Session 22: Research Track

Monitoring two large-scale prairie-like green roofs in Manhattan, Kansas

Lee R. Skabelund, Allyssa Decker, Trisha Moore, Priyasha Shrestha, Jeffrey L. Bruce
KSU-LARCP/KSU-EDP/ KSU-BAE/KSU-LARCP/JBC

Abstract

Providing diverse, living vegetative coverage helps capture and conserve rainfall and optimize other ecosystem services on green roofs. Kansas State University (KSU) faculty and students initiated studies of vegetation coverage and soil moisture on two large green roofs on the KSU campus in 2016. In combination, the two Memorial Stadium green roofs (MS-GRs) encompass approximately 3,900 square meters and were seeded and planted with a total of 30 native species in 2015 and 2016. Research includes: 1) tracking vegetative change to understand what species do well on these steeply-sloped (approximately 20º), 12-15cm deep prairie-like systems (to inform future designs and vegetative management strategies); and 2) monitoring substrate moisture levels and supplemental irrigation (thus encouraging wise use of potable water). In June 2016, nine soil moisture/temperature sensors and one solar radiation sensor were placed on each green roof. In late June 2016, researchers completed baseline studies of vegetation along eight, 30.5-meter (100-foot) transects on each roof. May-September 2016 observations documented total species richness and vegetative coverage—with July 2016 color-infrared and thermal imaging using an Unmanned Aircraft System (UAS) to support efforts to understand vegetation dynamics related to cover and composition. Substrate moisture data analysis should help managers minimize unnecessary irrigation.

I. Introduction

Green roof research is being conducted throughout the central United States and Canada to test green roof fitness for native prairie vegetation (Dvorak & Volder 2010; Sutton et al., 2012). The Arbor Day Foundation building green roof, Sandhills Publishing building green roof, and Larson-Parkhaus residential tower green roof are examples of research-based non-slope green roof trails in Lincoln, Nebraska. Suitability of vegetation native to the Central Great Plains were tested on these three green roofs between 2010-2014. Each of these semi-intensive green roofs were designed to test plant species success under different seeding and planting densities and seasons of adding plugs and/or seed (UNL, n.d.). Because substrate depths are similar to those at the MS-GRs, findings associated with the Sandhills Publishing Green Roof are of particular interest. At the Sandhills Publishing Green Roof, 23 of 43 native species seeded or planted in the15.25cm deep substrate showed good performance (>67% survival) at the end of a four-year period with supplemental irrigation provided on an as-need basis (Sutton, 2015).

MacDonagh and Shanstrom (2015) describe the Minneapolis City Hall Green Roof, and the PEEC Green Roof in Minneapolis, Minnesota, planted with native prairie grasses and forbs, and *Sedum* spp. The Minneapolis City Hall Green Roof sustained 34 of 44 native species in primarily 10cm deep substrate with supplemental sensor-controlled irrigation six years after its implementation in 2008, while 16 of 18 native species survived on the PEEC Green Roof with 5-15cm substrate depths without supplemental irrigation during four of ten years between 2004-2014 (MacDonagh & Shanstrom, 2015).

On the approximately 28 square-meter KSU Seaton Hall Upper Green Roof in Manhattan, Kansas,11 of 19 native species remained after five growing seasons (2009-2014) despite no supplemental irrigation between mid-August 2012 and November 2014 on 7.5-17.5cm substrates, although vegetation coverage was patchy due to dieback of many native plants during multi-week dry periods (Skabelund et al., 2014).

Irrigation is deemed essential in the Flint Hills Ecoregion to provide full or nearly full coverage (Skabelund, et al., 2014). Frequent droughts and limited water availability make the design and implementation of water-conserving green roofs critical. Irrigation is even more important on steep-sloped green roofs due to high solar exposure, evapotranspiration, and the strong pull of gravity (Jones et al., 2011). Monitoring soil moisture can help green roof researchers and managers determine when wilting points occur.

MacIvor et al. (2013) examined how vegetative cover, above ground biomass, and species diversity are influenced by irrigation and substrate/growing media. For grasses and forbs, plant diversity was unaffected by different growing media but was dependent on irrigation. Irrigation can relieve stress related to low soil moisture. Nevertheless, providing supplemental irrigation is not always ideal as excess water not held in the green roof system runs off the roofs and may into the storm sewer (Rowe, 2015). Nagase and Dunnett (2012) simulated rain events in greenhouses to quantify rainwater capture by plant communities consisting of either monocultures or species mixes. *Sedum* spp. showed the greatest amount of water runoff, while grasses were the most effective at water capture. Rain water interception is optimized by plant structure. Since grasses and forbs have more root growth than *Sedum* spp. they allow for greater water capture by the sponge-like system created in the substrate by their interconnected roots. Building on research by Lundholm et al. (2010) and Lundholm (2015), it is important to assess the ecosystem functions of diverse green roof plant communities.

Few studies evaluate the soil moisture characteristics for green roofs and even fewer studies do so on sloped roofs. There is a great need to understand how water is passing through green roof systems and how different levels of substrate moisture influence plant growth, coverage, and diversity. To understand the relationships between MS-GR substrates and vegetation, research is needed to evaluate the effects of soil moisture levels on vegetative growth and coverage on these green roof systems. Typically, the four primary physical factors limiting plant growth are: water, aeration, temperature, and mechanical impedance (Kirkham, 2014). Because of the lightweight and shallow characteristics of common green roof substrates, water and temperature are the two primary physical factors that limit plant growth in extensive and semi-intensive green roof systems (Dvorak and Volder, 2010).

The Kansas State University Memorial Stadium Green Roofs (Manhattan, Kansas)

Two large (nearly 0.20 hectare), steep-sloped (approximately 20º or 36%) prairie-like green roofs in Manhattan, Kansas provide excellent locations to research vegetation changes and explore how irrigation and precipitation influence soil moisture and species richness, vegetative coverage, and ecosystem functions, dynamics and services. This paper discusses the purposes of these native plant green roofs, and then introduces the monitoring and research efforts formally initiated at the Memorial Stadium Green Roofs (MS-GRs) in 2016 by an interdisciplinary group of designers and scientists.

The two green roofs designed for the KSU World War I Memorial Stadium are unique because of the native vegetation that has been established on their steeply-sloped green roof conditions (see Figure 1). The purposes of these two green roofs are two-fold: 1) protect the structural integrity of the two roofs by limiting the number of people on each roof (the green roofs being less weight than the potential loading by people assembling on the roofs); 2) improve KSU sustainability efforts by providing building insulation, urban heat-island mitigation, stormwater management, and ecological habitat (especially for butterflies and other pollinators).

Figure 1. KSU Memorial Stadium Green Roofs (MS-GRs): East MS-GR (left); West MS-GR (right)
Photographs by Lee R. Skabelund (May 12, 2016)

Implementation of these two green roof systems create a link between urban environments and natural ecosystems by creating habitat for insects, bees, butterflies, and birds in addition to the plant systems that have been established on the roofs. Besides improving the function and efficiency of building infrastructure (particularly insulating interior spaces of the two renovated buildings during hot summer and cold winter months), these green roof systems are expected to reduce the urban heat island effect otherwise caused by the conventional gray roof surface. They also provide a range of ecosystem services—including capturing and utilizing some rainfall and thus tempering stormwater runoff, improving air quality, and providing supplemental native vegetation and dynamic habitat for insects and avian species.

Memorial Stadium Green Roofs Monitoring Intentions

Because there are very few large, steep-sloped green roofs sporting a diverse suite of native plants it is important to understand how these two Memorial Stadium Green Roofs (MS-GRs) at Kansas State University (KSU) perform in regards to species richness and plant dynamics. KSU faculty and students initiated studies of vegetation coverage and soil moisture on two large green roofs on the KSU campus during May and June of 2016.This paper discusses initial plant identification and soil moisture work completed during the 2016 growing season—the first season for the East Memorial Stadium Green Roof (EMS-GR), and the second season for the West Memorial Stadium Green Roof (WMS-GR). 2017 data collection work is also discussed.

A primary motive for this green roof research is to improve how each green roof is managed, especially in regards to water use. Using supplemental irrigation can be wasteful, especially when it is used without considering the specific needs of the vegetation on the green roof. Our sense is that water inputs on green roof systems may be much higher than what is necessary to maintain healthy plants and adequate vegetative cover. Over or under-watering of green roof systems can be avoided by using soil moisture sensors to monitor substrate conditions and adjusting irrigation practices based off the soil moisture levels in the green roof system. The utilization of soil moisture sensors can help researchers understand how sub-surface soil/substrate conditions impact plant survival, and what levels of substrate moisture are required to maintain plant longevity and growth while conserving potable water.

If we are to collectively improve green roof design, implementation, and management in the Flint Hills Eco-region and other similar temperate climatic zones in the world, it is vital to understand the relationships between micro-meteorological variables, green roof substrate types and their functions, and the use of various mixed-species on green roof ecosystem performance. The best way to do this, we thought, was to systematically monitor sub-surface soil moisture and temperature conditions, surface temperatures, solar and photosynthetically active radiation, plant available moisture, essential micro-climatic variables (especially precipitation, air temperature fluctuations, relative humidity, and wind speed), along with vegetative coverage and the changes in plant species survival over time—learning from work by Skabelund et al. (2015) and other green roof researchers.

