Co-creating an arid-adapted, integrative green infrastructure research agenda

A workshop of the 2012 AridLID Conference

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Table of Contents

Introduction

The third Arid Low Impact Development Conference was held in Tucson, Arizona from March 27-29, 2012. With over 200 participants, the conference attracted people from 10 states and Canada who share an interest, enthusiasm, and curiosity for green infrastructure (GI) and low impact development (LID) as they pertain to arid areas. In the broadest sense, the terms GI and LID are used interchangeably to describe approaches that use living, natural systems to provide environmental services such as capturing, cleaning, and infiltrating stormwater; creating wildlife habitat; shading and cooling streets and buildings; and calming traffic. Most often, the term green infrastructure is used to refer to a class of stormwater control measures or practices that slow, capture, treat, infiltrate and/or store runoff at its source, and includes both structural (e.g. stormwater capture and treatment) and non-structural (e.g. preservation of open space) approaches. GI and LID practices can be applied at various scales ranging from individual sites to regional projects. In addition to a wide range of speakers, an interactive poster session, and field trips, the AridLID Conference also featured a workshop entitled "Co-creating an arid-adapted, integrative green infrastructure research agenda." The workshop centered around forming and prioritizing research questions that cannot be or have not been answered by studies conducted in wetter parts of the country. This report summarizes and synthesizes the outcomes of that workshop.

Background

Begun in 2010 in Albuquerque, New Mexico for professionals, educators, activists, and government officials, Arid LID has expanded into a regional conference and garnered national attention from the U.S. Environmental Protection Agency and others. The conference started as a way to address the fact that most efforts promoting and exploring green infrastructure and low impact development are being carried out in much wetter areas of the country than the arid and semi-arid West. Despite this, GI and LID techniques are being employed in these arid areas, giving rise to a conference devoted to understanding and supporting these efforts.

The title of the Arid LID conference held in Tucson was "Integrated Approaches to Green Infrastructure and Low Impact Development in Arid Environments." An integrated approach includes partnerships between states, jurisdictions, and municipal offices; residents and authorities; and researchers and practitioners from various disciplines. Indeed, proponents of GI/LID techniques frequently cite disconnects between the latter group—researchers and practitioners—as a significant barrier. Though many are willing to incorporate GI/LID practices, lack of research to back up methods and ensure results can hinder the implementation process. To address this, researchers from the Water Resources Research Center at the University of Arizona applied for and received a grant from the University of Arizona's Water, Environmental, and Energy Solutions (WEES) program to include a workshop at the 2012 conference aimed at forming a research agenda focused on implementing GI/LID in arid environments.

Process

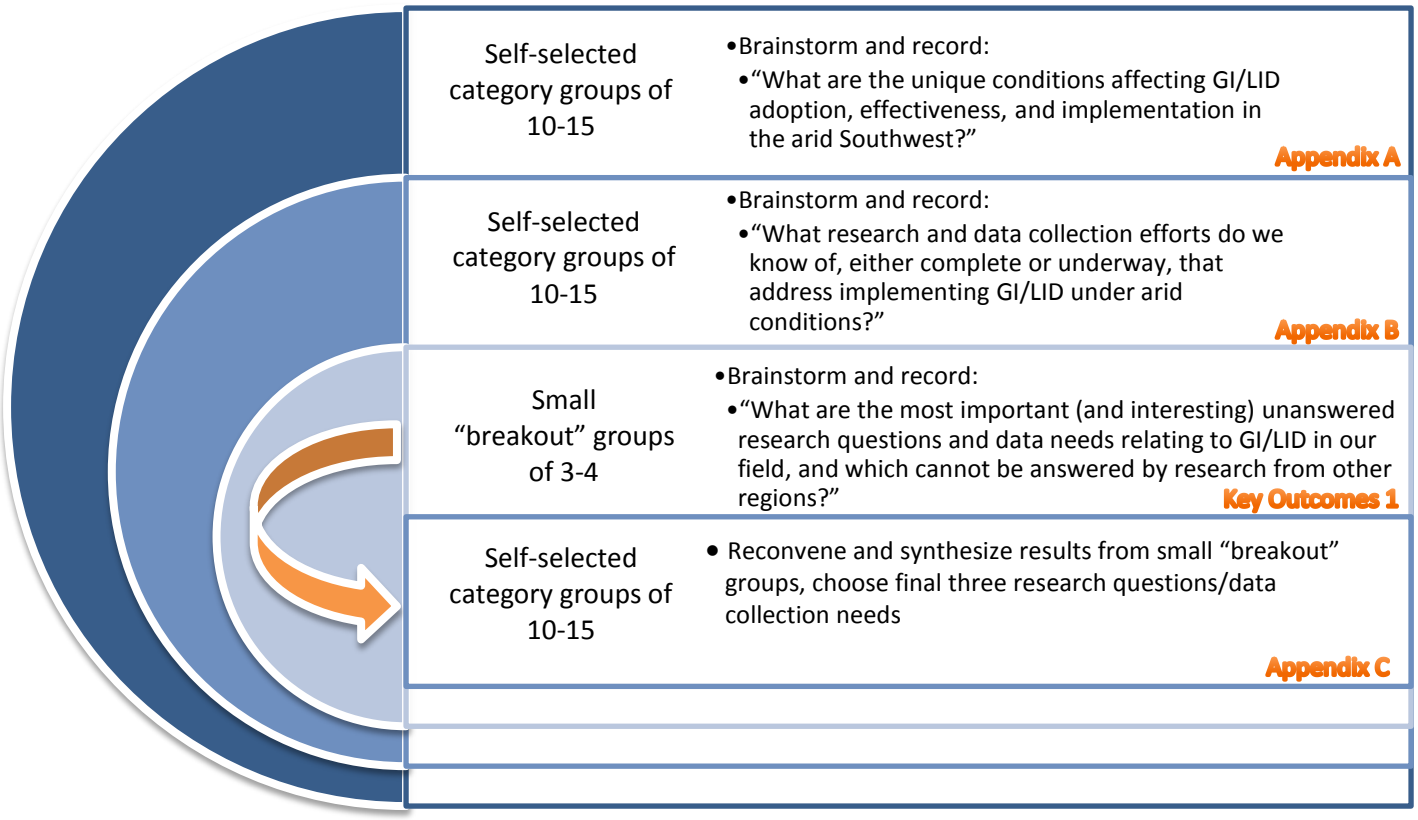
The 2012 conference steering committee created a workshop that sought to stimulate cross-disciplinary conversation, produce a prioritized list of research needs to make GI/LID more effective in arid areas, and generate suggestions for realistic, achievable ways to meet those research needs. First, a series of presenters spoke on subjects aimed at "priming the pump" for the workshop participants. Keynote speakers Alice Gilliland and Michelle Simon of the U.S. EPA's Office of Research and Development were followed by a panel of regional researchers who covered a wide variety of topics, from *Southwestern Climatic and Geologic Influences on Surface Water Flows* to *Environmental Justice in a Desert City: Green Space, Heat, and Social Inequality*.

Two breakout sessions followed the speakers. The first session was comprised of a focused dialogue to identify key research questions. Participants moved into groups based on self-selected categories, completed at registration:

Self-Selected Categories
1. Water quality, nonpoint source pollution, wastewater
2. Hydrology, flood control, floodplain management
3. Water supply, water rights, groundwater
4. Urban forestry, heat islands, air quality, parks & recreation
5. Urban planning, transportation, architecture, development, landscape architecture
6. Climate change, mitigation, and adaptation
7. Community development, education, outreach, economic revitalization, social programs, human health
8. Urban ecology, conservation, ecosystem services, linkages/corridors, restoration
9. Operations/maintenance

Once organized into these groups of 10-15 people, the facilitator assigned to each group walked participants through the following process:

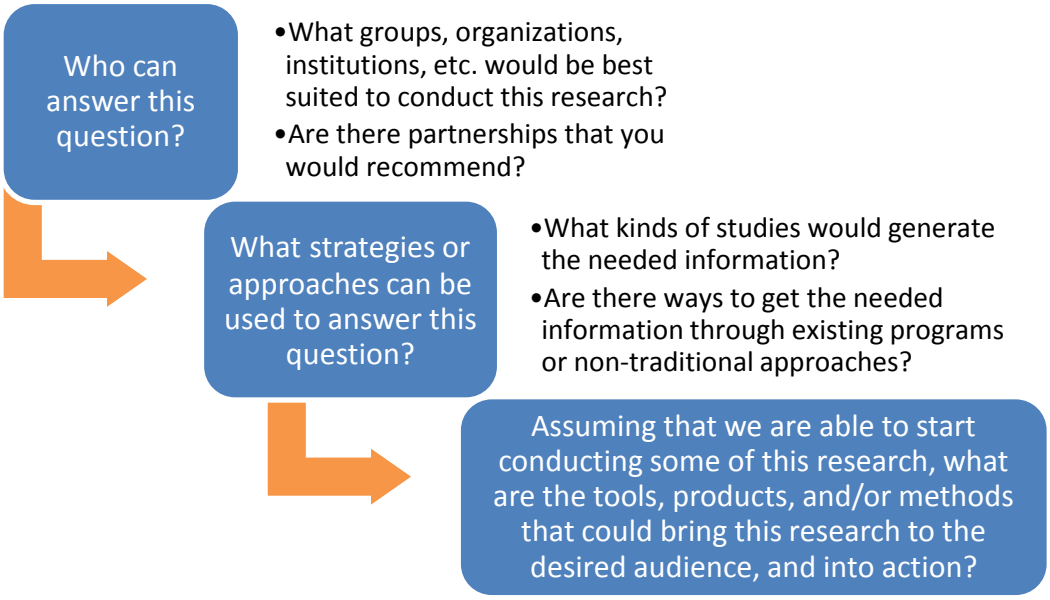
First breakout session process



These pages were collected and transcribed, and can be found in the appendices indicated. This process resulted in a final list of 44 of the most pertinent and important research questions and data collection needs. Group members were also asked to follow up with specific references, and were given an email address, aridlidresearch@gmail.com, as an avenue to do so. These emailed references can also be found in Appendix B.

