QUALITY ASSURANCE PROJECT PLAN

EVALUATION OF GREEN ROOF BIOLOGICAL PERFORMANCE

June, 2008

Characterization of Green Roof Performance
X3-83350101-0

QUALITY ASSURANCE PROJECT PLAN

for

EPA Region 8 Green Roof Biological Performance Project

Prepared by:

James E. Klett, Jennifer M. Bousselot

Colorado State University, Department of Horticulture and Landscape Architecture

Fort Collins, CO 80523-1173

Phone: 970-491-7179

E-mail: Jim.Klett@colostate.edu
Jennifer.McGuire.Bousselot@colostate.edu

http://hla.colostate.edu/

GROUP A: PROJECT MANAGEMENT

A1. TITLE AND APPROVAL PAGE

Prepared for:

U. S. ENVIRONMENTAL PROTECTION AGENCY

REGION 8

And:

COLORADO STATE UNIVERSITY

January, 2008

APPROVALS:

Tony Medrano/QA Manager, EPA Region 8 ______________________________

Carolyn Esposito/QA Officer, EPA ORD ______________________________

James E. Klett, Professor of Horticulture, CSU ______________________________

Panayoti Kelaidis, Director of Outreach, DBG ______________________________

A2. TABLE OF CONTENTS

A3. DISTRIBUTION LIST:

Official copies of this QAPP and any subsequent revisions will be provided to:
U.S. Environmental Protection Agency, Region 8
Tony Medrano, Quality Assurance Manager

U.S. Environmental Protection Agency, Office of Research and Development
Thomas O' Connor, Project Officer
Carolyn Esposito, QA Officer

Colorado State University, Department of Horticulture and Landscape Architecture
James E. Klett

Denver Botanic Gardens, Director of Outreach
Panayoti Kelaidis

Urban Drainage Flood Control District
Ben Urbonas

Copies of this Quality Assurance Project Plan will be available online at www.epa.gov/region8/greenroof

A4. PROJECT TASK/ORGANIZATION

Personnel Responsibilities

James E. Klett, Professor of Horticulture, Colorado State University, Department of Horticulture and Landscape Architecture

Responsible for overseeing the biological performance of the green roof, coordinating with DBG on expected outcomes, and producing annual reports.

Jennifer Bousselot, Graduate Student, Colorado State University, Department of Horticulture and Landscape Architecture

Responsible for experimental design, data collection and summary, literature review, writing for the annual reports and general maintenance of the biological performance experiments.

James zumBrunnen, Statistician, Colorado State University, Agricultural Experiment Station

Facilitate experimental design and data analysis.

Tony Medrano, Acting Laboratory Director/Quality Assurance Manager

Responsible for signing QA plans as the QA manager and ensuring that equipment and funding is available for laboratory analysis.

Collected data is made available to all interested government agencies and the general public. Primary data users include: EPA staff and its partner organizations; Denver Botanic Gardens (DBG), the City and County of Denver, Colorado State University Extension, Colorado State Agricultural Experiment Station, the Green Industries of Colorado and the Urban Drainage Flood Control District. All data will be provided in electronic format through the EPA web site.

A5. PROBLEM IDENTIFICATION/BACKGROUND

Green roofs are planted for many reasons, including stormwater management, reducing the Urban Heat Island (UHI) Effect and for general aesthetics. In order to provide these benefits, as well as many others, green roofs have to remain alive. In the semi-arid, high elevation environment of the Front Range of Colorado, green roofs have not been scientifically tested for long term survivability and adaptability. The low annual precipitation, low average relative humidity, high solar radiation due to elevation, high wind velocities and predominantly sunny days all add up to stress plant health. Therefore, plants that are adapted to extensive green roofs in other environments more suited to ideal plant performance (i.e. high moisture, high humidity and more cloud cover) may not survive in these conditions.

Plants native to Colorado, which inhabit areas with shallow, rocky, well-drained soils are good candidates for green roof plants. Ideally, when these plants are tested they will compare, if not out-perform, the *Sedum* species currently on the EPA Region 8 green roof. *Sedum* species are some of the plants most often used on green roofs currently because of their relative drought tolerance and the fact that many are evergreen groundcovers. Researching additional plant species not already in use on extensive green roofs will expand the plant palette. Hopefully, this will prevent *Sedum* species from becoming a monoculture on green roofs. A monoculture has a higher probability of pest problems than a system that has diversity because most pests are host specific and if there is plenty of their food available, their populations tend to increase dramatically.

The modern extensive green roof is based on a design that uses expanded clays and shales and research is still limited to a handful of case studies using these systems; therefore additional research on media mixes appropriate for use on green roofs is necessary. And, similar to the need for diversifying plant species on a green roof, additional media mixes will benefit green roof systems as well, especially as the plant palette increases.

A6. PROJECT/TASK DESCRIPTION

The data collected through this project will be used to achieve four objectives:

1. Determine herbaceous plant species suitable for green roof use in the semi-arid, high elevation Front Range of Colorado.
2. Determine media types or mixes suited to supporting extensive green roof plants.
3. Identifying additional areas for expanded research.

