NSF Sustainable Urban Systems Conference Report (Award #1929941)

Jay Banner[1], Kasey Faust[2], Steven Gray[3], Auroop Ganguly[4], Ashlynn Stillwell[5], R. Patrick Bixler[6], Dev Niyogi[7], Suzanne Pierce[8], and Darrel Tremaine[9]

1. Geological Sciences, University of Texas at Austin; 2. Civil, Architectural and Environmental Engineering, University of Texas at Austin; 3. Community Sustainability, Michigan State University; 4. Civil and Environmental Engineering, Northeastern University; 5. Civil and Environmental Engineering, University of Illinois at Urbana-Champaign; 6. Public Affairs, University of Texas at Austin; 7. Earth, Atmosphere, and Planetary Sciences, Purdue University; 8. Texas Advanced Computing Center, University of Texas at Austin; 9. Environmental Science Institute, University of Texas at Austin.

Changing climate, rapid urbanization, and the projected increase in population of 2.5 billion humans over next 25 years[1] has created a new socio-ecological paradigm. In order to achieve sustainability in cities within semi-arid regions, we need to understand the complex relationships between humans, nature, and urban systems and the role that data and emerging technologies may play in transforming these cities toward more preferred states in the face of these changes. To that end, the Organizing Committee of this NSF Sustainable Urban Systems (SUS) Conference created an engaging three-day conference agenda that included five plenary talks, three interactive panel discussions, interactive workshop sessions, several think-pair-share activities, and time for peer-to-peer dialogue around the themes of Big Data, Integrated Modeling, Processes and Feedbacks, and Co-production of Knowledge. The SUS conference entitled "*Challenges to and Opportunities for Developing Resilience in Rapidly Growing Urban Corridors in Semi-Arid Regions*" was held at the University of Texas at Austin on August 22-24, 2019.

The conference comprised an array of participants representing a geographical distribution of higher education institutions from Washington state to Massachusetts (n=14; **Figure 1**), as well as non-academic professionals from local and national non-profit organizations (n=3), regional water utilities (n=2), tech start-ups (n=2), urban design practitioners (n=1), energy providers (n=1), and environmental and sustainability offices (n=3), totaling 45 participants from 28 unique inter/trans-disciplinary backgrounds. The complete list of attendees is presented in Table 1.

Three intensive, interactive workshops were held during the conference to maximize the generation of ideas and assess their convergence. Operating on the premise that the Urban-Rural interface is a complex and important boundary for a SUS, these workshops focused on:

1. Defining the boundaries of Urban Systems, including the political, social, physical, and natural bounds, framing each as a function of systemic vulnerabilities
2. Examining cross-boundary flows of energy, water, food and other resources between Urban and Rural systems, culminating in a *Causal Loop Diagram* (CLD) for each group (**Figure 2**)
3. Layering into the CLDs the key stakeholders, their roles and relationships to each other, and then projecting systemic responses to the cascading effects of a catastrophic natural event such as a decade-long drought

Figure 1: A map of the institutions and their logos represented at the SUS conference at The University of Texas at Austin, August 22-24, 2019.

Figure 2: Top panels – Brainstorming Urban-Exurban relationships and creating Causal Loop Diagrams (CLDs) during a breakout workshop session. Bottom panels – Sara Meerow (left) and Laura Schmitt-Olabisi (right) reporting on the major themes and relationships of their group's CLD.

It became clear that while the scientific drive for generalized solutions that are applicable to multiple urban systems is ideal, *each city system is unique and pilot solutions likely need to be highly specific to local conditions.* During workshops and panel discussions, participants found that definitions of terms like 'sustainability' and 'resilience' can be discipline specific, and therefore require efforts to incorporate a unified lexicon to describe SUS science.

Pre and post-conference surveys were administered to gather baseline data on how participants approach sustainability, what kinds of people and services they interact with, how often they include stakeholders in their work, and to measure key indicators of conference success, such as convergence in research goals and increased awareness of interdisciplinary methodologies. Preliminary analysis of survey data coupled with observations of group dynamics suggests this conference was successful in cross-pollinating various disciplinary actors with SUS concepts outside of their normal sphere of observation.

