Urban Green Infrastructure and Water Conservation:
Monitoring irrigation and soil moisture on two large-scale prairie green roofs in the Flint Hills Eco-region with the aim of conserving potable water

Presented by Lee R. Skabelund, 2016-2018 Mary K. Jarvis Research Chair, Kansas State University
Dept. of Landscape Architecture and Regional & Community Planning

Collaborators & Affiliations:

**1) Lee R. Skabelund, KSU-LARCP; 2) Mary Knapp, KSU-Agronomy;
3) Stacy Hutchinson, Trisha Moore & Ajay Sharda, KSU-BAE; 4) Dale Bremer, KSU-HNR;
5) Deon van der Merwe, KSU-VetMed; 6) Allyssa Decker & Elizabeth Musoke, KSU-EDP; 7) Ryan Peters, KSU-HNR;
8) Kyle Koehler & Priyasha Shrestha, KSU-LARCP; 9) Devon Bandad, KSU-BAE;
10) Jeffrey L. Bruce, JBC.**

KSU Green Infrastructure Implementation, Monitoring, Management, Outreach & Research

We seek to……
1) engage in-depth research opportunities on campus;
2) develop focused monitoring programs for assessment of landscape and ecosystem functions related to green infrastructure systems;
3) generate empirical data to demonstrate the benefits of green infrastructure sites;
4) strengthen institutional and community understanding of green infrastructure benefits—including their role in enhancing ecosystem services & restoring watersheds;
5) inspire, inform, and guide future implementation of landscapes on the campus *and* within the community and region.

Ultimately our work aims to cultivate and disseminate new knowledge about the performance, while offering faculty, students & community members an opportunity to become skilled in green infrastructure implementation *and* landscape monitoring, assessment & management.

What is most important to know about green infrastructure implementation?

Green roofs, rain-gardens, bio-retention areas, and other designed green infrastructure features have the potential to be vital parts of interconnected and regenerative community open space networks.

Poorly designed, implemented and/or managed green infrastructure projects increase resource demands by creating untenable conditions for selected vegetation (which dies out or is out-competed by undesired plant species)—and may lead to the need for, or expectation, that vegetation be replanted or replaced.

what is most important to know about green infrastructure implementation

How and why vegetation within green infrastructure systems changes over time:
Depends on unique soil, hydrologic, micro-climatic, maintenance & contextual conditions.

Type and amount of maintenance required to retain viable stands of non-invasive & diverse vegetation on green roofs and in rain-gardens:
Requires intelligent & regular management. One must determine what to remove and how to do so to minimize soil disturbance and invasive/undesirable species.

Ecosystem services provided by these eco-design features:
Stormwater management close to where precipitation falls.
Movement of rainfall into healthy, living soils.
Reduced water and energy use.
Vibrant pollinator habitat.
Carbon sequestration.
Species diversity.

how green infrastructure makes an impact in our community

Green Infrastructure Demonstration and Training:

Monitoring and Interpreting Two Sites on the Kansas State University Campus

Prof. Jessica Canfield, Kansas State University KSU-Landscape Architecture and Regional & Community Planning (LARCP)

Dr. Stacy Hutchinson, KSU-Biological & Agricultural Engineering (BAE)

Prof. Katie Kingery-Page, KSU-LARCP

Prof. Lee R. Skabelund, KSU-LARCP

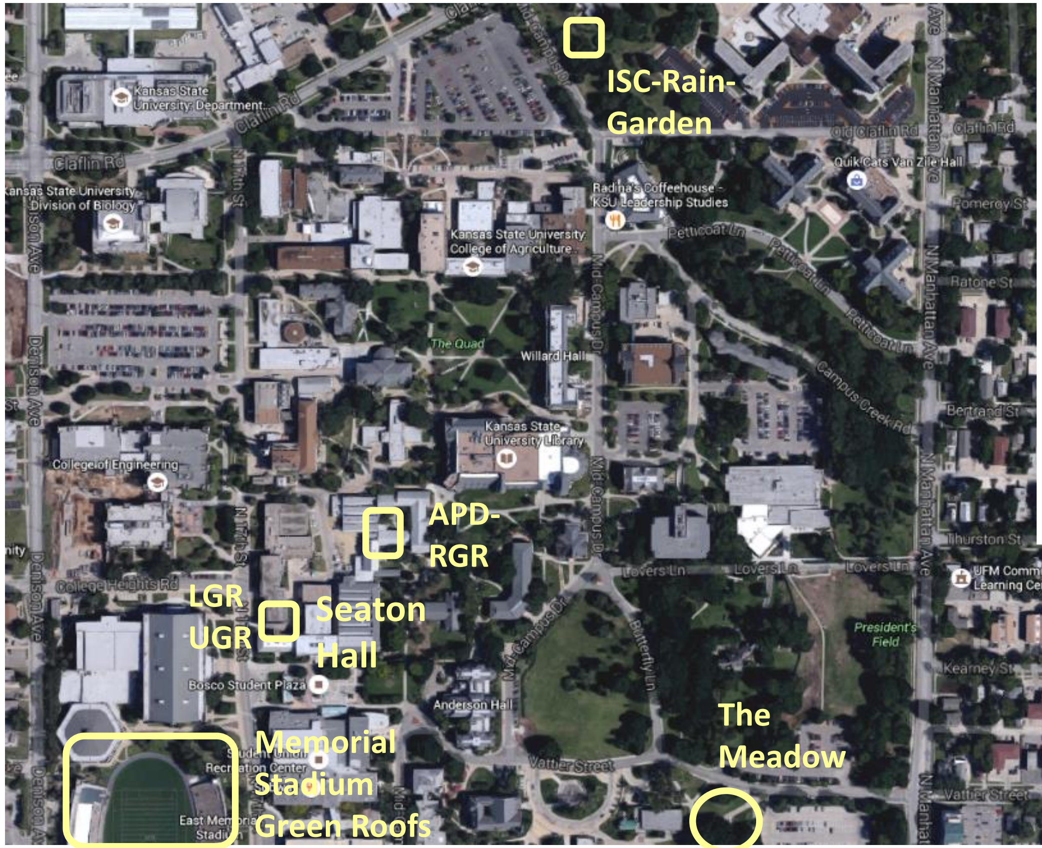
$20,000 from USEPA; $16,400 KSU cost-share; 18-month contract (began Sep. 2015)

EPA Campus RainWorks Award Winner

International Student Center Raingarden

The Meadow

KSU Central Campus Green Infrastructure



- Stormwater Runoff Analysis
- Water Quality Assessment
- Infiltration Capacity Testing
- Ecological Services/Health Assessment
- Species Diversity Assessment
- Pollinator Assessment
- Carbon Sequestration/Biomass Estimate
- Maintenance Procedures Assessment

For the dual purposes of **expanding student training/learning** and **advancing community outreach**—this project is utilizing the International Student Center (ISC) Rain-Garden, Beach Meadow, and other sites as living laboratories, where faculty, staff, students, community members, and visitors monitor, learn from, and interpret the multi-faceted performance benefits of green infrastructure.

Jeremy Sharp, KSU's Memorial Stadium Project Manager, noted the university's desire to protect the structure and waterproofing systems (including from solar radiation and fluctuating freeze-thaw cycles) and limit visitor access at one time to 1000 people or less on each stadium rooftop (personal communication, 23 Dec 2015).

A conversation with lead green roof designer (Jeffrey L. Bruce, 29 Dec. 2015) indicates that the primary purpose of the Memorial Stadium green roofs is to protect the structural integrity of each rooftop by limiting the number of people who can occupy these stadium roofs. In addition, the two green roofs were created to demonstrate KSU's commitment to sustainability, and create recognizable landmarks related to the prairie ecology of the Flint Hills on campus.

Per Bruce, additional benefits are expected to accrue (incl. providing aesthetic green roofs, creating a stormwater sponge [once plants are well established & irrigation is reduced to what is necessary for native plant health], and providing habitat for birds & pollinators).

Primary research objective: improve irrigation & maintenance practices by studying changes in vegetative coverage, species diversity, and sub-surface soil moisture levels on both of the MS-GRs.

Seeding, planting, and weed management & fertilizing:

WMS-GR – Blueville Nursery (2015 thru July 2016); KSU Facilities & LRS (Summer-Fall 2016)
Vermiplex (organic fertilizer) added three times in 2015 on WMS-GR (incl. Sep 11, 2015)

EMS-GR – LRS (May-June 2016); Blueville Nursery (July 7-8 & Sep 14-15, 2016 weed whacking);
Vermiplex (organic fertilizer) added three times in 2016 on EMS-GR (incl. one after July clipping)

Initial Question related to 2016 Data Collection: What is the relationship between vegetative cover, rooftop climatic conditions, supplemental irrigation, and soil moisture?

WMS-GR was seeded & planted in June and July 2015. EMS-GR was seeded & planted in March and April 2016. Nine (9) Decagon 5TM soil moisture/temperature sensors were installed in the center portion of each roof, with three (3) sensors positioned at high, mid, and low elevations.

Sensors were buried three inches below the substrate surface within a geo-web cell with the prongs oriented downslope and vertical on 20 June 2016 and thus sense the upper 2/3s of the substrate. Sand-based green roof substrate depths are six inches deep, with expanded shale added to lighten substrates on the EMS-GR. A single Apogee PYR solar radiation sensor was placed near the center of each roof. For 5TM and solar radiation sensors on the MS-GRs, we are collecting averaged 15-minute data, which is downloaded remotely from Decagon EM5G loggers using DataTrac3 software.