For the final breakout session, the self-selected groups were reorganized to ensure that dialogue was happening across, rather than within, disciplines. Workshop organizers felt this "cross-pollination" was important to inform others about ongoing research efforts, as well as to open channels of communications between the many different areas and practices involved with GI/LID techniques. Each interdisciplinary group was randomly assigned two of the 44 final research questions, and asked to address three components of producing an answer for each of those questions, roughly translating to "who," "what," and "how":

Second breakout session process



Groups were given the opportunity to choose additional questions to focus on if they finished both of their assigned questions, or to choose different questions if they felt they could not adequately engage with the ones assigned. The components of each question addressed were recorded by the groups on flip charts, collected, and compiled in Key Outcomes Document 2. Before the end of the workshop, participants were also asked to circle their top three priority research questions from the full list of 44. These votes were tallied, and the results can be found in Appendix D.

Key Outcomes

The various processes and steps undertaken in this workshop yielded a plethora of information. Two documents in particular, Key Outcomes Documents 1 and 2, below, together offer a concise and coherent summary of participants' input. Subsequent sections offer a synthesis of the full workshop results as well as appendices reflecting the information generated and captured at each stage.

Key Outcomes Document 1

What are the most important (and interesting) unanswered research questions and data needs relating to GI/LID in our field, and which cannot be answered by research from other regions?

(Results reported from large group synthesis)

Topic area 1: water quality, nonpoint source pollution, wastewater

1. What are the pre-treatment and treatment needs before infiltration? (growth solids? Test for metals, N, phosphorus, sediment, impact to groundwater quality, compared to natural soils)
2. What are the LID impacts to ephemeral washes over time (downstream studies)? (e.g. pollutant loads accumulation? Hydrology feedback loop, ecological responses, wildlife water quality needs, sediment transition)
3. How does the level of maintenance of LID sites impact the efficiency of water quality treatment? (e.g. lifespan studies, true cost studies)
4. How do we get researchers interested?
5. How can we improve performance/effectiveness in the most cost-efficient way?
6. How does LID BMPs' performance change over time?
7. Can we create a uniform database for LID BMPs for semi-arid areas?
8. How do you improve aesthetics and optimize water quality management?

Topic area 2: hydrology, flood control, floodplain management

9. How do different vegetation types/densities function in LID practices to develop healthy soils?
10. Need: calibration of models to real world conditions
11. Using hydrologic modeling, what are the non-vegetative practices that increase infiltration, stabilize slopes, promote vegetation, improve air quality, and mimic pre-development hydrology?
12. Need: data on effectiveness of BMPs in local area at different scales
13. Need: evaluate local soils for infiltration and erosivity and impact on built environment (i.e. streets, buildings)
14. Need: evaluate the impact of GI/LID on flood frequency and volume and as a downstream resource
15. Need: cost-benefit analysis for GI/LID/BMPs versus drainage infrastructure
16. What is the impact/benefit of moving from regulating floodplains based on regulatory discharges vs. a landscape/geographic approach

Topic area 3: water supply, water rights, groundwater

17. What are the socio-economic challenges to implementing LID? (cost-benefit, water rights laws, public acceptance)
18. What are the impacts of LID to current and future water infrastructure?
19. What are the groundwater impacts due to water infiltration, positive and negative? (infiltration rate, water quality issues, life of soil aquifer treatment)

Topic area 4: urban forestry, heat islands, air quality, parks & recreation

20. What are the mechanisms that generate and foster local stewardship that is community and culturally specific?
21. Considering species, how to maximize trees for LID: water use, leaf area index, water interception, need for species diversity, wildlife value?

Topic area 5: urban planning, transportation, architecture, development, landscape architecture

22. What are real, measurable numbers to quantify LID benefits, using BMP/case studies and new research?
23. What are the capital and life cycle costs (and savings) differences between LID and traditional development practices?
24. Need: comprehensive LID/GI manual(s) for locally-appropriate policies and best practices that is responsive to water/climate uncertainty
25. Need: identify specific techniques to inspire and motivate or energize the public and policy makers towards LID/GI adoption
26. What criteria do we need to measure to address changes in the urban ecosystem as a result of green infrastructure?
27. Need: criteria for identifying the most effective opportunities for green infrastructure location and cost effectiveness in urban redevelopment

Topic area 6: climate change, mitigation, and adaptation

28. Who are the high risk populations for each climate-related public health or safety risk that could be related to, or affected by, GI/LID (e.g. mosquitos, quality of water used for gardens/food production, disease vectors present in soil and water, change in fire frequency, etc.) due to climate change? How can these populations and problems be detected and addressed?
29. How should typical or new design criteria for GI/LID (rainwater harvesting, stormwater harvesting, and/or flood control-related structures) change due to climate change projections for different localities?
30. How will species shift (flora, fauna, invertebrates, disease vectors, fungi, etc.) due to climate change and how should this inform the design (species selection, size, depth, number, location etc.) of GI/LID design?

Topic area 7: community development, education, outreach, economic revitalization, social programs, human health

31. How can we measure mental and physical well-being impacts through long-term and ongoing involvement in GI activities that are unique to the SW?
32. How do we reach a wide populace of communities with GI jobs while recognizing community assets that are unique to the SW?
33. Given the outsourcing of landscape labor, how do we motivate and sustain long-term behavioral change at the community/individual level?

Topic area 8: urban ecology, conservation, ecosystem service, linkages/corridors, restoration

34. Regarding effluent use for GI/LID – how does the quality and salinity of effluent/reclaimed water impact GI/LID projects? (availability is also a question)
35. Need: database of existing findings, process for prioritizing projects within the context of a watershed, identify criteria
36. Need: additional research on plant/soil interaction and pollutant removal for LID/GI with potential application to quality, volume reduction, and recharge
37. How do you make GI, research, ecosystem services, etc. accessible and sexy?
38. How do we best quantify benefits (multipliers, triple bottom lines) of integrated approaches (i.e. bio and grey corridors)?
39. In the context of landscape and connection/corridors/scale- what percent of an urban watershed needs GI to provide services, corridors, etc.?
40. Need: review of institutional motivation for big projects- institutions, codes, ordinances for treating soil etc. as a resource
41. What are the implications of the urban heat island effect on evapotranspiration and what are the implications of this for BMPs and ecosystem services? What is the ability of BMPs to mitigate urban heat island effect and evapotranspiration?

Topic area 9: operations/maintenance

42. What tests or evidence are available/can be developed to tell if a system is healthy and working on an ongoing basis?
43. What is/leads to best plant performance? Aspects include local climate, best size to start with to enhance survivability, BMP or treatment control needed for water quality improvement (including through maturity)
44. What are the best maintenance frequency schedules, tool, methods, and life cycle costs (including operations and maintenance)?

Key Outcomes Document 2

Moving from Research into Action

Research Question	Who?	What?	How?
1. What are the pre-treatment and treatment needs before infiltration? (growth solids? Test for metals, N, phosphorus, sediment, impact to groundwater quality, compared to natural soils)	• University research • Geotechnical engineers • EPA • Science-based non-profits	• Determine watershed characteristics and constituents of runoff • What kind of treatment is accomplished by native soil? • Determine the life-cycle costs of soil (i.e. how long does treatment last without clogging etc.)	• Publish design guidance from research • EPA-NPS listserv • Educate regulators, elected officials • Educate practitioners, industry
2. What are the LID impacts to ephemeral washes over time (downstream studies)? (e.g. pollutant loads accumulation? Hydrology feedback loop, ecological responses, wildlife water quality needs, sediment transition)	• Universities • Municipalities (governments) • Community groups, citizens • For-profit partnerships	• Long-term sampling / monitoring of flow, water quality, pollution • "Paired" studies • Pilot projects	• Journals • Speakers' bureau • Conferences • Social media • City council report • Tours • University lectures • Reality TV • Design competition
3. How does the level of maintenance of LID sites impact the efficiency of water quality treatment? (e.g. lifespan studies, true cost studies)	• Project "owners" (eg. citizen scientists) • Stormwater agency • Cities and towns • University / research institutions • MS4 permit holders • Private (volunteer-led) / public partnerships	• Evaluate, identify existing case studies / installations • Design research "plots" i.e. pilot scale projects • Does treatment change with scale of project? Identify issues • Cost-benefit analysis for planning	• Guidance documents (eg. operation, design, maintenance, and watershed scale considerations) • Training (ongoing) and certification program • BMPs • Regularly updated info / data clearinghouse • Outreach, e.g. conferences, webinars, info share events
6. How does LID BMPs performance change over time?	• Non-profits • Academic groups • Product manufacturer / municipality partnerships	• Watershed characterization • Installation • Long-term monitoring	• EPA database • Peer-reviewed academic publications
9. How do different vegetation types/densities function in LID practices to develop healthy soils?	• Soil scientists and biologists • Horticulturalists • Master gardeners	• Export litter vs. keep litter • Engagement to supply data / observations in a structured way • Youth Achieving Resource Development	• Work with Natural Resource Conservation Districts (NRCDs) – NRCS • Make data / observations part of certification process for Master

