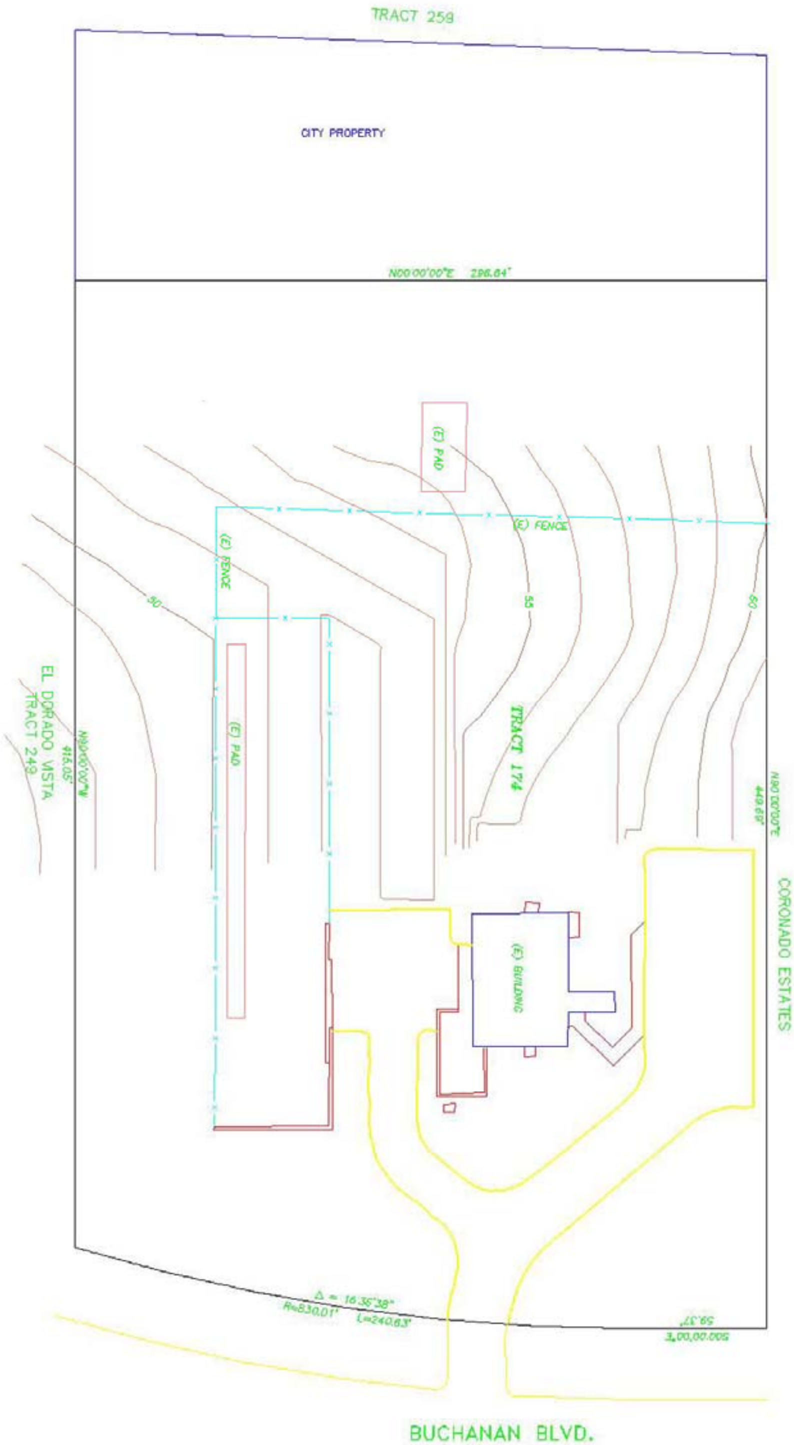
Scaling Environmental Processes in Heterogeneous Arid Soils (SEPHAS)

Boulder City, Nevada

Dr. Zhongbo Yu
Univ. of Nevada, Las Vegas
zhongbo@unlv.nevada.edu
702-895-2447

Dr. Michael H. Young
Desert Research Institute
michael.young@dri.edu
702-862-5489