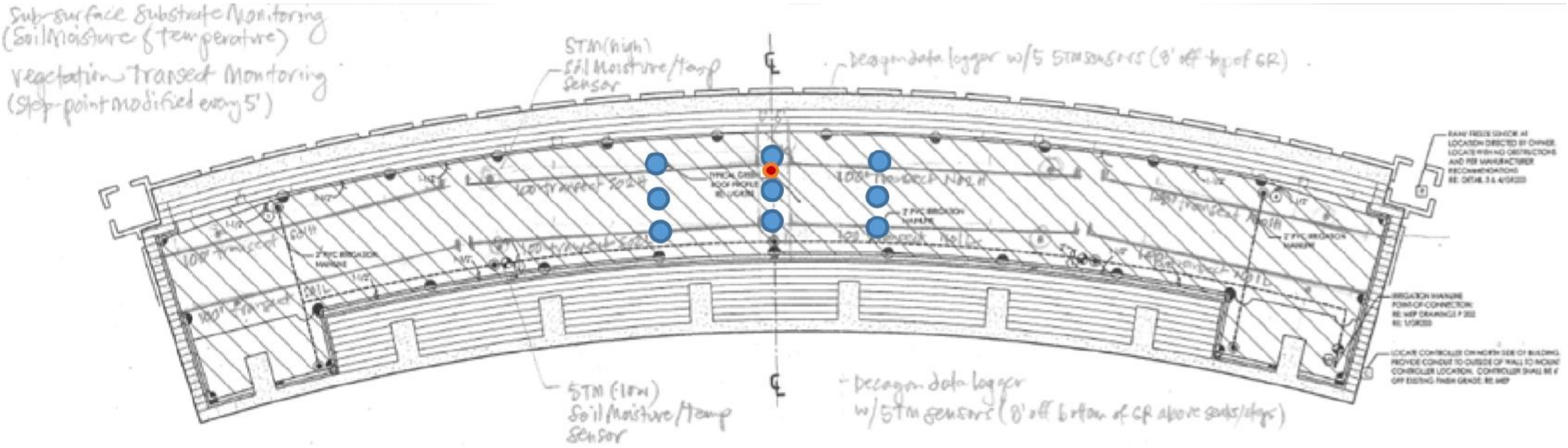
Sensors record soil moisture as volumetric water content (VWC), which is graphed in relation to a seven-day period associated with photo dates of vegetation present near each sensor.

This presentation focuses on providing context (especially in regards to vegetative coverage) and offering selected senor readings for the three highest elevation sensors on each green roof.

KSU Memorial Stadium Green Roofs - Design & Implementation, Monitoring & Management

Irrigation practices: 2015 water use for WMS-GR was approx. **538,600 gallons.**
WMS-GR – approx. **738,000 gallons used for irrigation (Mar 3 to Nov 8, 2016).**
Typically irrigated from 1:00-2:30am & 6:00-7:30am (Jun-Aug)
(~165,000 gallons in June; ~190,000 in July; ~151,000 in August).

EMS-GR typically irrigated three times per day (mid-morning; mid-day; late-afternoon)
Blueville Nursery planned to use Baseline irrigation sensors on EMS-GR, but this has not been done.



Blue dots denote approx. sub-surface 5TM (soil moisture/temperature) sensor locations; red dot denotes solar radiation sensor on each MS-GR.

Vegetation monitoring included:

Plant ID along Eight 100-foot Transects on each green roof

Species Richness Observations during transect work & “walk-abouts” around each green roof

UAV flights employing infrared & thermal cameras over each green roof

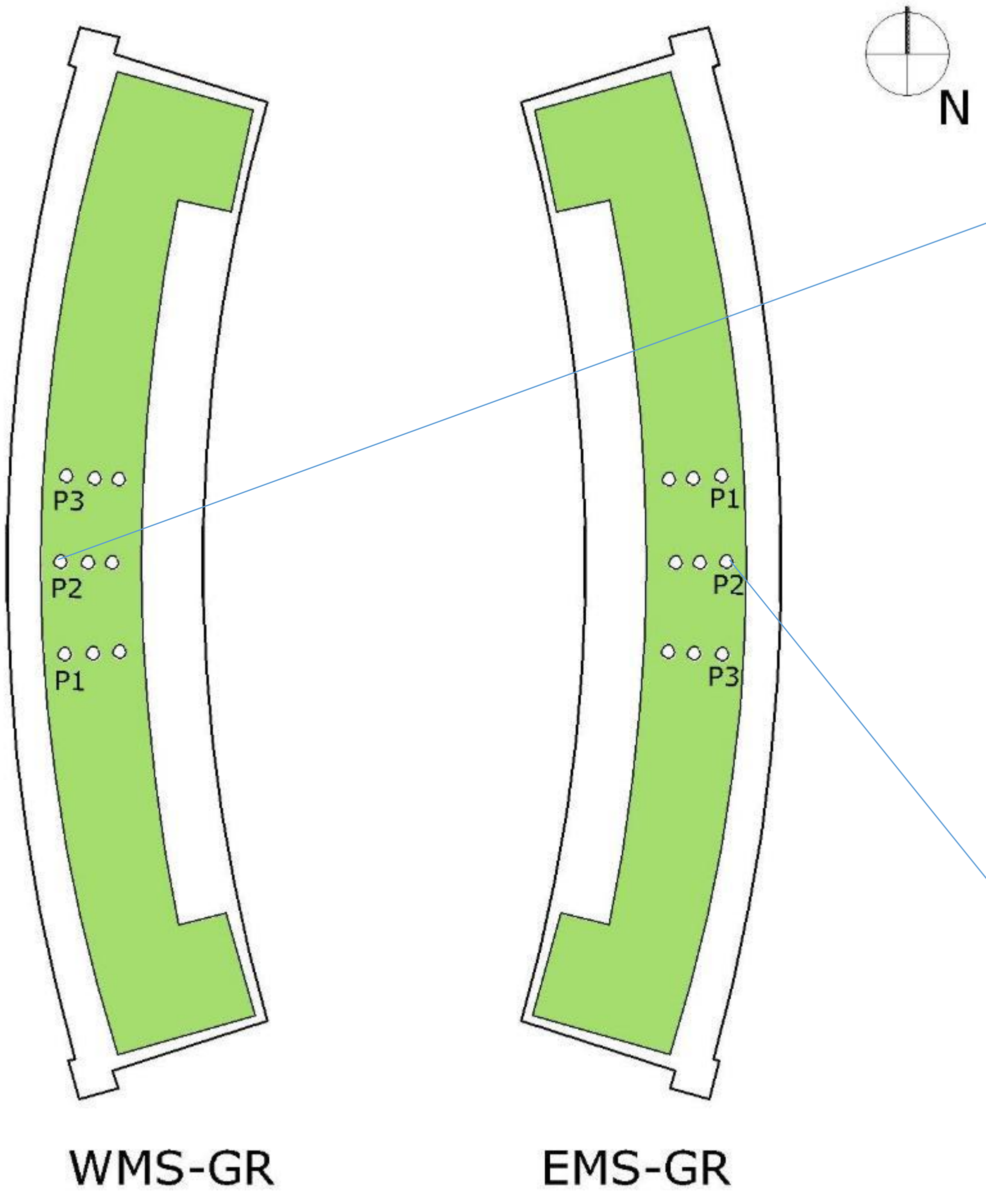
Due to more frequent irrigation (two times a day on the WMS-GR and three times a day on the EMS-GR), an early-in-the-season planting time, and abundant weed seeds finding their way onto the roof there is greater biomass and a very large number of agricultural weeds (including foxtail, piqweed & lambs-quarters) on the EMS-GR. Native grasses and forbs are more dominant on the WMS-GR.

In late June 2016, dominant native plants on the EMS-GR were Indian grass and Louisiana sage, while dominant native plants on the WMS-GR were blue & hairy grama, little bluestem, Louisiana sage, prairie coneflower, yellow coneflower, and stiff goldenrod.

Initial KSU Research Project Tasks

1) carefully track vegetative change and understand what species do well on these steeply-sloped, 5-6-inch deep prairie-like systems, to make it possible to suggest effective vegetative management strategies; and 2) track soil/substrate moisture and supplemental irrigation, thus encouraging the wise use of potable water.

