kansas Union. The building which is almost entirely in the blue watershed is the Adams Alumni Center. It will be discussed in that watershed. Only two KU properties lie in the Downtown watershed: the parking lot on the southeast corner of 12th and Louisiana and the Alumni Center parking lot.

[108] Lawrence interactive map.

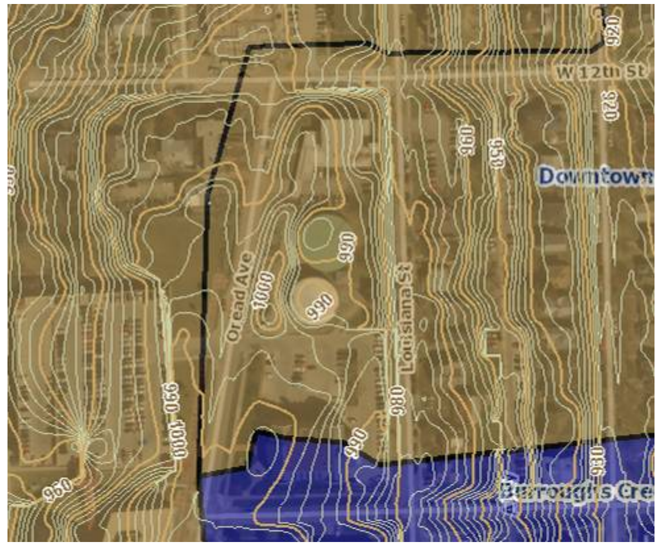

Figure 20: Downtown Watershed with contours

As can be seen on Figure 20,[109] elevations change rapidly in this section of the watershed, from 1000 feet on Oread Avenue to 980 feet on Louisiana, one block away. That means that the direction of the stormwater flow will be to the east. Figure 19 shows how little space there is along Louisiana for the installation of a BMP along the Alumni Center parking lot. There is, though, an area just to the west of the line of cars parked alongside Louisiana. Elevation 994 runs almost straight through this green area from north to south. A bioretention cell could possibly be located here, but because the stormwater can be expected to flow mainly to the east and a little to the south, a cell located here could only capture some of the stormwater in the lot. A second cell could be located just to the north of the Alumni Center, in the green area already there. It, too, could capture some of the stormwater flow.

There is space for a bioretention cell to be placed along the east side of the parking lot at 12th and Louisiana. It could be situated in the area which is already green, and given that the stormwater would be flowing due east, the cell could capture all of the runoff from that lot. The elevation drops 10 feet in a very short space here, and so velocity and erosion would have to be guarded against. This perhaps could be done by adding a limestone retaining wall like that between the rain garden and the detention basin at Ambler.

[109] Lawrence interactive map.

How much stormwater could be captured by these two lots? Assuming that the Alumni Center BMPs could capture the stormwater flowing across only half of its surface with one bioretention cell, then its square footage of 24,757.25, divided by two, equals 12,378.63. Using the formula for volume which has been used throughout this project, these two lots, as shown in Table 7, could capture a total of 543,867.36 gallons of stormwater per year, capture these gallons, delay them, and clean them.

Table 7: Gallons of stormwater to be captured annually in 2 parking lots in the Downtown watershed

Parking lot	Square footage of tributary area; then acreage	Required size of bioretention cell (in feet)	Number of cubic feet of stormwater captured per design storm	Number of cubic feet of stormwater captured annually	Number of gallons of stormwater captured annually
Adams Alumni Center	12,378.63; 0.28	16 x 25	1322.85	45,241.47	338,406.20
12th and Louisiana	7565.02; 0.17	12 x 20	803.16	27,468.07	205,461.16
Total gallons captured annually					543,867.36

F. Burroughs Creek Watershed:

Burroughs Creek watershed includes most of the buildings in KU's zones 5 and 11, and some of the parking lots in those two zones as well.

<u>1. Burroughs Creek Watershed Buildings:</u>

Twenty-four buildings lie wholly or almost wholly in the Burroughs Creek watershed. Of these 24, only four[110] have flat or almost completely flat roofs: Sprague Apartments, Smith

[110] This number was arrived at after concluding that the building to which DCM ascribes no name but simply lists as "Vacant" is in fact the Grider House at 14th and Louisiana, and that the building which DCM calls "Department of

Hall, Grace Pearson Scholarship Hall, and Douthart Scholarship Hall. The recommendation here is that the roofs of all of these buildings be greened. The combined square footage of the four buildings is 16,958.94. Subtracting the arbitrary allowance of 10 percent from that total, for pipes, vents, and other devices which may already be on these roofs, leaves 15,263.05 square feet available for greening.

The 15,263.05 square feet equal 2,197,879.2 square inches. As was done regarding the buildings discussed in other watersheds, multiplying that figure by 31.78 inches, the amount of the average annual rainfall which the green roofs can contain, produces a figure of 69,848,600.98 cubic inches, which converts to 40,421.64 cubic feet, and 302,353.87 gallons of stormwater per year which these roofs, if greened, could capture. The 6.22 inches annually which these roofs could not capture would still be at least partially cleaned before entering the downspouts. That would be 59,176.88 gallons per year.

One of the houses in the Burroughs Creek watershed is the Chancellor's house, "The Outlook." It can be seen here in Figure 21.[111] In case the Chancellor has ever wondered why the stormwater that falls on the section of the drive to the north of her home flows in one direction, and stormwater that falls on the section of the drive to the south of her home flows in a different direction, Figure 21 provides the answer.

Figure 21: Chancellor's home

Art Studios" is also named the Burton House, next door to the Grider House. The KU Campus Buildings Directory, at http://www.buildings.ku.edu, says that the Grider House was built in 1863 and is now vacant," and says of the Burton House that "part of it is used by art students for studios and workshops." Neither of these two buildings has a flat roof.

[111] Lawrence interactive map.

Figure 22: Burroughs Creek parking lot at 13th and Louisiana

2. <u>Burroughs Creek Parking Lots:</u>

Six parking lots lie within the Burroughs Creek watershed. One of them, the lot at 13th and Louisiana, is shown in Figure 22.[112] DCM gives a square footage for this lot of 11,805.76. What sort of BMP could be used here and where should it be sited?

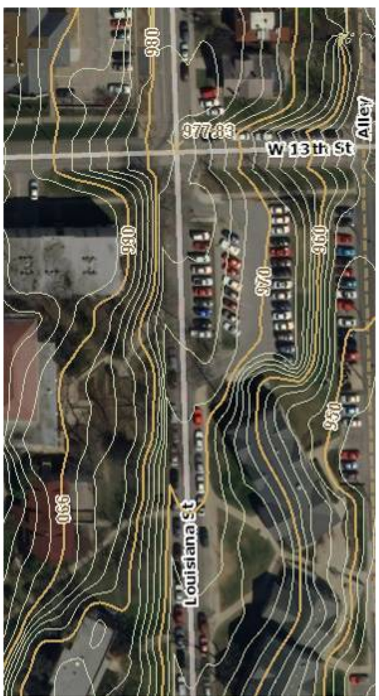

Figure 23: 13th and Louisiana parking lot with contours

As can be seen in Figure 22, there is a good-sized green space just to the east of the lot. Looking at the contour map of this same location, shown in Figure 23,[113] one can see how the green space east of this lot would be an ideal location for a bioretention cell. "The best method of capturing and treating runoff is to allow the water to sheetflow into the facility over grassed areas to reduce inflow velocity and to reduce the load of coarse sediment entering the bioretention area."[114] The stormwater flows due east the entire length of the lot, and the elevation drops 10 feet from the row of parked cars to the middle of the green space, so the stormwater could all enter the cell as sheetflow. This situation is unlike that found at Carruth-O'Leary, where, both because the green space did not extend the entire length of the lot and because of the contour of the green space itself, a bioretention cell would not be able to capture all of the runoff.

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[112] Lawrence interactive map.
[113] *Id.*
[114] *MARC Manual*, §8.4.5.10, unnumbered page.

How much stormwater runoff the bioretention cell here could capture is calculated by using the volume formula: 11,805.76 square feet equals 0.27 acres; 3630 times 1.37 inches times 0.95 (again assuming the entire lot to be impervious) times 0.27 equals 1275.60 cubic feet per design storm. That equals 43,625.52 cubic feet annually, or 326,318.89 gallons of stormwater captured and cleaned.