Dr. Scott W. Tyler
Univ. of Nevada, Reno
tylers@unr.edu
775-784-6250



TRACT 259
CITY PROPERTY
N00°00'00"E 296.64'
(E) PAD
(E) FENCE
(E) FENCE
50
55
60
(E) PAD
TRACT 174
EL DORADO VISTA
TRACT 249
N90°00'00"W
416.05'
N90°00'00"E
449.69'
CORONADO ESTATES
(E) BUILDING
Δ = 16°35'38"
R=830.01'
L=240.63'
59.37'
S00°00'00"E
BUCHANAN BLVD.

1.0 Introduction

The near surface (vadose and saturated zones) represents a critical interface between the earth's bio, hydro, and geospheres. Mass and energy movement across this critical zone strongly influence a suite of environmentally important processes including local and global element cycling (i.e., CO_2, nutrients, metals), water cycling, and many important coupled biogeochemical processes. Many of these processes are typically monitored and characterized at one spatial scale, and applied at a different scale. Better understanding of these fundamental processes has direct and immediate application to many environmental issues, including the impact of global climate change in arid environments, predictions of water recharge, flooding, and contaminant fate and transport. This research program, entitled Scaling Environmental Processes in Heterogeneous Arid Soils (or SEPHAS) focuses on scaling of subsurface and landscape-interface environmental processes. Scaling of environmental processes, defined as the transfer of knowledge from one spatial or temporal scale to another, is often hampered by natural heterogeneity which typically is not limited to the scale under which the majority of experiments are conducted. The disparity between the scale of measurement and the scale of interest limits our ability to characterize dominant environmental processes, and importantly, how the processes interact with one another. The inability to upscale or downscale influences research in areas of hydrology, biogeosciences, mathematical modeling, and global environmental change, in part because facilities that permit multi-scale environmental research are either rare or nonexistent. Thus, limited data are available to test hypotheses or make meaningful predictions. Our facility will be devoted to investigating environmental processes facing arid and semi-arid states like Nevada at the meso (or intermediate) scale to bridge existing eco-scale and laboratory (down to nano-scale) research efforts.

This document provides a broad overview of the facility, why it is needed, how it will fill an infrastructural gap in Nevada, and how the project will be implemented. Specific hypotheses and design criteria needed to address and test hypotheses are not included here. These aspects of the project will be determined based on discussions with scientists and collaborators during the Summer 2005, before construction and installation of the instruments.

2.0 What is the Current Status of Focal Area

The NSF EPSCoR proposal consisted of three scientific themes of focal areas. These focal areas were proposed by the research community in Nevada and were subject to evaluation by internal and external review panels. The themes that were submitted by the Nevada EPSCoR office and subsequently approved by NSF included this project; a sensor development theme focused on mercury identification and quantification; and a cognitive information processing theme that seeks to develop computer software that can mimic human thought by interpreting data and information on our surroundings and take action based on the interpretation.

With respect to the theme that is now SEPHAS, significant national-level dialog has occurred on the need to improve our understanding of subsurface processes and to appropriate scale the results. For example, the National Academy Sciences[1] (NAS) recently cited the need to focus subsurface research on "improved capabilities for characterizing the physical, chemical and biological properties of the subsurface," as an important step toward developing more

---

[1] National Academy of Sciences, 2000. Research Needs in Subsurface Science, National Academy Press, Washington, DC.

integrated and coupled conceptual models of processes at different scales. Regarding the need to address scaling, the NAS subsequently stated[2] "Predictions of contaminant transport behavior at scales of interest to environmental managers is currently problematic because of a general lack of understanding of both theoretical and applied approaches to scaling environmental phenomenon."

A key strategy of Nevada's technology development goals is to leverage current and future federal investments in Nevada. The proposed SEPHAS initiative is uniquely developed to maximize that leverage. The State of Nevada has recently made strong advances in research capacity focusing on arid and semi-arid environmental processes, and this proposal will build on that success. Nevada currently houses two NSF-funded facilities that focus on ecosystem environmental research. The EcoCELLS (DRI/Reno) are designed to control atmospheric inputs to soil caissons. The NSF-funded Desert FACE (Nevada Test Site, NV) is much larger in scale occupying many acres of the Nevada Test Site. Both of these facilities have proven quite effective in both attracting NSF funding and in making significant scientific contributions.