Achieving objective #1: Determine herbaceous plant species suitable for green roof use in the semi-arid, high elevation Front Range of Colorado.

Plants will be selected for experimentation based on certain criteria: drought resistance, if they are groundcovers (beneficial for extensive green roofs to obtain good coverage) or accent plants (good for contrast with groundcovers in heights and bloom times), if they are evergreen and length of bloom season (Table T-1). Species which are native to Colorado are important because they are adapted to the extreme conditions of the climate, hence the indication of nativity.

Table T-1: GREEN ROOF PLANT SPECIES TO BE TESTED

Species	Benefits					
	drought	groundcover	evergreen	native	long bloom	bloom color
Antennaria parvifolia	X	X	X	X	X	white
Bouteloua gracilis	X	X		X		turf
Delosperma cooperi	X	X	X		X	deep pink
Eriogonum umbellatum	X	X	X	X	X	yellow
Opuntia fragilis	X	accent	X	X		varies
Sedum lanceolatum	X	X	X	X		yellow

Plants that are drought resistant typically employ one of three methods: avoid, escape, or tolerate. Not all types of drought resistance in plants are well-suited to green roofs. For example, some plants avoid drought by rooting deeply to access a more stable supply of water; this will obviously not be possible on a green roof. Plants that use the escape tactic are not ideal for green roofs either because they have short life cycles, timed to grow and reproduce during the rainy season, and green roofs should ideally be green at least throughout the growing season, if not year round. True drought tolerance is not a trait commonly found in plants; these plants merit further investigation for use in green roofs.

One example of true drought tolerance that does fit in with green roof systems is Crassulacean acid metabolism (CAM). Many *Sedum* species are CAM plants. Crassulacean acid metabolism refers to the family name of these plants (Crassulaceae) and the way they metabolize or utilize carbon. CAM plants are truly drought tolerant because they keep their stomata (pore-like structures where gas exchange and transpiration occur) closed during the day when transpiration rates are high, and open them at night when transpiration rates are significantly lower. While it is good that CAM plants keep their stomata closed during the day, they have to manage their CO_2 intake much differently than other plants. Carbon dioxide is needed while photosynthesis is taking place (daytime) so CAM plants have to convert the CO_2, which is brought in only at night, into a useable form for use during the day. This process takes additional energy, slowing the growth of the plant. Still, the tradeoff of higher energy use for water savings is beneficial to the plant in drought conditions.

Environmental conditions will be monitored by use of Campbell Scientific weather monitoring equipment (Table T-2). This data will be used to help with interpretation of plant performance.

Table T-2: WEATHER MONITORING EQUIPMENT*

Campbell Scientific Equipment (Model #)	Description	Range of Tolerance	Accuracy/ Precision
Infrared Radiometer (IRR-P)	Surface temperature of vegetation	-55º to +80ºC	±0.2ºC @ -10º to +65ºC; ±0.5ºC @ -40º to 70ºC
Temperature and Relative Humidity Probe (HMP45C)	Measures temperature and RH at 12 inch height	-40º to +60ºC	±2% over 10-90% RH; ±3% over 90-100% RH
Young Wind Sentry set (03001-L)	Wind speed and direction	0 to 50 m/s	±0.5 m/s
Tipping Bucket (TE525WS-L)	Precipitation gage	0° to +50°C	Up to 1 in/hr = ±1%, 1-2 in/hr = +0, -2.5%; 2-3 in/hr = +0, -3.5%;
Snowfall conversion adaptor (CS705)	Converts snowfall into rain equivalent	to -20°C	assumes 1:0 starting ratio of antifreeze to water
Silicon Pyranometer (LI200X)	Solar radiation sensor	-40° to +65°C	Absolute error in daylight is ±5% max; ±3% typical
Datalogger (CR1000)	Data storage device		Battery: 12 volt PS100 Campbell Scientific

*See Urban Heat Island Mitigation QAPP for more detailed information on the weather station.

Achieving Objective #2: Determining media types or mixes suited to support extensive green roof plants

Most extensive green roof media is predominantly made up of expanded slate, shale or clay. While these materials are very well-drained, lightweight but do not blow away and do not break down like organic materials, they do have some limitations. They typically drain too quickly (too much macro-pore space, not enough micro-pore space) and do not hold nutrients very well (low cation exchange capacity - CEC).

A material that has all of the benefits of expanded slate, shale and clay, while having more micro-pore space and higher CEC is ideal. One example of a material that may fit this description is zeolite. Zeolites are currently being utilized as amendments for shallow, well-drained golf greens.