Table 8 shows the same calculations for the remaining five parking lots in the Burroughs Creek watershed.

Table 8: Gallons of stormwater to be captured annually in 5 parking lots in the Burroughs Creek watershed

Parking lot	Square footage of tributary area; then acreage	Required size of bioretention cell (in feet)	Number of cubic feet of stormwater captured per design storm	Number of cubic feet of stormwater captured annually	Number of gallons of stormwater captured annually
Smith and Union	23,490.50; 0.54	22 x 35	2551.20	87,251.04	652,637.78
E. Fraser Hall	10,152.96; 0.23	14 x 23	1086.62	37,162.40	277,974.75
E. Danforth Chapel	7034.41; 0.16	12 x 19*	755.91	25,852.12	193,373.86
Alumni Place	42,403.01; 0.97	29 x 47	4582.72	156,729.02	1,172,333.07
E. Sellards Hall	24,586.92; 0.56	22 x 36	2645.69	90,482.60	676,809.85
Total gallons captured annually					2,973,129.31

*The minimum size requirement for a bioretention cell is 10 x 20.

If to this figure of 2,973,129.31 gallons from the five parking lots there is added the figure of captured gallons from the 13th and Louisiana parking lot, then bioretention cells could capture, detain, retain, and clean a total of 3,299,448.20 gallons of stormwater annually from the Burroughs Creek parking lots.

IV. Other Suggestions for KU's Main Campus

Although the focus of this project is on stormwater runoff from the buildings and parking lots on KU's main campus, and not on the remaining categories of impervious surface here, still some ideas regarding these other surfaces may be useful, and so they are presented here.

A. Underground Storage Tanks:

KU's *Campus Sustainability Plan* sets the following as Strategy 3.1.2 in its Campus Grounds Vision: "Use existing underground tanks to collect stormwater runoff for irrigation."[115] Several of these storage tanks exist: the Booth Hall of Athletics, Eaton Hall, Wagnon-Parrott Athletic Center, and the Mississippi Street Parking Garage all have underground chambers. Further, Allen Fieldhouse has a 10-year underground chamber, that is, a chamber with the capacity to hold stormwater from a storm the size of which is likely to happen only once in ten years. Moreover, an underground chamber is currently being constructed at M2SEC with a ponding volume of 4,124 cubic feet.[116] However: "At this point, no water is being held on campus and re-used for other purposes."[117] In keeping with the *Campus Sustainability Plan*, KU could now work to utilize these already existing resources. Assuming that KU does indeed construct bioretention cells throughout the main campus, irrigation water will be needed until the native species planted in the cells take hold and can thrive without assistance.

But the tanks mentioned above are not the biggest which already exist on the main campus. Mr. Mike Russell, KU's Director of the Department of Environment, Health and Safety, explained that there now are two abandoned storage tanks on campus: one is near the Hall Center and the other is under the parking lot across the street from the Hall Center. One can

[115] At 35.
[116] Email from Jeff Severin, Director, Kansas University Environmental Sustainability Center, on November 8, 2011, to author; and email from Marion Paulette Waller, Landscape Architect, Kansas University Office of Design and Construction Management, on February 2, 2012, to author.
[117] *Id*., Waller email.

see their locations in Figure 24.[118] The tank north of Sunnyside is marked by the yellow lines on the pavement. The tank on the south side of Sunnyside can be located by the manhole covers visible between the fourth and fifth cars from the left of the lot.

These tanks, and others on campus, were originally used to store fuel for KU's use. When KU no longer needed the tanks, they were abandoned, with some oil still in them. One such tank was bioremediated by KU in approximately 2000: as much oil sludge as could be removed mechanically was so removed by an oil company, and then oil/sludge-eating microbes were released into the tank. Within a few years, the microbes had consumed the remaining sludge and what remained was pure water. That was a 275,000-gallon tank. In the 1990s it cost over $100,000 to clean the tank. Once cleaned, it was abandoned.[119]

Figure 24: Locations of abandoned fuel storage tanks

The tank in the Hall Center parking lot has a 230,850-gallon capacity; the second tank has a 259,000-gallon capacity. Neither has been cleaned. Now could be the time for KU to do so.

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[118] Lawrence interactive map.
[119] Interview with Mike Russell, Director, Kansas University Department of Environment, Health, and Safety, November, 2011.

B. Jayhawk Towers:

One small example of the need to address stormwater runoff can be seen in the three photos below. There is a parking lot of approximately 30,000 square feet directly east of the Jayhawk Towers complex. Because of the slope of this lot to the south and east, much of the runoff from the lot flows onto the grassy area abutting Tower C. This grassy area puddles and turns to mud when it storms, as can be seen in Figure 25. KU could utilize the runoff, protect the grassy area from erosion, and protect the foundation of its building by constructing a rain garden here. KU could also utilize the rainwater flowing off the roof of this building and out from the downspouts within inches of the building's foundations, as shown in Figures 26 and 27.

Figure 25: Runoff from E. Jayhawk Towers parking lot

Figure 26: Jayhawk Towers roof runoff

Figure 27: Jayhawk Towers roof runoff

C. Streets and Sidewalks

Streets and sidewalks are beyond the scope of this project, but they do constitute a significant amount of impervious surface on Mt. Oread, and so should perhaps be mentioned here. KU could utilize curb cutouts and curb extensions in areas of streets where stormwater would naturally flow into them. Tree trenches, set between the sidewalk and the street and set lower than both, could catch the stormwater runoff from both the street and the sidewalk. These could be placed at numerous locations on the campus, only two of which are shown in Figure 28,[120] as Hoch Auditoria Drive approaches Naismith Drive, and in Figure 29,[121] on Irving Hill Road between Daisy Hill and Stouffer Place. Once again, the contours of the land are of critical importance in determining where to site these BMPs throughout the campus. Everywhere that they would be located, they could slow down the stormwater runoff,

Figure 28: Possible locations of tree trenches and curb cutouts along Hoch Auditoria Drive

Figure 29: Possible locations of tree trenches and curb cutouts along Irving Hill Road

[120] Lawrence interactive map.
[121] *Id.*

and perhaps more importantly, since runoff where cars have been is the dirtiest stormwater runoff that there is, tree trenches could contribute toward cleaning the water. Certainly, too, they make the campus more beautiful.

Regarding sidewalks, KU might want to conduct an experiment with pervious asphalt. One possible location for such an experiment could be the lower patio at Jayhawk Tower Apartments.[122] Because it is surrounded on two sides by buildings close to it, and because it is lower than other buildings and the other patio at Jayhawk Towers, it may be protected from some of the severe cold that KU can experience in winters. If a percolation test showed that the soil under the currently existing concrete was more infiltratable than HSG C or D, KU might not find it necessary to install an underdrain. It is a relatively small, contained space, and might work well for such an experiment.

V. Stormwater BMPs on the Campuses of Other Universities

In 2009, the Harvard Business School Operations crew was responsible for the installation of a green roof on the Shad building there. Their announcement of this installation included the fact that a green roof "can cost more than twice as much as a conventional roof, but given its positive environmental impact, energy efficiencies, and extended life, it offers benefits over time that outweigh the additional costs." [123] Harvard has also installed a 4,500 square-foot green roof at its Rowland Institute.[124]

When Rensselaer installed a green roof on one of its buildings the following estimate was made: "B[y] using a green roof system on top of the rubber roof membrane, in the place of

[122] KU has recently received a grant from Kansas Department of Health and Environment to reconstruct Lot 54, the lot near its School of Law, with permeable pavement. Email from Jeff Severin, Director, Kansas University Environmental Sustainability Center, on April 13, 2012, to author.

[123] Thompson, R. (December, 2009). Up on the Green Roof. *Harvard Business School Alumni Bulletin*. Retrieved April 5, 2012, from http://www.alumni.hbs.edu/bulletin/2009/december/greenroof.html.