KSU Memorial Stadium Green Roofs - Monitoring



WMS-GR - 30 Jun 2016 (P2)

WMS-GR - 10 Sep 2016 (P2)

EMS-GR - 30 Jun 2016 (P2)

EMS-GR - 10 Sep 2016 (P2)

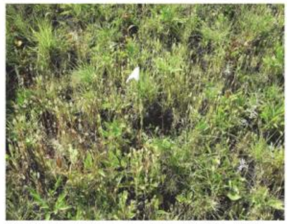
KSU Memorial Stadium Green Roofs - Monitoring

June 30, 2016 | July 19, 2016 | August 17, 2016 | September 10, 2016 - West Memorial Stadium Green Roof photos (3 high elevation sensors)


West High South Sensor Vegetation (P1-235) - 6/30

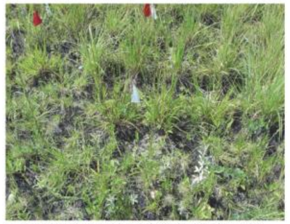

West High South Sensor Vegetation (P1-253) - 7/19


West High South Sensor Vegetation (P1-253) - 8/17

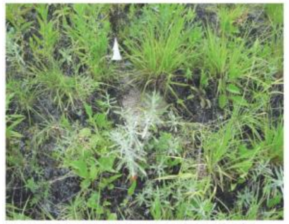

West High South Sensor Vegetation (P1-253) – 9/10


West High Center Sensor Vegetation (P2-253) - 6/30


West High Center Sensor Vegetation (P2-253) - 7/19


West High Center Sensor Vegetation (P2-253) - 8/17


West High Center Sensor Vegetation (P2-253) – 9/10


West High North Sensor Vegetation (P3-253) - 6/30


West High North Sensor Vegetation (P3-253) - 7/19


West High North Sensor Vegetation (P3-253) - 8/17


West High North Sensor Vegetation (P3-253) – 9/10

June 30, 2016 | July 19, 2016 | August 17, 2016 | September 10, 2016 - East Memorial Stadium Green Roof photos (3 high elevation sensors)


East High North Sensor Vegetation (P1-235) - 6/30


East High North Sensor Vegetation (P1-235) - 7/19


East High North Sensor Vegetation (P1-235) - 8/17


East High North Sensor Vegetation (P1-235) - 9/10


East High Center Sensor Vegetation (P2-235) - 6/30


East High Center Sensor Vegetation (P2-235) - 7/19


East High Center Sensor Vegetation (P2-235) - 8/17


East High Center Sensor Vegetation (P2-235) - 9/10


East High South Sensor Vegetation (P3-235) - 6/30


East High South Sensor Vegetation (P3-235) - 7/19


East High South Sensor Vegetation (P3-235) - 8/17


East High South Sensor Vegetation (P3-235) - 9/10


WMS-GR - 27 Jun 2016


WMS-GR - 25 July 2016


EMS-GR - 29 June 2016


EMS-GR - 25 July 2016

KSU Memorial Stadium Green Roofs - Monitoring

EMS-GR	High-North (P1)		High-Center (P2)		High-South (P3)	
	SM (VWC)	Temp (˚C)	SM (VWC)	Temp (˚C)	SM (VWC)	Temp (˚C)
avg	0.17	24.40	0.17	24.30	0.17	24.70
min	0.13	6.70	0.12	6.40	0.07	7.50
max	0.29	38.40	0.30	39.10	0.27	39.20

WMS-GR	High-South (P3)		High-Center (P2)		High-North (P1)	
	SM (VWC)	Temp (˚C)	SM (VWC)	Temp (˚C)	SM (VWC)	Temp (˚C)
avg	0.19	23.20	0.16	23.40	0.20	23.10
min	0.11	9.20	0.07	9.10	0.11	8.90
max	0.38	39.80	0.35	38.10	0.36	40.60

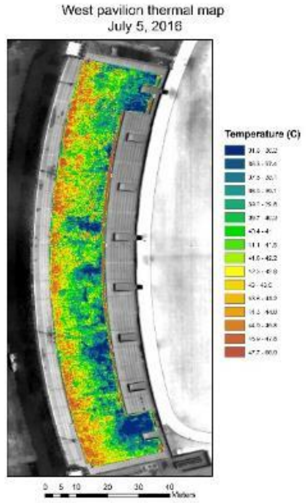
Summary (average, minimum, and maximum) values for soil moisture and temperature for the high sensors on the EMS and WMS green roofs (June 21-Nov 5, 2016).

Average soil moisture readings ranged from 0.16 to 0.20 m3/m3. The highest subsurface soil moisture value of 0.38 m3/m3 was observed on the WMS-GR, and the minimum subsurface soil moisture value was observed on both green roofs (0.07 m3/m3). High and low subsurface temperatures on the two MS-GRs ranged from 6.40 to 40.60 (C).

KSU MS-GRs- Monitoring

28-Jun Rain Event	**Variables**		**EMS-GR**		**WMS-GR**	
	Sky Cover	**28-Jun**	partly sunny		mostly sunny	
	Solar Radiation	max	1027	28-Jun	965	27-Jun
	Temperature (°C)	low	39.5	28-Jun	33.4	28-Jun
		high	22.5	28-Jun	22.9	28-Jun
	Soil Moisture (VWC)	before	0.15-0.17	5:45 AM	0.15-0.19	5:45 AM
		peak	0.30-0.34	6:45 AM	0.25-0.29	6:15 AM
		level	0.16-0.20	9:00 PM	0.18	4:00 PM
19-Aug Rain Event	**Variables**		**EMS-GR**		**WMS-GR**	
	Sky Cover	**19-Aug**	mostly cloudy		mostly sunny	
	Solar Radiation	max	844	19-Aug	932	19-Aug
	Temperature (°C)	low	21.1	20-Aug	35.1	19-Aug
		high	29.4	19-Aug	21.1	20-Aug
	Soil Moisture (VWC)	before	0.15-0.22	5:45 PM	0.16-0.18	5:30 PM
		peak	0.26-0.28	6:00 PM	0.23-0.25	6:00 PM
		level	0.19-0.24	1:00 AM	0.19	2:00 AM
13-Sep Rain Event	**Variables**		**EMS-GR**		**WMS-GR**	
	Sky Cover	**13-Sep**	mostly sunny		mostly cloudy	
	Solar Radiation	max	923	13-Sep	857	10-Sep
	Temperature (°C)	low	16.8	13-Sep	30.4	13-Sep
		high	23.8	13-Sep	21.3	13-Sep
	Soil Moisture (VWC)	before	0.10-0.15	1:45 AM	0.12-0.14	2:00 AM
		peak	0.27	4:15 AM	0.24-0.29	4:15 AM
		level	0.17-0.21	4:45 PM	0.19	3:00 PM

KSU Memorial Stadium Green Roofs Design & Implementation, Monitoring & Management

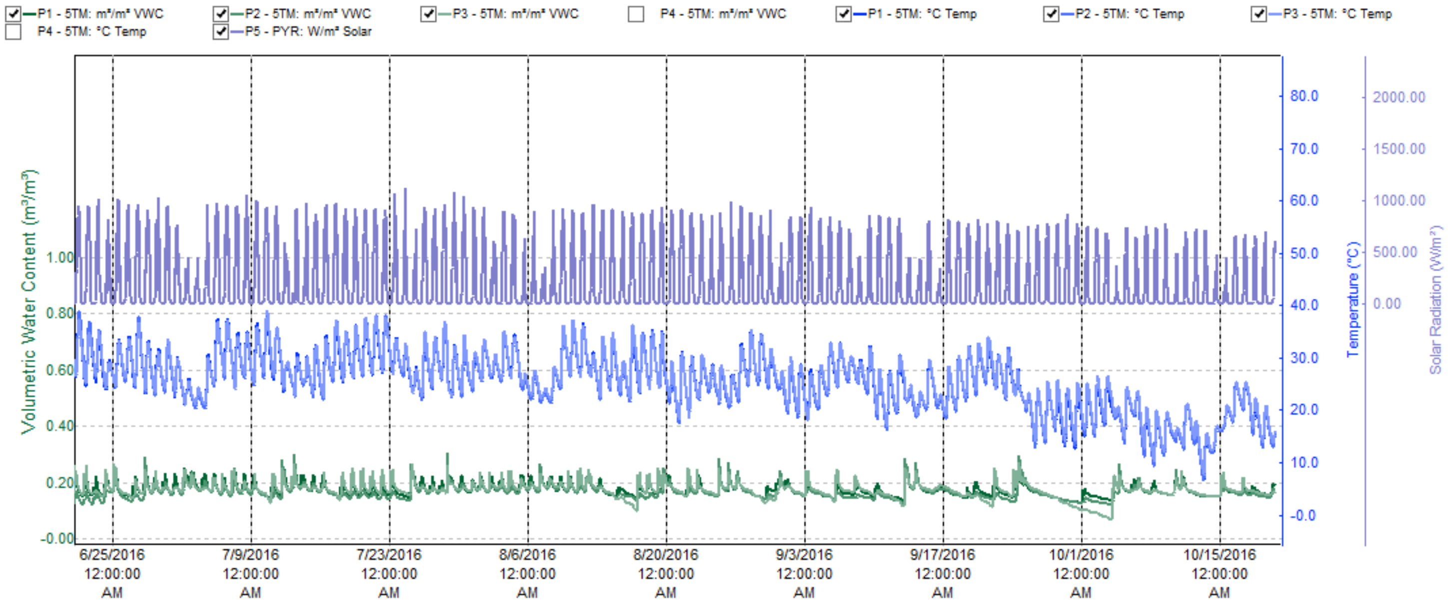


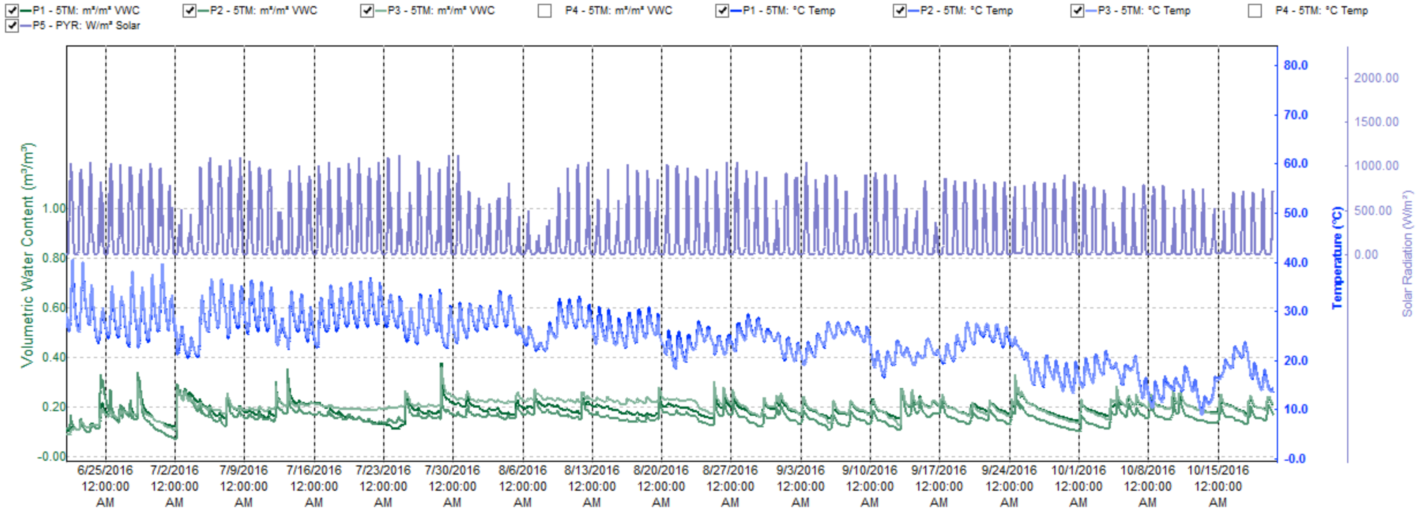
WMS-GR – 10 Sep. 2016

EMS-GR – 10 Sep. 2016

Dr. Deon van der Merwe was our 5 July 2016 UAV pilot and thermal & infrared image synthesizer.

