Green Infrastructure for Stormwater Management: Knowledge Gaps and Approaches

Pittsburgh Collaboratory for WATER
Research, Education, Outreach

A WHITE PAPER REPORT FROM THE AGENDA BUILDING MEETING ON NOVEMBER 20, 2018

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Common words from consensus building exercise: size of word is proportional to number of times it was written in workshop materials.

Executive Summary

As southwestern Pennsylvania continues to evolve from its industrial past to become a national leader in innovation and sustainability, it has encountered a complex set of water challenges that threaten the economy, ecology, and public health of the region. In this context, over the last year, the Heinz Endowments has funded the Pittsburgh Collaboratory for Water Research, Education, and Outreach at the University of Pittsburgh to hold a series of consensus-building meetings among regional academic scholars, community groups, governmental and non-governmental organizations. These meetings (one each on green infrastructure, water quality, and flooding) aim to identify key regional knowledge gaps and chart a collaborative research agenda to fill these gaps and enhance the region's ability to strategically and creatively solve water problems.

On June 19, a report describing the research agenda arising from the November 20, 2018 meeting on Green Infrastructure will be formally released. This report outlines several fundamental knowledge gaps in the region and suggests methods to span these gaps with new collaborative research.

Gaps

There is no single, organized home for storage of information about how green infrastructure systems perform. As the region moves forward to address stormwater management challenges, it is essential to be able to easily collect and share information on green infrastructure design, cost, effectiveness, and failures.

To adequately characterize the broad impact of green infrastructure systems, a wide range of data needs to be collected. However, consensus on the data required does not exist. This ambiguity slows regional progress.

Paths Forward

A concerted effort is necessary to gather information on regional green infrastructure performance, ranging from construction and maintenance costs to monitoring data. Buy-in from major institutions on collection and organization of data is essential for a successful regional data strategy.

The questions asked about green infrastructure need to be approached in a comprehensive context. For example, in addition to reducing stormwater runoff to sewer systems, green infrastructure installations can also impact nearby residents both negatively (wetter basements) and positively (increased green space). Decisions regarding future infrastructure need to fully consider these effects.

Preface

This white paper documents a regional, multi-stakeholder research agenda meeting held on November 20, 2018 in Pittsburgh, Pennsylvania. This meeting was the first of three topical research agenda meetings hosted by the Pittsburgh Water Collaboratory for Water Research, Education, and Outreach. The goal of the meeting was to identify key knowledge gaps in southwest Pennsylvania regarding green infrastructure and identify potential approaches that can help to fill those knowledge gaps. Participants were asked to answer the following questions:

1. What are the knowledge gaps in the planning, design, installation, monitoring, and maintenance of green infrastructure in southwest Pennsylvania?

2. What are the best approaches to fill knowledge gaps in the planning, design, installation, monitoring, and maintenance of green infrastructure in southwest Pennsylvania?

Participants brainstormed ideas and built consensus in groups of 2, 4, and 8, culminating as a summary list from the consolidation of consensus groups. The writing of this white paper was guided by the points that came up through this brainstorm activity, the prioritization by different groups, and the voting results. Participant consensus is summarized in this document to outline existing knowledge gaps identified during the meeting. Final consensus is presented in Section 2 and 3. In Section 4, suggested paths forward are recommended based on participant findings. While these recommendations grew out of the meeting results, they will require continued discussion and research within and beyond the Collaboratory to be successfully enacted. Group participants from the meeting are included in Appendix 1.

The Pittsburgh Water Collaboratory editorial board that helped prepare the final version of this white paper includes:

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More information about the Pittsburgh Collaboratory for Water Research, Education, and Outreach can be found at: **www.water.pitt.edu**.

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1.0 Background

Green infrastructure (GI) is a broad term used to encompass a wide array of specific practices. Within this document, GI is defined as a water management approach that aims to protect, restore or mimic the natural water cycle. In southwestern Pennsylvania, GI is primarily discussed as a stormwater control measure designed to slow storm water. Existing and proposed storm water management schemes in the region apply GI with design complexity ranging from storage and release (e.g. rain barrels) to capture and rerouting of storm water (e.g. infiltration) to slow runoff flows.

The Pittsburgh Collaboratory for Water Research, Education, and Outreach hosted an open meeting for members of the Pittsburgh community to contribute their thoughts on GI knowledge gaps and potential approaches to fill those knowledge gaps. The goal of the meeting was to extract opinions and thoughts from the community at-large and initiate a long-term dialogue toward identifying and resolving water challenges in southwestern Pennsylvania.