[124] *The greenroof projects database.* (n. d.). Rowland Institute at Harvard. Retrieved April 5, 2012, from http://www.greenroofs.com/projects/pview.php?id=1123.

simple rock ballast…or no covering at all, the rubber roof membrane needs replacing every 60-70 years instead of every 30 years."[125] The City of Chicago, where many green roofs have been installed, says that "green roofs extend the life of roofs two to three times."[126] Further, tests on Chicago's City Hall green roof conducted jointly by the City, the EPA, and the Lawrence Berkeley National Laboratory on August 9, 2001, when the ambient temperature was in the 90's, determined the following temperatures: on the paved City Hall roof, between 126 and 130 degrees Fahrenheit; on the planted City Hall roof, between 91 and 119 degrees Fahrenheit, and on the black tar County roof, 169 degrees Fahrenheit.[127]

The University of Wisconsin Madison has installed a 27,000 square foot, part-intensive, part-extensive green roof on its University Square building. It has constructed a parking-ramp rain garden of 7,500 square feet, as well as bioswales and an infiltration system. It has installed pervious asphalt and a 7,900 square foot infiltration basin, and it has conducted a pervious concrete trial.[128] The University of Wisconsin Milwaukee in 2008 installed a 33,000 square foot rooftop garden—the largest in the state--on its Sandburg Hall. It has grown tomatoes, lettuce, jalapenos, basil, and oregano there.[129]

The University of Florida has designed a stormwater wetland on its land, and a bioretention area, as well as a grassy swale, a stormwater pond, and porous pavement.

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[125] Hunt, Benjamin. Groundmaking: Class of 2010 Green Roof at Rensselaer. (2011). Case Study Database in *Association for the Advancement of Sustainability in Higher Education* (AASHE), Retrieved April 5, 2012, from http://www.aashe.org/resources.

[126] City of Chicago. (n. d.). *Green Roofs: Best Management Practices*. Retrieved April 4, 2012, from http://www.cityofchicago.org/city/en/depts/water/supp_info/conservation/green_design/green_roofs_bestmanagementpractices.html.

[127] City of Chicago. (n. d.). *Monitoring the City Hall Rooftop Garden's Benefit.* Retrieved April 4, 2012, from http://www.cityofchicago.org/content/city/en/depts/doe/supp_info/monitoring_the_cityhallrooftopgardensbenefit.html.

[128] Brown, G. A. (n. d.). *Powerpoint: Controlling Urban Stormwater at the University of Wisconsin Madison.* Retrieved April 4, 2012, from https://fpm-www3.fpm.wisc.edu/campusplanning/LinkClick.aspx?fileticket=RMy7tWJysq0%3D&tabid=69&mid=465.

[129] Fink, M. (October, 2009). Green roof puts plants on top. *The UWM Post*. Retrieved April 4, 2012, from http://www.uwmpost.com/2009/10/19/green-roof-puts-plants-on-top.

Additionally, it has eliminated some curbing and gutters.[130] Western Michigan University has installed rain gardens, vegetated slopes and swales, and a surface stormwater detention basin on its campus.[131]

Virginia Tech has put several BMPs in place on its campus: a detention pond, a green roof, stone swales, and bioretention cells, some with and some without pretreatment ponds.[132] The University of Colorado at Boulder has installed seven plazas or parking lots with porous pavement, 10 retention ponds, a few stone swales, numerous vegetated bioswales, constructed wetland channels, constructed wetlands, infiltration pipes, and detention ponds.[133]

Penn State University has created the Center for Green Roof Research whose mission is to "promote the use of green roofs in North America through Research, Teaching, and Outreach." The Center is "unique in that it is the only location in North America with small test green roofs on replicated buildings." Additionally, "[s]ome of the cutting edge research done at the center has included studies in storm water runoff quality and quantity, building energy consumption and insulation value, media chemical and physical characteristics, plant selection, plant water use, waterproofing resistance to root penetration, and drainage materials." Penn State has now installed five green roofs on its campus buildings.[134]

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[130] University of Florida. (n. d.). *UF Clean Water Campaign: Prevention: UF Best Management Practices on Campus—Interactive Map.* Retrieved April 4, 2011, from http://soils.ifas.ufl.edu/campuswaterquality/prevention/BMPs_flash_map.shtml. The bioretention cell is number 9 on the interactive map.
[131] Western Michigan University Facilities Management. (n. d.). *Powerpoint: Campus Storm Water Projects and Best Management Practices.* Retrieved April 4, 2012, from www.swmpc.org/downloads/wmu_example.pdf.
[132] Virginia Tech: Facilities Services. (n. d.). *Around Campus*. Retrieved April 4, 2012, from http://www.facilities,vt.edu/udc/sid/stormwater/home/photos.asp.
[133] AASHE STARS Sustainability Tracking Assessment and Rating System. (November, 2010). University of Colorado Boulder OP-23: Stormwater Management. Retrieved April 4, 2012, from https://stars.aashe.org/institutions/university-of-colorado-at-boulder-co/report/2010-11-09/2/16/54. UC Boulder has received an overall rating of gold from AASHE.
[134] Penn State College of Agricultural Sciences: *Horticulture.* (n. d.). Center for Green Roof Research . Retrieved April 5, 2012, from http://horticulture.psu.edu/research/labs/green-roof/front-page.

Villanova has established a BMP Research and Demonstration Park on its campus. The Park's most recent addition was an infiltration trench with the dual purpose of managing stormwater and also providing a gathering area for students and faculty. Other BMPs there include a stormwater wetland, bioinfiltration, an infiltration trench, a green roof, porous concrete, porous asphalt, and a pervious concrete/porous asphalt comparison study.[135] The University of North Carolina Chapel Hill has "more than 180 structural best management practices installed across the campus."[136]

These universities constitute only a small part of those working to improve the quality of stormwater runoff and limit its quantity on their campuses. Stormwater BMPs on university campuses are not a new thing, nor are they isolated. Universities are part of the leadership in the United States on the stormwater management issue, and this is a fitting role for universities.

VI. Conclusions

At the end, this project returns to its beginning, to the 216 million gallons of stormwater that fall on the impervious surfaces of KU's main campus annually. If KU installs all of the green roofs and all of the bioretention cells and other BMPs for its parking lots, how many of the 216 million gallons can be delayed or retained and cleaned?

First, none of the gallons of water retained by the green roofs will enter the stormwater drainage system of the university or the City. Only the overflow from these roofs will do that, and this overflow will have been partially cleaned by the roofs. Second, the gallons detained or retained by the bioretention cells and other BMPs proposed for KU's main-campus parking lots

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[135] Villanova Urban Stormwater Partnership. (n. d.). *Villanova Infiltration Trench*. Retrieved April 4, 2012, from http://www3.villanova.edu/vusp/bmp_research/inf_trench/inf_trench_des_comp.htm.

[136] The University of North Carolina at Chapel Hill Sustainability Office. (n. d.). *Water Management*. Retrieved April 5, 2012, from http://sustainability.unc.edu/Initiatives/WaterManagement.aspx.

will enter the stormwater drainage systems, but will enter them later in time, thereby putting less demand on these systems, and will enter them cleaned.

How many gallons can be delayed or retained and cleaned? Table 9 shows this summary.

Table 9: Summary of gallons of stormwater captured from all green roofs and all parking lots on KU's main campus

Watershed	Number of gallons captured by green roofs	Number of gallons from all parking lots, including those specifically described and those listed in Tables 4-8
Naismith	(p. 23): 12,825,792.49	(p. 33): 1,546,919.35 (p. 35): 11,288,228.89 (p. 43): 41,635,926.57
Meadowbrook	(p. 46): 244,518.97	(p. 48): 1,208,589.90 (p. 49): 7,469,087.88
Windmill	(p. 51): 154,782.22	(p. 52): 991,043.97
Jayhawk	(p. 53): 3,279,952.79	(p. 55): 821,842.19 (p. 58): 25,017,809.61
Downtown	NA	(p. 61): 543,867.36
Burroughs Creek	(p. 62): 302,353.87	(p. 64): 326,318.89 (p. 64): 2,973,129.31
Total number of gallons retained by roof BMPs	16,807,400.34	
Total number of gallons detained, retained, and cleaned by parking-lot BMPs		93,822,763.92
Total number of gallons from roofs' and parking lots' BMPs		110,630,164.26

This means that by greening its roofs and installing BMPs on its parking lots, KU can retain and clean or delay the release of more than half of its 216 million gallons of annual stormwater runoff.