The heterogeneous but controlled nature of the SEPHAS project will provide a mechanism for scaling up findings of research conducted under semi-controlled conditions, providing unique opportunities to investigate influences of physical, chemical and biocomplexity on organism function in arid environments. Nevada is currently a leader in arid ecosystem and subsurface science research using strong teams of researchers at UNLV, UNR and DRI. Thus, SEPHAS brings to Nevada a meso- (or intermediate-) scale research facility to further bridge these research efforts, giving Nevada unique capacity to address many basic scientific questions and address practical problems unique to Nevada and other arid and semi-arid states in the southwest.

3.0 Barriers and Strategies

Development of the SEPHAS proposal required that we identify barriers to Nevada's success in research. We developed strategies to success and how our project ideas might knock down those barriers. These barrier/strategy combinations are listed below, and show directly how completion and operation of the SEPHAS facility will assist researchers in Nevada and elsewhere.

Barrier #1: Facilities that permit multi-scale environmental research are rare or nonexistent.

Strategy #1: The SEPHAS project will construct and operate a research facility to investigate the role of heterogeneity at a hierarchy of scales using soil blocks of different dimensions. The larger-scale operation is anchored by outdoor weighing lysimeters of two different sizes. Two larger, weighing lysimeters (5 x 5 x 2 m) each containing an undisturbed soil block will be constructed and instrumented so that ecosystem, geochemical, and hydrologic processes can be studied. The undisturbed soil blocks will each contain several large desert shrubs, allowing us measure energy and mass partitioning. We will also construct five smaller, weighing lysimeters (2 x 2 x 2 m) filled with known materials in known geometries so that the effects of heterogeneity at the mesoscale can be ascertained. Outdoor lysimeters will be equipped with a balancing system similar to that used in the Large Weighing Lysimeter site in

[2] National Academy of Sciences, 2001. Science and Technology for Environmental Cleanup at Hanford, National Academy Press, Washington, DC.

Tucson, Arizona (Young et al., 1996, Soil Science, 161:491-497). An indoor facility will be designed and constructed that can evaluate smaller-scale processes, somewhere in the centimeter to decimeter range. Tanks (0.5 to 5 meters) will be constructed to study chemical, biological and hydrological processes at these scales. The results will be used to connect with larger-scale processes identified with the outdoor lysimeters. Both indoor and outdoor instruments will ultimately be used to scale up to the field level, similar to those considered at the Nevada Desert Research Center (i.e., FACE and Mojave Global Change Facility).

Barrier #2: Lack of a system that merges visualization and computational technology with experiments in porous media.

Strategy #2: The majority of visualization technology will be installed inside a pre-existing laboratory building that will be upgraded specifically for the SEPHAS project. The building will contain sufficient power and communications to handle data-intensive experiments. The strategy will be addressed using two approaches. From the visualization side, monitoring will be done using state-of-the-art imaging techniques (e.g., CCD cameras, particle image velocimetry, laser Doppler, and CT technology are all being considered) so that near-pore scale processes can be studied. From the computational side, output from sensors and visualization tools will be evaluated using Nevada's ACES program. ACES has established a computational and visualization infrastructure through which the experimental work at the facility can be integrated. The computer programmers hired through the ACES grant, under RING-TRUE II, will be used to help integrate the flow and transport experiments in the different lysimeters.

Barrier #3: Collaborative proposal development

Strategy #3: Due to difficulty to secure funding for multi-disciplinary teams to collaborate and develop large proposals, collaborative proposal development activities are currently limited. The SEPHAS project will facilitate development of proposals and new research ideas in three ways. First, research workshops will be held yearly to discuss research direction, coordination, and collaboration with other existing research programs. Second, yearly RFPs will be issued for seed research to obtain preliminary data for larger proposals. Third, funds will be made available for proposal development, including in-state travel to visit collaborators, and out-of-state travel (using RING-TRUE II funds) to view facilities or discuss ideas with colleagues. Through the proposed seed program, multi-disciplinary teams will benefit from the experimental facility, increasing the collaborative proposal development efforts.