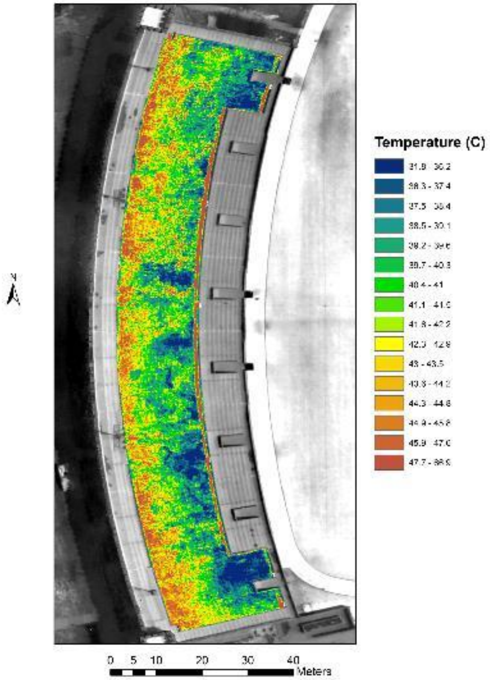
Solar radiation and sub-surface temperature & soil moisture readings on each MS-GR



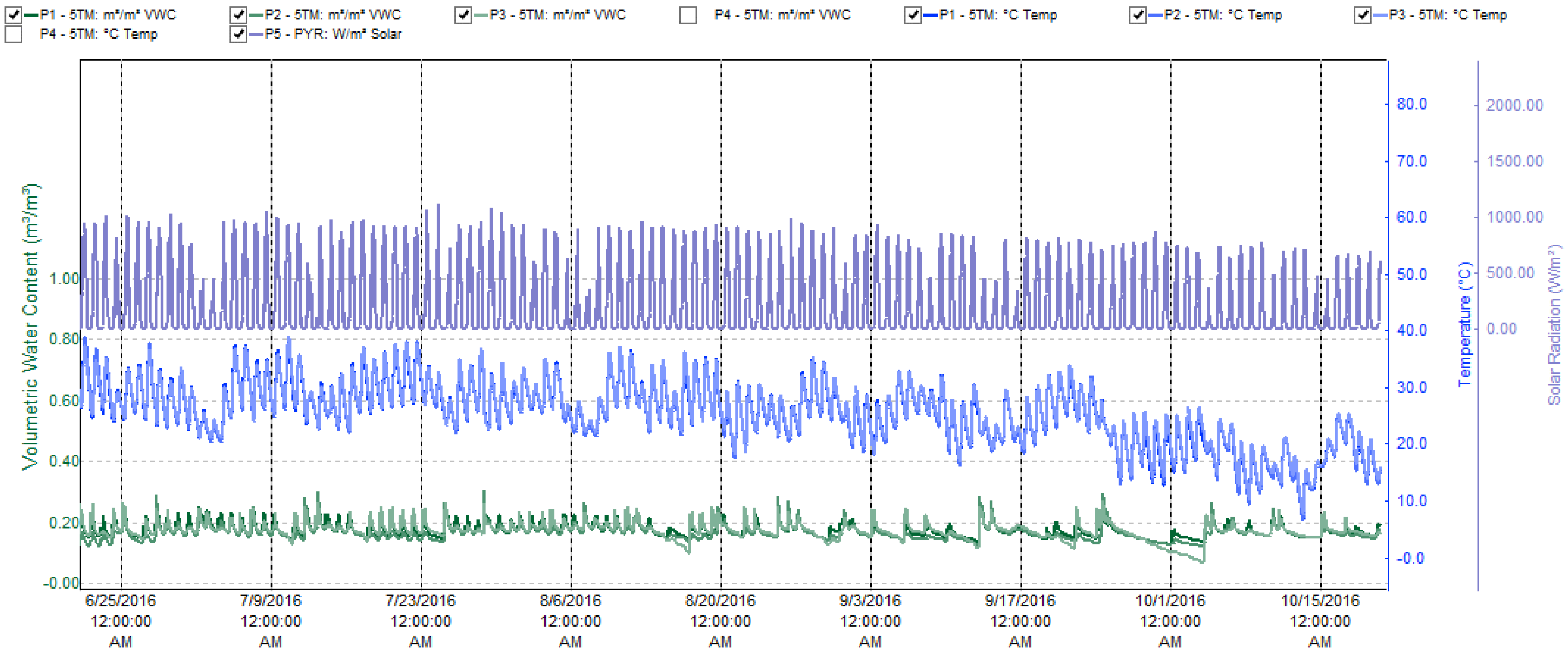


KSU West Memorial Stadium Green Roof Monitoring

West pavilion thermal map
July 5, 2016

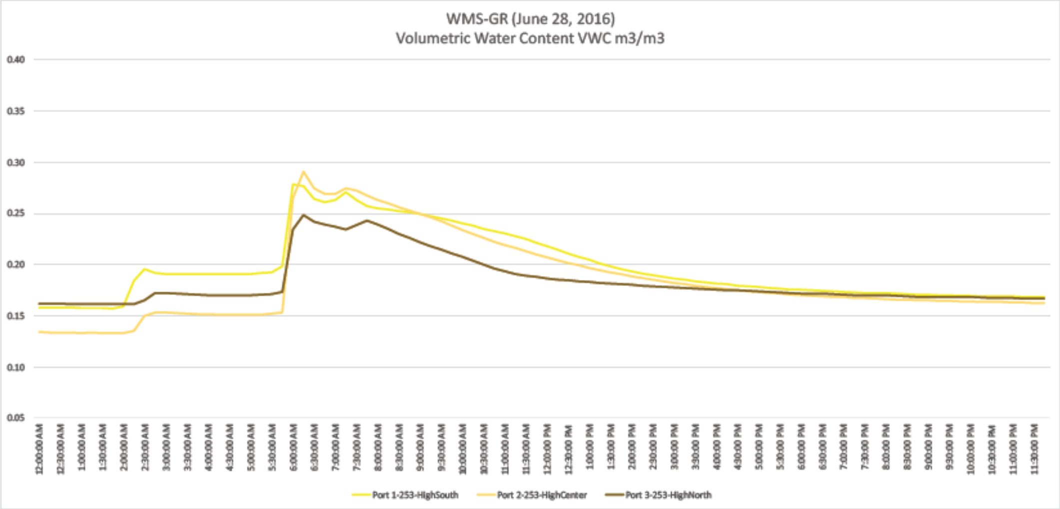


Solar radiation and sub-surface temperature & soil moisture readings on WMS-GR

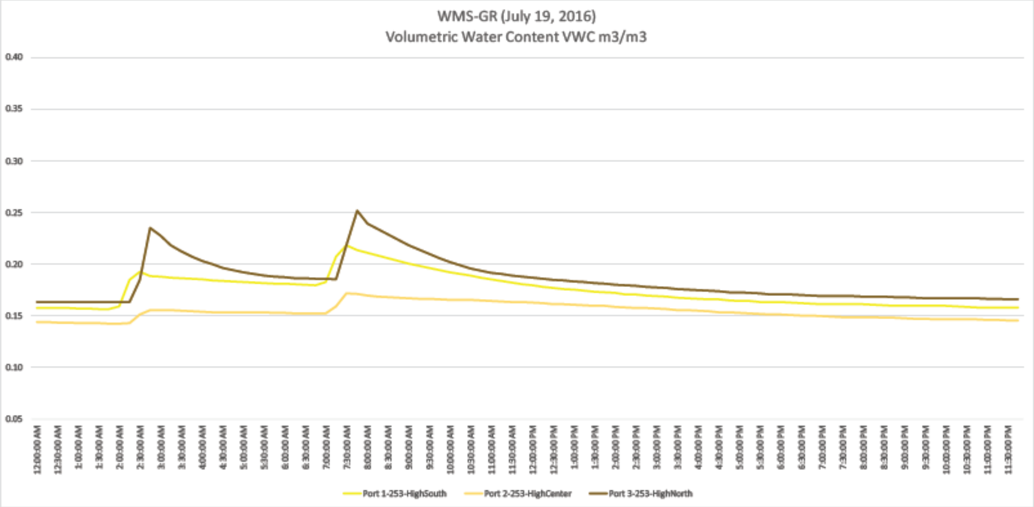


WMS-GR	High-South (P3)		High-Center (P2)		High-North (P1)	
	SM (VWC)	Temp (˚C)	SM (VWC)	Temp (˚C)	SM (VWC)	Temp (˚C)
avg	0.19	23.20	0.16	23.40	0.20	23.10
min	0.11	9.20	0.07	9.10	0.11	8.90
max	0.38	39.80	0.35	38.10	0.36	40.60

Volumetric water content levels for three upper sensors on WMS-GR in relation to rainfall on the Seaton Upper Green Roof (UGR) for four days during the 2016 growing season. Early morning irrigation occurred for all four selected dates.