		Skills (YARDS)	Gardener / Watershed • Youth at Risk – job training (YARDS) program
14. Need: evaluate the impact of GI/LID on flood frequency and volume and as a downstream resource	• Flood control districts • Universities • EPA, HUD, BOR, Army Corps USGS • Game and Fish • Professional associations	• Modeling LID practice and runoff reduction • Maintenance requirements and long-term costs • Monitoring to capture data from established sites and control (or before and after) • Impacts on downstream vegetation / riparian	• Models like Sustain, SWMM • Ongoing documentation of cost-benefit • Maps • Design guidelines / maintenance manuals
15. Need: cost-benefit analysis for GI/LID/BMPs versus drainage infrastructure	• Neighborhood: o Engineer / designer o Resource economist o Landscape architect • Regional: o Academic o Engineer / designer o Public land manager o Resource economist	• Take existing plan and reconfigure using GI/LID – compare • Comparative modeling at regional scale • Multi-disciplinary evaluation e.g. permaculture, climate change, heat island, wildlife	• Funding – federal, state, local • Cross-disciplinary steering committee • Targeted outreach – public, policy-makers, design professionals, trade associations, land managers
18. What are the impacts of LID to current and future water infrastructure?	• Water management agencies: stormwater, water utilities • Army Corp of Engineers • Hydrologists • Civil engineers • Flood control districts • Fluvial engineers • Planners, landscape architects • GI/LID/RWH practitioners • Irrigation engineers	• Stream flow – end of pipe water quantity / volume / rate • Pollutant flow • Population growth and infrastructure need • Cost-benefit analysis • Remote sensing • Ecosystem services • Community health • Network distribution system analysis – optimization, meso-scale studies • Retrofit vs. new	• Guide for urban infrastructure optimization • Large scale, visible demonstration, signage, and interpretation • Publication • Outreach
	• Infrastructure owners • Universities • Utility industry organizations e.g. American Water Works Association (AWWA) • Jointly funded efforts by watershed-wide organizations	• Neighborhood-scale projects • Modeling multiple barriers • Cost-benefit analyses • Infrastructure assessment study	• Water savings quantification tool • Incorporation into capital improvement program, etc

19. What are the groundwater impacts due to water infiltration, positive and negative? (infiltration rate, water quality issues, life of soil aquifer treatment)	• USGS, BOR, EPA, DEQ • Water utilities • NAU / UA / ASU • Desert Research Institute • Council for Watershed Health • ARS – agricultural research science	• Tracers in stormwater • Bench scale test of absorption rates of various pollutants • Sampling at each level of watershed and source analysis • Long-term viability of reclaim systems to recharge • Modeling infiltration • Comparative analysis between natural, concretized, bank-protected sandy bottom washes	• Conference like this (AridLID) • Design guidelines • Partnerships between stormwater and water utility staff • Feasibility and BMP studies • Concise compilation of research • Public outreach in plain language
21. Considering species, how to maximize trees for LID: water use, leaf area index, water interception, need for species diversity, wildlife value?	• Plant scientist / botany • USFS • American Forests • Environmental consultants • Landscape architects • Fish and Wildlife • Wildlife ecologist • Phytoremediation • Agriculture Extension	• Literature review • Integrated, interdisciplinary team approach • Refine focus question • Scaled approach : plot → pilot → field demo • Long-term v. short term (ongoing monitoring) • Replications of diverse systems • Plant water use – ET across related tree species • Stormwater offset of tree via leaf area index and water interception • Other data sources – parking lots	• Trade organizations: American Forests etc., non-profits • Graphic design guidelines • Standard construction detail – region specific • Integrated systems diagrams • Local adaptation of existing models • Adding local data to existing models • Demonstration site / LID laboratory • Outreach programs
23. What are the capital and life cycle costs (and savings) differences between LID and traditional development practices?	• University • Consultant • Non-profit	• Life-cycle performance and cost monitoring • Ecological economics (university) • Current average regional hard costs catalog (consultant) • Surveys of social benefits (non-profit)	• Publish and market catalog of hard costs • Professional development • Educate decision-makers and community groups

24. Need: comprehensive LID/GI manual(s) for locally-appropriate policies and best practices that is responsive to water/climate uncertainty	• State / regional regulatory body leadership (e.g. ADWR, PAG, MAG)
	• Consortium metro, education, public, arts, environmental developers (e.g. municipalities, land grant universities, NGOs)
		• Research and data gathering
		  o Local research, case studies
		  o BMP manuals, regional / national research
		• Prototype alternatives (build structure / outline)
		  o Outside consultant team
		  o Educational / peer review
		  o Identify vulnerable sectors
			• Tools
			  o Web portal
			  o Conferences
			  o Trade shows
			  o Arid GIS calculator
			• Feedback loop
			  o Local to regional
			  o Cultural / creative
			  o Health profession

		o This process has a parallel stakeholder feedback loop at project milestones • Draft product • Public outreach • Pilot projects	o Education o Municipality • Living document o Periodic review and updates o Neighborhood subsections
26. What criteria do we need to measure to address changes in the urban ecosystem as a result of green infrastructure?	• Scientists: ecology, soil, hydrology • Citizen scientists • Ancillary professionals (GIS)	• Guided citizen scientists – data collecting • Time series data on plants, wildlife • Soil samples • Data collection training	• Normalize data in a form everyone can use • Signage and outreach – publicly displayed results • Events that celebrate success will pass the knowledge and methods to future participants
27. Need: criteria for identifying the most effective opportunities for green infrastructure location and cost effectiveness in urban redevelopment	• Social scientists / universities • Economists • Consultants • NGOs (James McAdam! Watershed Management Group)	• Pilot projects • Community surveys • Case studies • Research regulatory framework • Modeling	• Design guidelines / BMP manual • Pilot project / larger scale project • Community action initiatives • Community development grants • Advisory board
30. How will species shift (flora, fauna, invertebrates, disease vectors, fungi, etc.) due to climate change and how should this inform the design (species selection, size, depth, number, location etc.) of GI/LID design?	• Climatologists • Biologists • Ecologists • Designers	• Comparative studies of similar ecological systems • Study historical data • Take key species to study adaptation to environmental changes • Design: testing designs, plant selection, placement in small-scale projects	• Pilot programs • Use in-lieu fees for pilot programs / research
31. How can we measure mental and physical well-being impacts through long-term and ongoing involvement in GI activities that are unique to the SW?	• Partnerships: social scientists, community groups • Non-profits • Counties	• Surveys: “happiness,” incidence of medical issues • Tracking long-term involvement • Outside time after vs. before • Neighborhood turnaround • Crime / domestic violence data before and after	• Face-to-face workshops / meetings (piggyback on existing meetings more effectively) • Public service announcements • Arts / cultural activities as vehicles • PARTY / fair / ☺ fun times
34. Regarding effluent use for GI/LID – how does the quality and salinity of effluent/reclaimed water impact GI/LID projects? (availability is also a question)	• Universities (agriculture) • USDA • Utilities • Consultants / NGOs / research institutes • End users	• Monitoring • Cost-benefit analysis • Pilot projects • Community education (connection with how to take research into action) • Modeling • Review, research, and revise current policy	• Pilot projects • Community education (incentives) • Implement results from research and pilot projects • Build partnerships (public / private) • Regulatory / policy change • Develop criteria design guidelines

35. Need: database of existing findings, process for prioritizing projects within the context of a watershed, identify criteria	• EPA Office of Research and Development, ARS – UA (Mitch) • How to involve community (e.g. WMG) • Process manual • Student organizations • Integrate data collection • Potential funding sources more holistic	• Technical manual → BMP • International BMP database • Rainwater harvesting – empty now • Groundwater recharge • Enter local knowledge of BMP effectiveness and type - water quality, soil health • Vegetation types and function • ESS, social services • Food security	• RARE grant – EPA to quantify effects of LID • Workshops • WERF / WRRF • UA water sustainability grants • Walton Foundation
36. Need: additional research on plant/soil interaction and pollutant removal for LID/GI with potential application to quality, volume reduction, and recharge	• NRCS – Tucson Plant Materials Center (AZPMC) • ADEQ • CO School of Mines • Academia → Mitch Pavao-Zuckerman(Biosphere 2) • EPA • Consultants • Private industry • USGA – soil maps • Brownfields has parallels in land farming info	• Small-scale models • Pilot comparative projects well-distributed to represent variation in region • Lysimeters to create chemical database • Short-term and long-term studies • Comparison of soil and vegetation maps • Consider accumulation of pathogens, salts, oils, and other contaminants • Study sunlight impacts, impacts at different depths	• Funding! • Education: publications • Research • Arid manuals • Cooperative agreements • Replicate EPA study here • Central database • Replicate EPA models with desert applicability • Require / regulate / incentivize
37. How do you make GI, research, ecosystem services, etc. accessible and sexy?	• Anthropologists, sociologists • Social movement researchers • Marketing specialists, PR firms	• Design studios – make the infrastructure sexy! • Product placement • Cross-marketing with other social movements • Local celebrity endorsements • Refined messaging • Conservation competitions and recognition for good practice • Tours and hands-on experience • Clear, attractive graphics and signage	• Demographic studies, focus groups, surveys • Maps
40. Need: review of institutional motivation for big projects-institutions, codes, ordinances for treating soil etc. as a resource	• EPA • Municipalities/MS4s • Public (vote)	• Look at open space • Remediation / soil restoration • Define valuable soil resource areas (depth, infiltration, slope, top soil geographically, compaction) • Research soil transport needs in arid environments	• Compare to action made toward tree ordinances • Examine conflicts with construction requirements • Remove barriers