Maybe the question now is why should KU do this? It would be expensive, and for the parking-lot runoff, KU would ultimately be simply releasing that stormwater into the City stormdrain system. How does that benefit KU? One could say that it doesn't, except minimally, in the sense that the water that comes back to it at some time in the future may be cleaner because of its actions. One could say, well, we are all downstream from somewhere, which is true, but hard to expense out on a cost-benefit analysis. One could point out that more than half of the State of Kansas is in a period of drought right now, so keeping water on roofs helps reduce indoor temperature and so energy demand and water usage, which is true, but does not necessarily get more water to drought-stricken areas.

One could also say, as has been said by others, that "water is the new oil." The amount of water on the planet today is the same amount which was present at the beginning. "And we only have that one allotment of water—it was delivered here 4.4 billion years ago. No water is being created or destroyed on Earth. So every drop of water that's here has seen the inside of a cloud, and the inside of a volcano, the inside of a maple leaf, and the inside of a dinosaur kidney, probably many times."[137] We do not create water, and we do not use it up. We do not destroy it. "None of the 1 million ways we use water each day actually consumes the water, including, of course, drinking it ourselves." What we *do* do is contaminate water.[138] And then the Earth cleans it, and we reuse it.

[137] Fishman, at 17.
[138] *Id.*, at 19.

Had impervious surfaces not been build on campus, the planet would clean the stormwater on its own, through natural hydraulic and hydrologic processes. By installing BMPs on campus, KU will be helping the natural processes of the land to clean the water. That seems like a fair, responsible thing for a citizen of the planet to do.

At the University of North Carolina Chapel Hill, total potable water consumption "has fallen 27 percent per square foot since FY 2003. Aggressive efficiency measures, leak detection, and rainwater harvesting account for the majority of the decrease." Furthermore, in 2009 at UNC, "a reclaimed water system became operational that will further reduce potable water consumption by more than 200 million gallons per year," or 25 percent of UNC's total water use. This is water from the Mason Farm Sewage Treatment Plant. It is "highly treated and dually disinfected wastewater," and it is used to provide cooling tower make-up water for UNC's chilled water plants and for athletic field irrigation.[139]

KU could do something equally as beneficial: it could double-plumb all of its buildings, collect the stormwater from all of them in filtered storage tanks and cisterns, and use this water for purposes that do not require potable water, and therefore do not waste the energy involved in bringing all water to potable standards.[140] KU now pays $16,490 every month to the City of Lawrence as its stormwater runoff fee.[141] If water is indeed the new oil, if the approximately seven billion people alive on the planet today are putting a greater and greater demand on the water supply, both personally and in terms of agricultural needs, then on a not-so-distant-future cost-benefit analysis, it might have made great sense for KU to have double-plumbed earlier in the 21st century as opposed to later. Rain comes every year, and it is free.

[139] *Op. cit.*, footnote 136.
[140] Sometimes this second-pipe system is referred to as "purple pipes." The exterior of the pipes really is purple, so that when a plumber is working on some plumbing problem, he or she does not confuse the potable system with the non-potable system, and by mistake connect one to the other.
[141] Interview with Matt Bond, Stormwater Engineer for the City of Lawrence, Kansas, on February 17, 2012.

Appendix A

Square Footages of Seven Categories

of Impervious Surface on the Kansas University Campus

KU CAMPUS BUILDING AREA

	Building Number	Building Name	Campus Map Locate	Total Area (s.f.)	Total Building Per Zone
KUSH Ground Zone 1	156	KPR & Baehr Audio-Reader Center	G2	5666.50	
	81	Sunflower Apartments	G2	18611.43	
	91	Max Kade Center	G2	2147.07	
	50	Memorial Stadium		108087.94	
	92	Sudler Annes KJHK	G2	718.25	
	219	Anderson Family Football Complex	G-H3	32535.92	
	80	Joseph R. Pearson Hall	G3	28526.13	196293.23
KUSH Ground Zone 2	1	Corbin Residence Hall	J3	15912.09	
	50	Memorial Stadium		97188.02	
	78	Gertrude Sellards Pearson Residence Hall	J3	23220.51	136320.61
KUSH Ground Zone 3 & 4	88	Learned Hall	F4	59734.28	
	-	Spahr Engineering Library	F4	9019.53	
	42	Lindley Hall	F4	15733.69	
	77	Carruth-O'Leary Hall	G3	13521.09	
	40	Snow Hall	G4	15770.29	
	100	Spencer Research Library	G4	26051.89	
	37	Strong Hall	G4	34941.98	174772.76
KUSH Ground Zone 5	152	Spencer Museum of Art	H4	20774.28	
	5	Dyche Museum	H4	21736.32	
	9	Sprague Apartments	H5	2752.28	
	2	Kansas Union	H4	33220.83	
	172	Adam Alumni Center	J4	10651.39	
	21	Smith Hall	H4	9024.37	
	4	Wesley Building, University Relations	H-J4	4846.89	
	-	Vacant	H-J4	2760.21	
	73	Grace Pearson Schloarship Hall	H5	2628.70	
	74	Douthart Scholarship Hall	H5	2553.59	
	203	Margaret Amini Schloarhsip Hall	J4	4700.88	
	194	K.K. Amini Schloarship Hall	J5	4708.62	
	215	Crawford Community Center	H-J5	1527.83	
	223	Krehbiel Hall	H-J4	5773.23	
	213	Dennis E. Rieger Scholarship Hall	J5	6010.91	
	-	Department of Art Studios	J5	2457.35	
	8	Lippincott Hall	H5	8232.46	
	209	International House (Pinet House)	H-J4	1791.38	
	6	Spooner Hall	H4-5	7763.57	
	222A	Sabatini Multicultural Resource Center	H4	16955.43	170870.52
KUSH Ground Zones 6,7 & 8	199	Continuing Education Building	A2	15899.43	
	177	Landscape & Construction Building	A3	17645.08	
	-	Motor Pool	A2	11361.96	
	143	Chamney House	A2	1859.29	
	185	University Press Offices	A3	5837.70	
	183	University Press Warehouse	B3	8491.31	
	116	Public Safety Building	B3	34268.43	
	184	Lied Center	C4	47563.67	
	201	Dole Institute & Archives	G5	13040.89	
	114	Housing Maintenance Warehouse	C3	15053.18	171020.93
KUSH Ground Zone 9	83A	Visitor Center & Templin Hall	D4	24401.32	
	99	Nunemaker Center	D4	4804.87	
	82	Lewis Residence Hall & Mrs. E's	D4	35893.10	
	87	Hashinger Residence Hall	D4	17321.86	
	84	Stouffer Place Apartments	D5	15747.59	
	85	Burt Hall	E4	10314.12	
	164	Jayhawk Towers Apartment	E4	44991.28	
	158	Burge Union	E4	18464.66	
	150	Green Hall	E4	23425.58	
	173	Anschutz Sports Pavilion	E5	104551.25	
	-	Anderson Family Strength & Cond. Center	E5	28387.37	
	189	Wagnon Athletic Complex	E5	24705.34	
	174	Parrott Athletic Center	E5	13299.86	
	197	Horejsi Family Athletics Center	E5	21313.45	387621.64
KUSH Ground Zone 10	204	Eaton Hall	F4	26324.54	
	151	Art & Design Building	F4	38801.79	
	39	Budig Hall	G4	34835.05	
	44	Marvin Studios	F4	7120.65	
	35	Bailey Hall	G4	12172.73	
	34	Stauffer-Flint Hall	G5	14506.39	
	3	Chiller Bldg	not on map	3737.82	
	180	Dole Human Development Center	G5	32343.43	
	153	Computer Services Facility	G5	21082.60	
	104	Haworth Hall	G5	37175.06	
	132	Wescoe Hall	G4	44888.09	
	179	Anschutz Library	F4	24501.22	
	46	Military Science Building	F4	16435.04	
	76	Muphy Hall	F4	82475.34	
	79	Summerfield Hall	F5	19683.76	
	59	Allen Field House & Hall of Athletics	E5	97127.59	
	94	Robinson Health& PE Center	F5	107359.37	
	58	Malott Hall	G5	40099.98	
	147	Watkins Memorial Health Center	F5	34770.72	