Objectives of Memorial Stadium Green Roofs Monitoring

Providing diverse, living vegetative coverage is deemed to be vital to capture and conserve rainfall and to optimize other ecosystem services on green roofs. Successful implementation of green roofs in hot and dry climates is important in enhancing environmental benefits (Simmons 2015). Prior to implementation of the nearby Seaton Upper Green Roof project in May-June 2009, no research had been done in the Flint Hills Eco-region to determine the viability of native plants and succulents on green roofs; nor had the influence of different substrate depths and management practices (particularly the temporary but very limited use of supplemental irrigation) in this seasonally hot, semi-arid to temperate climate been studied.

Our Memorial Stadium Green Roof monitoring has been guided to date by two primary objectives: 1) We have sought to understand the performance of native prairie plants on two semi-intensive substrate types, each on a steeply sloped roof structure, with the desire to improve future design and management of native plant green roofs. 2) We have collected data on soil moisture levels and trends at high, middle, and low elevations within the middle of these two, large native plant green roofs, and then related this data to specific precipitation and supplemental irrigation events, with an interest in improving supplemental irrigation practices on each of the MS-GRs. Our larger aim is to limit the amount of potable water applied to these roofs and develop best management practices to ensure that the green roof plants are receiving sufficient amounts of irrigation to survive and maintain healthy growth on a steeply sloped roof. Due to the slope of the green roof system, it was hypothesized that soil moisture would be highest at the bottom of the roof.

II. Materials & Methods

A. Design and Implementation of the Memorial Stadium Green Roofs (MS-GRs)

The substrate for each MS-GR was designed to meet drainage requirements, structural loading, stability demands, water retention, and agronomic requirements of the green roof system. Components of each green roof include: insulation, damp-proofing and waterproofing layers, roof protection and drainage layers, geo-web containment, sandy soil/substrate, and native vegetation as seed and live plants (refer to Figure 2).

Figure 2: WMS-GR Cross-Section - Redrawn by P. Shrestha; Source: contract documents by JBC et al.

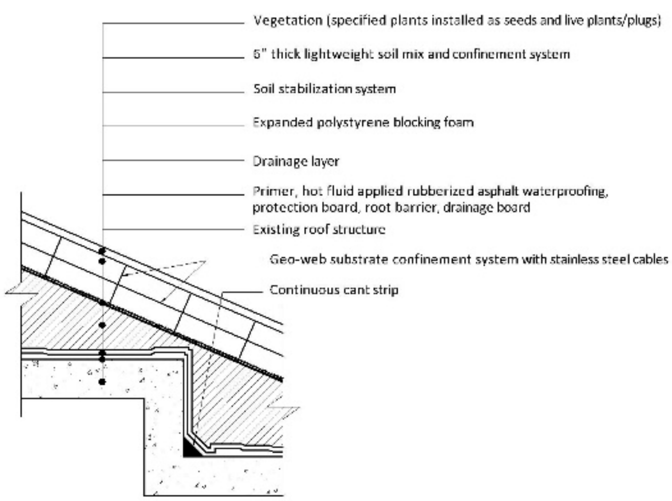


Table 1: KSU Memorial Stadium Green Roof Components

INSULATION - Extruded Polystyrene Rigid Board

WATERPROOFING MEMBRANE - Hot Fluid-Applied Rubberized-Asphalt Waterproofing (American Hydrotech Monolithic Membrane 6125EV), bonded to underlying cement (gypsum board)
Protection Course and Root Barrier: 160-mil thick polyester reinforced modified asphalt sheet (with growth inhibitor)
Drainage Board: GSE TenDrain 300 mil Geocomposite

SOIL/SUBSTRATE CONTAINMENT/STABILIZATION AND DRAINAGE:
Soil/Substrate Containment System: Presto Geoweb GW30V6, with stainless-steel cables
Erosion Mat: Enkamat 7003 infilled with Flexterra (flexible growth material to assist with slope protection)
Drainage Channel (EMS-GR/Welcome Center only): North American Green P550
Drainage Channel (WMS-GR/Purple Masque Theatre only): Hydroflex RBII beneath HyDroDrain 300

SOIL/SUBSTRATE:
5 inches of sandy soil mix for longer (~68-foot) slopes; 6 Inches of sandy soil mix for shorter (~48-foot) slopes – substrate mix prepared by Blueville Nursery, Inc. at their Manhattan, Kansas property (near agricultural cropland).
WMS-GR analysis – Organic Matter (OM): Peat Inc. Fine Grade Reed Sedge. OM was 1.82% of mix by dry weight for the WMS-GR, with 95.2% 2.0-0.50 mm sand, 1.8% 0.05-0.002 silt, 1.2% <0,002 clay, 0.3% 4.0 gravel, and 1.5% 2.0 gravel (ASTM F1632 Method B & Determination of Size Factors SOP); particle density of 2.63 g/cc; bulk densities of 1.56-1.62 g/cc; total pore space of 38.2%; infiltration rate of 36.1 cm/hr (Turf Diagnostics & Design, July 2014).
EMS-GR analysis – OM was 1.8% of mix by dry weight for the EMS-GR, with 58.1% 2.0-0.075 mm sand, 2.6% 0.075-0.002 silt, 1.7% <0,002 clay (ASTM F1632 Method B & Determination of Size Factors SOP); particle density of 2.61 g/cc; bulk density of 1.42 g/cc; total pore space of 45.6% (Turf & Soil Diagnostics, 2015).
LWA: (EMS-GR/Welcome Center only) Buildex Expanded Shale or Stalite Expanded Slate, Gradation 3/8" - #8 size.

Selection of MSGRs Substrates and Vegetation: Rationale and Implementation

Because the pre-grown native prairie vegetative mat envisioned by the designer was not available (due to the grower not being bonded) the MS-GR construction documents were changed to accommodate the use of native prairie seed and live plants/plugs. Thus, each green roof was seeded and then planted with native live plugs in sandy substrates typically 12 to 15 cm deep, contained by a 12.7 to 15.24 cm plastic geo-web system (Presto GW30V6).

Planting design intentions were to create prairie-like systems on each green roof which reflect the spirit of the Flint Hills Tallgrass Prairie Ecoregion. Vegetation selected for these green roofs were tallgrass prairie species native to the Great Plains. Both green roofs have sand-based substrates, however, the East Memorial Stadium Green Roof (EMS-GR) includes expanded shale to lighten its structural load. The EMS-GR had fewer native grasses at the time of installation due to grasses not being included in the seed mix. Native species seeded and/or planted as live plants or plugs are listed in Appendix A: Table 1.

Implementation of the planting design and subsequent management occurred as follows:

The West Memorial Stadium Green Roof (WMS-GR) was first seeded on June 23, 2015 and July 2, 2015 and then planted on July 2, 2015, while the East Memorial Stadium Green Roof (EMS-GR) was seeded and planted approximately nine months later—with seeding on March 18, 2016 and planting initiated on April 7, 2016. Live plants (plugs of both grasses and wildflowers) were planted in the middle of the geo-web cells, roughly 30 cm apart.

The vegetation on each green roof is irrigated using Hunter I-20-12 rotor sprayheads at about 1.0 cm per hour (although coverage can vary markedly due to slope, wind-speed and direction, water pressure, and whether-or-not water lines and rotors are functioning properly).

Given the very sandy soils the green roofs have been fertilized using an organic fertilizer—Aggrand with Vermaplex™—sprayed onto each roof several times a year. Mid- and late-summer applications were also used to burn out weed seeds.

Both green roofs were clipped and weeded by hand and/or trimmed/weed-whacked at least several times a year (the timing at least partially dependent on field observations by KSU faculty and staff; with trimming to height of 20-30 cm occurring in mid-July and mid-September 2016 on the EMS-GR). Weeding and clipping undertaken on the two MS-GRs occurred during the spring and early summer of 2016 (prior to the July 5, 2016 UAS flights) with the goal of reducing agricultural weeds and tree seedlings mid-May to late-June on both MS-GRs. Weeding and clipping has occurred multiple times on each MS-GR during the 2017 growing season, with KSU faculty, staff, and students seeking to limit seed-head formation by common weeds (including wild sweet clover and marestail, and a number of other species). The downside to pulling weeds in a manner that exposes the substrate is that it can open areas up to new pioneering weeds.

Some of the weeds likely arrived on the roof in both the substrates and as seeds blown by wind into the native plant pots/plugs, but have also been carried onto the green roofs (especially by birds and the wind) after planting and seeding. There is clear evidence that birds drop thousands of seeds from the light towers at the top of the two MS-GRs. Elm trees are also nearby and add seeds to the MS-GRs.

MS-GR Seeding and Fertilization:

On the WMS-GR a total of 6 pounds of native grasses and sedges were placed on the green roof as seed, with 2.5 pounds of seed for each species of wildflower (27 pounds; 12.25 kg) for a total of 33 pounds (~15 kg) of prairie seed. On the EMS-GR only wildflower seed was added to the green roof, with 2.5 pounds of seed for each species of wildflower (20 pounds, or ~9 kg).

One 50-pound (22.7 kg) bale of Profile Products Flexterra product was included with the seed and sprayed onto each green roof. The contractor then sprayed over the top of the seeds with Flexterra at 3,000 pounds per acre (0.34 kg/m2).

Table 2 shows the biological soil fertility amendments specified by the designer for the two MS-GRs. The organic fertilizer used for both green roofs was Aggrand 4-3-3 liquid (obtained from Amsoil). Roughly 14 gallons (53 liters) of Aggrand were diluted in 2,000 gallons (7,570 liters) of water per roof, per each application. VermaPlex™ was also used with the Aggrand fertilizer.