Barrier #4: Student and post-doc involvement (growing the Statewide brainpower)

Strategy #4: The SEPHAS facility will provide an excellent opportunity to maximize the benefits from educational programs by providing graduate student and post-doc fellowships. Student fellowships would be made available to UNR, UNLV, and DRI for those individuals seeking to work with advisors who are conducting research at the SEPHAS facility. Post-doc fellowships will be made available for larger-scale projects that will result in development of significant independent projects while being guided by UCCSN faculty. Post-docs will be encouraged to further develop research proposals that can be submitted to external funding agencies, thus creating and maintaining a more stable funding stream. Fellowships will be phased in during Year 2, when the experimental facility is nearing the end of construction.

4.0 Impact on Existing and Future Research in Nevada

This facility will have the ability to uniquely address a broad spectrum of important processes and questions related to the role of physical heterogeneity and scaling in subsurface sciences including plant root/water interaction, thermal, solute gas and colloidal transport, and microbially-coupled geochemical processes. The facility is designed so that research with different purposes is conducted simultaneously (e.g., colloid transport in one tank and tank and nitrogen dynamics in another). The UCCSN is strategically well positioned to undertake this project. Nevada has a significant number of subsurface scientists (experimentalists, theorists, observationists, and modelers), many of whom have active research programs focused on heterogeneity in the subsurface. This facility, located close to two UCCSN campuses, will provide a competitive edge to scientists competing for funding across a broadly defined spectrum of geosciences research, and become an excellent educational tool for future Nevada scientists. The faculty listed above generated a sampling of potential research fields, and associated directorates where proposals could be submitted. They fall into broad areas of pertinent research, and are paraphrased here:

Hydrology: Research related to scaling of transport behavior of chemicals and microorganisms, remediation of contaminants, and scaling phenomenon in heterogeneous porous material.

Biogeosciences: Research related to biotic and abiotic controls on mineral formation, dissolution and transport in Mojave Desert ecosystems; influence of atmospheric CO_2, nitrogen deposition, and soil moisture on root activity, stomatal conductance and C sequestration; investigations of biocomplexity in arid and semi-arid environments.

Mathematics: Computational aspects of kinetic effects on very long desorption time frames, and the changes to forms of the transport equations (e.g., fractional derivatives).

The proposed facility would facilitate ongoing research by allowing for more detailed belowground measurements than can be done with the existing NDFF-MGCF or EcoCELL facilities, both of which currently exist in Nevada, and which were funded by NSF. This new facility would allow for closer monitoring of rhizosphere processes and measurements of gas exchange from isolated roots with minimal disturbance, both of which are extremely difficult to perform in the field. Also it will allow for measurements of spatial 3-D patterns in soil moisture and soil gas concentrations that could help identify locations where $CaCO_3$ precipitation and dissolution occurs most actively. No controlled meso-scale experimental facility that focuses on subsurface phenomena exists on any UCCSN campus in the State of Nevada, and the facilities located outside of Nevada (e.g., Oregon State University, Idaho National Laboratories) are not designed to study the processes that . Yet, numerous researchers throughout the State deal with the characterization of these phenomena using theoretical and field-scale experimental avenues. The missing connection between the precision of theoretical development and the breadth of field environments, are the experiments in which the porous media and boundary conditions can be controlled at relevant scales. We believe that the SEPHAS Project will provide that link. We are unaware of any facility that merges visualization, monitoring and numerical technologies for observing how water, chemicals, microbes and energy interact in heterogeneous porous media. As the State of Nevada increases in population, and as the Universities increase their research portfolios in size and diversity, the availability of a well controlled experimental facility will be a tangible asset and a draw for future funding.