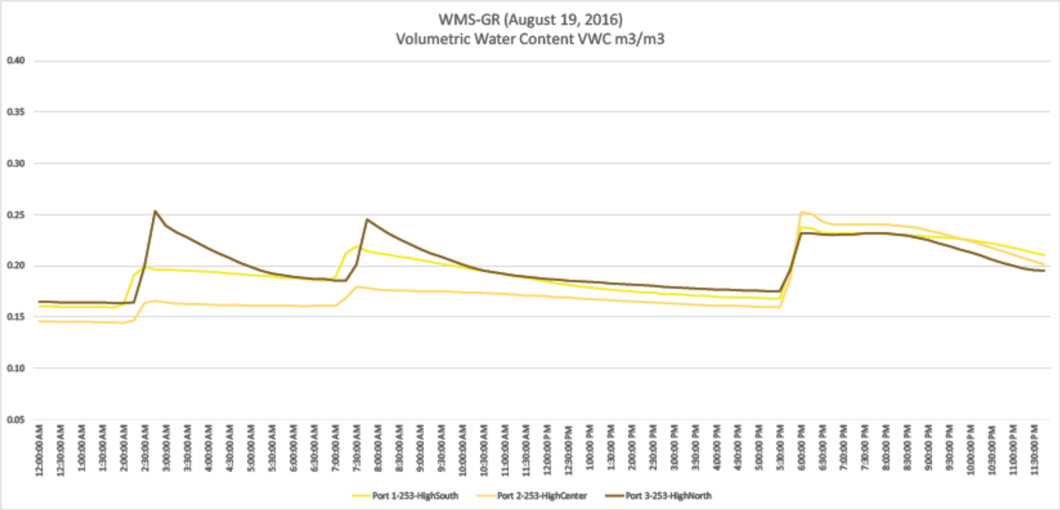
Rain event (0.83″ on Seaton UGR) over ~2.5 hour-period early morning (with 0.55″ in less than 30 minutes around 6:00am). Two irrigation events around 2:00am and 7:30am.



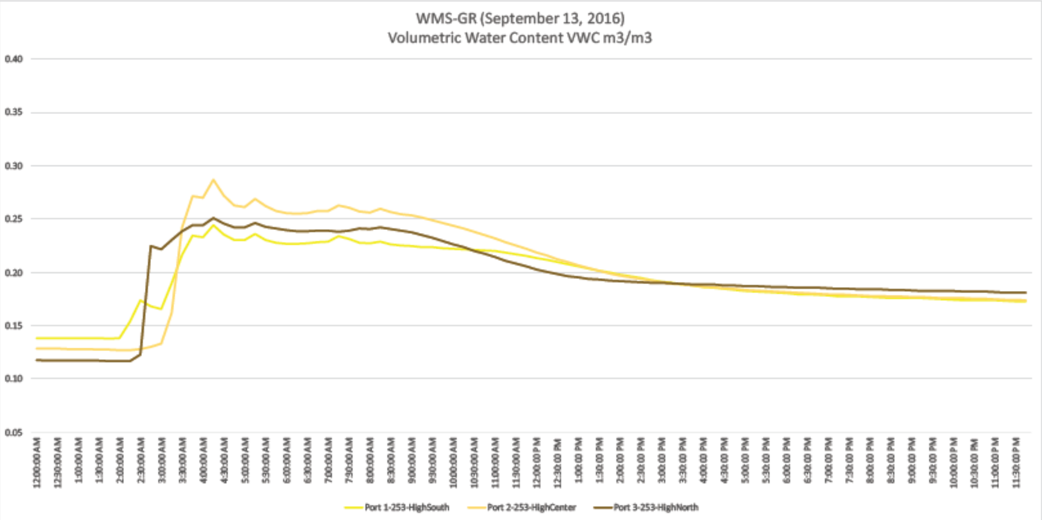
No rainfall. Two irrigation events around 2:00am and 7:30am.

Seaton UGR –
10 Sep. 2016

WMS-GR –
10 Sep. 2016



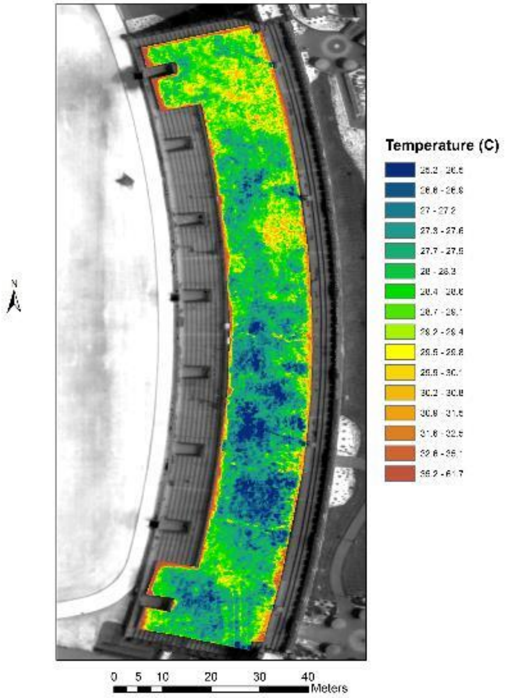
Rain event (0.94″ on Seaton UGR) over ~2.5 hour-period late afternoon (with 0.73″ in less than an hour between 5:15-6:00pm). Two irrigation events (2:00am and 7:30am).



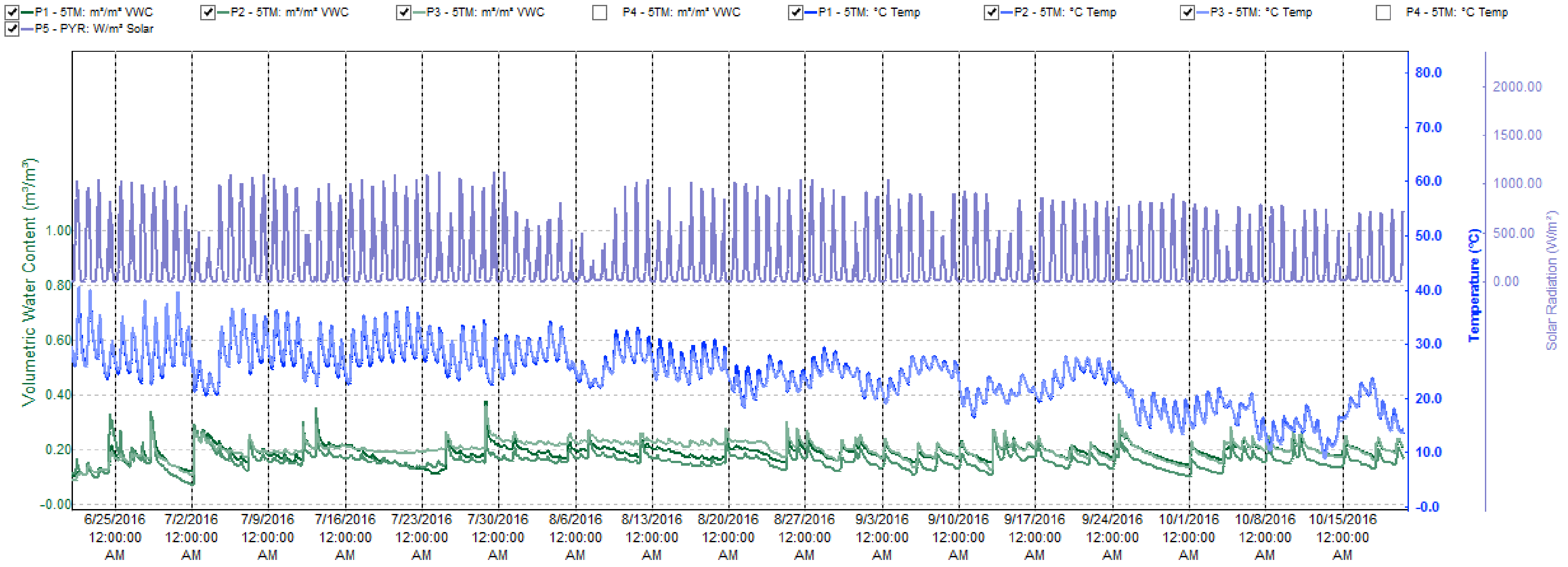
Rain event (1.52″ on Seaton UGR) over ~7.5 hour-period early morning (with 1.03″ in less than two hours between 2:00-3:30am). Two irrigation events (2:00am and 7:30am).