Table 2: KSU Memorial Stadium Green Roof Soil Amendments (per the designer, the specified biological soil fertility applications were to be based on fertility testing during establishment)

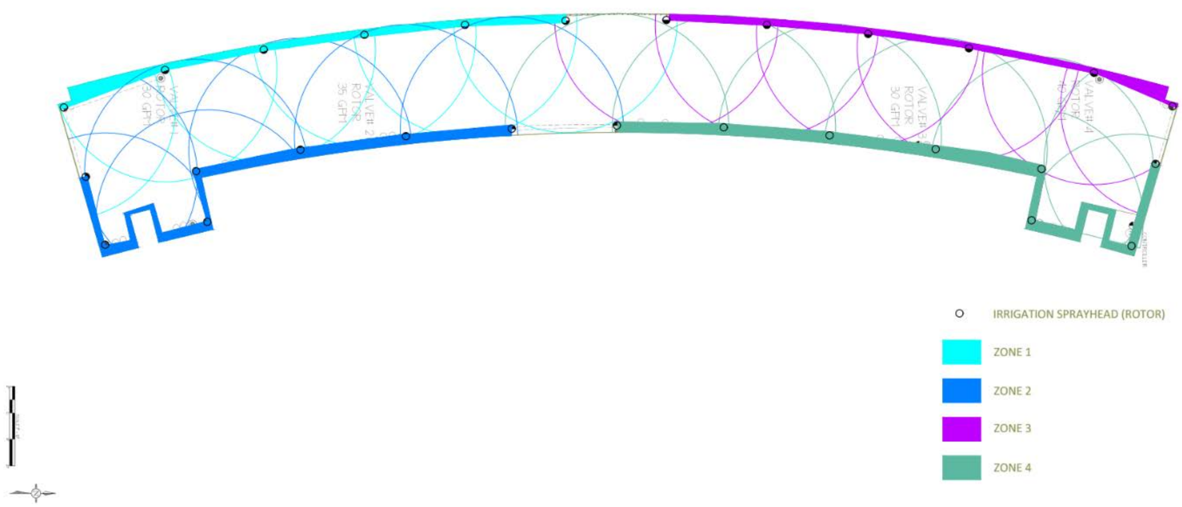
Amendment	Application
Vermamax™ Organic Pre-Plant Fertilizer Amendment	18.14 kg per 92.9 sq. m. (40 pounds per 1000 sq. ft.)
Nutrients Plus 7-2-12 - Organic Pre-Plant Fertilizer Amendment.	-
VermaPlex™ - Liquid Soil Inoculant Amendment	0.28 kg per 92.9 sq. m. (10 ounces per 1000 sq. ft.)
Nutri-Cast - Granular Pre-Plant Bio-Stimulant Amendment with biological nitrogen fixation bacteria	-
Coral Calcium Wettable Powder	2.47 kg/ha equivalent with total spray volume of 935.4 liters per hectare (2.2 pounds/acre equivalent with total spray volume of 100 gallons per acre)
Liquid Humate Plus	0.23 to 0.28 kilograms per 92.9 sq.m. (8 to 16 ounces per 1000 sq. ft.)

KSU MS-GR Irrigation Components and Design:

The intent of the irrigation design was to provide complete rain-like coverage of the two green roofs, recognizing that irrigation systems provided at a modest cost, cannot provide the same consistency as rainfall—especially on large, steep-sloped rooftops with the combination of curvilinear edges and an incised footprint on the lower side of the MS-GRs.

The type of irrigation equipment and irrigation heads used are noted below, while Figure 3 shows the four irrigation zones on the WMS-GR. Irrigation equipment consists of controller and accessories (Hunter-I-Core), sprinkler heads (Hunter I-20-12 with manufactured application rate of 1.0 cm/hour; flow rate of 113-151 LPM [30-40 GPM]; operating pressure of 45 PSI; and wetted radius of 12.8 meters [42 feet]), and distribution pipelines (3.81cm [1.5-inch] Cresline SDR 200 PVC – lateral lines; 5.08cm [2-inch] Cresline Sch. 40 PVC – main lines).

Figure 3. WMS-GR Irrigation Sprayhead (Rotor) Location and Irrigation Zone Diagram
Diagram by P. Shrestha (based in construction documents, and field measurements by A. Decker & P. Blackmore)



B. <u>Vegetation Analysis</u>

Understanding Plant Coverage, Species Dominance, and Species Richness

Splitting the roof into plots and counting plants, as was done by Carlisle and Piana (2015), was deemed to be too labor intensive for these very large green roofs. KSU range management assessment experts Stacy Hutchinson and Clenton Owensby and green roof monitoring expert Olyssa Starry indicated that using vegetation transects on the MS-GRs would be a scientifically valid way of assessing dominant species and help document species richness. Mid-growing-season aerial imagery was deemed to be a helpful approach to document vegetative coverage.

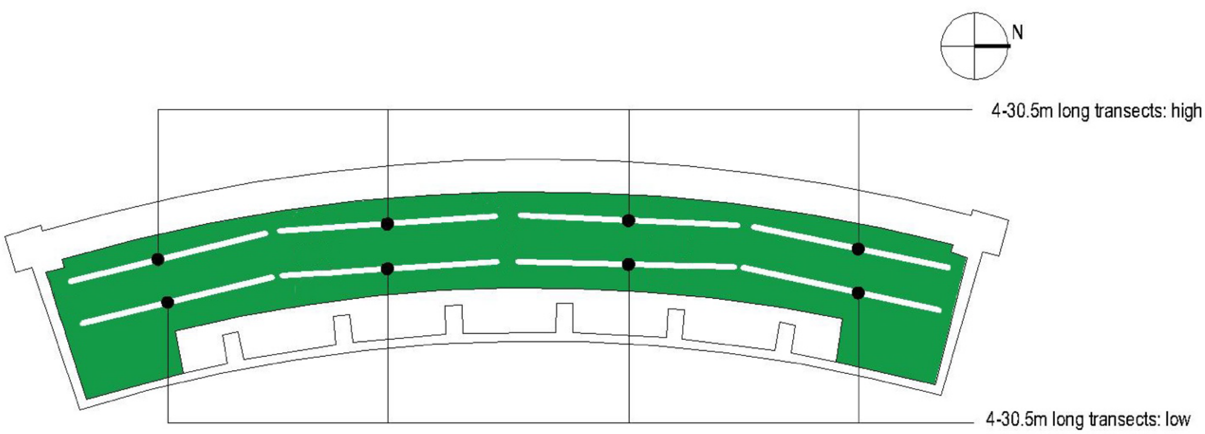
Two methods were selected. First, to document MS-GR species dominance, the use of eight 30.5 meter transects were employed, adapting methods developed by Owensby (1973). Second, for plant coverage on the MS-GRs, the use of unmanned aerial vehicles (UAVs) with infrared cameras were used (learning from Watts et al. [2010] and Zweig et al. [2015]).

Between 27-30 June 2016, KSU researchers (including one faculty member and one student proficient in plant identification) established eight (8) 100-foot (30.5 meter) transects on each roof, four at a higher elevation (approximately 2.5 meters from the top of each green roof) and four at a lower elevation (approximately 3.0 meters from the bottom of the main part of each green roof). Pins were placed at 0.6 meter intervals along each transect (Figure 3) and the grass/forb species that occurred nearest to each pin were recorded. If there was one forb clearly nearest to the pin, then only one plant name was recorded. However, if there was a grass or grass-like plant nearest the pin, then the next closest forb was identified and recorded. In some instances, several plants were seen to be the same distance from the pin and all plant names were recorded.

Plant Identification was aided by a visual and written plant guide prepared by KSU researchers from observations made in prior weeding efforts and reconnaissance walks, while some of the plants were verified with the help of a botanist from the KSU Herbarium. Metal eye-bolts were placed at beginning and end points of each transect for future plant identification work.

Figure 3. KSU Memorial Stadium Green Roof Transect Layout (WMS-GR lower-north transect)
Photograph by Lee R. Skabelund (June 28, 2016)

Figure 4. KSU Memorial Stadium Green Roof Transect Plan (WMS-GR)
Diagram by P. Shrestha (based on L. Skabelund transect layout plan)



In addition to plant identification along the transects, a comprehensive list of plants was compiled for each roof by combining plants identified while working along transects (including species noted anywhere on each roof). Plants were also identified during weeding and clipping work and by using both informal and systematic “walk-abouts.” These walk-abouts were undertaken at various times during the growing season—by the lead researcher (a landscape architecture faculty member having reasonable plant knowledge), by two different horticulture students with good plant knowledge, and with a botanist with in-depth knowledge and expertise in plant identification. Plants that could not be identified in the field were photographed (or samples were taken) so that the botanist could examine these.

To better understand the role of weeds on MS-GRs a one-meter square plot was clipped near the high end of each roof, measured from the same distance from the edge and top of the green roof (as determined prior to going to the field on August 29, 2016) so as not to bias the selection of the area to be clipped. All weeds with this one-meter area were then clipped and collected.

Figure 5a shows the weeds clipped within two of the two one-meter square areas on the EMS-GR and WMS-GR. Observation indicated that weeds were far more abundant on the EMS-GR than the WMS-GR and this was confirmed by the clipping. Total dried weight of weed biomass clipped within the two EMS-GR plots was 828 grams, compared to a total dried weight of 41.6 grams on the WMS-GR.