Achieving Objective #3: Identifying additional areas for expanded research

There is significant interest nationwide in the green roof project proposed at the EPA Region 8 office. It is important that EPA work with other interested parties to determine new areas for research and design. EPA has established a working relationship with the Urban Drainage Flood Control District in Denver to study aspects of stormwater management on green roofs. EPA Region 8 has also agreed to work with EPA's Office of Research and Development to determine areas for technology transfer. As this project moves forward, additional areas for expanded research will be explored. Potential projects which may elicit further research include:

1. Quantifying actual water requirements of plant species
2. Measuring carbon flux
3. Evaluating effects of green roofs on the longevity of roofs on commercial and industrial buildings in the Denver region
4. Providing assistance to developers in citing and selecting green roof matrices
5. Evaluating effects on temperature and minimizing urban heat islands

Table T-3: SCHEDULE OF TASKS

Major Task Categories	J08	F08	M08	A08	M08	J08	J08	A08	S08	O08	N08	D08
Initiate species trials			X									
Initiate media trials			X									
Initiate digital imaging			X									
Initiate moisture sensing					X							

A7. DATA QUALITY OBJECTIVES FOR MEASUREMENT DATA

Automated data will be taken for environmental conditions by the weather station such as precipitation, diurnal temperature measurements, wind speed and direction and solar radiation (Table T-2). A similar weather station will be set up on a nearby building that does not have a vegetated roof. Comparisons in environmental conditions will be made.

Photographs and visual data will be taken weekly to measure the success of the experimental trials. See Section B1 for more information on image acquisition and Section B2 for description of photo analysis.

A8. TRAINING REQUIREMENTS/CERTIFICATION

No special training requirements or certification is required for these trials.

A9. DOCUMENTATION & RECORDS

All quantitative data measurements gathered will be recorded on a Colorado State University laptop. Data will then be transferred to a Region 8 EPA server to be backed up. Printed copies can be available.

Environmental monitoring data from the green roof will be recorded in the Campbell Scientific datalogger and instantly transferred to a Region 8 EPA computer. Telemetry will be used for the control roof to transmit data from that weather station. Data will be saved on the computer and automatically transmitted via the internet to any interested parties.

Any changes or alterations to the procedures laid out in this manuscript will be documented in addendums provided as the need arises. Any addendums will be distributed electronically and will also be available on the EPA Region 8 green roof website: http://www.epa.gov/region8/greenroof/documents/index.html.

GROUP B: DATA GENERATION AND ACQUISITION

B1. SAMPLING PROCESS DESIGN

Blocking

For all three studies, there will be five blocks or replications. The five areas are zoned as 3 x 8 tray areas on the existing EPA Region 8 headquarters green roof. See Figure F-1 for a graphical depiction of the design layout on the roof for all three studies. Of the 24 existing trays in each block, 12 of them will be randomly chosen and assigned to one of the three studies. Six of the trays will be for Study 1 (species study) the area of four trays will be for Study 2 (media study) and two trays will be for Study 3 (mixed study). The rest of the trays (12) will remain as the existing green roof to provide an *in situ* environment (see Figure F-2).

Figure F-1: TRAY CONFIGURATION FOR ALL THREE STUDIES

Figure F-2: PHOTO DEPICTION OF TRAY LAYOUT (04/09/08)

Data (See Section B2 for descriptions of data capturing methods.)

For all three studies, data will be taken first on survivability, and of those that survive growth rate measurements will be used to determine success. Photographs to determine growth rate by measuring change in area covered per week will be taken. The photographs will be taken once a week, every Wednesday, during the growing season (~April 1st - November 1st) in a predetermined order at the same time of day. The predetermined order will help ensure the plants are photographed at about the same time of day each week. Plant widths and heights will also be recorded. Top growth dry weights of each plant in the experiment will be taken at the end of the experiment.

Drought resistance in the shallow, well-drained media of extensive green roofs is a significant factor of plant survivability. Plus, different plants use water at different rates; therefore their water use efficiency will be valuable in determining how appropriate they are in green roof applications. Soil moisture content will be measured to compare relative drought resistance of plants. Delta-T Theta Probe ML2X (Delta-T Devices, Cambridge, UK) will be used to take instantaneous readings of volumetric soil moisture content (Figure F-3). Researchers at Michigan State University have successfully used Delta-T Theta Probes ML2X in green roof research with similar media types (Durhman *et al.* 2006, Monterusso *et al.* 2005, VanWoert *et al.* 2005).

Figure F-3: DELTA-T THETA PROBE ML2X SOIL MOISTURE SENSOR
(www.delta-t.co.uk)

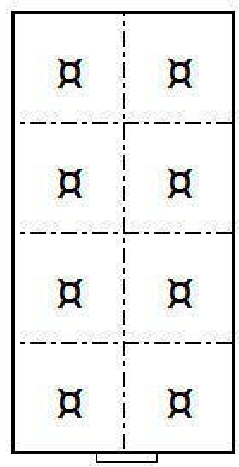
Overwintering success will be of vital importance as Front Range Colorado winters are typically characterized by warm sunny days (frequently up to 60ºF [15ºC] or above) and freezing nights with high winds occurring often and unpredictable precipitation and snow cover duration. These environmental conditions are difficult for plants due to moisture limitations. Plants still require moisture during the winter to prevent winter desiccation and maintain adequate root metabolism. Between November 1st and April 1st, monthly visits (at a minimum) will be performed to check on plant health and take data.