					695441.17
KUSH Ground Zone 11	30	Facilities Operations	G5	9366.72	
	24	Power Plant	-	8343.07	
	27	Hall Center for Humanities	G5	8685.91	
	22	Watson Library	G-H5	32791.49	
	19	Twente Hall	G5	5606.99	
	17	Blake Hall	H5	6201.01	
	49	Danforth Chapel	H5	1830.83	
	97	Fraser Hall	H5	12961.43	
	10	Battenfeld Scholarship Hall	H5	4565.66	
	11	Watkins Scholarship Hall	H5	3204.83	
	12	Miller Scholarship Hall	H5	3210.10	
	14	Chancellors Residence	H5	2785.09	
	13	Guest House	-	896.68	
	70	Stephenson Scholarship Hall	H5	2810.05	
	71	Pearson Scholarship Hall	H5	3067.37	
	72	Sellards Scholarship Hall	H5	3034.53	109361.76
KUSH Ground Zones 12,13&14	218/202	F.O. Shops & Warehouses&Storeroom	A4	87535.71	
	214	Library Annex	A4	14707.91	
	86	Youngberg Hall	B4-5	11810.31	
	135	Nichols Hall	B4	23812.64	
	-	Endowment Association	B-C5	17454.93	155321.50
KUSH Ground Zones 15, 16&17	89	Ellsworth Residence Hall	D5	24045.06	
	93	McCollum Residence Hall	C5	34353.20	
	84	Stouffer Place Apartments	D5	64717.81	
	196	Hilltop Child Development Center	D-E5	23871.52	
	197	Horejsi Family Practice Facility	E5	21306.84	
	95	Oliver Residence hall	E6	35342.71	
	147	Watkins Memorial Health Center	F5	34783.83	
	205	Student Recreation Fitness Center	F6	98356.28	336777.24
KUSH Ground Zones 18 to 23	190	Kurata Thermodynamics Laboratories	B5	7377.62	
	225	Pharmacy Building		37718.21	
	220	Multidisciplinary Research Building	A-B6	30515.76	
	227	Incubator Lab		15269.33	
	163	Foley Hall	B6	4685.39	
	212	Structural Biology Center	B6	40870.30	
	98	Bridwell Botany Research Lab	B6	8497.71	
	133	Annex	-	1411.53	
	157	Smissman Research Lab	B6	25563.58	
	136	Higuchi Hall	B6	6621.70	
	121	Pharmaceutical Chemistry Lab	B6	16136.93	
	141	McCollum Lab	B6	6448.65	
	195	Simons Biosciences Research Lab	B6	23507.52	
	122	Parker Hall	B6	4906.00	
	-	Core Library	B6	9436.21	
	-	Hambleton Hall	B6	4791.68	
	139	Moore Hall	C6	4552.03	248310.15
Gz_off	206, 207	Life Sciences		30261	
	365	Transit Facility		18028	
	410, 412, 413, 414	Regents Center, Regnier Hall, Jayhawk Central, B.E.S.T. Building		102037.25	150326.25

TOTAL BUILDING AREA= 2932437.75

KU Parking Area Calculation				
	Parking Name	Lot # (Parking Map)	Total Area (ft^2)	Total Area per Zone
KUSH Ground Zone 1	KPR & Baehr Audio-Reader Center	51	35913.88	
	Sunflower Apartment	128	15162.77	
	East of JRP	50	79357.72	
	N. of JRP	11	15680.31	
	W. Football Stadium	65&58&59	81686.08	
	W. Football Stadium	55&56&57	123320.57	351121.33
KUSH Ground Zone 2	East of Stadium Parking	94	96194.17	
	Mississippi St. Parking	53	19444.97	
	GSP & Corbin Halls Parking	111	179883.02	
	S. Stadium Parking	91	89268.42	
	W. GSP & Corbin Halls Parking	60	8676.80	393467.38
KUSH Ground Zone 3 & 4	W. Learned Hall	41	33561.37	
	S. Lindley Hall	33	41283.77	
	S. Marvin, Budig Hall	2&21	28412.40	
	E. Carruth-O'Leary	1	29451.88	
	E. Carruth-O'Leary	52	31357.95	
	N. Snow Hall	36	13757.21	
	Jayhawk Blvd/Snow Hall	4	2601.34	
	N. Strong Hall	3	51108.51	
	Jayhawk Blvd/Strong Hall	4	3593.90	
	W. Memorial Drive	39	9316.29	244444.64
KUSH Ground Zone 5	12th & Louisiana	120	7565.02	
	Mississippi Street Parking Facility	Garage	6627.39	
	Alumni Center Parking	H-J4	24757.25	
	Smith Hall & Union	16&115	23490.50	
	N. Spencer Museum	lot 91	74571.33	
	13th & Louisiana	122&124	11805.76	148817.25
KUSH Ground Zone 6, 7 & 8	N. Continuing Education Parking	501&502	56526.44	
	S. Continuing Education Parki ng	503&504	31906.27	
	Motor Pool Parking	220	83605.58	
	University Press Parkin	200&201	50054.68	
	W. Housing Warehouses	201&203	65198.31	
	Lied Center Parking	300	451832.46	739123.73
KUSH Ground Zone 9	W. Visitor Center Parking	102	42852.74	
	Hashinger, Lewis, Templin, Nunemaker Lot		269353.64	
	E. Jayhawk Tower	110	30041.92	
	E. Burge Union	72	103056.04	
	S. Jayhawk Tower	123	23658.77	
	Hilltop	19&20	55203.84	
	W. Jayhawk Tower	109	69035.28	593202.24
KUSH Ground Zone 10	E. Learned/Eaton Hall	129	9895.24	
	E. Green Hall	54	63742.52	
	Allen Filed Parking Facility	E4-5	62256.85	
	S. Wescoe Hall	18	27712.67	
	N. Summerfield Hall	17&22&35	36730.92	
	N. Haworth Hall	37	50755.85	251094.05
KUSH Ground Zone 11	E. Computer Services Facility	34	79932.82	
	Sunnyside & Illionis	61&62	121670.26	
	E. Hall Center	38	9966.97	
	S. Waston Library	10&12	16262.09	
	E. Blake Hall	15	16849.12	
	E. Fraser Hall	14	10152.96	
	E. Danforth Chapel	13	7034.41	
	Alumni Place	100	42403.01	
	Facilities Operations	126	30364.18	
	E. Sellards Hall	107	24586.92	359222.74
KUSH Ground Zone 12, 13 & 14	F.O. Shops & Warehouses&Storeroom	A4	110316.43	
	Youngberg Hall	B4-5	121697.08	
	N. Nicole Hall	B4-5	13460.71	
	Pioneer Cemetary/Iowa Street	C5	20861.01	
	Endowment Association	B-C5	69586.78	335922.01
KUSH Ground	Ellsworth Hall&McCollumn Hall	104&105	176183.83	
	Stouffer Place	114	167672.83	

Zone 15, 16 & 17	W. Oliver Hall & S. Horejsi Center	112&125&127&71	294103.11	
	S. Robinson Center	90&117	526721.57	
				1164681.33
KUSH Ground Zone 18 to 23	W. Park & Ride	302	197312.13	
	E. Park & Ride	301	295377.58	
	Pharmacy Building		25374.43	
	Multidisciplinary Building Parking	225	64064.07	
	Incubator Lab		22161.49	
	N. Smissman & W. Bridwell Labs	214	74195.97	
	S. Moore & S. Parker Halls	211	43341.02	
	S. Higuchi	223 & 224	45875.96	
	E. McCollum Labs	216	16559.26	
	E. McCollum Labs	215	11970.54	
	N. Parker Hall	210	18064.99	814297.44
Gz_off	Life Sciences Bldgs A, B, C		90094.00	
	Transit Facility		194923.00	
	Regents Center, Regnier Hall, Jayhawk Central, B.E.S.T. Building		290904.77	575921.77