		• Remove barriers	
41. What are the implications of the urban heat island effect on evapotranspiration and what are the implications of this for BMPs and ecosystem services? What is the ability of BMPs to mitigate urban heat island effect and evapotranspiration?	• Universities, different systems set up for monitoring • City / County, department of sustainability, urban forester • Science community	• Neighborhood study • Data from city water harvesting • Use remote sensing to map UHI	• Pilot projects – retrofitted • Test BMPs before putting in manual
42. What tests or evidence are available/can be developed to tell if a system is healthy and working on an ongoing basis?	• Community residents / users • Local experts in the particular system • Professionals, e.g. landscape architects, stormwater experts • City / county	• Monitor and test existing systems • Develop criteria for monitoring • Collaboration among disciplines and with residents	• Education for maintenance • Oversight • Pilot programs with monitoring
	• Partnerships among government agencies • "average Joe" end user • Builder / developer / manufacturer	• Develop BMP standards for each component • Photo points • Accessible and accurate measuring tools	• HOA / community manual • Online trainings • Youtube / social media • Nonprofits like WMG

Synthesis

Unique Conditions (Appendix A, below)

One of the most frequently-mentioned unique conditions pertaining to the arid Southwest, not surprisingly, focused on precipitation. Respondents cited the nature of storms ("flashy," "stochastic," "distribution," "intensity/timing") in the region as a major factor affecting GI/LID, especially "higher concentrations of trash/pollutants due to infrequent events". Issues regarding soils also received a lot of attention, including elements such as a wide variation in soil types, lack of organic material and erodibility, infiltration, texture, and salt buildup. Participants brought up high evapotranspiration rates and the nature of ephemeral washes as additional components relating to GI/LID effectiveness in arid areas. Human impacts were also seen to play a role, especially the sprawl-oriented form of development commonly found in the region, as well as issues resulting from historic water rights laws.

Research and Data Collection Efforts (Appendix B, below)

Participants recorded many ongoing research efforts in both the academic and civic realm. Workshop attendees cited federal and municipal agencies as sources of data, as well as nonprofit and advocacy groups. Specific researchers, agencies, projects, and groups mentioned included:

Researchers	Federal and Municipal Agencies/Programs	Non-Profit and Advocacy Groups
Mitchell Pavao-Zuckerman (UA, Biosphere 2)	City of Tucson/Pima County Water and Wastewater Infrastructure Study	The Nature Conservancy
Erika Gallo (UA, Biosphere 2)	City of Phoenix's Tres Rios project	Surfrider Foundation's Ocean Friendly Gardens program
Julie Stromberg (ASU)	Pima County's Kino Environmental Restoration Project	National and Tucson Audubon Societies
Eve Halper (UA-BOR)	Cochise County's Stormwater Recharge Project	Council for Watershed Health
Bonnie Colby (UA)	Pervious concrete at the Tucson Zoo and NAU research facilities	Santa Barbara Channelkeeper
Gary Woodward (UA)	Tempe Transit Center green roof	Center for Biological Diversity
Stevan Earl (ASU)	Muscular Dystrophy Association's headquarters green roof (Tucson)	Quivira Coalition
Diane Austin (UA)	Parks at water recharge areas in Gilbert and Chandler	
rainlog.org (UA)	Riverside's low impact development BMP studies	
	Participant survey from LA rainwater harvesting program	
	Long Beach Water Department's lawn-to-garden program	
	Research from the Elmer Street retrofit in LA	

Research and Data Collection Needs (Key Outcomes Document 1, above, and Appendix C, below)

The research questions and data collection needs generated by the smaller breakout groups spanned a wide range of topics and interests, and provide a measure of specificity that was sometimes lost when groups came back together to synthesize those responses into three questions for the larger group. Appendix C lists *all* research and data needs organized by topic area and can be perused to appreciate the full range of research needs that participants evaluated, while Key Outcomes Document 1 reflects the synthesis the larger groups used to produce just three questions. Several themes emerged from the small group brainstorms.

Participants brought up economic aspects of GI/LID frequently, both in terms of data needed to address life-cycle costs of green infrastructure (as compared to traditional, "grey" infrastructure) and data needed to quantify the full range of benefits (both quantitative and qualitative) accrued from the use of GI/LID techniques. Other research needs associated broadly with cost included those pertaining to proper routines and procedures for operations and maintenance and the ways in which GI/LID implementation differs between retrofits and new development.

Many groups called for research into interactions between green infrastructure sites and soil and the ways in which those soils may change over time, from salt build-up to increased or decreased infiltration capacity. Other oft-mentioned topics include the need for research on health issues related to actively- or passively-harvested water and on how to engage the public. Finally, many of these research questions touched on the need for locally-appropriate BMPs and policies, whether relating to plants, placement near sidewalks, size of detention basins, or water rights issues.

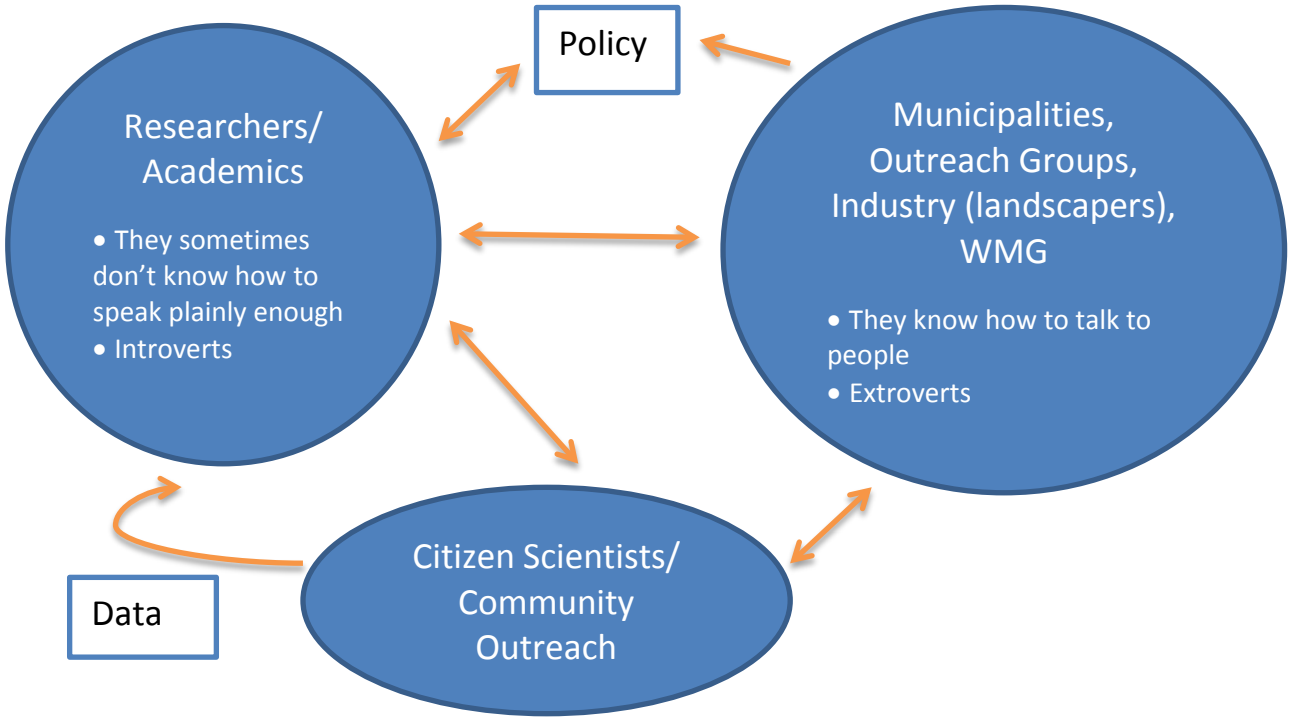
Moving from Research into Action (Key Outcome Document 2, above)

As mentioned above, workshop organizers assigned research questions to cross-discipline groups in the afternoon breakout session. Unfortunately, because these assignments were random in nature, some of the research questions and data collections needs that participants later prioritized most highly were not addressed by any groups. However, 24 questions of the 44 questions submitted did go through the "answering" process. Groups were directed to address each research/data need very specifically and to make suggestions based on that question's unique aspects. For this reason, the most meaningful way to digest this information would be to peruse all questions and their corresponding recommendations for fulfilling those research needs. However, similar suggestions made for various questions are detailed below.

As one could expect, many participants proposed university researchers as potential "solvers" of the research and data needs. Particular universities were mentioned for several of the questions, including some specific departments and even researchers. Participants also pointed to several different federal agencies, from the Bureau of Reclamation, to the Environmental Protection Agency, to the Department of Housing and Urban Development, as avenues for conducting and/or funding necessary research. Some of the more non-traditional groups mentioned to fill the research gap included non-profits, private/public partnerships, "end users," utility organizations, consultants and PR firms, and citizen scientists.

For the "what" portion of addressing the research needs, workshop participants gave many detailed suggestions. Loosely, these included pilot projects, long-term sampling/monitoring, modeling, cost-benefit analyses, and technical manuals (BMPs). As for how to distribute information on the research, participants pointed to design guidelines/manuals, public outreach, demonstration sites with interpretation, education of decision-makers and communities, a central database or data clearinghouse, and partnerships (including joint meetings) as ways to disseminate information and

maximize its usefulness. Several specific funding sources were also mentioned to help in this effort, including Regional Applied Research Effort (RARE) grants from the EPA, University of Arizona water sustainability grants, and grants through the Walton Foundation. One group contributed a model that they developed to address three different questions (numbers 26, 33 and 37).