Figure 5a. KSU Memorial Stadium Green Roof: Two of Four One-Meter Square Clipping Samples
Photographs by Lee R. Skabelund (August 29, 2016)

Left image: EMS-GR weeds (south end)
Right image: WMS-GR weeds (south end)

Given that KSU Grounds staff was reduced in 2016 and 2017 due to state budget cuts, and the unwillingness on the part of KSU administrators to require the contractor to provide two relatively weed-free green roofs, the lead researcher decided to play an active role in weeding and clipping perceived "nuisance species," doing this with help from KSU Grounds staff on several occasions. On the WMS-GR most of "weedy" or nuisance species (including wild sweet clover, marestail, and cottonwood) have been largely controlled. On the EMS-GR a much larger number of nuisance species have been more difficult to control.

In July 2017, researchers clipped or pulled roughly 10,000 marestail (*Conyza canadensis*) on the EMS-GR to keep these plants from forming viable seed. Despite this effort, thousands of additional marestail (considered to be a problematic native weed in Kansas) formed seedheads in early August on the EMS-GR. Figure 5b shows several masses of *Conyza canadensis* present on the EMS-GR as of August 19, 2017—along with a range of seeded and planted native species and many non-native species. In mid-August and early September, 2017 the lead researcher worked with five students to remove more than 8,000 marestail from the EMS-GR. It is estimated that 8,000-10,000 marestail stems remained (per the lead researcher's visual "best guess") on the EMS-GR as of September 1, 2017. It is expected that additional volunteer labor will be needed to manage marestail and other weedy species in the coming years.

Figure 5b. KSU East Memorial Stadium Green Roof: *Conyza canadensis* remains abundant despite active management during July 2017 - Photograph by Lee R. Skabelund (August 19, 2017)

Understanding Imagery from Unmanned Aircraft System Flights

On July 5, 2016 and July 5, 2017, our KSU research team completed UAS flights at the MS-GRs. The color-infrared orthomosaics of each green roof in its entirety were transformed into normalized difference vegetation index (NDVI) maps. Our research team plans to assess color infrared aerials, NDVI maps, and thermal imagery to better understand the interrelationships between plant coverage, surface temperatures, and soil moisture. (For more detail on this aspect, refer to the KSU MS-GR UAS Cities Alive 2017 paper—Session 12: Research Track).

C. Soil moisture Sensor Installation and Data Collection

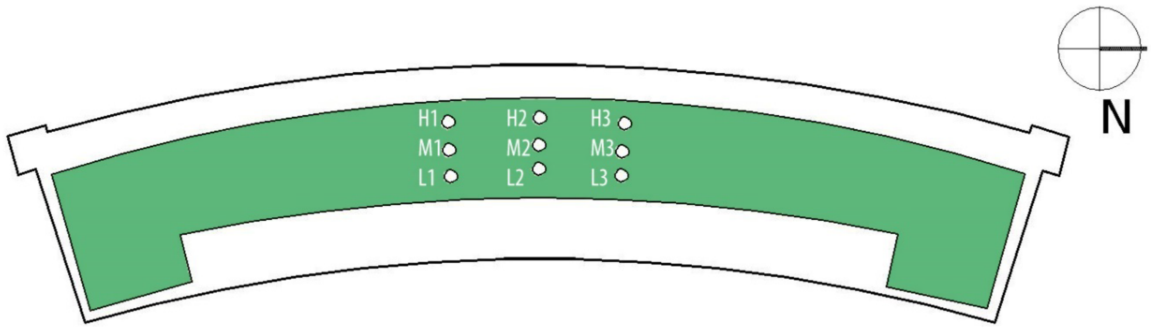
Early Summer 2016 Sensor Calibration

One Decagon 5TM soil moisture and temperature sensor was placed in a small pot containing the sandy engineered soil (approximately 12cm deep) used on the MS-GRs. The pot was placed on an electronic scale and the single sensor was connected to a Decagon Em50G data-logger. The procedure was carried out on a sunny, south-facing window-sill of Seaton Hall (third floor) where direct sunlight influenced evaporation and soil drying rates for part of the day. Nearby window air conditioning was limited to about 2.25 hours during the first 13 days of the calibration process (June 2-15, 2016). The Decagon 5TM sensor was pushed into the soil with the prongs down and spaced at least 10 cm from the sides of the black plastic pot. The sandy soil was pushed firmly around the top of the sensor housing. The soil was fully saturated and measurements of the change in the weight of the pot and its contents were made. Changes in soil moisture and temperature were recorded by the Decagon Em50G data-logger every 15 minutes and the trends compared with weight changes. The single-sensor Decagon 5TM calibration procedure was initiated June 2, 2016 and ended June 20, 2016. Mass-based volumetric water content measurements were within 10% of the volumetric water content calculated by the Topp's Equation as a function of dielectric permittivity on average.

Summer and Fall 2016 Soil Moisture Sensor Installation and Adjustment

In mid-June 2016, KSU faculty and students added nine (9) Decagon 5TM soil moisture and temperature sensors, two (2) Em50G Data Loggers, and a pyranometer on each roof (approximately three inches below the surface of each six-inch substrate). On November 26 and 28, 2016, all 18 sensors were buried deeper (one inch from the bottom of the substrate, with five inches of substrate above each sensor) to monitor a different part of the soil profile and the lower part of the root zone. The placement (location) of the sensors on the WMS-GR is represented in Figure 5. 5TM sensors are located similarly on the EMS-GR.

Figure 6. WMS-GR 5TM Decagon Sensor Location Diagram (Prepared by Priyasha Shrestha)



Decagon 5TM soil moisture and temperature sensors deliver temperature readings measured by an onboard thermistor. Soil moisture values are given by measuring the dielectric constant of the media by utilizing capacitance/frequency domain technology and converting to volumetric water content using the Topp's Equation (per the July 2017 Decagon 5TM sensor manual - http://manuals.decagon.com/Manuals/13441_5TM_Web.pdf). Each sensor has a 715-mL volume of influence. Em50G data loggers allow for plug and read use of sensors with immediate access to data through DataTrac 3 software. Volumetric water content and temperature are recorded every 15 minutes by all 18 Decagon 5TM sensors and can be accessed through DataTrac 3 via the cellular network. Only data from the nine (9) sensors on the West Memorial Stadium green roof were used for soil moisture analysis due to data gaps on the East Memorial Stadium Green Roof caused by sensor cables accidentally being pulled out from data-loggers and two data-logger malfunctions.

Observation of Nearby Weather Data

A local weather station on the Seaton Hall Upper Green Roof measures ambient environmental conditions and is utilized so that this data can be used as a best estimate of climatic conditions on the two MS-GRs. We chose to analyze "response to precipitation" instead of irrigation due to the uniformity of water inputs during rain events versus irrigation events. Rain events for 2016 on July 7, July 12, July 13, July 24, July 28, August 25, August 26, September 13, September 14, September 26, and October 4 were selected for analysis—to compare the response of each 5TM sensor to precipitation during the time that sensors were three (3) inches below the surface (Scenario 1). The rain events selected for analysis after 5TM sensors were buried deeper (five [5] inches below the surface) were March 24, March 26, March 29, April 3, April 4, May 18, and May 22, 2017 (Scenario 2).

D. Selected Soil Moisture Monitoring and Analysis

Data Analysis of Recorded Soil Moisture on the MS-GRs

A differential analysis was conducted by calculating the change in volumetric water content per unit time for the recession period after each peak in volumetric water content for the selected rain events. After calculating the slope of the recession period, the slopes were ranked from highest to lowest for all nine sensors. A Kruskal Wallis test was used to compare soil moisture slope rankings for all nine sensors to determine if the response to precipitation was statistically different at each sensor location on the roof ($p \leq 0.05$). The research team conducted the same test for rain events before and after the sensors were lowered. A Tukey post-hoc test was conducted to determine what sensors have a statistically different response to precipitation.

Appendix D provides selected Decagon 5TM data collected July 1, 2106 to September 1, 2017.

III. Results

A. Results of Vegetation Assessments on MS-GRs

Table 3a shows the species richness on the west and east MS-GRs for June 2016 to August 2017. The results are based on a comprehensive plant list created following transect work, and observations during walkabouts. Tables 3b and 3c show the dominant plant species identified along the eight transects on each green roof in late June 2016 and late June 2017.

Table 3a: Findings from Vegetation Assessments on KSU MS-GRs: Species richness.
Note: 8-10 different pigweed (*Amaranth*) species observed (most on the EMS-GR) were combined as one. Given the similarity of a few species (namely two Erigeron spp, and two Euphorbia spp.) and/or uncertainty in plant identification, several other species were also combined. Thus, the species richness figure shown below is lower than the actual number of species appearing on the roofs in 2016-2017.

Roof	Time period	Graminoid	Forb/herb	Shrub/tree	Vine	Species Richness	Remarks
WMS-GR	June 2016-August 2017	13	48	9	0	70+	Approximate
EMS-GR	June 2016-August 2017	28	71	13	1	113+	Approximate

Between June 2016 and August 2017, more than 130 unique species (including a number of un-named species) were catalogued. At least 102 of these plant species were volunteers on the MS-GRs, while 86 of these species are considered Kansas natives or possible native species (based on Lady Bird Johnson Wildflower Center and/or USDA Plants Database information reviewed online). 39 of the documented species are considered “weedy” and attempts to reduce many of these species of weeds via management have been undertaken. More than 30 weedy species were present on the EMS-GR, as opposed to 19 on the WMS-GR.