KSU East Memorial Stadium Green Roof Monitoring

East pavilion thermal map
July 5, 2016

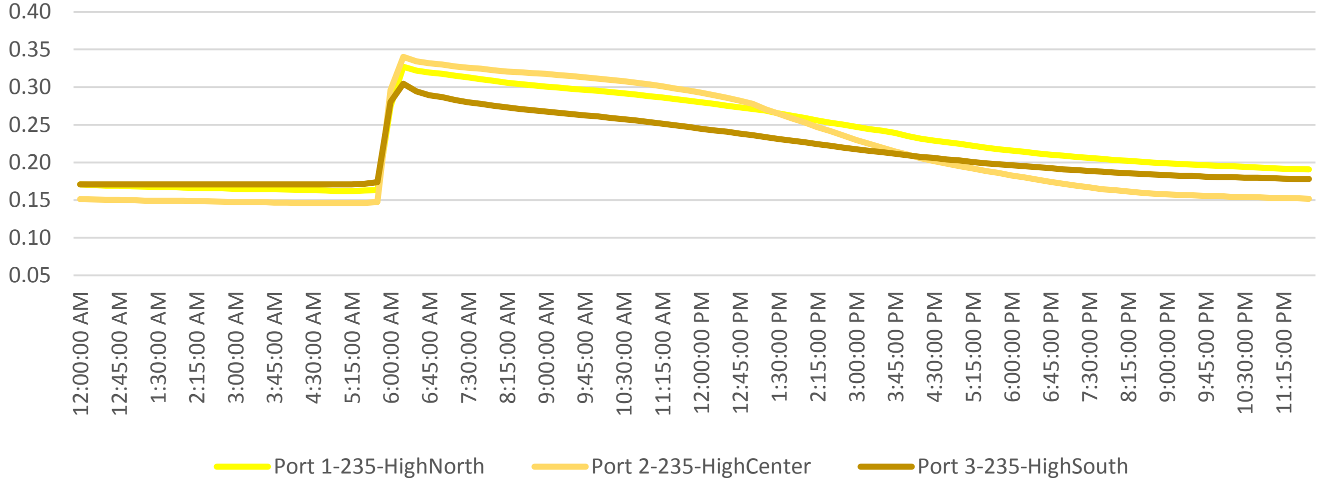


Solar radiation and sub-surface temperature & soil moisture readings on EMS-GR



EMS-GR	High-North (P1)		High-Center (P2)		High-South (P3)	
	SM (VWC)	Temp (˚C)	SM (VWC)	Temp (˚C)	SM (VWC)	Temp (˚C)
avg	0.17	24.40	0.17	24.30	0.17	24.70
min	0.13	6.70	0.12	6.40	0.07	7.50
max	0.29	38.40	0.30	39.10	0.27	39.20

EMS-GR (28 June 2016)
Volumetric Water Content VWC m3/m3

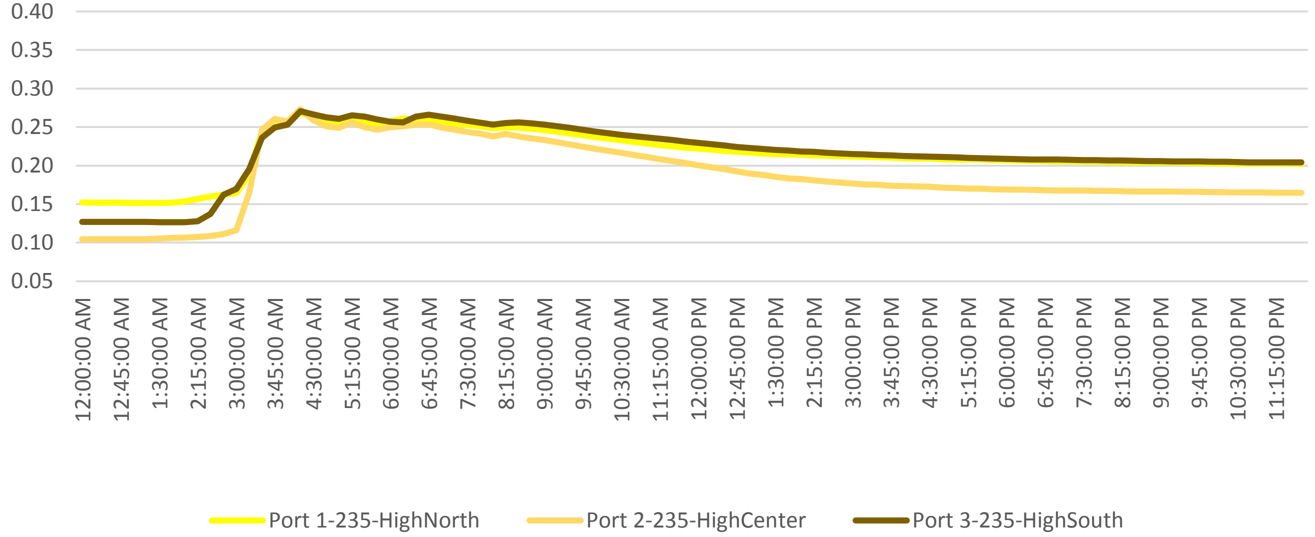






EMS-GR –
29-30 June 2016

EMS-GR (13 September 2016)
Volumetric Water Content VWC m3/m3







EMS-GR –
10 Sep. 2016

KSU Memorial Stadium Green Roofs
2017 Midwest Fish & Wildlife Conf. abstracts and 2016 KS Water Conference Student Poster

Helping stakeholders understand vegetative changes on two large-scale prairie green roofs in the Flint Hills Eco-region

Providing diverse, living vegetative coverage is deemed vital to optimize ecosystem services on green roofs. Kansas State University (KSU) faculty and students initiated studies of vegetation growing on two large green roofs on the KSU campus in 2016. Combined, the Memorial Stadium green roofs were seeded and planted with 30 native species and encompass more than 34,000 square feet. Research interests are two-fold: 1) to track vegetative change and understand what species do well on these steeply-sloped, 5-6-inch deep prairie-like systems (then suggest vegetative management strategies); and 2) to track soil/substrate moisture and supplemental irrigation (thus encouraging wise use of potable water). We hope that pollinator and bird studies might be done in the future by entomology and biology/ecology researchers. The success of the two MS-GRs depends on how they evolve over time, including how they conserve resources while achieving project goals and providing expected benefits. As such, understanding and communicating the goals and values of the designer and key stakeholders (especially KSU-Facilities personnel, responsible for managing the green roofs long-term) are vital. The primary purpose of the Memorial Stadium green roofs is to protect the structural integrity of each rooftop by limiting the number of people who can occupy these stadium roofs. Additionally, the two green roofs were created to communicate KSU's commitment to sustainability and create recognizable landmarks related to the prairie ecology of the Flint Hills on campus. Other ecosystem services are expected to accrue, including capturing some rain and snowfall, and restoring habitat for prairie birds and pollinators.

Green roof vegetation characterization using color-infrared and thermal sensors mounted on a small unmanned aircraft system

Monitoring green roof soil moisture dynamics on two large-scale prairie green roofs in the Flint Hills Eco-region with the aim of conserving potable water and promoting native plant coverage

A. Decker, P. Shrestha, R. Peters, E. Musoke, K. Koehler & D. Bandad (Kansas State University students)working with L. Skabelund, D. van der Merwe, M. Knapp, T. Moore, S. Hutchinson, A. Sharda & D. Bremer (KSU faculty)

Introduction

Green roofs are engineered ecosystems consisting of vegetation and a thin layer of growth media over a series of root barrier and waterproofing membranes (Oberndorfer et al., 2007). Providing diverse, living vegetative coverage on green roofs is vital to capture, conserve, and utilize rainfall and optimize various economic, aesthetic, and ecological services. Potable water is valuable and increasing in cost, yet it is often used to irrigate green roofs. This project aims to determine how much irrigation is needed to provide nearly complete coverage on a green roof and sustain species diversity (which in turn will promote greater pollinator and other faunal diversity). In the spirit of conclusions drawn by Klett et al. (2012) and MacIvor et al. (2013), if we are to improve green roof design, implementation, and management in the Flint Hills Eco-region and other similar temperate climatic regimes across the world, it is vital that we understand the relationships between micro-meteorological variables, substrates, and mixed-species performance on green roof systems (Nagase & Dunnett 2010; MacIvor et al. 2013). The best way to do this is to systematically monitor sub-surface soil moisture and temperature conditions, surface temperatures, solar and photosynthetically active radiation, plant available moisture, and essential micro-climatic variables (especially precipitation, air temperature fluctuations, relative humidity, and wind speed).

The Memorial Stadium Green Roof Research Project aims to better understand a number of these interrelated variables, with particular attention paid to vegetative coverage and soil moisture levels.

Fig. 1. Memorial Stadium green roofs on west (WMS-GR on left) and east (EMS-GR on right) at Kansas State University (photos taken looking north by Lee R. Skabelund – September 10, 2016).

Sensor Area Vegetation Photos (LR Skabelund)

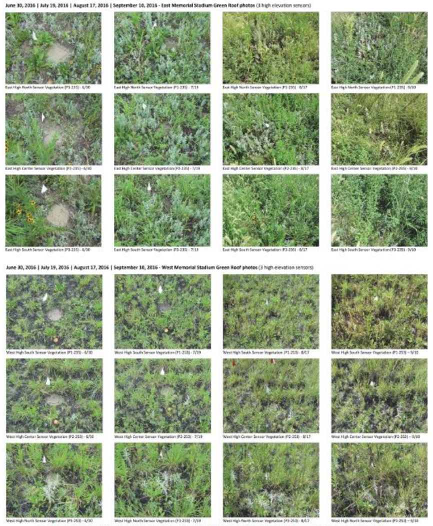
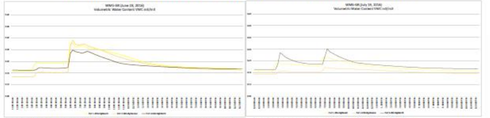


Fig. 2. Vegetation surrounding the high elevation Decagon 5TM soil moisture sensors on each MS-GR.