Prioritized Research Questions

At the end of the workshop, participants were asked to circle three of the 44 research questions that they rated most important or urgent. 82 participants submitted their votes and these selections were compiled to produce the prioritized list found in Appendix D. Several participants chose more than three research needs, while others circled less. To best reflect the choices of participants, all selections were tallied, resulting in scores for each question ranging from one to fifteen. Only one question received fifteen votes, while several rated next highest at fourteen. The remainder of the questions ranged in rank, with many falling in the mid-range of five to eight votes. The following questions, and their scores, represent the top five research and data needs identified through the workshop:

- # 17: What are the socio-economic challenges to implementing LID? (cost-benefit, water rights laws, public acceptance) **15 votes**
- #20: What are the mechanisms that generate and foster local stewardship that is community and culturally specific? **14 votes**
- #22: What are real, measurable numbers to quantify LID benefits, using BMP/case studies and new research? **14 votes**
- #23: What are the capital and life cycle costs (and savings) differences between LID and traditional development practices? **14 votes**
- #33: Given the outsourcing of landscape labor, how do we motivate and sustain long-term behavioral change at the community/individual level? **12 votes**

Conclusion

Workshop participants identified many characteristics of the Southwest region that affect green infrastructure and low impact development implementation and performance and that lack sufficient research. Natural factors such as precipitation regimes and soil characteristics figured largely, as well as socio-economic factors such as water rights, sprawl-oriented development, and difficulties with public outreach and engagement. In fact, the most highly prioritized research question centered on these human components of the GI/LID equation. Participants put forward many specific options for filling the identified research gaps, which included not only universities and federal agencies, but municipalities, non-profits, citizen scientists, and partnerships formed from all of the above.

There are many possible next steps and ways in which the workshop results could be built upon. One possibility would be the creation of a GI/LID literature review, with the current research and ongoing efforts mentioned in the breakout sessions used as a starting point. Tracking of partnerships between traditionally unconnected groups (such as researchers, municipalities, and non-profits) to further GI/LID practices could also prove extremely useful. Perhaps most importantly, further conferences could address the research questions not discussed during the second half of the workshop.

The diversity of the information generated by the "Co-creating an arid-adapted, integrative green infrastructure research agenda" workshop reflects the range of expertise and input received at each step of the process. This heterogeneity also demonstrates the broad reach of GI/LID practices. While the syntheses presented here are not scientific in nature, the hope is that GI/LID practitioners and investigators will be able to use this report to guide further research, funding, and implementation efforts.

Appendix A

What are the unique affecting GI/LID adoption, effectiveness, and implementation in the arid Southwest?

Topic area 1: water quality, nonpoint source pollution, wastewater:

- Increased volume is destabilizing washes
- Tax base for receiving federal funding
- Limited rainfall, huge ET
- Soil conditions
- Rain event types: short duration, seasonal variability/distribution, rain on snow, flooding/stochastic
- Infrastructure designed for flood control, not water quality or infiltration
- Supplemental irrigation needed to establish plants
- Not much precedent of municipal adoption
- High growth rate and retrofit needs
- No combined sewers
- Prior appropriation laws (especially Colorado)
- Surface water and groundwater connection not well known and laws are separate
- Sediment transition, regional water balance – ex. increased infiltration can mobilize
- Natural mineral content and mining industry impacts (background minerals)
- Wide variation of soil types
- Huge urban islands within natural areas
- Seasonality – location of utilities and access for maintenance
- Infiltration/soils low saturated hydraulic conductivity
- Spatial heterogeneity of rainfall
- Understanding water quality of stormwater → what goes into BMP – quality changes over time
- Atmospheric deposition (dry)
- MS4 – land use-based monitoring
- "Cowboy" mentality – non-collaborative, want it now
- Engineering community to think outside the box
- Code/regulatory compliance – very direct, no deviations
- Difficult to convince folks that this works
- Short-term approach dominates
- Funding to implement LID
- Who takes over operation and maintenance?
- Perceptions on the part of users and agencies as to the reality of implementation

Topic area 2: hydrology, flood control, floodplain management:

- Auto-centric layout of towns and cities
- Native vegetation – hard to establish
- Short, intense storms (monsoons)
- Climate (heat, dust, ETO)
- Soils – lack of organic material, erodibility

- Topography
- Ephemeral streams – high sediment loads
- Gage data, soil data, effectiveness of rainwater harvesting (studies from moist conditions – need studies in arid/translate to arid lands)
- Outside of major urban centers
- Surface water rights
- International boundary – lack of data
- Stream ownership, private channels, undersized channels
- Conflicting jurisdictions
- On-the-ground research projects
- Separation of flood goals and resources
- Channel evolution
- Sink holes from water use
- Water quality – water resources
- Peak of hydrographs, sediment
- Localized storms – nature of storms and effects (flashy storms, headcuts)

Topic area 3: water supply, water rights, groundwater:

- Water balancing
- Infiltration and ET (soil characteristics)
- Seasonality and intensity difference
- Using local resources and supplementing regional resources
- Transiency of population and water use
- Perceptions of supplies and water quality – education?
- Price/value of water
- Reuse of wastewater
- Regulations which are barriers to water harvesting

Topic area 4: urban forestry, heat islands, air quality, parks & recreation:

- Feast/famine – extreme events (precipitation)
- Differences in ecosystems → quantity of vegetation → diversity of natural woodlands
- Slope/velocity of run = control → vegetation at elevation extremes (topo)
- Salt on soil texture
- Low humidity
- Distribution of rainfall patterns (even within a section of community – scale)
- Soil texture different from temperature regions → vertical layers
- Population density = sophistication of information → potential adoption rate affected = advocate (rural vs. metro)
- Cities without sidewalks → varying infrastructure
- Cultural diversity = differences in cultural preferences (not necessarily income)
- ? Increase of urban canopy in certain areas → ? impact of maintenance
- Daily temperature extremes

Topic area 5: urban planning, transportation, architecture, development, landscape architecture:

- Historic water rights issues

- Approved construction technologies and methodologies
- Skewed public participation and political will of water as a finite resource
- Disconnect of urban design and natural environments
- Need more education on technology, financial costs/benefits, marketing
- Integration of engineering with design
- Climate > site, + environment
- Uncertain water supply
- Conflicting codes, regulations, models, and jurisdictions (water rights)
- Developer-driven design – lack of incentives to innovate
- High evaporation rates and topsoil/sediment runoff affect site-level design
- Unique political climate
- Historical development patterns are sprawl-oriented
- Wide roads
- Limited plant palette
- Ephemeral streams serve multiple purposes

Topic area 6: climate change, mitigation, and adaptation:

- Climate will be hotter and drier, may have higher intensity, lower duration peak flow events
- "100-year" storm and "100-year flood" are moving targets. Don't know what they will look like as time goes on
- As first flush contaminants are building up more and there are bigger storm events, more contaminants may get past the LID sites into waterways
- Many "at risk" populations in the arid Southwest and West including elderly populations, remote populations, poor populations, isolated Native American communities, etc. may be more vulnerable to various effects of climate change such as changes in disease vectors, drought, high temperatures, decrease in water availability, food insecurity
- With less frequent storms, pollutants, bacteria, and other disease vectors are concentrating more when it does rain, bringing higher levels to GI/LID areas, and getting into water used to grow gardens, edible wild foods, small-scale agriculture that utilizes stormwater, etc., concentrating in the sludge in tanks, etc.
- Increased risk of forest fire due to climate change. Need more awareness of the health effects of fire ash, which concentrates metals that are then distributed through the air
- More invasive nonnative species are spreading beyond their previous ranges.
- Fugitive dust is becoming more common and spreading valley fever fungus and causing other health and safety problems.
- Mosquito problems are growing as more water is standing from larger storm events.

Topic area 7: community development, education, outreach, economic revitalization, social programs, human health:

- Too spread-out urban design
- Knowledge of local ecology
    - Education (migratory)
    - Sense of place
- Tourism – economic drivers (ex. resorts, golf courses)
- Data/research

    - Socioeconomic impacts (ex. property values)
    - Environmental/economic benefits
- Absent voices (is this a SW issue only?)
    - Demographics
    - Immigrants
    - Impacted groups have no voice
- Health/GI impacts
    - Physical, psychological, preventable
- Land interests
    - Valuation increases
    - Affordability
- Small-scale/community decision-making
- Shared resources and labor – all reap benefits
- Political climate - effects

Topic area 8: urban ecology, conservation, ecosystem service, linkages/corridors, restoration:

- Rainfall (intensity/timing) variability
- Urban soils (compaction, no vegetation) – restoration takes more work/intention
- Urban sprawl / fragmentation
- Percent impervious surfaces (low, med, high density development)
- Native plants (wetting/drying cycles)
- Wildlife corridors / washes / riparian areas
- Effluent resource
- Salt
- Inorganic rock v. organic mulch
- Local government / regulations
- Need more place-based regulations (rain cycles)
- Heat island in the desert (increase)
- Sprawl – low stature buildings
- Evapotranspiration in the desert, outside of ag
- Soils low organic material, low micro/macroscopic material, termites
- Biological soil crust (desert)
- Plant palette
- GI = good water conservation in the SW
- Non-native humans
- System of washes
- Stormwater infrastructure – street = stream
- On-site renewable NRG in SW → solar!!, passive potential
- Groundwater recharge – matters a lot in the SW
- Huge biodiversity – pollinators, birds, etc.
- Cultural history

Topic area 9: operations/maintenance:

- Regional relationship to Colorado River and how to reduce this
- More dust-clogging issues

- Rain patterns – time between events, low rainfall intensity
- Higher concentrations of trash/pollutants due to infrequent events – first flush
- Dry soil – crusts – hydrophobic
- Stream sediment transport
- Adapting to variability of conditions – performance
- Developing realistic expectations for cost/time of maintenance – impacted by these arid conditions
- With large events → need for contingency bypass
- Poorly infiltrating soils and high evaporation – salt build-up
- Soils collapsing/expanding – understand specific soil types, not just universal rules of thumb
- System refresh needed over time – how to plan this? What should happen?
- Different vegetation in SW

Appendix B

What research and data collection efforts do we know of, either complete or underway, that address implementing GI/LID under arid conditions?