For a reasonably complete list of plant species identified during the 2016 and 2017 growing seasons refer to "Appendix E: Identified MS-GR Plants."

Table 3b: Findings from Vegetation Assessments on KSU MS-GRs: Dominant species (2016). Note: Only those species that were observed at least 10% of the time along the four high and four low transects on each green roof (for forbs and grasses) are shown in the table below.

Year	Green Roof	Grass/forb	Plant species	Common names	Percentage
2016	**WMS-GR-high**	**Grasses**	*Bouteloua hirsuta or gracilis*	Hairy or Blue grama	63%
			Schizachyrium scoparium	Little bluestem	15%
			Sorghastrum nutans	Indiangrass	12%
		Forbs	*Ratibida pinnata*	Pinnate prairie coneflower	23%
			Artemisia ludoviciana	Louisiana sagewort	17%
			Oligoneuron rigidum	Stiff goldenrod	14%
			Ratibida columnifera	Upright prairie coneflower	13%
	WMS-GR-low	**Grasses**	*Bouteloua hirsuta or gracilis*	Hairy or Blue grama	55%
			Schizachyrium scoparium	Little bluestem	15%
			Sorghastrum nutans	Indiangrass	12%
			Bouteloua curtipendula	Sideoats grama	11%
		Forbs	*Artemisia ludoviciana*	Louisiana sagewort	27%
			Oligoneuron rigidum	Stiff goldenrod	17%
			Ratibida columnifera	Upright prairie coneflower	12%
			Ratibida pinnata	Pinnate prairie coneflower	11%
2016	**EMS-GR-high**	**Grasses**	*Setaria sp.*	Foxtail	28%
			Sporobolus heterolepis	Prairie dropseed	26%
			Echinochloa sp.	Barnyard grass	21%
			Sorghastrum nutans	Indiangrass	13%
		Forbs	*Artemisia ludoviciana*	Louisiana sagewort	64%
			Ratibida columnifera	Upright prairie coneflower	10%
	EMS-GR-low	**Grasses**	*Sporobolus heterolepis*	Prairie dropseed	34%
			Setaria sp.	Foxtail	22%
			Schizachyrium scoparium	Little bluestem	12%
			Sorghastrum nutans	Indiangrass	10%
		Forbs	*Artemisia ludoviciana*	Louisiana sagewort	55%

Intentionally seeded and planted native Kansas species were more dominant on the WMS-GR along MS-GR transects in late June 2016. The dominant native grass on the WMS-GR in June 2016 was blue (and/or hairy) grama, while foxtail and prairie dropseed were the dominant grasses on the EMS-GR. The dominant native forbs on the WMS-GR in June 2016 were stiff goldenrod, Louisiana sagewort, and pinnate prairie coneflower, while Louisiana sagewort was very dominant on the EMS-GR.

Table 3c: Findings from Vegetation Assessments on KSU MS-GRs: Dominant species (2017). Note: Only those species that were observed at least 10% of the time along the four high and four low transects on each green roof (for forbs and grasses) are shown in the table below.

Year	Green Roof	Grass/forb	Plant species	Common names	Percentage
2017	**WMS-GR-high**	**Grasses**	*Bouteloua hirsuta or gracilis*	Hairy or Blue grama	37%
			Bouteloua curtipendula	Sideoats grama	28%
			Schizachyrium scoparium	Little bluestem	12%
		Forbs	*Ratibida pinnata*	Pinnate prairie coneflower	23%
			Oligoneuron rigidum	Stiff goldenrod	18%
			Baptisia australis	False indigo	11%
			Artemisia ludoviciana	Louisiana sagewort	11%
	WMS-GR-low	**Grasses**	*Bouteloua hirsuta or gracilis*	Hairy or Blue grama	49%
			Bouteloua curtipendula	Sideoats grama	18%
			Sorghastrum nutans	Indiangrass	15%
			Schizachyrium scoparium	Little bluestem	10%
		Forbs	*Artemisia ludoviciana*	Louisiana sagewort	21%
			Oligoneuron rigidum	Stiff goldenrod	20%
			Ratibida pinnata	Pinnate prairie coneflower	15%
2017	**EMS-GR-high**	**Grasses**	*Setaria sp.*	Foxtail	48%+
			Sorghastrum nutans	Indiangrass	27%
		Forbs	*Ratibida columnifera*	Upright prairie coneflower	19%
			Artemisia ludoviciana	Louisiana sagewort	16%
			Conyza canadensis	Marestail	13%
			Oligoneuron rigidum	Stiff goldenrod	11%
			Oxalis dillenii	Slender yellow woodsorrel	10%
	EMS-GR-low	**Grasses**	*Sporobolus heterolepis*	Prairie dropseed	28%
			Sorghastrum nutans	Indiangrass	27%
			Festuca arundinacea	Fescue/blue grass	27%
			Setaria sp	Foxtail	12%+
		Forbs	*Ratibida columnifera*	Upright prairie coneflower	30%
			Artemisia ludoviciana	Louisiana sagewort	14%
			Ratibida pinnata	Pinnate prairie coneflower	12%

Intentionally seeded and planted native Kansas species were more dominant on both the WMS-GR and EMS-GR along MS-GR transects in late June 2017. However, agricultural weeds were very abundant on the EMS-GR. The dominant native grasses on the WMS-GR were blue (and/or hairy) grama, followed by sideoats grama, while foxtail, Indiangrass, prairie dropseed, and fescue (and/or bluegrass) were dominant on the EMS-GR. The dominant native forbs on the WMS-GR in June 2017 were stiff goldenrod and pinnate prairie coneflower, followed by Louisiana sagewort, while upright prairie coneflower and Louisiana sagewort were dominant on the EMS-GR, followed by marestail and pinnate prairie coneflower.

Despite weeding and clipping of many agricultural weeds and other introduced species in 2016 and 2017, foxtail, marestail, oxalis, tall fescue, elms, lambsquarters, wild-sweet clover, and ragweed were also abundant on the EMS-GR. In disturbed areas on the WMS-GR (due to lack of sufficient irrigation water during dry periods and/or partial burial of upper elevation vegetation by relocated sandy substrate) foxtail and marestail were observed.

Figure 7. WMS-GR and EMS-GR Vegetation looking South (mid-August 2017)
Photographs by Lee R. Skabelund (August 19, 2017)

WMS-GR

EMS-GR

B. Results of Soil Moisture Analyses

Scenario 1 – Sensors placed three inches below the surface: During the months that sensors were located in the middle of the substrate profile (three inches below the surface of the sloped WMS-GR), the Kruskal Wallis test provided evidence for "statistical difference" among the sensors ($p = 0.001$). The Tukey post-hoc test shows that sensors H2 and L3 are statistically different from each other. Table 4 shows slope rankings for all 11 selected rain events and Tukey groupings for all nine sensors.

Scenario 2 - Sensors placed five inches below the surface (one inch from the bottom of the substrate): After burying the sensors deeper, the Kruskal Wallis test provides evidence for no statistical difference between all nine sensors ($p = 0.253$). Table 5 shows sensors rankings for all seven selected rain events that were considered for the analysis.

Table 4. Scenario 1 sensor rankings and tukey groupings on slope of soil moisture recession curve following precipitation events. Means that do not share a letter are significantly different for the nine (9) WMS-GR 5TM sensors. Only H2 and L3 are considered "significantly different."

Scenario 1 Sensor Rankings and Tukey Groupings									
Rain Event	**H1**	**H2**	**H3**	**M1**	**M2**	**M3**	**L1**	**L2**	**L3**
7/7/2016	8	9	6	3	7	5	2	4	1
7/12/2016	6	9	2	1	5	3	7	7	3
7/13/2016	3	4	1	6	4	1	8	9	7
7/24/2016	8	2	9	4	6	5	3	6	1
7/28/2016	3	2	3	6	7	5	9	7	1
8/25/2016	4	8	5	9	3	1	7	6	1
8/26/2016	6	9	7	8	4	2	3	4	1
9/13/2016	5	9	8	3	5	4	1	5	2
9/14/2016	7	9	5	3	5	4	1	8	1
9/26/2016	1	3	2	5	6	7	7	9	4
10/4/2016	7	9	3	7	5	3	2	6	1
Sum	58	**73**	51	55	57	40	50	71	**23**
Groupings	AB	**A**	ABC	ABC	ABC	BC	ABC	AB	**C**

Table 5. Scenario 2 sensor rankings on slope of soil moisture recession curve following precipitation events. Differences in soil moisture recession slopes for the WMS-GR 5TM sensors are not statistically significant.