2.0 Meeting Results

Participants at the meeting spanned governmental and non-governmental organizations and community members and totaled 32 participants (Appendix 1). At the meeting, all participants were asked to answer the following questions:

1. What are the knowledge gaps in the planning, design, installation, monitoring, and maintenance of green infrastructure in southwest Pennsylvania?

2. What are the best approaches to fill knowledge gaps in the planning, design, installation, monitoring, and maintenance of green infrastructure in southwest Pennsylvania?

Participants brainstormed ideas and built consensus in groups of 2, 4, and 8, culminating as a summary list from four groups of eight persons. Then the consensus lists were distributed between these four groups for comment and review. After these reviews, the answers to both questions from each group were posted on a wall and each participant voted on their top answers choosing from all posted answers. Participants voted on final consensus built by groups of 8 using the following criteria:

Question	Dot color	Place dot next to the
What are the knowledge gaps in the planning, design, installation, monitoring, and maintenance of green infrastructure in southwest Pennsylvania (in order of importance)?	Green	Most important gap
	Yellow	Hardest knowledge gap to fill
	Red	Gap most easily addressed with existing data
What are the best approaches to fill knowledge gaps in the planning, design, installation, monitoring, and maintenance of green infrastructure in southwest Pennsylvania?	Green	Best approach
	Yellow	Most intriguing approach, but risky
	Red	Worst approach

Final consensus from the groups of eight varied in both the number of knowledge gaps and approaches and in the specificity of knowledge gaps and approaches. Resulting group consensus and participant voting results are summarized in Table 1.

Table 1. *Voting on the knowledge gaps/approaches identified by the various consensus groups. Columns correspond to the gap that was viewed to best meet the criteria outlined above. Colored rows indicate the gaps/approaches that received the most corresponding colored votes from the group (see key on page 7).*

Knowledge Gaps (What are the knowledge gaps in the planning, design, installation, monitoring, and maintenance of green infrastructure in southwest Pennsylvania?)	**Green** (most important gap)	**Yellow** (hardest knowledge gap	**Red** (gap most easily addressed with
Performance/Data Monitoring • Change over time • Who keeps the data? • Co-benefits resulting from GI (social, health, financial, ecological)	**13**	3	
Maintenance—Guidance/Protocols • Workforce development • Volunteer • Public • Where does the money come from?	5		
Measurement and verification of GI performance including maintenance	5		
Governance/Stakeholder Participation • What works? • Governance models that work (Where are they?) • Where does stakeholder participation work best?	2		10
Monitoring—Gain local knowledge • Validate national standards • Performance of GI	1	1	2
Triple bottom line full-life cycle analysis [environment (e.g., contaminants); social (e.g., workforce); economic (e.g., property value)]		**13**	
Operations and Maintenance over time • Costs knowledge/drivers • Knowledge of maintenance protocols • Ownership of GI • Who implements operations and maintenance		3	
Identify roles and responsibilities of stakeholders at different scales (community, government, …)		1	**9**

Approaches (What are the best approaches to fill knowledge gaps in the planning, design, installation, monitoring, and maintenance of green infrastructure in southwest Pennsylvania?)	**Green** (best approach)	**Yellow** (most intriguing approach)	**Red** (worst approach)
Develop localized best practices based on local research and data collection (design/maintenance/monitoring/ construction guidelines)	**15**	1	
Publicly accessible data • Data synthesis publications/events • Lessons learned/feedback loop	6	**8**	
Execute life cycle assessment and economic models before, during design, after completion, and ongoing	2	5	
Coordinate across multiple sectors (universities, municipalities, non-profits, communities, schools, consulting firms, government entities) • Establish database with common metrics/ indicators • Annual GI meeting to bring all sectors together	2	7	
Engage community at multiple levels (citizen science research, train emerging workforce, engage volunteers)	1		
Be transparent • Publicly acknowledge/inform re: successes and failures; ongoing campaign	1		
Systemic impacts exploration and research			**1**
Costs database and curator performance			
Monitoring • Partner with universities to interpret and analyze data			
Maintenance • Educate and train			

3.0 Discussion of Major Themes in Meeting Results

Recurring themes emerged from the meeting as suggested in the tables above. In this section, specific themes are further explored to identify key questions and/or guidance and provide a framework to guide continued efforts of the water community and the Collaboratory.

3.1 Closing the Adaptive Management Loop

One of the primary findings of this consensus-building exercise is that regional green infrastructure efforts are implemented without effective means to share information about this implementation. There is no centralized source to consult for estimates of maintenance costs, economic benefits, or expected water quality impacts. Likewise, there is no simple way for organizations to share hard won lessons in implementation, maintenance and function as new technologies are pioneered. Sharing such information can guide installation efforts and assure the monitoring and maintenance needs are accounted for as GI systems are being installed. Finally, there is a lack of information on up-front costs and replacement costs for GI structures (life-cycle costs).