TOTAL AREA =	5971315.91

KU Campus Sidewalk Area Calculation				
	Sidewalk Name	Location	Total Area (ft^2)	Total Area per Zone
KUSH Ground Zone 1	Sudler Max Kade Center	G2	3015.9793	
	KPR & Baehr Audio-Reader Center	G2	1792.18	
	E. JRP	F-G3	3887.9571	
	N. JRP	F-G3	1275.9676	
	E. JRP	F-G3	4141.0717	
	Sunflower Apartment	G2	4921.9271	
	S. 11th Street	H2-3	1883.5286	
	N. & W. of Stadium		31016.33	
	N. Lot 56&57	G3	2454.2364	54389.1778
	NE Stadium		9373.61	
KUSH Ground Zone 2	Corbin Residence Hall	J3	9715.8242	
	Gertrude Sellards Pearson Residence Hall	J3	5615.5761	24705.0103
KUSH Ground Zone 3 & 4	N. Learned Hall	E-F4	3286.6282	
	S. Learned hall & N. Spahr Library	E-F4	791.3444	
	Chi Omega Fountain & N. Jayhawk Blvd	F4	18700.2791	
	Naismith Hall Sidewalks	F4	11484.2471	
	All Sides around Marvin Hall	F-G4	31089.042	
	N. Budig Hall	G4	11449.2109	
	Strong Hall	G4	22504.7398	
	Spencer Research Library	G4	6747.719	
	Potter Lake	G3-4	11396.162	
	W. Carruth O'Leary Hall	F-G3	8336.2613	
	S. New Football Facility	G-H3	25975.699	
	S. Campanile	G4	3167.9509	154929.2837
KUSH Ground Zone 5	Stadium Sidewalk	H3-4	8844.7934	
	W. Spencer Museum of Art	H4	9560.2153	
	S. & E. Spencer Museum	H4	11636.8898	
	Mississippi Parking Facility	H-J4	36647.0046	
	International House	ad Ave. &	3459.5682	
	W. Kansas Union	H4	2773.572	
	E. Kansas Union	H4	19407.3407	
	Alumni Center	J4	9464.323	
	W. Spooner Museum	H4-5	12010.7107	
	W. Smith Hall	H4	5629.1239	
	E. Douthart Scholarship Hall	H5	5473.8608	
	M. & K. K. Amini Scholarship Halls	J4 & J5	4602.2763	
	S. Crawford Community Center	H-J5	1457.5967	
	Krehbiel & Rieger Hall	H-J4-5	7241.3229	
	Dept. of Art Studios (Burton)	J5	1863.9878	
	W. Dyche Nuseum	H4	3136.7467	
	N. Stephenson Hall	H5	1700.621	
	Danforth Chapel	H5	6023.9977	150933.9515
KUSH Ground Zone 6 ,7 & 8	Continuing Education Building	A2	4436.1271	
	University Press Offices	A3	3181.5746	
	Public Safety Building	B3	3156.879	
	Crestline Drive	B3	8823.9924	
	Iowa Street (parcels 6 & 7)		8326.62	
	Lied Center	C4	60618.9997	88544.1928
KUSH Ground Zone 9	W. Templin Hall	D4	13029.8691	
	E. Templin Hall	D4	12122.2355	
	N. Lewis Residence Hall & Mrs. E's	D4	10585.2881	
	Hashinger Residence Hall	D4	14813.6177	
	Nunemaker Center	D4	9074.909	
	N. Jayhawk Towers Apartment	E4	10685.9448	
	S. Jayhawk Towers Apartment	E4	16755.8138	
	N. Burge Union	E4	5899.2926	
	E. Burge Union	E4	11240.5963	
	S. Burge Union	E4	8005.0661	
	Stouffer Place Apartment	D5	19404.3845	
	Burt Hall	E4	39909.6433	
	N. Green Hall	E4	5743.4917	
	S. Green Hall	E4	14644.0569	
	E. Burge Union Parking Lot	E4	10987.9281	202902.1375
	E. Green Hall	E4	12415.30	
	E. Parking Facility	E5	21398.82	
	E. Allen Filed House	E5	23348.16	

KUSH Ground Zone 10	W. Art and Design	F4	3749.73	
	N. Murphy Hall	F4	11095.07	
	S. Murphy Hall	F4	14568.89	
	Robinson Health& Physical Education Center	F5	39359.13	
	E. Military Science Building	F4	18337.53	
	N. Malott Hall	G5	7144.37	
	E. Malott Hall	G5	10820.88	
	N. Summerfield/W. Malott Hall/S. Military Building	F5	16533.68	
	E. Wescoe Hall	G5	38625.41	
	S. Dole Human Development Center	G5	7168.28	
	Computer Center	G5	11644.03	
	E. Watkins Health Center	F5	4180.53	
	Summerfield Hall	F5	18844.75	259234.56
KUSH Ground Zone 11	E. Bailey Hall	G4	4944.4435	
	N. Watson Library	G-H5	21431.1431	
	Fraser Hall	H5	24429.0552	
	Hall Center of Humanities	G5	10379.6591	
	Twente Hall	G5	10443.8762	
	Watkins Home	H5	3069.8915	
	E. Computer Service	lot 61-62	12976.0885	
	Battenfeld/Watkins/Miller Scholarship Hall	H5	6351.7526	
	Chancellors Residence	H5	5231.6598	
	Sellards Scholarship Hall	H5	6391.3576	
	E. Sprague Apartments	H5	2745.3384	108394.2655
KUSH Ground Zone 12, 13 & 14	F.O. Shops & Warehouses&Storeroom	A4	2500.0582	
	Library Annex	A4	2224.6194	
	Youngberg Hall	B4-5	1349.0929	
	Irving Hill		3811.05	
	E. Constant Ave. & W. Iowa St.		20575.23	
	Nichols Hall	B4	15460.8833	
	Endowment Association	B-C5	10142.8727	56063.8065
KUSH Ground Zone 15, 16 & 17	Ellsworth Hall&McCollumn Hall	C-D5	16849.0132	
	McCollum Hall	C-D5	16777.1654	
	Stouffer Place	D5-6	49381.3677	
	Child Care	D5-6	4515.7001	
	E. Naismith Hall	E6-7	6827.3309	
	N. Oliver Hall	E6-7	9411.675	
	Student Recreation Center	F6	19933.5336	
	S. Watkins Health Center	F5	7659.9509	131355.7368
KUSH Ground Zone 18 to 23	Park and Ride Parking Lots	A6	69281.588	
	Pharmacy Building		29237.57	
	Incubator Lab		3549.47	
	Multidisciplinary Research Building	A-B6	7428.2952	
	Laboratories	B6	20055.6867	
	Parker/Moore/Hambleton Halls	C6	17555.597	
	Kurata Thermodynamics Laboratories	B5	710.6119	147818.8188
Gz_off	Life Sciences Bldgs A, B, C		23239	
	Transit Facility		2388	
	Regents Center, Regnier Hall, Jayhawk Central, B.E.S.T. Building		18122.061	43749.061

TOTAL AREA =	1423020.00

Retaining Walls Area Calculation				
	Area Name	Location	Total Area (ft^2)	Total Area per Zone
KUSH Ground Zone 1	KPR		996.8108	
	Football Stadium		403.2537	
	Sunflower Apartment		611.6787	2011.7432
KUSH Ground Zone 2	Corbin Residence Hall		213.0205	213.0205
KUSH Ground Zone 3 & 4	Learned Hall		1037.0558	
	Lindley Hall		49.6277	
	Marvin Hall		31.0966	
	Budig Hall		44.1912	
	Spencer Research Library		684.6484	
	Snow Hall		352.3249	2198.9446
KUSH Ground Zone 5	Union		770.9252	
	Alumni Center		381.0875	
	Grace Scholarship Hall		246.1498	
	Spooner Hall		64.2112	
	Dyche Museum		270.8013	
	Lippincott Hall		501.397	
	University Relation		331.1168	
	Mississippi Street		57.6169	2623.3057
KUSH Ground Zone 6, 7 & 8	Continuing Education		116.9899	
	Lied Center		28.9262	
	W. Warehouse		78.5924	224.5085
KUSH Ground Zone 9	Templin Hall		154.1566	
	Lewis Residence Hall		167.6019	
	Jayhawk Tower		575.7186	897.4771
KUSH Ground Zone 10	Eaton Hall		262.59	
	Art & Design		844.9266	
	Computer Services Facility		120.3139	
	Robinson Health Center		218.115	
	Summerfiled Hall		165.7255	
	Wescoe Hall		172.8447	
	Dole Human Center		687.1244	
	Murphy Hall		240.4528	2712.0929
KUSH Ground Zone 11	Hall Center		561.2196	
	Watson Library		107.4101	
	Watkins Home/Blake Hall		1225.4566	
	Chancellors		547.6596	
	Watkins Hall		189.4191	
	Danforth Chapel		629.4571	3260.6221
KUSH Ground Zone 12,13 & 14	Youngberg Hall		26.1356	
	Nichols Hall		140.2607	166.3963
KUSH Ground Zone 15,16 & 17	McCollum Hall		390.603	
	Anshutz Sports Pavilion		1371.5127	
	Oliver Residence Hall		510.7935	
	Student Recreation Center		228.4745	2501.3837
KUSH Ground Zone 18-23	Smissman Research Laboratories		55.3139	
	Simons Bio-science Center		35.8439	
	Moore Hall		106.7221	197.8799
Gz_off	Regents Center, Regnier Hall, Jayhawk Central, B.E.S.T. Building		786.138	786.138