Rain event (0.83" on Seaton UGR) over ~2.5 hour-period early morning (with 0.55" in less than 30 minutes around 6:00am). Two irrigation events around 2:00am and 7:30am.

No rainfall. Two irrigation events around 2:00am and 7:30am.

Rain event (0.94" on Seaton UGR) over ~2.5 hour-period late afternoon (with 0.73" in less than an hour between 5:15-6:00pm). Two irrigation events (2:00am and 7:30am).

Rain event (1.52" on Seaton UGR) over ~7.5 hour-period early morning (with 1.03" in less than two hours between 2:00-3:30am). Two irrigation events (2:00am and 7:30am).

Fig. 3. Volumetric water content levels for three upper sensors on WMS-GR in discussion of rainfall on the Seaton Upper Green Roof (UGR) for four days during the 2016 growing season. Early morning irrigation occurred for all four selected dates.

Research Questions

The intent of this study is to assess how the planted vegetation evolves over time, recognizing that diverse prairie vegetation can provide important ecosystem services, including capturing a portion of rainfall and snowfall, and serving as transitory or permanent habitat for prairie birds, pollinators, and other fauna.

Very Broad Question: What are the interrelationships between substrate type and depth, roof slope, vegetative cover and growth, rooftop climatic conditions, evapotranspiration, supplemental irrigation, maintenance strategies, and soil moisture and temperature? **Initial Question related to the 24-hour Graphs:** What is the relationship between vegetative cover, rooftop climatic conditions, supplemental irrigation, and soil moisture?

Initial Project Tasks

1) carefully track vegetative change and understand what species do well on these steeply-sloped, 5-6-inch deep prairie-like systems to make it possible to suggest effective vegetative management strategies; and 2) track soil/substrate moisture and supplemental irrigation, thus encouraging the wise use of potable water.

Methods and Tools

The WMS-GR was seeded and planted in June and July 2015. The EMS-GR was seeded and planted in March and April 2016. Nine (9) Decagon 5TM soil moisture/temperature sensors were installed in the center portion of each roof, with three (3) sensors positioned at high, mid, and low elevations. Sensors are buried three inches below the substrate surface within a geo-web cell with the prongs oriented downslope and vertical. Sand-based green roof substrate depths are six inches deep, with expanded shale added to lighten substrates on the EMS-GR. A single Apogee PYR solar radiation sensor was placed near the center of each roof. For 5TM and solar radiation sensors on the MS-GRs, we are collecting averaged 15-minute data, which is downloaded remotely from Decagon EM5G loggers using DataTrac3 software.

Sensors record soil moisture as volumetric water content (VWC), which is graphed in relation to a seven-day period associated with photo dates of vegetation present near each sensor. For this poster we have focused on important senor readings, trends, and context (especially vegetative coverage) for the three highest elevation sensors on each green roof.

An Unmanned Aerial Vehicle (UAV) was flown over each roof mid-day on July 5, 2015. Data from thermal camera imagery is shown on this poster (as synthesized by Deon van der Merwe).

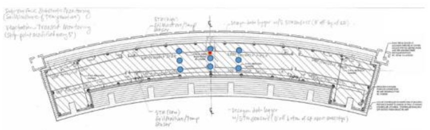


Fig. 4. Sensor Locations related to vegetative transect layouts and irrigation.

Fig. 5. WMS-GR photos (Lee R. Skabelund – July 19, 2016).

Fig. 6. UAV flight preparations (Lee R. Skabelund - July 5, 2016).

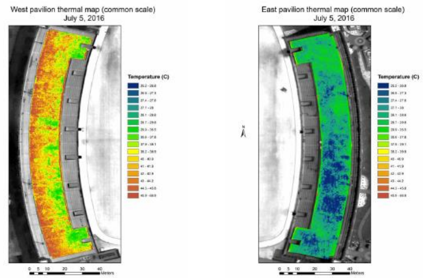
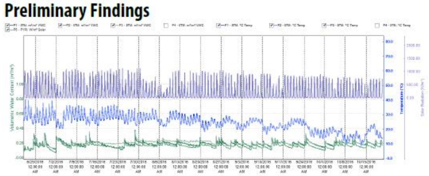


Fig. 7. Thermal image maps synthesized by Deon van der Merwe.

Preliminary Findings



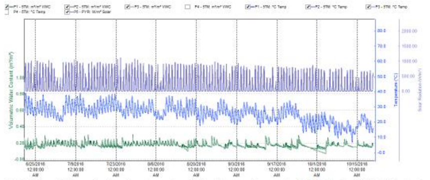


Fig. 8. Solar radiation, and sub-surface temperature/soil moisture readings on the EMS-GR (top) and WMS-GR (bottom).

Data Analysis

The chart on the right shows the summary (average, minimum, and maximum) values for the soil moisture and temperature for the six high sensors on the EMS and WMS green roofs. The chart below illustrates the variation between solar radiation, and sub-surface temperatures and soil moisture values, on each of the green roofs for three different rain events (June 28, August 19, and September 13, 2016).

EMS-GR	High-North (P1)		High-Center (P2)		High-South (P3)	
	SM (VWC)	Temp (°C)	SM (VWC)	Temp (°C)	SM (VWC)	Temp (°C)
avg	0.17	24.40	0.17	24.30	0.17	24.70
min	0.13	6.70	0.12	6.40	0.07	7.50
max	0.29	38.40	0.30	39.10	0.27	39.20

WMS-GR	High-South (P3)		High-Center (P2)		High-North (P1)	
	SM (VWC)	Temp (°C)	SM (VWC)	Temp (°C)	SM (VWC)	Temp (°C)
avg	0.19	23.20	0.16	23.40	0.20	23.10
min	0.11	9.20	0.07	9.10	0.11	8.90
max	0.38	39.80	0.35	38.10	0.36	40.60

28-Jun Rain Event	Variables		EMS-GR		WMS-GR	
	Sky Cover	28-Jun	partly sunny		mostly sunny	
	Solar Radiation	max	1027	28-Jun	965	27-Jun
	Temperature (°C)	low	39.5	28-Jun	33.4	28-Jun
		high	22.5	28-Jun	22.9	28-Jun
	Soil Moisture (VWC)	before	.15-.17	5:45 AM	.15-.19	5:45 AM
		peak	.30-.34	6:45 AM	.25-.29	6:15 AM
		level	.16-.20	9:00 PM	0.18	4:00 PM
19-Aug Rain Event	Variables		EMS-GR		WMS-GR	
	Sky Cover	19-Aug	mostly cloudy		mostly sunny	
	Solar Radiation	max	844	19-Aug	932	19-Aug
	Temperature (°C)	low	21.1	20-Aug	35.1	19-Aug
		high	29.4	19-Aug	21.1	20-Aug
	Soil Moisture (VWC)	before	.15-.22	5:45 PM	.16-.18	5:30 PM
		peak	.26-.28	6:00 PM	.23-.25	6:00 PM
		level	.19-.24	1:00 AM	0.19	2:00 AM
13-Sept Rain Event	Variables		EMS-GR		WMS-GR	
	Sky Cover	13-Sep	mostly sunny		mostly cloudy	
	Solar Radiation	max	923	13-Sep	857	10-Sep
	Temperature (°C)	low	16.8	13-Sep	30.4	13-Sep
		high	23.8	13-Sep	21.3	13-Sep
	Soil Moisture (VWC)	before	.10-.15	1:45 AM	.12-.14	2:00 AM
		peak	0.27	4:15 AM	.24-.29	4:15 AM
		level	.17-.21	4:45 PM	0.19	3:00 PM

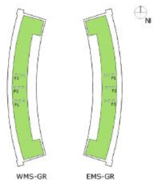


Fig. 9. June 21 to Nov. 5, 2016 MS-GR Soil Moisture and Temperature Summaries (top right), Selected Rain Event Data (bottom left) and Associated High Sensor Locations (synthesized by Decker, Shrestha, Skabelund - November, 2016)

Discussion

Due to more frequent irrigation (two times a day on the WMS-GR and three times a day on the EMS-GR), an early-in-the-season planting time, and abundant weed seeds finding their way onto the roof there is greater biomass and there are a very large number of agricultural weeds (including foxtail, pigweed, and lambs quarters) on the EMS-GR. Native grasses and forbs are more dominant on the WMS-GR. In late June 2016, dominant native plants on the EMS-GR were Indian grass and Louisiana sage, while dominant native plants on the WMS-GR in June 2016 were blue & hairy grama, little bluestem, Louisiana sage, prairie coneflower, yellow coneflower, and stiff goldenrod.

For the season, the average soil moisture readings ranged from 0.16 to 0.20 m3/m3. The highest subsurface soil moisture value of 0.38 m3/m3 was observed on the WMS-GR, and the minimum subsurface soil moisture value was observed on both green roofs (0.07 m3/m3). High and low (see Fig. 9) subsurface temperatures on the two MS-GRs ranged from 6.40 to 40.60 (C). Throughout the growing season there were many instances when irrigation and rain events were occurring simultaneously. In order to conserve potable water inputs on the two green roofs we need to limit instances when irrigation and rain events are occuring close to one another or at the same time. It is important to note that there is variability in the high sensor readings. Additionally, there are many variables to consider when monitoring green roof subsurface soil moisture and temperature, and further investigation is required to determine what is influencing variability throughout the substrate of the two green roofs.