5.0 Brief Description of Outdoor Lysimeters

The attachment shows figures that were created for the proposal process. Figure 1 on shows a map view of the outdoor lysimeters as originally envisioned. Small lysimeters on the east side of the facility, closer to the lab building (perhaps 10-30 m away), and large lysimeters are on the west side closer toward open ground. Each lysimeter will be weighed on a separate balance and stored in a room that can be accessed through a central tunnel (Figure 2 shows images taken from the lysimeters in Tucson, from which SEPHAS is patterned. In Tucson, each lysimeter had a live mass of 45,000Kg with a resolution of +/- 200g (or equivalent to 0.04 mm water on the surface). Specifics for the SEPHAS lysimeters may differ, but the resolution will still be excellent! One distinct difference between Tucson and SEPHAS lysimeters is that the former tanks are round and the latter will be square (this may have not functional impact on the experiments). Each lysimeter will have separate data collection capacity using remote loggers or other data acquisition systems. It is envisioned that the data will be posted immediately to the web so that investigators can monitor individual sensors and systems as needed. High speed uploading and downloading will/should also be available. Two entrances allow better air flow and keep the facility from being designated as an OSHA confined space. Each room can be isolated from the outdoor air, if needed, using heavy plastic sheeting, but we found in Tucson that the temperatures were rather constant in the rooms from season to season and air drafts were not a problem from a weighing standpoint.

Note on Figure 2 that each tank has build in sampling ports. The number, location, and size of ports are to be determined by the Nevada researchers. Ports will contain a variety of instruments for monitoring subsurface conditions and for sampling a variety of media (gas, liquid, solid). Again, what to sample, when to sample, and how to sample are all up for discussion. Also, it is possible that a plexiglass wall could be used instead of plate steel so that actual roots, bioturbation, etc. can be viewed. Figures 3 and 4 are schematics that show different configurations of the lysimeters. A key element of the design is that 360° access will be possible for each lysimeter, allowing researchers to sample the soil environment from different sides of the tank. It could be also possible to sample completely across the soil or from the surface to base of the tank. Finally, the bottom boundary of the lysimeter will be controllable using porous ceramic or stainless steel tubing. This will allow us to (1) mimic an infinitely deep soil profile by creating uniform soil water potential; (2) create shallow water table conditions if we need/want; and (3) to sample media.

The overall goal of the design is flexibility to conduct multiple experiments without antagonistic effects on other experiments. The tables found at the end of this document suggest a number of hypotheses and lysimeter designations, though, of course, the approach is entirely up for discussion.

6.0 Brief Schedule

Year 1: Architectural design of outdoor facility; hire facility manager to oversee design, bidding, and construction; excavation and installation of infrastructure (foundation, scales) for outdoor lysimeters; modify building infrastructure to support indoor facilities; design indoor tanks; proposal development; issue RFP for seed grants; recruit graduate students with fellowships.

Year 2: Hire technician to facilitate instrumentation; excavate undisturbed caisson and installation at lysimeter site; hire two post-doctoral researchers to begin baseline data collection and experimentation; install indoor tanks, including the visualization hardware; award first round of seed grants; proposal development.

Year 3: Complete outdoor facility and begin experiments; complete hardware installation for indoor facility; award second round of seed grants; proposal development.

7.0 Program Management

The SEPHAS Project will be housed at DRI's Boulder City facility, a three-acre property that contains a building for offices, laboratories, a high bay for larger experimental structures, and sufficient open land for constructing the outdoor lysimeters. DRI is committed to this project and the long-term maintenance of the facility, and will provide internal, non-cost support to upgrade building utilities including HVAC, DI water, pressure/vacuum systems, air handlers, and general laboratory upgrades and intends to maintain this infrastructure in to the future. DRI support will include personnel, materials and equipment necessary to upgrade the facility so that it maximizes the potential for inter-disciplinary research.

The focal area will be organized around NSF major themes of: Hydrology, Biogeosciences, Mathematics, Global Climate Change, and Biocomplexity. The overall project will be managed through the efforts of the Principal Investigator, technical leads at each of the three UCCSN institutions, a steering committee (internal to the System), and an external advisory committee to consist of national and/or international research leaders in the field of scaling and lysimetry. The steering committee will be populated with research leaders at the UCCSN level who are familiar with many facets of large-scale research projects funded by NSF. The advisory committee is envisioned to include three persons who will meet bi-annually to discuss project direction, relevance to national scientific programs, and changes in research environments that could impact future funding. Currently, we have verbal commitments from Peter J. Wierenga (University of Arizona), Steven R. Evett (USDA-ARS-Bushland, TX), and Robert Graham (UC Riverside).