Topic area 1: water quality, nonpoint source pollution, wastewater:

- Washington State Department of Ecology / Eastern state focus – all materials tested before approved for use (Fil-Tera)
- CALTRANS (California Department of Transportation)
- Check natural BMP database
- MS4s required to monitor
- City of Chandler recharge in storm drainage (GSA)
- NRDC LID – San Diego
- NRC – 2008 Stormwater Policy Analysis
- Mitch Pavao-Zuckerman →Biosphere 2 and Dunbar Spring neighborhood
- Riverside County Flood Control and Water Conservation District – LID effectiveness study (Jason Uhley)
- Bioaccumulation and recycling in retention basins – Steven Earl
- Contech rainwater harvesting calculator – rain gauges
- Modeling-industry-population models as data is more available
- Funding – yields information where knowledge gaps are
- Water quality design – storm standard update
- Some consultants / municipalities have data – required to collect data by law

Topic area 2: hydrology, flood control, floodplain management:

- ASU pervious pavement
- Tres Rios project (City of Phoenix)
- Riverside – LID BMP studies
- Consultant research
- Desert Research Center – BMP for road salt removal
- NPDES research – hydrograph research (CA- uses BMPs)
- Eriko Gallo – landscape controls on urban runoff quality and quantity
- DEQ – stormwater quality monitoring (public agencies)
- Kino Environmental Research Project (Tucson, AZ)
- Commercial vendors for stormwater products
- FCDMC/USGS/DRI – Southwest infiltration study Bureau of Reclamation
- Ongoing water data from Walnut Gulch (Agricultural Research Service)
- The Nature Conservancy
- Arizona Flood Warning precipitation and stream flow
- NOAA 14
- Rainlog.org
- Cochise County stormwater recharge project
- Remove invasive species – Friends of the Verde River
- Sonoran Institute research

- Truckee River – The Nature Conservancy – stream restoration, flood control

Topic area 3: water supply, water rights, groundwater:

- San Pedro stormwater infiltration rates and impact on streamflow
- Elmer Street infiltration and runoff
- EPA stormwater characteristics database and BMPs
- Phase 1 stormwater quality from 5 land uses
- City of Tucson/Pima County lot-scale and regional scale (Water Environment Research Foundation, WERF)
- SAT water quality treatment capacity
- USGS stormwater studies (Ft. Huachuca)
- Gary Woodward's work on Casa del Agua
- USGS National Water Quality Assessment (NAWQA) Program
- Literature search and theses and PhDs

Topic area 4: urban forestry, heat islands, air quality, parks & recreation:

- Rainlog.org
- Tucson H2O = commercial water harvesting data
- EPA = urban heat island site (Heat Island Reduction Initiative, HIRI) → stormwater and trees
- UC Davis, Center for Urban Forest Research (Geography Graduate Group) – community tree guides = ecosystem benefits
- Air quality data for individual districts (CA = Sacramento Tree Foundation, Sac Tree) – EPA standards
- Talk of bringing research group to LA
- Groups (Arizona Community Tree Council, ACTC- aztrees.org)/individuals collecting tree data within state
- iTree tree benefits calculator
- Vibrant Cities & Urban Forests (vibrantcities.org)
- Data collected by utility companies (Tucson Electric Power and tree locations)
- California Urban Forests Council
- Casey trees data, DC-based but good methodology – geo-based info/maintenance, hazardous trees
- Research for canopy study – NOWAK/Davey/AMEC
- ACT data
- UHI – ASU Central Arizona-Phoenix Long-term Ecological Research (CAP LTER)
- US Forest Service, various data collection efforts
- ISA research – very few in West (WISA starting – TX chapter doing local research)
- Consortium of tree researchers – UCLA, U Utah, Million Trees Initiative
- Various state agencies (i.e. AZ Forest Dept.) collect data

Topic area 5: urban planning, transportation, architecture, development, landscape architecture:

- CA- local government commission- "Roadblocks to LID Implementation"
- Albuquerque, NM – pervious floors of flood channels
- Sustainability Code Audit
- Stormwater detention on a regional scale v. LID

- Urban ecology research
- Maryland manual
- Barrio de Tubac (developer: Gary Brasher)- ADEQ requirements made plans to capture runoff and greywater capture and recharge impossible to actually do → Master-planned community in Tubac has own water company and couldn't meet runoff capture requirements (ADEQ) because they didn't create runoff
- Electric Power Research Institute (EPRI) and Water Environment Research Foundation (WERF) – Tucson/Pima County were site for defining new water infrastructure management paradigm
- Federal Highway Administration (FHWA) doing research that hinders GI/LID implementation
- UA research on lead/interstate proximity relationship in harvested rainwater
- City of Tucson Dunbar Spring plan and solar lighting in Barrio Centro as case studies
- Mitch Pavao-Zuckerman's research on how surfacing materials degrade urban soils
- Muscular Dystrophy Center and Tempe Transit Center green roofs
- Pervious concrete at Tucson Zoo and NAU research facilities
- Springs Preserve in Vegas – RWH was off-grid, forced on-grid
- Gilbert and Chandler both have parks at water recharge area

Topic area 6: climate change, mitigation, and adaptation: (NOTE: the group reported that since there is so much well-known literature available on climate change they did not focus on it. But a few notes were assembled)

- EPA-funded UA/Tucson Audubon Study on water quality in tanks
- Center for Disease Control has information on climate change related to health, food supply, etc.
- Central Arizona Project has DVD on climate change
- International Council for Local Environmental Initiatives (ICLEI)

Topic area 7: community development, education, outreach, economic revitalization, social programs, human health:

- Focus groups with diverse representation
    - Environment education groups
    - Phoenix social survey – 5 years
- Report – stormwater and community engagement/employment
    - Pacific Institute
    - Green for All
- Educational workshops
- Ocean-friendly gardens
    - Establish metrics to drive agency action
    - Self-monitor/research own efforts
    - Need more training within neighborhoods – empower and plant local leaders
- Need to research what <u>drives</u> change
- ASU – research attitudes/perception of water managers vs. scientists
- Long Beach Water Department's lawn-to-garden program – survey of participants
- City of Los Angeles's rainwater harvesting program – survey of participants
- Las Virgenes water district's landscape rebate program – wealthier customers not responding (Weather Based Irrigation Controllers, turf removal)

- Surfrider Foundation's Ocean Friendly Gardens (OFG) Program: survey of participants in OFG Watershed Basics classes regarding interest in attending hands-on activities

Topic area 8: urban ecology, conservation, ecosystem service, linkages/corridors, restoration:

- Sustainable sites initiative
- UC Fresno – birds
- Diane Austin / Steph U (Bureau of Applied Research in Anthropology, BARA)
- Landscape Architecture Foundation
- US Fish and Wildlife
- National Phenology Network
- ASU - sustainability
- Central Arizona-Phoenix – Long-term Ecological Research (ASU)
- FEMA – risk map program / redefining flood plains
- Sonoran Desert Conservation Plan (Pima County, AZ)
- Council for Watershed Health
- NOAA – soil and groundwater mapping
- G3 and Surfrider
- Non-point Education for Municipal Officials (NEMO)
- Arizona-Sonora Desert Museum
- Ladybird Johnson / freeway?
- Brad Lancaster Vol. 1 – Solcan, second edition
- San Diego Channelkeeper
- Tucson Audubon
- Geodesign – GIS modeling ESRI, UA and NAU
- Tucson Water/UA hydrology (Larry Winter)
- Dunbar Spring/Biosphere 2
- Brad via Will – saltbush
- Center for Biological Diversity
- CLIMAS – climate outreach center at UA
- Santa Barbara Watershed Resource Center
- Arid Land Institute
- Juliet Stromberg (ASU, Human Dimensions of Biology)
- Travis Audubon Society (TAS) bird surveys, Sky Island Alliance (SIA) wildlife surveys, Arizona Game and Fish Department (AZGFD) surveys, U of A, Tucson bird count
- Desert Laboratory (Tucson, AZ)
- Water quality research – Erika Gallo, municipal mont.
- Sonoran Desert Conservation Plan (SDCP) – Pima County
- Santa Cruz River Researchers' Day – connect research efforts
- Soil ecology – Mitchell Pavao-Zuckerman
- US Forest Service – research
- Effluent – Westcees research, Santa Cruz River Researcher's day
- Trust for Public Land – ecosystem services of green spaces
- World Resources Institute
- ASU – ecology research
- Rainlog.org, ALERT data – site-specific, helps LID projects

- UA – upcoming research
- Vegetation research – tree canopy: City of Tucson home values in relation to urban water bodies/washes, Bureau of Reclamation (Eve Halper), Colby paper (property values near riparian areas/open space)
- Imagine Greater Tucson – research