Study 1 (species study)

The treatment will be one of six species (Table T-1). A series of the six species/treatments (one species per tray) will then be put into one of the five blocks described above. Therefore a total of six species, replicated five times will equal 30 trays (since one species is equal to one tray). In a tray, eight individual plants will be planted, each with a square foot (~0.09m^2) of growing space (2ft x 4ft [0.61m x 1.22m] trays) (Figure F-4).

Figure F-4: EXAMPLE OF TRAY LAYOUT FOR STUDY 1 (SPECIES STUDY)

Plants are represented by ¤, solid lines correspond to tray edges and dotted lines show the imaginary lines between the 1 ft^2 (0.093 m^2) areas.



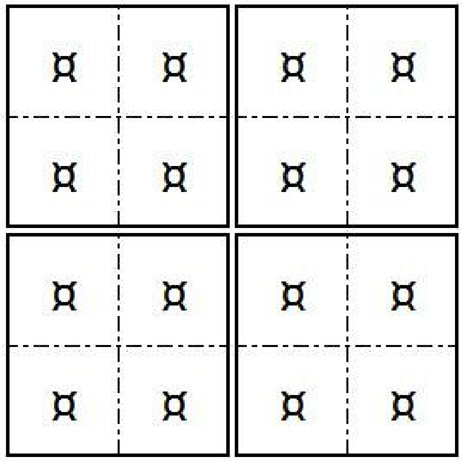
Study 2 (media study)

For the green roof media trial, three species (one species will have two varieties) of *Sedum* already on the green roof (*Sedum acre*, *S. album*, *S. spurium* 'Dragons Blood' and *S. spurium* 'John Creech') will be planted into one of four percentages (0%, 33%, 66% or 100%) of zeolite mixes to determine which concentration is most suitable for plant growth. The remaining percentages of media will be made up of the media already in use on the EPA Region 8 green roof. The media mix is a proprietary blend owned by Weston Solutions for use in the Green Grid product line. The mix is 80% inorganic and 20% organic materials.

The experiment will be replicated 10 times and set up as a randomized complete block design, similar to the Study 1 (species study) but the variable will be media type instead of species. One difference between the Study 1 (species study) and the Study 2 (media study) is that the trays are a smaller size. They are 2ft by 2ft (0.61m x 0.61m) (Figure F-5). Four trays together will be a replication. All four percentages of media will be randomly assigned to one of the four areas in each replication. The Study 2 (media study) will be set up in this manner to keep environmental variability to a minimum.

Figure F-5: EXAMPLE OF TRAY LAYOUT FOR STUDY 2 (MEDIA STUDY)

Plants are represented by ¤, solid lines correspond to tray edges and dotted lines show the imaginary lines between the 1 ft^2 (0.093 m^2) areas.



Also similar to the Study 1 (species study), the Study 2 (media study) will use Delta-T Theta Probe ML2X (Delta-T Devices, Cambridge, UK) to take instantaneous readings of soil moisture content in millivolts (mV). As zeolite is reputed to have good micro-pore space available for holding water, at least compared to other extensive green roof media materials, soil moisture holding capacity of the media should increase with zeolite content in the mix.

Study 3 (mixed study)

The mixed Study 3 (mixed study) will be set up like the Study 1 (species study) except eight different species (Table T-4) will be planted together in each of 10 2ft x 4ft (0.61m x 1.22m) trays. Five of the trays will be planted with the existing green roof media and another five will have 50% by volume zeolite mixed in with the existing media. One tray of each will be placed in each of the five blocks. Besides the usual data taken, special attention will be paid to plant interactions and changes in available soil moisture compared to the Study 1 (species study).

Table T-4: PLANT SPECIES IN STUDY 3 (MIXED STUDY)

Species, Scientific Name	Common Name
Allium cernuum	Nodding Onion
Antennaria parvifolia	Small-leaf Pussytoes
Bouteloua gracilis	Blue Grama
Delosperma cooperi	Hardy Ice Plant
Eriogonum umbellatum	Kannah Creek® Buckwheat
Opuntia fragilis	Brittle Pricklypear
Sedum lanceolatum	Lanceleaf Stonecrop
Sempervivum rubrum	Hens and Chicks, Houseleek

Other

Additional experiments may be necessary to see how an expanded palette of plants reacts to the experimental media types or mixes. This experiment would be a two-factor randomized complete block design. Additional experiments will be added by addendum.

B2. SAMPLING METHODS REQUIREMENTS

Photos

As a measure of plant growth rate and success, plant expansion (grown rate) will be measured each week during the growing season (~April 1st - November 1st) by using a series of digital photographs. The camera will be mounted to a Bogen Manfrotto 190xprob tripod (Ramsey, NJ) with an extendable horizontal arm. A plum bob will be used to ensure that all photos are taken from a preset distance and a bubble level on the back of the camera will ensure the photo orientation is consistent for every picture. The same camera (Fuji Film S3000 with a 6x optical zoom 3.2 mega pixels lens) and image settings will be used to keep constant any differences these factors could make in image quality.

The photos will be measured by SigmaScan Pro 5.0 image analysis software (SPAA Science, Chicago). This image analysis will be used to draw outlines for each plant in each photograph. Changes from one week to the next in area covered will indicate growth rate. Researchers at Michigan State University have successfully used this method in their trials to measure growth rates of green roof species (Durhman *et al*. 2007).