Current list of Interested Investigators:

Focal area leads
Michael Young (PI; DRI Lead)
Scott Tyler (UNR Lead)
Zhongbo Yu (UNLV Lead)

Participating UCCSN Faculty

Name	Affiliation	Area of Research
Jay Arnone	DRI	Ecophysiology
Clay Cooper	DRI	Energy and solute transport
Dave Decker	DRI	Solute transport and remediation
Dale Devitt	UNR	Soil-plant-water interactions
Patrick Drohan	UNLV	Soil genesis and morphology
Ahmed Hassan	DRI	Numerical modeling and scaling behavior
David Kreamer	UNLV	Solute transport
Steve Mizell	DRI	Groundwater flow and recharge in arid environments
Mike Nicholl	UNLV	Environmental fluid mechanics
Robert Nowak	UNR	Arid system ecophysiology
Lambis Papelis	DRI	Water quality, near-surface interactions
Greg Pohll	DRI	Numerical modeling of flow and transport
Karl Pohlmann	DRI	Numerical modeling of flow and transport
Eduardo Robleto	UNLV	Plant microbiology
Craig Shirley	DRI	Numerical modeling
Stan Smith	UNLV	Plant physiological ecology
Henry Sun	DRI	Environmental microbiology
Paul Verburg	DRI	Biogeochemical cycling
Stephen Wheatcraft	UNR	Groundwater contamination and remediation
Ming Ye	DRI	Scaling and uncertainty in porous media
Jianting Zhu	DRI	Numerical modeling and spatial scaling processes

DRAFT Table of Hypotheses and Potential Designation of SEPHAS Infrastructure to Address Hypotheses*

Hypotheses/Ideas	Indoor Tank†	Outdoor Tank‡
(1) the nature of sandbox preconditioning that may be required to yield flow and transport results comparable to field conditions	XX	L5
(2) biotic and abiotic controls on $CaCO_3$ formation in desert ecosystems		B1, B2, L1, L2
(3) the extent of light, non-aqueous phase smearing with water table fluctuations	XX	
(4) implications of the existence of an enormous nitrate reservoir in the arid West (and other deserts)		B1, B2
(5) energy and mass partitioning in arid soil ecosystems and the role of biogeochemical cycling		B1, B2
(6) how new computational and theoretical methods, tested with data collected at this site, can be used to understand energy and mass transport phenomenon	XX	Any or all
(7) creation of facility to test and benchmark sensors for subsurface monitoring. What are the environmental limitations and constraints to new classes of sensors, developed as part of this NSF program		L5
(8) what is the role of soil structure in water movement and plant uptake in arid settings. Can we use that knowledge to predict future pedological development?		L3, L4
(9) wetting front instability: no understanding of behavior of wetting front instability beyond ~10 cm; this has delayed progress in our understanding of gravitational fingering as a far-reaching fluid flow and transport process in the unsaturated zone.	XX	L4, L5
(10) capillary barriers: theory and bench-scale experiments have shown this to occur, but performance in systems larger than several tens of centimeters is unknown.	XX	

† - XX = indicates primary location
‡ - B=big tank; L=little tank; number indicates specific tank

Tank Designation	Descriptions	Idea
B1	Large undisturbed soil caisson - ambient conditions	2, 4, 5, 6
B2	Large undisturbed soil caisson – enhanced precip	2, 4, 5, 6
L1	Small undisturbed soil caisson – rep of B1	2, 6
L2	Small undisturbed soil caisson – rep of B2	2, 6
L3	Small undisturbed soil caisson – structured soil condition	8, 6
L4	Disturbed soil caisson – Treatment of L3	8, 9, 6
L5	Repacked engineered sand	9, 6
Indoor		1, 3, 6, 9, 10

- - The vast majority of the hypotheses listed above were supplied by investigators on this list. The list is subject to addition, deletion and modification based on input from the investigators. **Infrastructure used to study environmental processes is also DRAFT.**