Topic area 9: operations/maintenance:

- American Rainwater Catchment Systems Association (ARCSA) – first flush devices, needs more what picked up (active)
- Dry water – on Ruthrauff Road, Tucson (inconclusive)
- Monitoring sedimentation in Rincon Heights neighborhood (Tucson) and pruning, weeds
- Jen P. thesis on RWH basin performance
- Erika Gallo – sediment/stream transport
- Elmer St. (LA) research – information for next project
- Basins – Biosphere 2
- Quavira foundation – research to prevent topsoil getting into streams
- Tracking vegetation survivability – Gary, 1 year etc establishment, tall pots
- Utah – vegetation types for arid climates and LID, Christina (see prior conference proceedings)
- Mitch Pavao-Zuckerman – streetwater harvesting and impact of plants
- Possible: city of Albuquerque – water quality testing pilot
-

Research efforts and questions submitted via email:

- Just how do we connect water quality to water quantity?
- We need to be focused on using whatever means possible to disconnect the impervious from the conveyances, find solutions that are affordable, buildable and maintainable within the climatic, geologic and economic framework that is our reality.
- http://www.nrdc.org/water/lid/ - "A Clear Blue Future" by NRDC
- "Want to create 1.9 million American jobs and add $265 billion to the economy? Upgrade our water infrastructure. That's the message of ***Water Works: Rebuilding Infrastructure, Creating Jobs, Greening the Environment***, a report by Green For All, in partnership with American Rivers, Pacific Institute, and the Economic Policy Institute." http://www.greenforall.org/resources/water-works
- Drywells used by the City of Chandler, AZ: "Drywells: One County's Novel Approach to Stormwater Management and Disposal." *Southwest Hydrology*, January/February 2010. http://www.aridlid.org/wp-content/uploads/2012/12/SWH_Drywells.pdf
- http://www.aridlid.org/wp-content/uploads/2012/12/Chandler-Stormwater-Recharge - "Preliminary Assessment of Increased Natural Recharge Resulting from Urbanization and Stormwater Retention within the City of Chandler," prepared by GeoSystems *Analysis*, Inc.
- http://www.aridlid.org/wp-content/uploads/2012/12/LID-Barriers-White-Paper-FINAL-1.pdf - "Breaking Down Barriers to Low Impact Development in Colorado" by Andrew Earles, Derek Rapp, Jane Clary, and Janice Lopitz

Appendix C

What are the most important (and interesting) unanswered research questions and data needs relating to GI/LID in our field, and which cannot be answered by research from other regions?

(Collected from small group brainstorm)

Topic area 1: water quality, nonpoint source pollution, wastewater:

- Need for multiple test sites designed for replicability across larger regions throughout the SW
- What are our water quality goals? E.g. sediment, wildlife needs
- Rainfall runoff dynamics and ephemeral stream understandings
- How does maintenance impact efficiency of water quality treatment? E.g. lifespan (true cost)
- What are the LID impacts to ephemeral washes over time (to pollution loads and to hydrology and ecology)
- What are the pre-treatment and treatment requirements before infiltration? (growth solids, metals, nitrogen, sediment, phosphorous)
- Baseline data
- Traditional v. retrofit BMP
- What processes are doing what?
- Are the modeling results valid?
- Sharing of data
- More detailed information in BMP assessment
- How do BMPs age?
- Better risk assessment and BMP for managing risk
- Lack of data to justify cost
- Operation and maintenance protocol and costs
- What happens with quality after 1 year?
- Science to support regulatory requirements
- How does water collection alter water quality?
- Construction is very important

Topic area 2: hydrology, flood control, floodplain management:

- Preferred simulation methods v. real world
- What is the ideal detention/retention time/volume to maximize infiltration and offset effects of urbanization?
- Compare effect of vegetation density, imperviousness, frequency of event, and impact on BMP
- What vegetation types and densities will function in LID practices that would help in the development of healthy soils that result in higher infiltration rates?
- What are non-vegetation practices that increase infiltration, stabilize slopes, and promote vegetation? What would be the air quality benefits of these solutions?
- Have studies been conducted on the benefits of flooding?
- Are we using appropriate storm frequencies for design? 2 year, 10 year, 100 year? 1 hour, 3 hour?
- Cost-benefit analyses for water harvesting versus storm drain retrofitting

- Impact of LID practices in regulatory (100-year) storm
- Better infiltration and erosion data for specific soil types
- How do we design LID features that are sustainable vis-à-vis water rights and water as a resource? (LID BMPs specific to arid climates)
- Effects of water harvesting next to pavement (how to protect pavement integrity)
- Better soil mapping and research on soil type effects
- Study to quantify correlation between water harvesting and flood peak reduction
- Effectiveness of "regulatory" floodplain regulation vs. geologic/geomorphic floodplain approach
- Quantifying rainfall/runoff relationships across landscapes accounting for vegetation and soil characteristics
- Quantifying BMPs for impact/effectiveness based on local conditions/characteristics

Topic area 3: water supply, water rights, groundwater:

- Space and time scale- when is it appropriate to do small v. large?
- Impacts of LID on aquifer (quantity-quality)
- What are the water rights for harvested stormwater by state?
- Quantity recharged from LID
- Reducing potable water impacting sewer flow to wastewater treatment plant (greywater used outside instead of going into sewer)
- What are the impacts of LID on water supply infrastructure? (i.e. reclaimed water is reduced)
- What is the capacity of native soils to purify water? (TCE, metals, pesticide, nitrogen, phosporus, pharma) (human health, ecosystem)
- How does harvesting water offset existing water use/supply?
- What is the benefit to implementing LID in terms of future supply costs?
- How do we do outreach/public education to conserve v. import rainwater in the short-term and long-term/sustainably?
- Do bacteria need to be researched in tank for good potable water? (limit uses water is used for)
- If you harvest water and use it for irrigation, can you substantively recharge the aquifer? (average mutation, recharge)
- What are issues related to storing/using harvested water for potable water use?

Topic area 4: urban forestry, heat islands, air quality, parks & recreation:

- In an era of shrinking budgets, is there a viable model for transferring maintenance to communities?
- What are mechanisms that generate and foster local stewardship that is community specific and culturally specific?
- Canopy cover distribution: how do we address inequitable distribution in a culturally-appropriate way? Trees not valued equally or for the same reasons
- How do trees interact with stormwater? Consider: species variability, matching deciduous/evergreens with rainfall patterns, land use, geography
- Does pool/camp closure correlate with juvenile crime (parks and rec)?
- When tree palettes change: how does change in leaf surface area impact environmental benefits of trees?
- What are "thrive vs. survive" water requirements: species specific (cost to survive?)

- Considering species, how to maximize trees for LID? H2O use, leaf area index, interception, diversity needs, wildlife needs

Topic area 5: urban planning, transportation, architecture, development, landscape architecture:

- Plant list with phytoremediation
- How do you reduce detention via rainwater harvesting? How do they coincide?
- How do you define evapotranspiration in an engineering way?
- What happens to the urban ecology after you introduce LID practices/technology?
- What does an urban arid-ecosystem look like?
- What are the comparative health impacts between conventional and ecologically sensitive environments (cities)?
- What are some basic principles so designers, ecologists, planners, etc. can collaborate on LID?
- What is the most effective way to retrofit built environments?
- Identify certain techniques to motivate public and policy makers with GI
- Comprehensive LID/GI manual for locally-appropriate policies and best practices responsive to water/climate uncertainty
- Cost: need research on:
    - O & M costs associated with building/developing differently
    - Capital costs for LID
    - Lifecycle costs for LID vs. "normal" development
- What are real, measurable numbers that we can use for quantifying LID benefits?
- Is there an inventory for tracking LID/BMP implementation and effectiveness using existing case studies/BMPs/new research?
- How should water uncertainty be integrated with urban planning, architecture, landscape architecture, etc.?
- Has there been any research about using roundabouts as storage or recharge facilities?
- How can we use stormwater detention areas to harvest rainwater rather than releasing it?
- How do we adapt plant palettes for changing environmental urban conditions?
- What are the capital and lifecycle cost (saving) differences between GI/LID and traditional development practices?
- Does quantifiable data exist for storage and diversion BMPs for use in calculating pipe sizing?
- Synthesize transportation energy and resource flows (current and future) in order to set milestones and goals for tracking progress toward regional sustainability
- Standard practices for neighborhood retrofits. Costs and best practices
- Data collection on rain garden configurations in arid climates
- Guidebook for different scales of development or retrofit i.e. parking lots, streets

Topic area 6: climate change, mitigation, and adaptation:

- How to manage peak flows?
- How should design standards for GI/LID be changed to address 100-year storm and flood events, since these seem to be changing?
- How should design standards for GI/LID be changed to address other aspects of climate change such as storm duration, intensity, frequency, drought, heat, etc.?
- What are the 100-year events now and what will they be in the future?
- Should design criteria even be tied to a 100-year event?

- Are lead, mercury, arsenic and other metals getting more concentrated in GI/LID areas due to urban contaminants and ash from forest fires that bear these contaminants?
- What species shifts will occur in the short-term and long-term (plants, animals, etc.) and how should planting designs change in GI/LID as a result?
- What shifts may occur in pests that spread due to climate change and then affect plant and forest health?
- What shift may occur in public health due to changes in plants, temperature, drought, ranges for mosquitos, beetles, fungus, and more as a result of climate change impacts?
- How will soil microbiology change with climate change, and what impacts would that have on design of GI/LID?
- Need to understand in detail who the vulnerable human populations are, and what their needs are, for those who will be impacted by multiple direct and indirect effects of climate change
- How can we mitigate for fugitive dust in general, and that coming from GI/LID areas (under construction, or under-vegetated), which cause problems with disease, public safety (traffic), etc.?
- What size storms should we try to collect given the varying goals of passive and active water harvesting, stormwater catchment and management, and flood control?
- What is the safety of food grown with concentrated/harvested water? How would this change with increasing changes to climate?