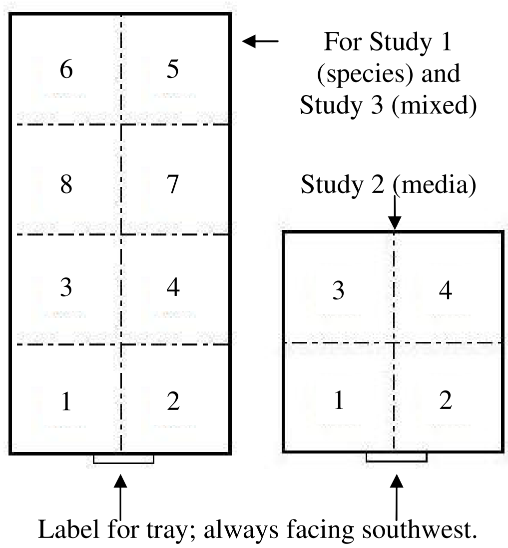
Comment [jmb1]: I talked to Durhman from Michigan State at the green roof conference. She said the colors of the plants were not the same greens (too many reds, blues, etc.) so trying to count pixel numbers was not feasible. She used the outline function. Tedious but doable.

Widths and Height

Individual plant widths and heights will be measured weekly for each of the three studies. Plants are numbered as described in Figure F-6. Two widths will be taken. One will be parallel to the short end of the tray (2ft [0.61m]) and the other will be perpendicular to it. Plant height will be taken at the center of the plant. See Appendix 1, Figures F-8, F-9 and F-10 for an example of the datasheets for all three studies.

Figure F-6: LAYOUT OF PLANTS IN TRAYS FOR ALL THREE STUDIES.

The plants are labeled to keep measurements consistently throughout the experiment. There is a label pasted on one end of each tray and all trays are oriented the same direction.



Dry Weights

All above media portions of each plant in both studies will be harvested at the end of the experiment. Root weights will not be measured because neighboring plant roots will grow together and be difficult to separate. Plants will be cut at media level, rinsed in water to remove media debris, patted dry with a paper towel and fresh weight mass will be recorded. Samples will be inserted into a prelabeled 13x7.9x27cm brown paper bag (Rite Aid, Harrisburg, PA, USA) to allow air and water movement through the paper. The samples will be dried in an oven at 70ºC for 72 hours and weighed for dry weights. The balance used to measure fresh and dry weights will be a Sartorius model number R200D (Sartorius Bohemia, New York, USA). Scale calibration is performed every six months by the Vivanco laboratory group to 0.00 mg with calibration weights.

End of experiment dry weights will be compared to initial dry weights taken at the beginning of the experiment. Plants for initial dry weights planted on the same date as the experimental trays will be harvested at the time the experimental trays are delivered to the green roof. Therefore initial dry weight plants were treated the same as experimental plants in the greenhouse during the establishment period. The treatment of fresh and dry weight samples (handling, temperature, etc.) is the same for initial dry weights as for end of experiment dry weights.

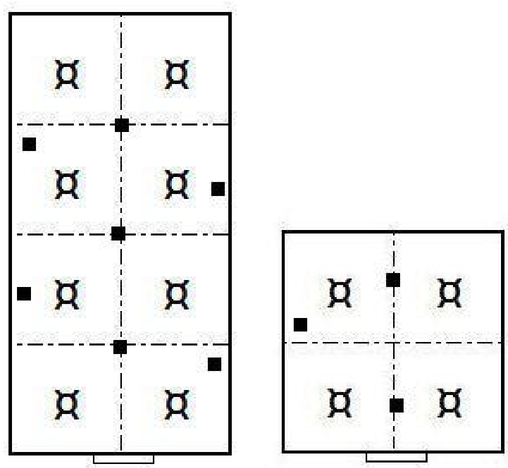
Media Moisture

Delta-T Theta Probe ML2X (Delta-T Devices, Cambridge, UK) will be used to take instantaneous readings of soil moisture content in millivolts (mV). The probe is simply inserted into the media until the probe ends rest on the bottom of the tray. A reading can be taken via the attached meter instantly and copied down on a data sheet (Appendix 1, Figure F-11).

Soil moisture content will be measured once a week during the growing season (~April 1st - November 1st) in a predetermined order at the same time of day keeping constant the number of hours since watering. Seven total measurements will be taken in the larger 2ft x 4ft (0.61m x 1.22m) trays for Studies 1 and 3 and three total measurements will be taken in each of the smaller 2ft x 2ft (0.61m x 0.61m) trays. For the larger trays, three measurements will be taken down the center of the tray and two on each side of the tray to get an even distribution of media moisture within the tray. Similarly, two measurements will be taken down the center and one on the side of the smaller trays. (Figure F-7)

Figure F-7: EXAMPLE OF MEDIA MOISTURE MEASUREMENT LOCATIONS

An example of media moisture measurement locations (represented by the black squares) for the two different tray sizes. Plants are represented by ¤, solid lines correspond to tray edges and dotted lines show the imaginary lines between the 1 ft^2 (0.093 m^2) areas.