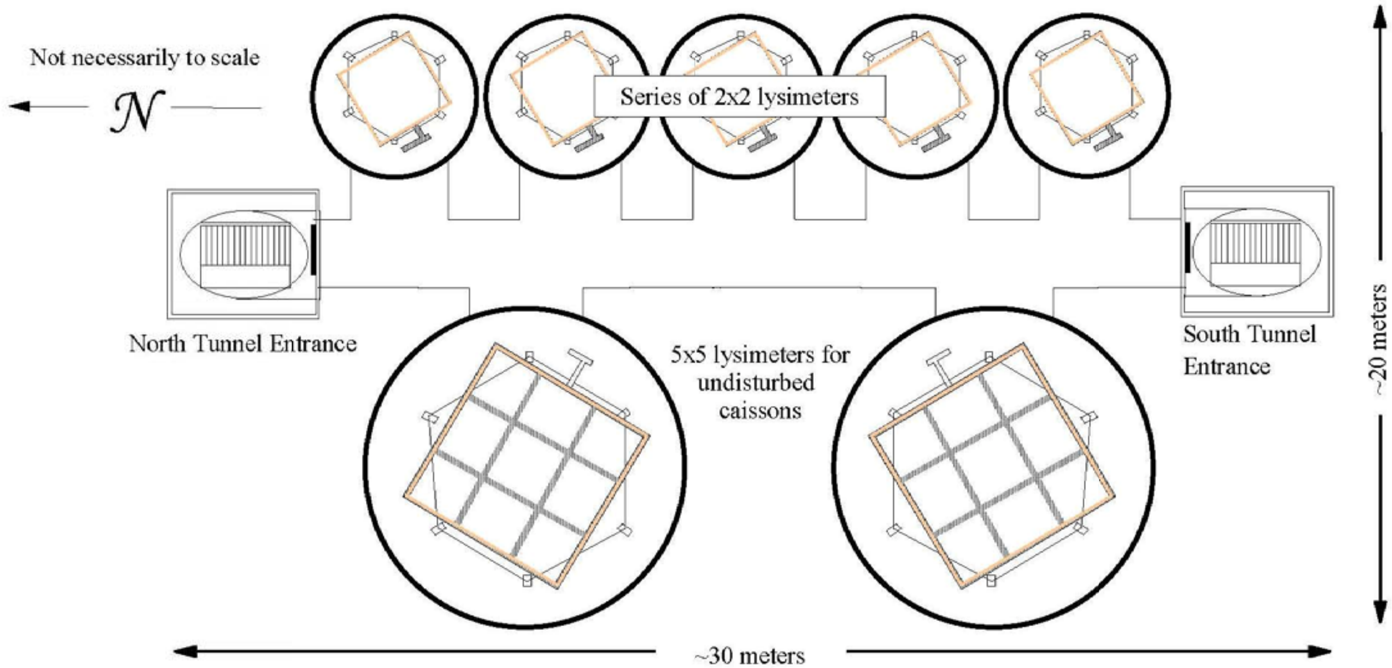


Figure 1 - Map view of lysimeters

SEPHAS Project

Potential view of tunnel, leading to rooms with independently monitored and managed lysimeters. Photo by permission of M. Stoklos.

Final condition lysimeter site, showing top of lysimeter and full cover of turf. NSF lysimeters will be completed at grade, but will covered with desert plants. Photo courtesy of M. Young.

Image of lysimeters delivered to Tucson, Arizona facility. Instruments proposed herein are square in shape; they will be equipped with sampling ports as seen in image. Photo courtesy of M. Young.

Similar to those constructed by the PI in Tucson, Arizona, each lysimeter room will be equipped with instruments to measure the soil environment, each designed to address specific science questions. Photo by permission of M. Stoklos.

Figure 2. Selected images of large weighing lysimeter facility, located at Karsten Turfgrass Center, Tucson, Arizona.