Post-conference surveys (n=23) are currently being analyzed. Pre-conference surveys (n=37) have been coded and the results suggest that from the perspective of this particular group of actors, **important challenges to urban resilience can be grouped into seven primary categories,** where parenthetical numbers below indicate the quantity of responses in each category that were perceived as near-term challenges (N) and long-term challenges (L):

1. Human System Barriers (N=18, L=12) – (a) Changing the institutional environment; (b) Lack of political will; and (c) Equity
2. Organizational Barriers (N=3, L=2) – (a) Lack of coordination across stakeholders; (b) Lack of coordination across sustainability efforts; and (c) Lack of leadership
3. Public Barriers (N=7, L=4) – (a) Misinformation dissemination to the public, and uninformed public opinions; (b) Lack of public engagement; and (c) Lack of public support
4. Engineering System Barriers (N=3, L=3) – (a) Infrastructure capacity; (b) Lack of flexible/adaptive infrastructure; and (c) Aging infrastructure
5. Natural System Barriers (N=0, L=8) – (a) Frequency and severity of extreme events; (b) Finite resources; and (c) Climate
6. Financial Barriers (N=5, L=3) – (a) Lack of financial incentive; (b) Lack of financial investment; and (c) Return on investment is long-term without near-term gains
7. Research Related Barriers (N=7, L=6) – (a) Lack of problem definitions and goal definitions; (b) Data availability; and (c) Disciplinary silos

Participants also ranked how they would expect certain actions to positively impact urban resilience/sustainability, and four actions ranked highest:

1. Increased investment at the local and state level

2. Increased collaborations between legislators, stakeholders, and scientists

3. A well-articulated and convergent Sustainable Urban Systems research agenda

4. Increased multi- and transdisciplinary research collaborations

The recognition that increased collaboration is of primary importance was evident in the fact that when asked to rank why these sustainability experts were motivated to participate in the conference, sharing their own knowledge about sustainability ranked lowest, learning from other sustainability professionals ranked intermediate, and the potential for future collaborations ranked highest.

Several important themes and numerous research questions emerged from the surveys and workshops. The themes were distilled into four primary categories, with scientific questions that participants felt were eminently addressable under a convergent SUS research agenda:

Theme 1: Urban-external entity relationships. *Hypothesis: Urban systems are inextricably linked to the larger ecosystems, watersheds, and populations that provide resources to urban* centers[2, 3, 4, 5].

1. What are the essential feedbacks and features needed to describe and model urban-external-entity relationships?
2. How do these feedbacks and features change across spatial and temporal scales? To what extent do outcomes differ across scales and within systems? Is there a balance in resilient, sustainable urban systems that integrates both the local and the global?
3. Does increased sustainability through optimization of existing infrastructures lead to increased vulnerability (e.g., continued use of aging, low-throughput highway infrastructure [low resource consumption, inefficient transit, increased air pollution] in lieu of massive capital expenditure to create new highways [high resource consumption, faster transit, lower pollution])?
4. How do we manage the multiple flows of materials and energy in ways that achieve system stability and resilience across the integrated urban/rural system? What governance structures and institutions are needed to support system stability and resilience?
5. What are the tradeoffs between ecosystem health and urban systems when planning for sustainability of urban systems?
6. Which urban and rural ecosystem services are substitutable with other services, and how can they be substituted?
7. The ways in which rural areas benefit from connections with their nearest urban area differ in form from the ways in which urban areas benefit from their nearest rural areas. Does that mismatch lead to inefficiencies and lost opportunities for mutual benefit?
8. How can urban systems invest in rural resilience to increase their own sustainability?
9. How does cultural variation (across regions, nations, cities) influence problem definition and solution sets for sustainable urban systems?
10. How does the sharing of resources and the balance between conflict and cooperation among various sectors and actors change from urban to exurban nodes? What social, political, economic, behavioral, and ecological factors affect this relationship?

Theme 2: Co-design of Research and Co-production of Knowledge. *Hypothesis: Building a successful SUS research agenda is predicated on comprehensive collaboration between researchers and stakeholders* [6, 7, 8].

1. What metrics and expressions of uncertainty are needed for the kinds of projections that will support decision making?
2. What are the best ways to co-design and co-produce with under-represented stakeholders?
3. What factors motivate participants of different backgrounds (e.g., researchers, policy makers, residents, youth, minorities etc.) to become involved and to remain involved in these efforts?
4. What suite of approaches, tools, and facilitation strategies are transferable across cases and scales, and which are context sensitive?
5. What are the unique and necessary partnerships required to support urban sustainability?
6. How do we support the co-production of knowledge required for adaptive management of integrated urban/rural systems?