Accuracy of the Theta Probe is ±0.01 m^3/m^3 in 0-40ºC. Soil specific calibrations will be performed to ensure accuracy at this level. There is no method for calibrating the sensor; however, accuracy will be tested weekly by dipping the probe in a cup of water and getting a reading of 100% volumetric moisture content.

B3. SAMPLE HANDLING & CUSTODY REQUIREMENTS

The digital photos taken once a week from ~April 1st - November 1st (see description in Section B2) will be stored in a green roof photo database through the Region 8 EPA headquarters. Colorado State University will be responsible for taking the photos, labeling (with block, study, treatment and date), keeping copies of each and analyzing the data provided by the photos.

B4. ANALYTICAL METHODS REQUIREMENTS

The digital photo data will be analyzed using Sigma Scan Pro 5.0 image analysis software (SPAA Science, Chicago). This program measures growth rates by analyzing pixels on digital photographs. Statistical analysis will be performed on the photo data.

Statistical Analysis Software (SAS®) version 9.13 will be used to determine if data is significantly different based on p-values of $p<0.005$. Means, standard deviations, standard errors and correlations will be determined for all data in Microsoft Office Excel 2007.

B5. QUALITY CONTROL REQUIREMENTS

Data that do not meet project accuracy and precision objectives are not entered in the green roof data system and will not be used in reports. Colorado State University is responsible for determining the cause of data errors.

B6. INSTRUMENT/EQUIPMENT TESTING, INSPECTION & MAINTENANCE

All equipment is checked upon receipt to ensure that operations are within technical specifications before use. All equipment will be calibrated prior to use and calibrated again at the end of the experiment to measure drift of measurement. All instruments will be checked once a month to make sure they are running properly.

B7. INSTRUMENT CALIBRATION PROCEDURES

Calibration of all instruments will be documented in an instrument calibration/ maintenance log. If, at any time, there are data quality concerns which might be related to equipment error, it will be recalibrated.

B8. INSPECTION & ACCEPTANCE REQUIREMENTS FOR SUPPLIES

Monitoring equipment and supplies ordered from Campbell Scientific and Delta-T Devices will be inspected upon arrival. Materials or instruments that do not meet EPA standards will be shipped back to the manufacturer for replacement.

B9. DATA ACQUISITION REQUIREMENTS

Data will be gathered and analyzed by Colorado State University personnel, specifically the graduate student (Jennifer M. Bousselot) responsible for carrying out the research, or individuals working in conjunction with the graduate student (David Staats, Research Associate or half time Research Associate to be hired). The graduate student and other Colorado State University personnel (previously mentioned) will be supervised by the professor (James E. Klett).

B10. DATA MANAGEMENT

The digital photos taken on the green roof once a week from ~April 1st - November 1st (see description in Section B2) will be stored in a green roof photo database through the Region 8 EPA headquarters. Colorado State University will be responsible for taking the photos, keeping copies of each and analyzing the data provided by the photos using SigmaScan Pro 5.0.

GROUP C: ASSESSMENT AND OVERSIGHT

C1. ASSESSMENTS & RESPONSE ACTIONS

[Not applicable at this time.]

C2. REPORTS

Official annual reports will be produced in January of each year and will describe activities during the previous twelve months. These reports will consist of data results, interpretation of data, information on project status, and internal assessments. Monthly updates will be drawn up for the EPA ORD Project Officer to keep current on project development.

Colorado State University is responsible for report production and distribution. Annual reports will be forwarded to any interested party including the Denver Botanic Gardens, EPA Region 8 staff, City and County of Denver, the Green Industries of Colorado and the Urban Drainage Flood Control District.

The EPA Region 8 green roof web site will be updated with all reports and data summaries as they are generated. Real time data will not be available through the web site, but the latest version of the green roof data system will be available upon request through the contacts provided on the website.

GROUP D: DATA VALIDATION AND USABILITY

D1. DATA REVIEW, VALIDATION & VERIFICATION REQUIREMENTS

All data collected is subject to review by the Project QA Officer. Decisions to reject or qualify data are made by the Colorado State Agriculture Experiment Station Statistician or the Project QA Officer.

D2. VALIDATION & VERIFICATION METHODS

Annual reports will include discussion of any data quality problems and will be distributed to all data users.

D3. RECONCILIATION WITH DATA QUALITY OBJECTIVES

Data will be reviewed once a week to look for major outliers. Any outliers will be investigated to assure there is no equipment failure. The statistician will be contacted if a problem persists (Still not totally clear on how to approach this area).

REFERENCES CITED

Durhman, A., D.B. Rowe, C.L. Rugh. 2006. Effect of Watering Regimen on Chlorophyll Fluorescence and Growth of Selected Green Roof Plant Taxa. HortScience 41(7): 1623-1628.

Durhman, A., D.B. Rowe, C.L. Rugh. 2007. Effect of Substrate Depth on Initial Growth, Coverage, and Survival of 25 Succulent Green Roof Plant Taxa. HortScience 42(3): 588-595.