SEPHAS Project

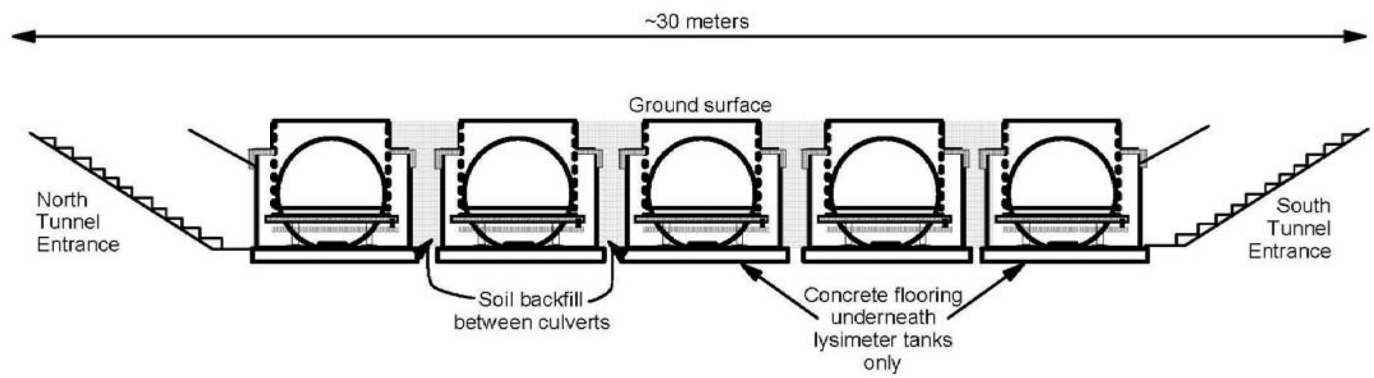
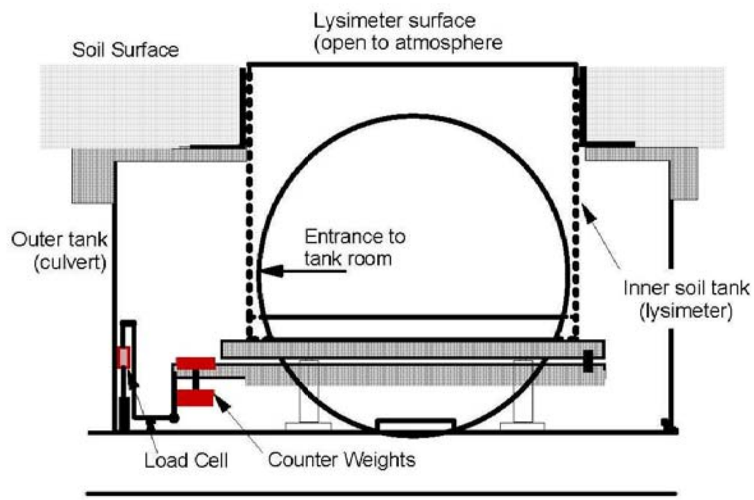
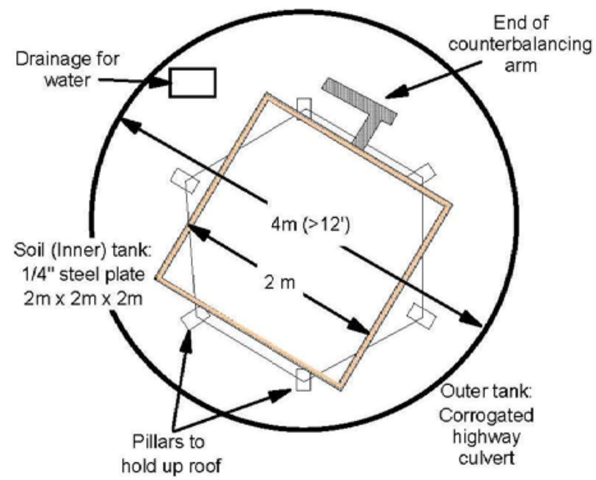


Figure 3. Cross-sectional view of outdoor lysimeters (looking West)



Notes:
- Lysimeter dimensions = 2m x 2m x 2m
- Entrance = 2.5m (8') diameter



Notes:
- 5 m x 5m lysimeter is similar in general design

Figure 4. Cross-section and map view of lysimeter and scale

SEPHAS Project