Theme 3: Integration of Social/Physical Modeling and Observations. *Hypothesis: Projections of future scenarios are essential for providing decision makers with actionable information for fostering a sustainable future of urban systems* [8, 9, 10].

1. How can we integrate models for social and physical processes needed for decision making?
2. What are the controlling processes and feedbacks needed to constrain integrated models?
3. What are the dimensions/variables that are necessary to measure and model when approaching SUS?
4. What advances are needed to integrate physical and social models comprising changes in climate, hydrology, economics, public health, population, agriculture, transportation, and the growth of cities?
5. How do we merge scientific knowledge with the social constructs that drive urban and rural environments?
6. How are metrics and uncertainties propagated when we integrate models?
7. How do we model in real time across spatial and temporal scales?
8. What is the proper way to distinguish persistent trends and their drivers from random variability in locally important environmental and climate indicators?
9. How do we integrate existing and future data and modeling infrastructures to support effective SUS modeling in a way that enables adaptive decision-making?

Theme 4: Governance of Sustainable Urban Systems. *Hypothesis: Understanding unique governance challenges and opportunities is essential to attaining SUS* [11, 12, 13].

1. What are the behavioral, political, and other social barriers to (and opportunities for) designing effective governance systems and processes to enhance societal cooperation and coordination?

2. How does social capital (e.g., social networks, identity, access) influence SUS-related policy design and implementation?
3. How can adaptive governance bring unique solutions to SUS?
4. What configurations of laws, policies, and organizational practices enable key actors and their organizations/collectives to self-organize, learn, and adapt for sustainability and resilience?
5. How do governance actors and relationships between actors change with scale (or across the urban-external entity gradient)?
6. Are there clear links between the ways in which social/physical phenomena are modeled and the relevant policy levers or interventions?

The semi-arid landscape of central Texas is among a handful of climatological hotspots across the globe[14]. It is in these regions where small changes in climate will drive much larger perturbations in the social-natural-engineered subsystems, with cascading effects that are not well understood or even predictable with current modeling and assessment tools in a way that is meaningful for a range of decision makers[15, 16]. This is an especially urgent challenge in semi-arid regions with a projected doubling of population by 2050, such as is the case in central Texas. The themes described above arose organically as conference activities led to co-produced knowledge that transcended our original four conference themes. In addition to these themes and research questions, **we recommend that NSF changes future SUS request for proposals to formalize the inclusion of a *stakeholder engagement plan* that supports the co-production of knowledge**. This plan should include time horizons, a vision for stakeholder activities, and budget line-items for compensating stakeholders when appropriate.

It is our intent to develop these themes more fully and to present them to the scientific community as a white paper. This paper will also include a social network analysis of our newly formed collaborative research group, a deeper analysis of the pre/post-conference survey data, a summary of effective and ineffective aspects of our conference program, and a summary of emergent and convergent research opportunities that contributes to NSF's vision for next-generation SUS science.

On behalf of all conference participants, we thank the National Science Foundation for this unique opportunity to convene researchers and stakeholders from numerous disciplines and backgrounds. Given the broad composition of this new research network, we stand prepared to investigate and address fundamental SUS issues at a range of scales, from single cities to aggregated urban networks. We look forward to the next NSF SUS call for proposals.

Table 1: SUS Conference Attendees

Name	Title	Sector	Affiliation
Jay Banner	Professor, Geology & Director, Environmental Science Institute	Hydrogeochemistry	The University of Texas at Austin
McKenzie Beverage	Senior Academic Program Coordinator, Environmental Science Institute	Sustainability Education	University of Texas at Austin
Patrick Bixler	Asst. Professor of Practice, Public Affairs	Public Affairs	The University of Texas at Austin
Marc Coudert	Environmental Conservation Program Manager	Environmental Conservation	City of Austin, Texas
Daniel DeCaro	Asst. Professor, Urban and Public Affairs	Urban and Public Affairs	University of Louisville
Kasey Faust	Asst. Professor, Civil, Architectural, and Environmental Engineering	Civil, Architectural, Environmental Engineering	The University of Texas at Austin
Marisa Flores Gonzalez	Engineering Project Manager	Regional Water Utility	Austin Water Utility
Auroop Ganguly	Professor, Civil and Environmental Engineering & Director, Sustainability and Data Sciences Laboratory	Civil and Environmental Engineering	Northeastern University
Marta Gonzalez	Assoc. Professor, City & Regional Planning	Urban & Regional Planning	University of California, Berkeley
Steven Gray	Assoc. Professor, Community Sustainability	Community Sustainability	Michigan State University
Robert Greer	Asst. Professor & Director, Graduate Certificate in Public Management	Public Affairs	Texas A&M University
Marilu Hastings	Vice President, Sustainability Programs	Non-Profit	Cynthia and George Mitchell Foundation
Chris Herrington	Environmental Officer	Environmental Conservation	City of Austin, Texas