Scenario 2 Sensor Rankings									
Rain Event	**H1**	**H2**	**H3**	**M1**	**M2**	**M3**	**L1**	**L2**	**L3**
3/24/2017	8	5	5	2	2	7	2	1	9
3/26/2017	8	4	5	5	1	2	9	2	7
3/29/2017	9	8	2	3	3	1	7	3	3
4/3/2017	2	5	5	4	1	7	7	7	3
4/4/2017	6	1	1	6	3	8	5	3	9
5/18/2017	4	1	1	4	2	1	3	2	1
5/22/2017	1	1	2	4	2	3	3	1	1
Sum	38	25	21	28	14	29	36	19	33

IV. Discussion

WMS-GR Soil Moisture Scenarios:

For Scenario 1 the sensors are sensing most of the sandy WMS-GR substrate profile. Although there is a statistical difference between H2 and L3 sensors there is not a distinction between the different "zones" or sensors at each of the three elevations of the roof (refer to Table 4). Little to no statistical difference in hydrological response for all nine sensors seems to indicate that it is best to apply irrigation as uniform as possible across the roof to ensure that the plants at each level of the roof are receiving the same amounts of water. Of interest, a previous study by Bengtsson (2005) found that runoff does not occur until the green roof substrate reaches field capacity. To ensure the least amount of green roof runoff and limit potable water use, we suggest that green roof soil moisture content should be kept below field capacity.

Plant Growth and Substrate Dynamics:

As Memorial Stadium Green Roofs age, it is important to monitor the hydrological processes of the system. Over time, soil particles may be lost, organic matter may increase, and root development can cause the soil porosity to change. In combination, these changes can affect the structure of substrate and in turn affect how water passes through the green roof substrate.

Due to more frequent irrigation (two times a day on the WMS-GR for part of the 2016 growing season, and three times a day on the EMS-GR for most of the 2016 growing season), an early planting time, and abundant weed seeds finding their way onto the roof (likely via a combination plant storage and planting practices, wind, and animals) there were a very large number of agricultural weeds (including foxtail, pigweed, lambs-quarters, and marestail) on the EMS-GR. Due to cleaner green roof soils and live plugs, and immediately planting live plants on the green roof in June and July 2015, after they were received from the supplier, native grasses and forbs are more dominant on the WMS-GR than on the EMS-GR. Observations by the lead researcher (during weeding, and in tallying marestail) indicated that few if any weeds found their way into plug pots for WMS-GR plants, whereas this was not true for the EMS-GR pots (see Figure 8).

Figure 8. Marestail growing immediately adjacent to two native plug rootballs (EMS-GR)
Photographs by Lee R. Skabelund (July 28, 2017)

Plant Growth, Vegetation Management, and Wildlife Relationships:

Range management specialist Clenton Owensby (KSU Agronomy Jan 2016 pers. comm.) noted the importance of removing biomass from prairie-like systems on some type of regular basis to renew prairie grasses and which provide the critical matrix for covering soils and preventing wind and water erosion. Ornithologist Alice Boyce (KSU Biology Feb 2017 pers. comm.) indicated that "vegetative structure is vital for passerine birds should they find the green roofs as places to rest, take cover, and feed before moving on. Nesting is possible but may be unlikely given the location of these created ecosystems and the size of vegetative patches." For the sake of any migrating passerine birds that might use the green roofs we believe it would be wise to clip the vegetation in mid-to-late-April as dead plant material and undisturbed soil provide cover for fauna needing safe places to overwinter. During 2016 and 2017, birds such as meadowlarks and sparrows were seen using the green roofs. Many bees and butterflies were also observed. KSU researchers are currently studying the use of each MS-GR by butterflies and comparing this to other areas of prairie within or near Manhattan, Kansas.

V. Future Research

Although there have been several studies in the past involving sloped green roofs (Kohler, 2007; Thuring and Dunnett, 2014) there is extremely limited knowledge on how water passes through sloped green roof systems. It is important for researchers to monitor the hydrology and internal hydraulics of the MS-GRs to see if changes in vegetation composition or substrate structure affect how water travels through the system over time.

After monitoring the two Memorial Stadium green roofs from June 2016 to the present there is much we do not know about surface and subsurface vegetation-and-soil relationships due to the inherent complexity of climatic and subsurface soil and root conditions for these two steeply-sloped green roofs. The soil moisture and temperature sensors help the research team better understand some aspects related to soil moisture levels and trends, and they may help reveal how substrate conditions influence vegetation (and how vegetative cover influences soil moisture levels) with additional analysis. Particularly, evapotranspiration rates for different vegetation types need to be better understood, and researchers need to look more closely at the data and complete focused statistical analyses to recognize trends or patterns regarding soil moisture changes related to vegetative type and coverage.

Our interdisciplinary team of faculty and student researchers plans to continue studying changes in vegetative coverage, species diversity, and sub-surface soil moisture levels on the WMS-GR through at least mid-August 2018. EMS-GR vegetation will also be studied in 2018. It is our hope that our research will enable KSU to apply more sustainable green roof irrigation and maintenance operations and minimize potable water use—and thus improve stormwater retention, reduce unnecessary runoff, minimize green roof maintenance demands and rooftop disturbance, and retain a diverse complement of grasses and wildflowers.

MS-GR research findings are expected to inform future designs and maintenance activities for sloped green roof systems, particularly those using prairie plants in hot, temperate climates.

By testing various approaches to understand green roof performance and change we expect to reveal ecological functions and dynamics in ways that our interdisciplinary team and many different stakeholders can appreciate and learn from.

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Appendix A: Table 1. Taxa (Plant Species) Placed on the Memorial Stadium Green Roofs in 2015 and 2016 (as synthesized from AES and Blueville Nursery documentation).

Taxa (Plant Species)	Seed or Live Plant/Plug	Green Roof
Allium stellatum	Seed	East and West
Baptisia australis	Seed	East and West
Camassia scilloides	Seed	East and West
Ratibida columnifera	Seed	East and West
Tradescantia ohiensis	Seed	East
Symphyotrichum ericoides	Seed	East and West
Artemisia ludoviciana	Seed	East and West
Oligneuron rigida	Seed	East and West
Achillea millefolium	Live Plant	East and West
Dalea purpurea	Live Plant	East and West
Echinacea pallida	Live Plant	East and West
Liatris aspera	Live Plant	East and West
Liatris pycnostachya	Live Plant	East and West
Monarda fistulosa	Live Plant	East and West
Penstemon cobaea	Live Plant	East and West
Penstemon digitalis	Live Plant	East and West
Salvia azurea	Live Plant	East and West
Schizachyrium scoparium	Live Plant	East and West
Sorghastrum nutans	Live Plant	East and West
Sporobolus heterolepis	Live Plant	East and West
Symphyotrichum novae-angliae	Live Plant	East and West
Asclepias tuberosa	Live Plant	West
Scutellaria leonardii	Seed	West
Ratibida pinnata	Seed	West
Carex glauca	Seed	West
Symphyotrichum sericeum	Seed	West
Tradescantia occidentalis	Seed	West
Bouteloua curtipendula	Seed	West
Bouteloua gracilis	Seed	West
Bouteloua hirsuta	Seed	West

Native species were seeded and/or were planted on the MS-GRs as live plants or plugs.

Plants shown in red were specified and requested but were not available. For some unknown reason, none of the specified native grasses were included in the seed mix that was sprayed on the EMS-GR.

The West Memorial Stadium Green Roof (WMS-GR) was planted and seeded in June and July of 2015, while the East Memorial Stadium Green Roof (EMS-GR) was seeded and planted in March and April of 2016. All seeds and live plants were supplied by Applied Ecological Services' Taylor Creek Restoration Nurseries (AES) from Brodhead, Wisconsin and Baldwin City, Kansas.

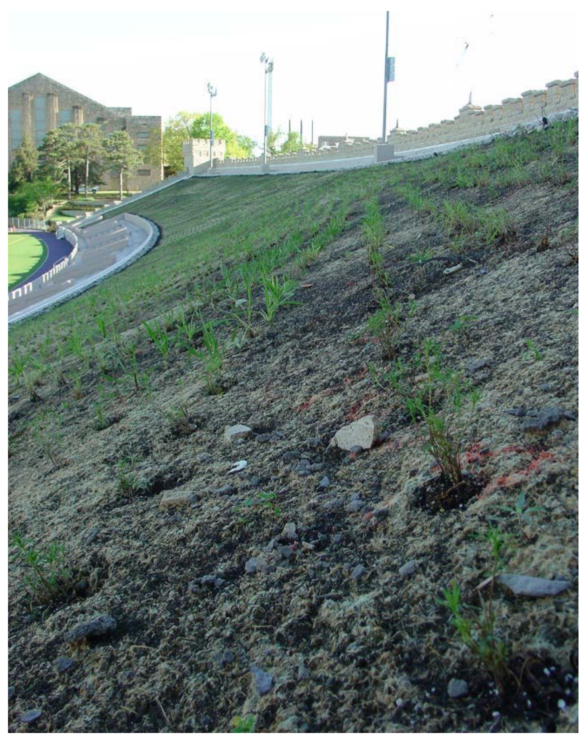
Hydro-seeding of the native seed mix followed by planting of plugs within the geo-web cells on each green roof were both completed by Blueville Nursery Inc. of Manhattan, Kansas. Vegetation on these two green roofs is irrigated using rotor sprayheads, fertilized using an organic fertilizer sprayed on to each roof (typically several times a year), and clipped and weeded by hand and/or mechanically trimmed/weed-whacked several times a year.