Monterusso, M.A., D.B. Rowe, and C.L. Rugh. 2005. Establishment and persistence of Sedum spp. and native taxa for green roof applications. HortScience 40:391–396.

VanWoert, N., D. Rowe, J. Andresen, C. Rugh, and L. Xiao. 2005. Watering Regime and Green Roof Substrate Design Affect Sedum Plant Growth. HortScience 40(3): 659-664.

APPENDIX 1: STUDY DATASHEETS

Figure F-8: Datasheet for widths and heights of plants, Study 1 (species study).

Columns labeled “1, 2…8” are representative of plant number in tray. (See Figure F-6 for layout of individual plants in trays.) Subheadings on columns are w1=first width taken, w2=second width and h=height at center of plant. Rows are labeled with B=block number, S=study number, and T=treatment letter (first letter of species).

Labels	1			2			3			4			5			6			7			8		
	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h
B1 S1 TA																								
B1 S1 TB																								
B1 S1 TD																								
B1 S1 TE																								
B1 S1 TO																								
B1 S1 TS																								
B2 S1 TA																								
B2 S1 TB																								
B2 S1 TD																								
B2 S1 TE																								
B2 S1 TO																								
B2 S1 TS																								
B3 S1 TA																								
B3 S1 TB																								
B3 S1 TD																								
B3 S1 TE																								
B3 S1 TO																								
B3 S1 TS																								
B4 S1 TA																								
B4 S1 TB																								
B4 S1 TD																								
B4 S1 TE																								
B4 S1 TO																								
B4 S1 TS																								
B5 S1 TA																								
B5 S1 TB																								
B5 S1 TD																								
B5 S1 TE																								
B5 S1 TO																								
B5 S1 TS																								

Figure F-9: Datasheet for widths and heights of plants, Study 2 (media study).

Columns labeled "1,2,3,4" are representative of plant number in tray. (See Figure F-6 for layout of individual plants in trays.) Subheadings on columns are w1=first width taken, w2=second width and h=height at center of plant. Rows are labeled with B=block number, S=study number, percentage of zeolite in media (i.e. 0%, 33%, 66%, 100%) and T=tray number. Each set of measurements is labeled by what species/variety is there. The four possibilities are: S. acre=*Sedum acre*, S. album=*Sedum album*, D. Blood=*Sedum spurium* 'Dragons Blood' and J. Creech=*Sedum spurium* 'John Creech'.

Labels	1			2			3			4		
	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h
B1 S2 0% T1		S. album			J. Creech			S. acre			D. Blood	
B1 S2 33% T1		S. acre			S. album			D. Blood			J. Creech	
B1 S2 66% T1		S. album			D. Blood			J. Creech			S. acre	
B1 S2 100 T1		S. album			J. Creech			D. Blood			S. acre	
B1 S2 0% T6		D. Blood			J. Creech			S. acre			S. album	
B1 S2 33% T6		S. album			S. acre			J. Creech			D. Blood	
B1 S2 66% T6		S. acre			J. Creech			S. album			D. Blood	
B1 S2 100 T6		S. album			S. acre			J. Creech			D. Blood	
B2 S2 0% T2		J. Creech			D. Blood			S. album			S. acre	
B2 S2 33% T2		J. Creech			S. album			D. Blood			S. acre	
B2 S2 66% T2		D. Blood			J. Creech			S. acre			S. album	
B2 S2 100 T2		S. album			D. Blood			J. Creech			S. acre	
B2 S2 0% T7		J. Creech			S. acre			S. album			D. Blood	
B2 S2 33% T7		J. Creech			D. Blood			S. album			S. acre	
B2 S2 66% T7		D. Blood			S. album			S. acre			J. Creech	
B2 S2 100 T7		S. acre			J. Creech			D. Blood			S. album	
B3 S2 0% T3		S. acre			S. album			J. Creech			D. Blood	
B3 S2 33% T3		J. Creech			S. album			D. Blood			S. acre	
B3 S2 66% T3		S. acre			S. album			D. Blood			J. Creech	
B3 S2 100 T3		S. acre			J. Creech			D. Blood			S. album	
B3 S2 0% T8		S. album			S. acre			J. Creech			D. Blood	
B3 S2 33% T8		S. album			J. Creech			S. acre			D. Blood	
B3 S2 66% T8		D. Blood			S. acre			S. album			J. Creech	
B3 S2 100 T8		S. acre			S. album			D. Blood			J. Creech	
B4 S2 0% T4		S. album			D. Blood			S. acre			J. Creech	
B4 S2 33% T4		J. Creech			S. acre			D. Blood			S. album	
B4 S2 66% T4		J. Creech			D. Blood			S. acre			S. album	
B4 S2 100 T4		J. Creech			S. album			S. acre			D. Blood	
B4 S2 0% T9		S. album			J. Creech			D. Blood			S. acre	
B4 S2 33% T9		S. acre			D. Blood			S. album			J. Creech	
B4 S2 66% T9		S. acre			J. Creech			S. album			D. Blood	
B4 S2 100 T9		S. album			S. acre			J. Creech			D. Blood	
B5 S2 0% T5		J. Creech			S. acre			D. Blood			S. album	
B5 S2 33% T5		J. Creech			D. Blood			S. album			S. acre	
B5 S2 66% T5		S. acre			J. Creech			S. album			D. Blood	
B5 S2 100 T5		S. album			J. Creech			S. acre			D. Blood	
B5 S2 0% T10		S. album			D. Blood			J. Creech			S. acre	
B5 S2 33 T10		S. acre			J. Creech			S. album			D. Blood	
B5 S2 66 T10		D. Blood			S. album			S. acre			J. Creech	
B5 S2 100 T10		S. acre			D. Blood			S. album			J. Creech	