Future Research

After monitoring the Memorial Stadium green roofs between June and November 2016 there is still a lot we do not know about the subsurface relationships. This is due to the inherent complexity of climatic conditions and these two steeply-sloped green roofs. In the future, evapotranspiration rates need to be measured and we need to look more closely at the data and complete focused statistical analyses to recognize any trends or patterns in regards to soil moisture changes related to vegetative 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 two new MS-GRs. Such research is expected to enable KSU to apply more sustainable green roof irrigation and maintenance operations and minimize potable water use – thus improving stormwater retention, reducing unnecessary runoff to storm sewers, and reducing green roof maintenance demands and rooftop disturbance). MS-GR research findings are expected to inform future designs and maintenance activities for sloped green roof systems. We plan to continue to monitor the MS-GRs in 2017 and use the lessons learned on the Architecture, Planning & Design Research Green Roof (to be created in 2017).

Literature Cited

Klett, J.E., J.M. Bousselot and R.D. Koski. 2012. Evaluation of green roof plants and materials for semi-arid climates. Prepared for USEPA-Research & Development, Cincinnati, OH. EPA/6000/R-12-592.

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Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R.R., Doshi, H., Dunnett, N., Gaffin, S., Kohler, M., Liu, K.K.Y., Rowe, B., 2007 Green roofs as urban ecosystems: ecological structures, functions, and services. Bioscience 57, 823-833.

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Special thanks to Stephanie Rolley & Tim Keane (KSU-LARCP) for their research proposal reviews and guidance.
Thanks also to Jeremy Sharp & Joe Myers (KSU Facilities) and Tim Sharp (Blueville Nursery) for their assistance.

Future Research

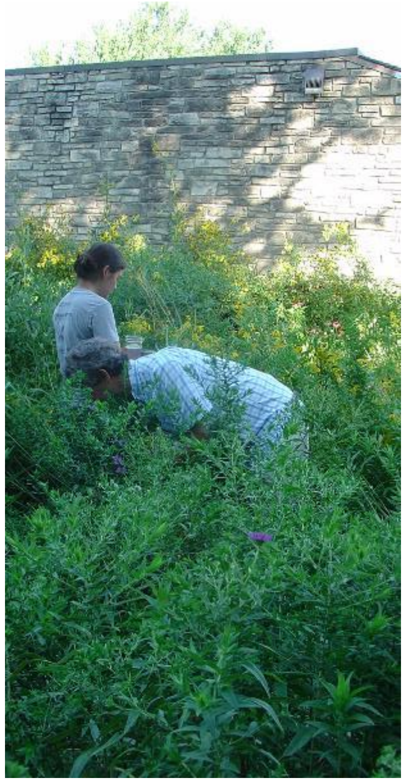
After monitoring the Memorial Stadium green roofs between Jun-Nov 2016 there is still much we do not know about surface and subsurface relationships due to the inherent complexity of climatic conditions and these two steeply-sloped green roofs.

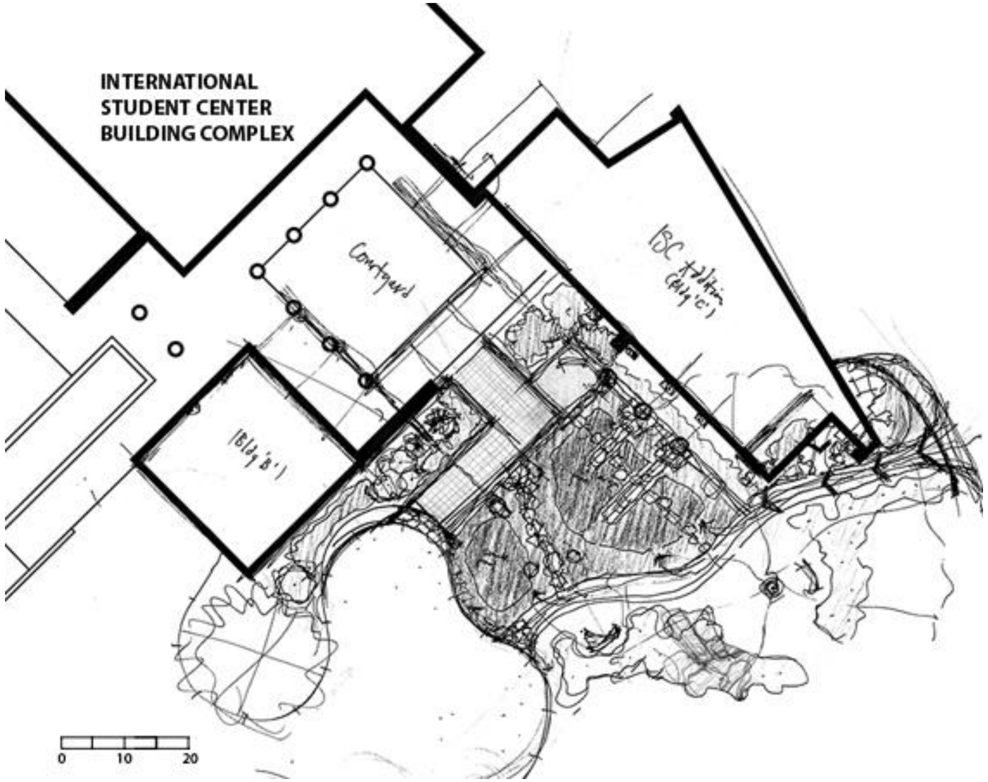
Evapotranspiration rates need to be estimated, and we need to look more closely at the data and complete focused statistical analyses to recognize trends or patterns in regards to soil moisture changes related to vegetative coverage.

Since the Decagon 5TM sensors were placed so as to interrogate the upper 2/3's of the substrate we plan to move and rotate the sensors so they sense the lower portion of the substrate (including the drainage mat area) for the 2017 growing season.

Our interdisciplinary team of faculty and student researchers plans to continue studying changes in vegetative coverage, species diversity & sub-surface soil moisture levels on the two new MS-GRs. Such research should enable KSU to apply more sustainable green roof irrigation & maintenance operations and minimize potable water use – thus improving stormwater retention, reducing unnecessary runoff, and reducing green roof maintenance demands & rooftop disturbance.

MS-GR research findings are expected to inform future designs & maintenance activities for sloped green roof systems.
We plan to continue to monitor the MS-GRs in 2017 and use the lessons learned on the Architecture, Planning & Design Research Green Roof (to be created in 2017).





ISC Rain-Garden Design, Implementation, Monitoring, Management & Outreach

Project Director/Lead Designer:
Lee R. Skabelund

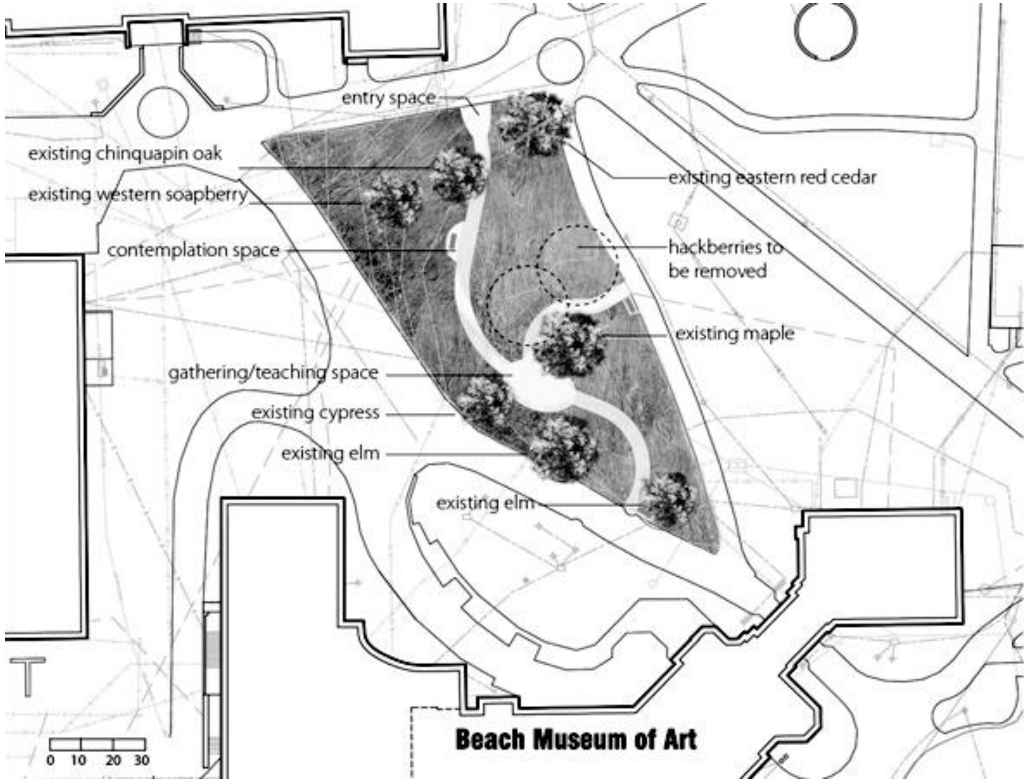
Project Completion (Construction):
March-June 2007 (gardens and pathways);
May 2008 (rain-bowls)

Pre-existing Land Use Type:
Turfgrass

Project Funding/Support:
USEPA, KDHE, WaterLINK, KSU,
and many partners

Size:
Approx. 3,000 square feet

turfgrass to garden; pipe to non-pipe



The Meadow Design, Implementation, Monitoring, Management & Outreach

Project Director/Designer:
Katie Kingery-Page

Project Completion (Construction):
Summer 2013 (seeding, pathways, benches);
June 2015 additional planting

Pre-existing Land Use Type:
Turfgrass

Project Funding/Support:
Hummel Family Memorial Fund, KSU,
and many partners

Size:
Approx. one half acre (21,000 square feet)

turfgrass to prairie-like meadow