Total Area =	17793.51

KU Campus Exterior Stairs/Ramps Area Calculation				
	Builiding Name	**Location**	**Total Area (ft^2)**	**Total Area per Zone**
KUSH Ground Zone 1	KPR & Baehr Audio-Reader Center	G2	228.3375	
	Sunflower Apartment	G2	771.5893	
	JRP	F-G3	552.881	
	Sudler Max Kade Center	G2	740.8068	
	Football Stadium	H2-3	3411.1228	5704.7374
KUSH Ground Zone 2	Corbin Residence Hall	J3	1234.306	
	Gertrude Sellards Pearson Residence Hall	J3	765.7304	2000.0364
KUSH Ground Zone 03 & 04	Learned Hall	E-F4	818.505	
	Lindley Hall	F4	1720.4393	
	Marvin Hall	F-G4	511.4211	
	Art & Design	G4	282.2426	
	Strong Hall	G4	1149.0225	
	Spencer Research Library	G4	3994.2205	
	Potter Lake	G3-4	1814.1842	
	Carruth O'Leary Hall	F-G3	3293.8355	
	Snow Hall	G4	1522.8278	
	Campanile	G4	1070.8601	16177.5586
KUSH Ground Zone 5	Football Stadium	H4	167.7061	
	E. Strong Hall	G4	711.2059	
	Spencer Museum of Art	H4	3470.3171	
	Dyche Museum	H4	2867.4256	
	Kansas Union	H4	2704.3339	
	Sprague Apartment	H5	115.1974	
	Spooner Hall	H4-5	1150.253	
	Grace Pearson Schloarship Hall	H5	801.9056	
	Vacant	H-J4	755.3684	
	Wesley Building University Relation	H-J4	174.271	
	Adam Alumni Center	J4	355.1815	
	Krehbiel & Rieger Hall	H-J4-5	780.2438	
	K.K. Amini Schloarship Hall	J5	2084.3464	16137.7557
KUSH Ground Zone 6, 7 & 8	Public Safety Building	B3	117.5644	
	Continuing Education	A2	117.6429	
	Houseing maintenance Warehouse	C3	100.2457	
	Dole Institute & Archives	G5	469.5802	805.0332
KUSH Ground Zone 9	Visitor Center & Templin Hall	D4	35.5694	
	Nunemaker Center	D4	994.9242	
	Lewis Residence Hall & Mrs. E's	D4	466.2534	
	Hashinger Residence Hall	D4	482.1384	
	Stouffer Place Apartment	D5	1875.5357	
	Jayhawk Towers Apartment	E4	4343.6644	
	Burge Union	E4	862.0716	
	Green Hall	E4	2132.7196	
	Anschutz Sports Pavilion	E5	1583.47	
	Anderson Family Strength & Conditioning Center	E5	1077.8635	
	Burt Hall	E4	862.7848	14716.995
KUSH Ground Zone 10	Eaton Hall	F4	1552.38	
	Art & Design Building	F4	1594.46	
	Memorial Garden	G4	2299.91	
	Green Hall Parking	E4	552.03	
	Muphy Hall	F4	2440.75	
	Dole Human Development Center	G5	289.62	
	Computer Services Facility	G5	580.88	
	Haworth Hall	G5	2662.89	
	Wescoe Hall	G4	5721.41	
	Anschutz Library	F4	2385.13	
	Military Science Building	F4	1897.58	
	Summerfield Hall	F5	194.96	
	Allen Filed House & Booth Family Hall of Athletics	E5	160.03	
	Malott Hall	G5	7063.16	29395.18
	Facilities Operations	G5	566.2516	
	Blake Hall	G5	224.9709	
	Hall Center for Humanities	G5	1601.6822	
	Watson Library	G-H5	1289.1703	

KUSH Ground Zone 11	Twente Hall	G5	462.357	
	Bailey Hall	G4	294.008	
	Danforth Chapel	H5	80.565	
	Fraser Hall	H5	1443.2407	
	Battenfeld Scholarship Hall	H5	1886.3803	
	Watkins Scholarship Hall	H5	859.316	
	Miller Scholarship Hall	H5	241.2845	
	Chancellors Residence	H5	1031.3305	
	Wakin Homes	G5	2580.1551	
	Pearson Scholarship Hall	H5	38.4016	
	Sellards Scholarship Hall	H5	360.6242	
	Stephenson Scholarship Hall	H5	1184.9424	14144.6803
KUSH Ground Zone 12, 13 & 14	F.O. Shops & Warehouses&Storeroom	A4	204.1424	
	Youngberg Hall	B4-5	281.974	
	Nichols Hall	B4	324.3944	
	Endowment Association	B-C5	52.1857	862.6965
KUSH Ground Zone 15, 16 & 17	Ellsworth Residence Hall	D5	392.67	
	McCollum Residence Hall	C5	208.1817	
	Stouffer Place Apartments	D5	3227.5633	
	Horejsi Family Practice Facility	E5	605.993	
	Oliver Residence hall	E6	550.3598	
	Watkins memorial health Center	F5	154.8734	
	Student Recreation Center	F6	1225.8278	**6365.469**
KUSH Ground Zone 18 to 23	Core Library	B6	1306.3292	
	Moore Hall	C6	62.7569	
	Hambleton Hall	B6	27.4909	
	Pharmacy Building		575.05	
	Incubator Lab		0	
	Higuchi Hall	B6	226.3194	
	Pharmaceutical Chemistry Lab	B6	167.0726	2365.019
Gz_off	Life Sciences		359	
	Transit Facility		0	
	Regents Center, Regnier Hall, Jayhawk Central, B.E.S.T. Building		1261.806	1620.806

TOTAL AREA =	110295.96

KU Campus Streets Area Calculation			
	Streets Name	Total Area (ft^2)	Total Area per Zone
KUSH Ground Zone 1	K. J. H. K.	9170.4851	
	Main Street	24836.29	34006.7751
KUSH Ground Zone 2	NE Stadium/Illinois	8752.24	
	North College Drive	23350.9627	32103.2027
KUSH Ground Zone 3 & 4	Memorial Drive	87763.3232	
	West Campus Road	71335.2861	159098.6093
KUSH Ground Zone 5	Jayhawk Blvd. & Oread Ave.	48913.06	
	Mississippi Street	113838.875	162751.935
KUSH Ground Zone 6, 7 & 8	Westbrooke Dr	30272.58	
	Westbrooke Circle	36018.39	
	N. Crestline Drive	38453.3389	
	Petefish Drive (gravel)	29834.93	
	Petefish Drive	17993.1834	152572.4223
KUSH Ground Zone 9	15th Street	35907.3027	
	Engel Rd.	49727.09	
	Burdick Drive	17045.8202	
	Irving Hill Road	67234.0311	169914.244
KUSH Ground Zone 10	N. Part of Naismith Drive	87716.11	
	E. Irving Hill Rd.	12292.71	
	Hoch Auditoria Drive	26825.72	126834.53
KUSH Ground Zone 11	Sunnyside Ave.	69139.6478	
	Sunflower Drive	47790.5595	
	Alumni Place	20248.07	
	Jayhawk Blvd.	78041.9817	
	Lilac Lane	32700.6952	247920.9542
KUSH Ground Zone 12, 13 & 14	Westbrooke Street & gravel road	50593.78	
	Petefish Drive (gravel)	32144.75	
	Constant Avenue	53773.5314	
	19th Street	12420.1443	
	Irving Hill Street	44639.6187	
	S. Portion of Crestline Drive	15496.0016	209067.826
KUSH Ground Zone 15, 16 & 17	S. Part of Naismith Dr.	84787.6915	
	Irving Hill Rd.	9892.91	
	18th Street	28576.8357	
	Schwegler Dr	18100.5218	141357.959
KUSH Ground Zone 18 to 23	Crestline Dr.	64773.0545	
	Constant Ave.	175363.4396	240136.4941
Gz_off	Life Sciences Bldgs A, B, C	0	
	Transit Facility	0	
	Regents Center, Regnier Hall, Jayhawk Central, B.E.S.T. Building	594.59	594.59
		TOTAL AREA =	1676359.55