Name	Title	Sector	Affiliation
Charles Jackson	Research Scientist, Institute for Geophysics	Geophysics	University of Texas at Austin
Antonie Jetter	Assoc. Professor, Engineering and Technology Management	Engineering and Technology Management	Portland State University
Rebecca Jordan	Professor & Chair, Department of Community Sustainability	Community Sustainability	Michigan State University
Fernanda Leite	Assoc. Professor, Civil, Architectural and Environmental Engineering	Civil, Architectural, Environmental Engineering	University of Texas at Austin
Phil Levin	Professor of Practice, Environmental and Forest Sciences	Environmental and Forest Sciences	University of Washington
Jonathan Lowell	Communication Officer for Planet Texas 2050	Institutional Research	The University of Texas at Austin
Robert Mace	Professor of Practice & Chief Water Policy Officer: Meadows Center for Water and the Environment	Water Policy	Texas State University
Sara Meerow	Asst. Professor, Geographical Sciences and Urban Planning	Urban & Regional Planning	Arizona State University
Peter Merwin	Principal Architect	Architecture	Gensler Corporation
John Neilsen-Gammon	Professor, Atmospheric Science & Texas State Climatologist	Atmospheric Science	Texas A&M University
Jennifer Nelson Gray	Director, Planet Texas 2050	Institutional Research	The University of Texas at Austin
Dev Niyogi	Professor, Atmospheric Science & former Indiana State Climatologist	Atmospheric Science	Purdue University
Suzanne Pierce	Research Scientist, Texas Advanced Computing Center	Computer Science	The University of Texas at Austin

Name	Title	Sector	Affiliation
Kent Portney	Professor & Chair, Department of Public Policy and Finance; Director, Institute for Science, Technology and Public Policy	Public Policy	Texas A&M University
Robert Puente	Chief Executive Officer	Regional Water Utility	San Antonio Water System
Varun Rai	Assoc. Professor & Assoc. Dean for Research of Department of Public Affairs	Public Affairs	University of Texas at Austin
Katherine Romans	Executive Director	Non-Profit	Hill Country Alliance
Sarah Schlessinger	Executive Director	Non-Profit	Texas Water Foundation
Laura Schmitt-Olabisi	Assoc. Professor, Community Sustainability	Community Sustainability	Michigan State University
Stefan Schuster	Chief Marketing Officer & Senior Hydrologist	Hydrology	EQO, Aqua Strategies
Tyler Scott	Asst. Professor, Environmental Science and Policy	Environmental Policy	University of California, Davis
Joe Smith	Water Resources Engineering Supervisor	Water Resources Engineering	Austin Water Utility
Ashlynn Stillwell	Assoc. Professor, Civil and Environmental Engineering	Civil, Architectural, Environmental Engineering	University of Illinois Urbana-Champaign
Darrel Tremaine	Research Coordinator, Environmental Science Institute	Hydrogeochemistry	The University of Texas at Austin
Courtney Vletas	Assoc. Director for Development, Jackson School of Geosciences	Financial Development	University of Texas at Austin
Jim Walker	Director of Sustainability	Institutional Sustainability	The University of Texas at Austin
Emily Warren	Water Program Officer	Non-Profit	Cynthia and George Mitchell Foundation

Name	Title	Sector	Affiliation
Michael Webber	Professor, Mechanical Engineering & Chief Science and Technology Officer	Energy Engineering	University of Texas at Austin, ENGIE Energy Group
Sunny Williams	Program Analyst	Program Analyst	National Science Foundation
Bev Wilson	Assoc. Professor, Urban and Regional Planning	Urban & Regional Planning	University of Illinois Urbana-Champaign
Michael Young	Professor, Geology & Assoc. Director, Bureau of Economic Geology	Hydrogeology	University of Texas at Austin
Moira Zellner	Assoc. Professor & Director, Urban Data Visualization Laboratory	Urban Planning and Policy	University of Illinois, Chicago

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