Figure F-10: Datasheet for widths and heights of plants, Study 3 (mixed study).
Columns labeled “1, 2…8” are representative of plant number in tray. (See Figure F-6 for layout of individual plants in trays.) Subheadings on columns are w1=first width taken, w2=second width and h=height at center of plant. Rows are labeled with B=block number, S=study number, and T=treatment letter (first letter of genus for each species).

Labels	1			2			3			4			5			6			7			8		
	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h	w1	w2	h
B1 S3 T0%	Allium			Opuntia			Delosperma			Eriogonum			Sempervivum			Antennaria			Sedum			Bouteloua		
B1 S3 T50%	Sedum			Opuntia			Bouteloua			Antennaria			Delosperma			Eriogonum			Sempervium			Allium		
B2 S3 T0%	Sedum			Antennaria			Sempervivum			Opuntia			Eriogonum			Bouteloua			Delosperma			Allium		
B2 S3 T50%	Opuntia			Antennaria			Delosperma			Sempervivum			Allium			Bouteloua			Sedum			Eriogonum		
B3 S3 T0%	Eriogonum			Sempervivum			Delosperma			Sedum			Bouteloua			Allium			Opuntia			Antennaria		
B3 S3 T50%	Eriogonum			Delosperma			Sedum			Allium			Sempervivum			Antennaria			Opuntia			Bouteloua		
B4 S3 T0%	Delosperma			Bouteloua			Antennaria			Opuntia			Sedum			Sempervivum			Allium			Eriogonum		
B4 S3 T50%	Sempervivum			Bouteloua			Eriogonum			Opuntia			Allium			Sedum			Antennaria			Delosperma		
B5 S3 T0%	Opuntia			Allium			Sedum			Delosperma			Antennaria			Bouteloua			Sempervivum			Eriogonum		
B5 S3 T50%	Opuntia			Sedum			Alluim			Delosperma			Eriogonum			Bouteloua			Sempervivum			Antennaria		

Figure F-11: Datasheet for Measuring Soil Moisture Content

There are fewer measurements for the Study 2 (media study) trays because they are smaller in size (2 ft x 2 ft [0.61m x 0.61 m] trays instead of 2ft x 4ft [0.61m x 1.22m] trays for the species and mixed species trays). B=block number, S=study number, T=treatment (or tray number for Study 2), %=percent zeolite in each treatment of Study 2 (media study) and mixed Study 1 (species study).

Labels	Measure 1	Measure 2	Measure 3	Measure 4	Measure 5	Measure 6	Measure 7
B1 S1 TA							
B1 S1 TB							
B1 S1 TD							
B1 S1 TE							
B1 S1 TO							
B1 S1 TS							
B1 S2 0% T1				0% T6			
B1 S2 33% T1				33% T6			
B1 S2 66% T1				66% T6			
B1 S2 100 T1				100% T6			
B1 S3 T0%							
B1 S3 T50%							
B2 S1 TA							
B2 S1 TB							
B2 S1 TD							
B2 S1 TE							
B2 S1 TO							
B2 S1 TS							
B2 S2 0% T2				0% T7			
B2 S2 33% T2				33% T7			
B2 S2 66% T2				66% T7			
B2 S2 100 T2				100% T7			
B2 S3 T0%							
B2 S3 T50%							
B3 S1 TA							
B3 S1 TB							
B3 S1 TD							
B3 S1 TE							
B3 S1 TO							
B3 S1 TS							
B3 S2 0% T3				0% T8			
B3 S2 33% T3				33% T8			
B3 S2 66% T3				66% T8			
B3 S2 100 T3				100% T8			
B3 S3 T0%							
B3 S3 T50%							
B4 S1 TA							
B4 S1 TB							
B4 S1 TD							
B4 S1 TE							
B4 S1 TO							
B4 S1 TS							
B4 S2 0% T4				0% T9			
B4 S2 33% T4				33% T9			
B4 S2 66% T4				66% T9			
B4 S2 100 T4				100% T9			
B4 S3 T0%							
B4 S3 T50%							
B5 S1 TA							
B5 S1 TB							
B5 S1 TD							
B5 S1 TE							
B5 S1 TO							
B5 S1 TS							
B5 S2 0% T5				0% T10			
B5 S2 33% T5				33% T10			
B5 S2 66% T5				66% T10			
B5 S2 100 T5				100% T10			
B5 S3 T0%							
B5 S3 T50%							