KU Campus Outdoor Recreation Area Calculation				
	Area Name	**Location**	**Total Area (ft^2)**	**Total Area per Zone**
KUSH Ground Zone 1	Football Stadium		141660.5013	**141660.5013**
KUSH Ground Zone 5	Football Practice Fields		148004.4768	**148004.4768**
KUSH Ground Zone 12,13,14	Band Practice Field		57203.8449	**57203.8449**
KUSH Ground Zone 15, 16 &17	S. Allen House Practice Field	E5-6	629294.5193	
	Hoglund Baseball Stadium	E5-6	126460.6003	
	S. Recreation Center Basketball Ct	F6	11606.1754	
	S. Robinson Center Tennis Ct	E-F5	101409.3346	**868770.6296**

Total Area =	**1215639.453**

Appendix B

F. Hahne's Excel Program for Rain Garden Sizing:

Updated for 2009 NCDENR Manual

FW HAHNE

3/15/2012
Updated for 2009
NCDENR BMP Manual
as Amended

Rain Garden Sizing

Project Name: | Kansas 1.37 inch Storm
Bioretention Basin No.

Water Quality Volume WQv

Rv = runoff coefficient (Runoff/Rainfall)
Rv = 0.05 + 0.009(I)
Rv = Volumetric Runoff Coefficient (Runoff/Rainfall)
"I" = % Impervious
("Simple Method" - Schueler, 1987)
NCDENR Manual July 2007 pg. 3-3
Meck. Cty. BMP Manual pg. 3.2

Water Quality Protection Volume

$$WQv = \frac{1.37"RvA}{12}$$

Uses 1.37" Rainfall

Fill in Values:

"I" = 97 Percent Impervious of Site
"A" = 1.34 Acres 5 Acre Maximum
Rv = 0.923

Answer:
WQv = 0.141 Ac. Ft.
6151 Ft.³ = WQv (1.37" Storm)

SCS Method 3916 Ft.³

FOR SHEET FLOW ENTRY:
3.17 CFS Peak Flow for 1.37"- 6 Hr. Storm
38 Length of Level Spreader for 1" deep @ 1 fps into Rain Garden

Compute CNm

Rv= 0.923
WQv= 0.92 inches
CNm= 99.33 Use to compute Q_f.

Rain Garden Area

Formula:

$$Af = \frac{(WQv)(Df)}{((k)(Hf+Df)(Tf))}$$

From Georgia Design Manual
Section 3.2.3.6
(Based on Darcy's Law)
Maryland Design Manual
Page 3.40

Where:
Af = Surface area of Rain Garden (S.F.)
WQv = Water Quality Volume to be Captured
Df = Filter Bed Depth (2 feet min. for grasses, 3 to 4 feet for trees)
k = permeability coefficient of filter media (use 2 Ft./Day for amended soil mix)
* See NCDENR BMP Manual Page 12-15, Fig. 12.5
Hf = "Average" height of water above filter bed (Mulch) Must drain within 12 hours. (NCDENR)
(use 3 to 6 inches, which is one-half of 6" to 12" ponding depth)
Tf = Design filter bed drain time in days
* MAXIMUM 2 Days, (Use 1 Day) Mecklenburg County says 1.425 days

Fill in Values:

"k" = 2 Ft./Day*
Df = 3 Feet
Hf = 6 inches
Tf = 1.425 Days*

Permeability Coefficients		
Soil Type	K (in./hr.)	K (Ft/Day)
Sand	6	12
Loamy Sand	2	4
Sandy Loam	* 0.5 - 1	1 - 2
Silty Loam	0.02	0.05

*Use 1.0 "/Hr. 2 Ft./Day (NCDENR)

Required Size

For Routing Calcs.

2417 SF Surface Area 1' Deep p

3056 SF Surface Area 2' Deep

Af = 1850 SF Required accounts for infiltration during 6 hour rainfall

6151 SF Req. by NCDENR Manual (Vol./Depth) discounts any infiltration during storm

31 SF Impervious Treated Per SF of Rain Garden

3.27 % of impervious site

5% - 7% "Normal" Range

34 Ft. Width — Approximate Size

55 Ft. Length — Can Be Freeform in Shape

10' x 20' Minimum

5.25 Depth from top of water surface to invert of underdrain.

Fill in: 100.00 Maximum Water Surface Elevation

94.75 Invert of Underdrain for tie-in

Water Draw Through Rate:

Darcy's Equation:

Q = (.0000232)*K*A*(H/L)

Where:

Q = Flow (Rate of Draw) through Bioretention Soil (cfs)

K = Hydraulic Conductivity of soil (in./hr.) (Usually 1/2"/Hour)

A = Surface Area of Bio-Retention Area (SF)

H = Height of Water above Drainage Pipe (Underdrain)

L = Thickness of Soil Bed (Minimum 3' for Trees, 2' for Shrubs)

Assume (H/L) ~ 1

Q = 0.057 cfs

Use this value for routing infiltration

Time to Drawdown water from Inundation to Saturation at Surface:

Volume/Q: 32328 Seconds

9.0 Hours to Saturation

Time to lower Water Table to 2.0 feet below surface:

Assume 40% Porosity

Volume = Area x 2' x 0.40

= 1479.9 Cubic Feet

= 25862 Seconds

= 7.2 Hours to Lower Water 2' below surface

16.2 Hours to Draw Water Through Soil Layer

Size Underdrains

As a rule of thumb, the length of underdrain is based on 10% of Af

Source: (NY State Stormwater Manual)

$L_{min.}$ = 62 Feet in 3' wide stone bed

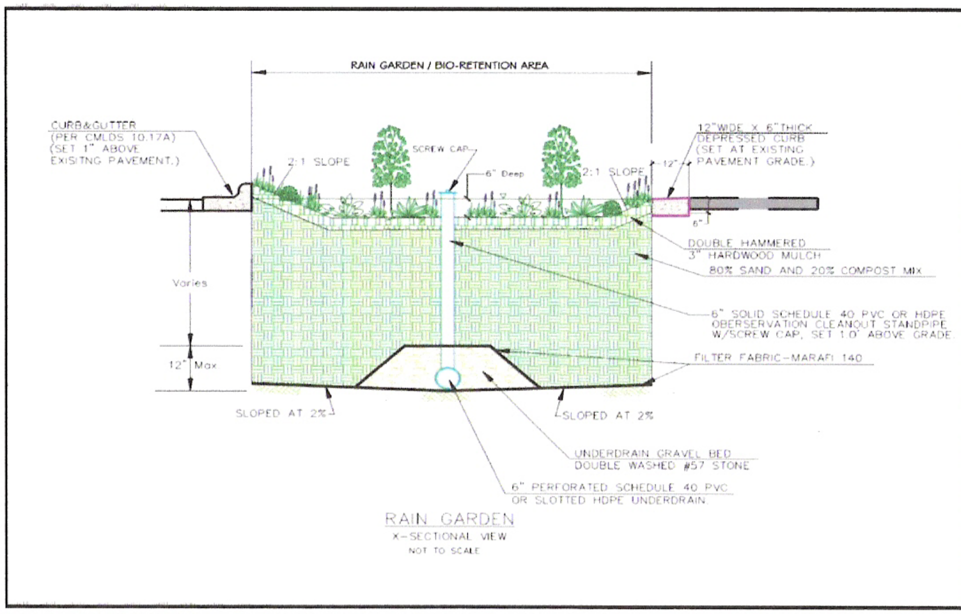
Required Diameter 7.3 Inches (Minimum 6 Inches) Use PVC or "Double Wall" Slotted HDPE

Source: (NCSU Rain Garden Design Worksheet, Bill Hunt, PHD)

2 Or More Underdrains required

Minimum of 2 Underdrains

2 Cleanouts (1 per 1000 SF)



Cost Estimate

Excavation	$4,110.84
Stone Bedding	$334.33
6" HDPE Pipe	$820.64
6" Cleanout	$462.47
Filter Fabric	$822.17
Soil Mix	$6,988.43
Mulch	$1,130.48
Plants	$2,229.54
Cost	$16,898.90
Cost/SF	$9.14
Cost / SF Impervious	$0.30

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