Topic area 7: community development, education, outreach, economic revitalization, social programs, human health:

- How do we quantify monetarily the assets citizens can bring to participate in GI (i.e. local Sonoran Desert communities)? – welfare costs v. job skills
- What is the relationship between economic drivers and conservation?
- How can we measure mental well-being impacts through involvement in GI activities? (specific demographic groups i.e. formally (currently) incarcerated, veterans, immigrant groups)
- What are the public health implications of environmental inequalities?
- How can different programs address pet waste (feral dogs, homeless dogs) impacts on our stormwater quality i.e. desert poop bricks slow decomposition
- What drives changes in behavior, attitudes, knowledge?
    - Effects
    - Strategies
    - Effective education
- Livelihood, green jobs – what is the relationship between economic drivers/opportunities and conservation? What would this data look like?
- What economic incentives and tax policies would encourage GI?
- What are the barriers to policy integration? – codes and policies
- Measure responsiveness and capacity to implement methods of community installation projects. Given unique conditions transforming industries
- What drives changes in behavior, attitudes, knowledge?
- How do we reduce the burdens on low-income communities to increase activism?

Topic area 8: urban ecology, conservation, ecosystem service, linkages/corridors, restoration:

- Effect of UHI on ET and BMP / mitigation ecosystem services
- Review institutional motivation to merge functions in large projects

- Drip and spray irrigation and salt loading
- Biological remediation of salt loading
- Design and efficacy of GI
- Research: urban case studies of codes and ordinances related to protecting/restoring limited natural resource…virgin soils
- How can we quantify benefits (multiplier effect, triple bottom line) of integrated approaches such as rights of way as corridors of transportation, flood control, heat island abatement, wildlife, food production, biomass, pedestrians, water, etc.?
- What percent of urban watershed needs GI to provide measurable differences and wildlife linkages and corridors?
- How can on-site resource inputs (green "waste", mulch) or planting mitigate salt build-up in soil?
- How do we make these concepts more accessible and applicable and sexy to the general public?
- Exotic v. native plants – different ecosystem functions?
- Urban/wildlife interface
- Further research positive/negative interactions – how development can be improved to preserve habitat
- Research to integrate and codify GI/LID research that is being done – index this work (research the research done and put it in accessible database)
- (lower Santa Cruz River) upgrade in wastewater treatment plant – how improved water quality will improve aquatic ecosystem - some research done at 91st Ave. wastewater treatment plant (10 years)
- What are the salinity impacts of using reclaimed water on GI projects?
- Will existing GI/LID efforts provide wildlife habitat and corridors? For what types of wildlife?
- What percent of hardscape water needs to be "planted" in order to prevent flooding?
- Improved research translation for the general public. Research design that allows for real world application
- Human/ecology interface research – how to get public participation in LID practices/projects?
- Identify cost effectiveness
- Identify ecosystem services that are derived from projects in order to drive planning projects
- Planning suitability analysis – create suitability indices to identify and prioritize small scale projects so they comply with each other and fit within a broader context
- Use of GI for stormwater capture and recharge. What are the potential impacts of capture/recharge?
- How best to maximize the use of runoff for restoration?
- Plant/soil interactions within LID BMPs – research done? Research needed?

Topic area 9: operations/maintenance:

- What tests/evidence to tell if system is healthy/working? – ongoing
- Materials/plants to apply to system to work appropriately – plant material, focus work in our climate → for various types of plants, determining water demands for both 1. Establishment periods and long-term maintenance 2. Managing public expectations
- More test with BMPs with higher TDS levels (to mimic arid conditions)
- Maintenance schedule for arid region BMPs and what to do with extracted material
- More testing on xeriscape plant material to provide bioretention benefits – deal with sediment and channels

- Maintenance frequency – scheduler and tools and methods
- Lifecycle costs, including O&M
- Testing BMP that produces effluent that doesn't cause natural attraction to pick up more sediment downstream
- How to mitigate or manage the erosion between a treatment train containing multiple BMPs
- How to improve natural infiltration rates and how maintenance affects these rates
- Pollution and sediment sources (urban)
- Public education tools that work best in arid regions

Appendix D

List of research questions as prioritized by participants

Question	Votes
17. What are the socio-economic challenges to implementing LID? (cost-benefit, water rights laws, public acceptance)	15
20. What are the mechanisms that generate and foster local stewardship that is community and culturally specific?	14
22. What are real, measurable numbers to quantify LID benefits, using BMP/case studies and new research?	14
23. What are the capital and life cycle costs (and savings) differences between LID and traditional development practices?	14
33. Given the outsourcing of landscape labor, how do we motivate and sustain long-term behavioral change at the community/individual level?	12
2. What are the LID impacts to ephemeral washes over time (downstream studies)? (e.g. pollutant loads accumulation? Hydrology feedback loop, ecological responses, wildlife water quality needs, sediment transition)	11
15. Need: cost-benefit analysis for GI/LID/BMPs versus drainage infrastructure	11
10. Need: calibration of models to real world conditions	9
11. Using hydrologic modeling, what are the non-vegetative practices that increase infiltration, stabilize slopes, promote vegetation, improve air quality, and mimic pre-development hydrology?	9
44. What are the best maintenance frequency schedules, tool, methods, and life cycle costs (including operations and maintenance)?	9
7. Can we create a uniform database for LID BMPs for semi-arid areas?	8
24. Need: comprehensive LID/GI manual(s) for locally-appropriate policies and best practices that is responsive to water/climate uncertainty	8
28. Who are the high risk populations for each climate-related public health or safety risk that could be related to, or affected by, GI/LID (e.g. mosquitos, quality of water used for gardens/food production, disease vectors present in soil and water, change in fire frequency, etc.) due to climate change? How can these populations and problems be detected and addressed?	8
31. How can we measure mental and physical well-being impacts through long-term and ongoing involvement in GI activities that are unique to the SW?	8

9. How do different vegetation types/densities function in LID practices to develop healthy soils?	7
21. Considering species, how to maximize trees for LID: water use, leaf area index, water interception, need for species diversity, wildlife value?	7
3. How does the level of maintenance of LID sites impact the efficiency of water quality treatment? (e.g. lifespan studies, true cost studies)	6
6. How does LID BMPs performance change over time?	6
8. How do you improve aesthetics and optimize water quality management?	6
25. Need: identify specific techniques to inspire and motivate or energize the public and policy makers towards LID/GI adoption	6
26. What criteria do we need to measure to address changes in the urban ecosystem as a result of green infrastructure?	6
1. What are the pre-treatment and treatment needs before infiltration? (growth solids? Test for metals, N, phosphorus, sediment, impact to groundwater quality, compared to natural soils)	5
16. What is the impact/benefit of moving from regulating floodplains based on regulatory discharges vs. a landscape/geographic approach	5
19. What are the groundwater impacts due to water infiltration, positive and negative? (infiltration rate, water quality issues, life of soil aquifer treatment)	5
29. How should typical or new design criteria for GI/LID (rainwater harvesting, stormwater harvesting, and/or flood control-related structures) change due to climate change projections for different localities?	5
30. How will species shift (flora, fauna, invertebrates, disease vectors, fungi, etc.) due to climate change and how should this inform the design (species selection, size, depth, number, location etc.) of GI/LID design?	5
36. Need: additional research on plant/soil interaction and pollutant removal for LID/GI with potential application to quality, volume reduction, and recharge	5
39. In the context of landscape and connection/corridors/scale- what percent of an urban watershed needs GI to provide services, corridors, etc.?	5
42. What tests or evidence are available/can be developed to tell if a system is healthy and working on an ongoing basis?	5
35. Need: database of existing findings, process for prioritizing projects within the context of a watershed, identify criteria	4

37. How do you make GI, research, ecosystem services, etc. accessible and sexy?	4
41. What are the implications of the urban heat island effect on evapotranspiration and what are the implications of this for BMPs and ecosystem services? What is the ability of BMPs to mitigate urban heat island effect and evapotranspiration?	4
13. Need: evaluate local soils for infiltration and erosivity and impact on built environment (i.e. streets, buildings)	3
14. Need: evaluate the impact of GI/LID on flood frequency and volume and as a downstream resource	3
18. What are the impacts of LID to current and future water infrastructure?	3
38. How do we best quantify benefits (multipliers, triple bottom lines) of integrated approaches (i.e. bio and grey corridors)?	3
5. How can we improve performance/effectiveness in the most cost-efficient way?	2
27. Need: criteria for identifying the most effective opportunities for green infrastructure location and cost effectiveness in urban redevelopment	2
32. How do we reach a wide populace of communities with GI jobs while recognizing community assets that are unique to the SW?	2
34. Regarding effluent use for GI/LID – how does the quality and salinity of effluent/reclaimed water impact GI/LID projects? (availability is also a question)	2
43. What is/leads to best plant performance? Aspects include local climate, best size to start with to enhance survivability, BMP or treatment control needed for water quality improvement (including through maturity)	2
4. How do we get researchers interested?	1
12. Need: data on effectiveness of BMPs in local area at different scales	1
40. Need: review of institutional motivation for big projects- institutions, codes, ordinances for treating soil etc. as a resource	1