Appendix B: Selected MS-GR Vegetation Implementation Photographs (Lee R. Skabelund)

West MS-GR (June 4, 2015) - Substrate

West MS-GR (June 23, 2015) - Seeding

East MS-GR (April 7, 2016) - Planting



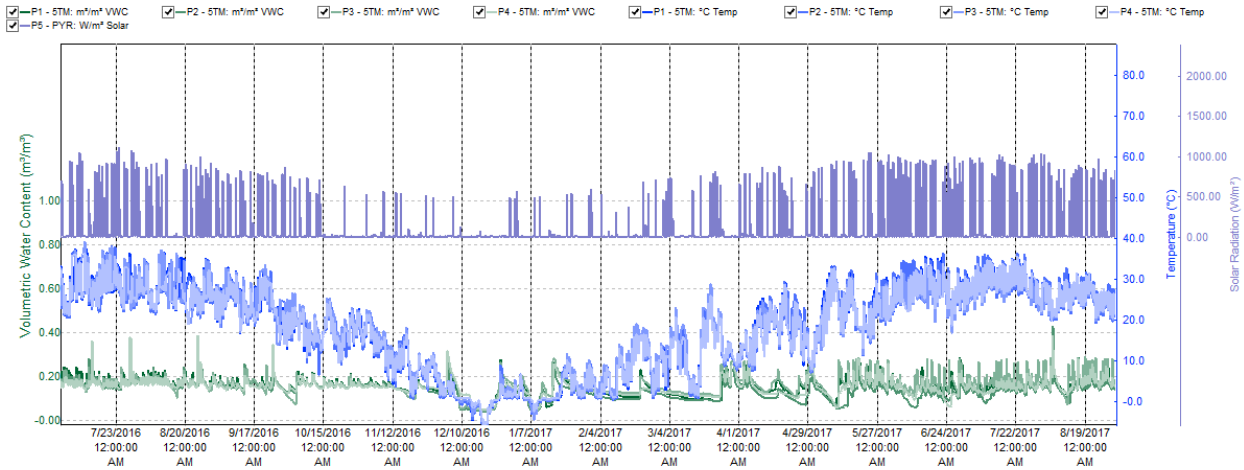
East MS-GR (April 25, 2016) – Early growth

Appendix C: Selected MS-GR Vegetation Monitoring Photographs (Lee R. Skabelund)


WMS-GR – one of four 100-foot transects at lower elevation (June 28, 2016)

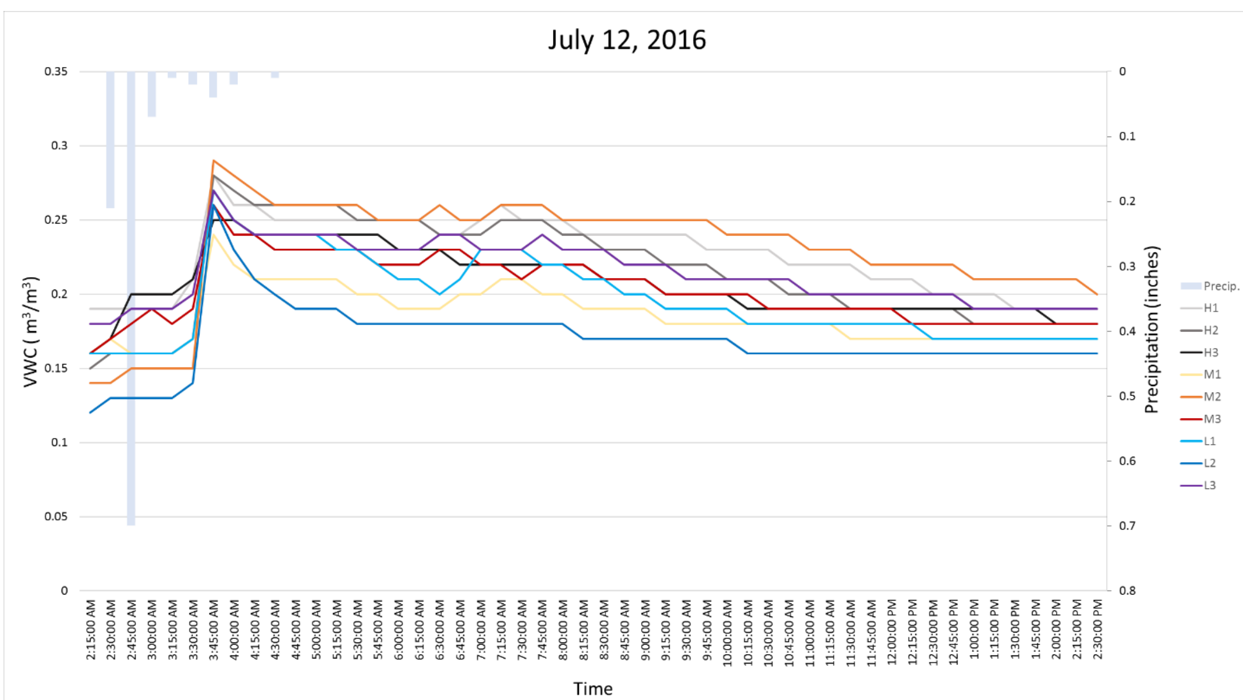

EMS-GR – one of four 100-foot transects at the higher elevation (June 29, 2016)

Appendix D: Figure 1. WMS-GR Decagon 5TM Solar Radiation (PYR), Soil Moisture, and Temperature Data (for 3 high and 1 mid-level sensors—1 July 2016 to 1 September 2017)



Source of chart: WMS-GR Data collected using a Decagon Em50G Solar Data-logger and DataTrac3 software.

Appendix D: Figure 2. WMS-GR Decagon 5TM Soil Moisture Data for all 9 5TM sensors, 3 high, 3 mid-level, and three low (12 July 2016) following a 1.08-inch rain event



Source of chart: WMS-GR Data analyzed by Allyssa Decker.

Appendix E: Table 1. Identified MS-GR Plants (2016-2017)

Plants observed and/or identified by Lee R. Skabelund, Ryan Peters, Kyle Koehler, Mark Mayfield, Pamela Blackmore and Jeffrey Taylor.

location	growth habit	genus	species	common name	Volunteer on GR	KS Native	"Weed"
E	Forb/herb	*Abutilon*	*theophrasti*	velvetleaf	Y		Y
W/E	Forb/herb	*Achillea*	*millefolium*	common yarrow		Y	
W/E	Forb/herb	*Allium*	*stellatum*	autumn onion		Y	
E	Forb/herb	*Amaranthus*	*sp. (incl. albus)*	pigweed (many diff. sp.)	Y	NI	Y
E	Forb/herb	*Ambrosia*	*artemisiifolia*	annual ragweed	Y	Y	Y
E	Forb/herb	*Ambrosia*	*trifida*	great ragweed	Y	Y	Y
W/E	Forb/herb	*Asclepias*	*tuberosa*	butterfly milkweed		Y	
W/E	Forb/herb	*Baptisia*	*australis*	blue false indigo		Y	
E	Forb/herb	*Cerastium*	*brachypodum*	short-stalked chickweed	Y	Y	
E	Forb/herb	*Chamaecrista*	*fasciculata*	partridge pea	Y	Y	
W	Forb/herb	*Chenopodium*	*sp.*	goosefoot	Y	NI	Y
E	Forb/herb	*Chenopodium*	*album*	lambsquarters	Y		Y
E	Forb/herb	*Chenopodium*	*berlandieri*	berlander's goosefoot	Y	Y	
W/E	Forb/herb	*Cichorium*	*intybus*	chicory	Y		
W/E	Forb/herb	*Cirsium*	*vulgare*	bull thistle	Y		Y
E	Forb/herb	*Commelina*	*erecta*	whitemouth dayflower	Y	Y	
E	Forb/herb	*Convolvulus*	*arvensis*	field bindweed	Y		Y
W/E	Forb/herb	*Conyza*	*canadensis*	marestail/horseweed	Y	Y	Y
W	Forb/herb	*Coreopsis*	*grandiflora*	tickseed	Y		
W/E	Forb/herb	*Coreopsis*	*tinctoria*	plains coreopsis		Y	
E	Forb/herb	*Coronilla*	*varia*	crown vetch	Y		Y
W/E	Forb/herb	*Daucus*	*carota*	queen anne's lace	Y		
E	Forb/herb	*Desmanthus*	*illinoensis*	Illinois bundleflower	Y	Y	
W	Forb/herb	*Desmodium*	*canadense*	showy ticktrefoil	Y	Y	
W/E	Forb/herb	*Echinacea*	*pallida*	pale purple coneflower		Y	
W	Forb/herb	*Erigeron*	*sp. (strigosus)*	daisy fleabane	Y	Y	
E	Forb/herb	*Euphorbia*	*dentata*	toothed spurge	Y		
E	Forb/herb	*Euphorbia*	*hexagona*	sixangle spurge	Y	Y	
W/E	Forb/herb	*Euphorbia*	*prostrata*	prostrate spurge	Y	Y	
E	Forb/herb	*Eupatorium*	*serotinum*	late-flower thoroughwort	Y	Y	
E	Forb/herb	*Helianthus*	*annuus*	common sunflower	Y	Y	
E	Forb/herb	*Hibiscus*	*trionum*	flower of an hour	Y		
E	Forb/herb	*Holosteum*	*umbellatum*	jagged chickweed	Y		
E	Forb/herb	*Heliopsis*	*helianthoides*	false sunflower	Y	Y	

W	Forb/herb	*Kummerowia*	*stipulacea*	Korean clover	Y		Y
E	Forb/herb	*Lactuca*	*serriola*	prickly lettuce	Y		
W/E	Forb/herb	*Lepidium*	*densiflorum*	common pepperweed	Y	NI	
W/E	Forb/herb	*Liatris*	*aspera*	tall blazing star		Y	
W/E	Forb/herb	*Liatris*	*pycnostachya*	prairie blazing star		Y	
W	Forb/herb	*Lobelia*	*siphilitica*	great blue lobelia	Y	Y	
W	Forb/herb	*Lycopus*	*americanus*	water horehound	Y	Y	
E	Forb/herb	*Malva*	*neglecta*	common mallow	Y		
W/E	Forb/herb	*Medicago*	*lupulina*	black medic	Y		Y
W/E	Forb/herb	*Medicago*	*sativa*	alfalfa	Y		
W/E	Forb/herb	*Melilotus*	*sp.*	sweetclover	Y		Y
E	Forb/herb	*Mollugo*	*verticillata*	green carpetweed	Y	Y	
W	Forb/herb	*Oenothera*	*villosa*	hairy evening primrose	Y	Y	
W/E	Forb/herb	*Oxalis*	*dillenii*	slender woodsorrel	Y	Y	
W	Forb/herb	*Pastinaca*	*sativa*	wild parsnip	Y		Y
W/E	Forb/herb	*Penstemon*	*cobaea*	cobaea beardtongue		Y	
W/E	Forb/herb	*Penstemon*	*digitalis*	foxglove beardtongue		Y	
W/E	Forb/herb	*Phytolacca*	*americana*	American pokeweed	Y	Y	
E	Forb/herb	*Plantago*	*lanceolata*	narrowleaf plantain	Y		
E	Forb/herb	*Polygonum*	*ramosissimum*	bushy knotweed	Y	Y	
E	Forb/herb	*Polygonum*	*sp. (lapathifolium?)*	curlytop knotweed	Y	Y	
E	Forb/herb	*Portulaca*	*oleracea*	purslane / little hogweed	Y		
W/E	Forb/herb	*Potentilla*	*recta*	sulphur cinquefoil	Y	NI	
W/E	Forb/herb	*Ratibida*	*columnifera*	upright coneflower		Y	
W/E	Forb/herb	*Ratibida*	*pinnata*	pinnate coneflower		Y	
W/E	Forb/herb	*Rudbeckia*	*hirta*	black-eyed susan	Y	Y	
E	Forb/herb	*Rumex*	*crispus*	curly dock	Y		Y
W/E	Forb/herb	*Salvia*	*azurea*	azure blue sage		Y	
E	Forb/herb	*Sida*	*spinosa*	prickly fanpetals	Y	Y	
E	Forb/herb	*Solanum*	*sp.*	nightshade/horsenettle	Y	NI	Y
E	Forb/herb	*Solidago*	*canadensis*	common goldenrod	Y	Y	
W/E	Forb/herb	*Solidago*	*rigida*	stiff goldenrod		Y	
W/E	Forb/herb	*Sonchus*	*sp.*	sow thistle	Y		Y
W/E	Forb/herb	*Symphyotrichum*	*ericoides*	white heath aster		Y	
W/E	Forb/herb	*Symphyotrichum*	*novae-angliae*	New England aster			
W	Forb/herb	*Symphyotrichum*	*sericeum*	western silver aster		Y	
W/E	Forb/herb	*Symphyotrichum*	*pilosum*	common/oldfield aster	Y	Y	
W/E	Forb/herb	*Taraxacum*	*officinale*	common dandelion	Y		Y

W/E	Forb/herb	*Tradescantia*	*occidentalis*	prairie spiderwort		Y	
E	Forb/herb	*Tradescantia*	*ohiensis*	Ohio spiderwort		Y	
W/E	Forb/herb	*Trifolium*	*pratense*	red clover	Y		
E	Forb/herb	*Verbascum*	*thapsus*	flannel/common mullein	Y	Y	
E	Forb/herb	*Verbena*	*stricta*	hoary verbena	Y	Y	
W	Forb/herb	*Veronica*	*peregrina*	common speedwell	Y	Y	
E	Forb/herb	*Veronica*	*polita*	wayside speedwell	Y		
W/E	Forb/herb, Subshrub	*Artemisia*	*ludoviciana*	Louisiana sagewort		Y	
W/E	Forb/herb, Subshrub	*Dalea*	*purpurea*	purple prairie clover		Y	
W/E	Forb/herb, Subshrub	*Monarda*	*fistulosa*	wild bergamot		Y	
W	Graminoid	*Andropogon*	*gerardii*	big bluestem	Y	Y	
E	Graminoid	*Agrostis*	*hyemalis*	winter bentgrass	Y	Y	
W/E	Graminoid	*Bouteloua*	*curtipendula*	sideoats grama		Y	
W/E	Graminoid	*Bouteloua*	*gracilis*	blue grama		Y	
W	Graminoid	*Bouteloua*	*hirsuta*	hairy grama		Y	
E	Graminoid	*Bromus*	*tectorum*	cheat grass	Y		Y
W	Graminoid	*Carex*	*sp.*	unknown sp.	Y		
W/E	Graminoid	*Carex*	*bicknelli ?*	Bicknell's sedge	Y	Y	
W/E	Graminoid	*Carex*	*brevior*	shortbeak sedge	Y	Y	
E	Graminoid	*Carex*	*gravida*	heavy sedge	Y	Y	
E	Graminoid	*Carex*	*vulpinoidea*	Fox sedge	Y	Y	
E	Graminoid	*Cyperus*	*lupulinus*	Great Plains flatsedge	Y	Y	
E	Graminoid	*Cyperus*	*strigosus*	strawcolored flatsedge	Y	Y	
E	Graminoid	*Digitaria*	*sanguinalis*	hairy crabgrass	Y		Y
E	Graminoid	*Echinochloa*	*sp. (muricata?)*	rough barnyardgrass	Y	Y	
E	Graminoid	*Eleusine*	*indica*	Indian goosegrass	Y		Y
E	Graminoid	*Eragrostis*	*cilianensis*	stinkgrass	Y		Y
E	Graminoid	*Eragrostis*	*trichodes*	sand lovegrass	Y	Y	
E	Graminoid	*Eriochloa*	*contracta*	prairie cupgrass	Y	Y	
E	Graminoid	*Festuca*	*arundinacea*	tall fescue	Y		Y
E	Graminoid	*Hordeum*	*jubatum*	squirrel tail	Y	Y	
W/E	Graminoid	*Hordeum*	*pusillum*	little barley	Y	Y	
E	Graminoid	*Panicum*	*capillare*	witchgrass	Y	Y	
E	Graminoid	*Paspalum*	*setaceum*	thin paspalum/thinseed	Y	Y	
E	Graminoid	*Poa*	*annua*	annual bluegrass	Y		
E	Graminoid	*Poa*	*pratensis*	Kentucky bluegrass	Y		Y

W/E	Graminoid	*Schizachyrium*	*scoparium*	little bluestem		Y	
W/E	Graminoid	*Setaria*	*sp. (viridis +)*	foxtail / bristlegrass	Y	NI	
W/E	Graminoid	*Sorghastrum*	*nutans*	Indiangrass		Y	
E	Graminoid	*Sorghum*	*bicolor*	Sorghum	Y		
W/E	Graminoid	*Sporobolus*	*heterolepis*	prairie dropseed		Y	
W	Graminoid	*Tridens*	*flavus*	purpletop tridens	Y	Y	
E	Shrub/ Tree	*Acer*	*rubrum ?*	red or silver maple cross	Y	Y	Y
W/E	Shrub/ Tree	*Celtis*	*occidentalis*	common hackberry	Y	Y	Y
W/E	Shrub/ Tree	*Fraxinus*	*pennsylvanica ?*	green (or white) ash	Y	Y	Y
W/E	Shrub/ Tree	*Lonicera*	*maakii*	Amur honeysuckle	Y		Y
E	Shrub/ Tree	*Malus*	*sp.*	Crabapple	Y		Y
E	Shrub/ Tree	*Morus*	*alba*	Mulberry	Y		Y
W/E	Shrub/ Tree	*Platanus*	*occidentalis*	American sycamore	Y	Y	Y
W/E	Shrub/ Tree	*Populus*	*deltoides*	eastern cottonwood	Y	Y	Y
E	Shrub/ Tree	*Pyrus*	*calleryana*	Callery pear	Y		Y
E	Shrub/ Tree	*Rhamnus*	*cathartica*	common buckthorn	Y		Y
W	Shrub/ Tree	*Salix*	*sp.*	Willow	Y	Y	Y
W	Shrub/ Tree	*Sophora*	*japonica*	Japanese pagoda tree	Y		Y
W/E	Shrub/ Tree	*Ulmus*	*americana*	American elm	Y	Y	Y
E	Shrub/ Tree	*Ulmus*	*parvifolia*	lacebark elm	Y		Y
W/E	Shrub/ Tree	*Ulmus*	*pumila*	Siberian elm	Y		Y
E	Vine	*Euonymus*	*fortunei*	creeping euonymus	Y		Y

Notes:
E = East Memorial Stadium Green Roof (EMS-GR)
W = West Memorial Stadium Green Roof (WMS-GR)
W/E = observed on both green roofs

GR volunteer = not intentionally planted on one (or both) of the MS-GRs
KS Native: Y = Native to Kansas; NI = may be native or introduced

Physical plants or specimens were not, in many instances, examined and identified by a botanist.
The above species list may have some errors, but is deemed to be reasonably accurate.

Weed = invasive non-native, woody, known to be severely allergenic, prickly and/or overly competitive.
(This definition of a "weed" is subjective and should be refined via dialogue over time.)
Identified weeds should be managed to keep them in check.