This is particularly problematic in southwestern PA as the rugged topography and clay-rich soils are distinct from many of the regions that have developed GI (e.g., Philadelphia/ Chesapeake Bay, Figure 1). Therefore, as GI technologies are deployed in this geologic context, design tweaks will be a necessity. Capturing and disseminating that information is essential for the effective implementation of the larger-scale green infrastructure systems necessary to meet regional storm water management challenges.

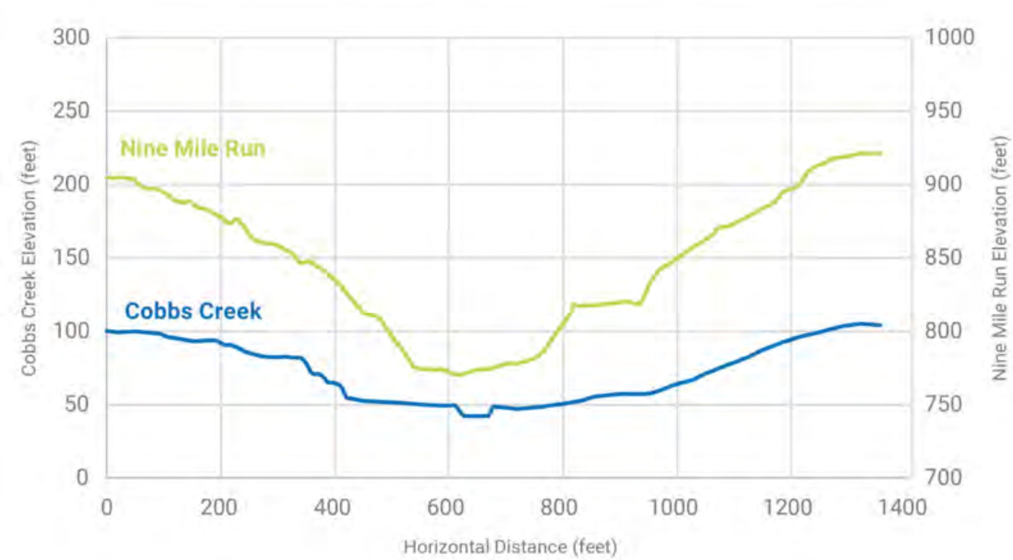

Figure 1. *Comparison of topography in Pittsburgh and Philadelphia. The lines are elevation cross-sections extracted from LiDAR DEMs. Nine Mile Run is a prominent restored stream in Pittsburgh and Cobbs Creek is a stream in Philadelphia with a major restoration planned in the near future. The elevation axes have been adjusted to be consistent and contrast the topography, though Philadelphia is much closer to sea level.*

In addition, the region's fragmented jurisdictional structure makes the need to effectively communicate learning about GI implementation, operations, and maintenance even more vitally important. In more cohesive management geographies (e.g., Portland) single entities conduct all of these tasks and can communicate lessons through organizational frameworks. With fragmented organizations, additional regional data sharing structures are needed to enhance the ability to share lessons and enhance regional efforts.

There are several tools identified during the meeting that would facilitate this information-sharing. The most popular tool was a database containing information on the implementation, effectiveness, and management of green infrastructure. There are important parameters that need to be defined about such a database:

- What collected data should be included in a regional GI database? This fundamentally important issue is discussed in detail in Section 3.2.

- How will regional practitioners and end-users be compelled to ensure their data is contributed to this database? The poor utilization of databases is a common problem that often derails these efforts. Examination of existing databases for green infrastructure function (e.g., The International BMP database, **http://www.bmpdatabase.org**) provides a telling example. There are only 11 best management practices (BMPs) from Pennsylvania included in the database, five from State College, five from the Philadelphia area, and one in Harrisburg. Despite Pittsburgh's rising reputation in the utilization of green infrastructure BMP's, this collective experience is not necessarily transferred to broader audiences or being organized for regional use. For example, there are a wide variety of GI projects in the ground in Pittsburgh (Figure 2). The disconnect between existing projects and their inclusion in data structures can be solved in part by making more stringent reporting responsibilities part of funding storm water management installations, but this will require support from the major institutional players in stormwater management. For example, ALCOSAN's Green Revitalization of our Waterways (GROW) program stipulates that GI funded by the program must be monitored to ensure that storm water reduction is achieved. However, there is no requirement to then share this data.

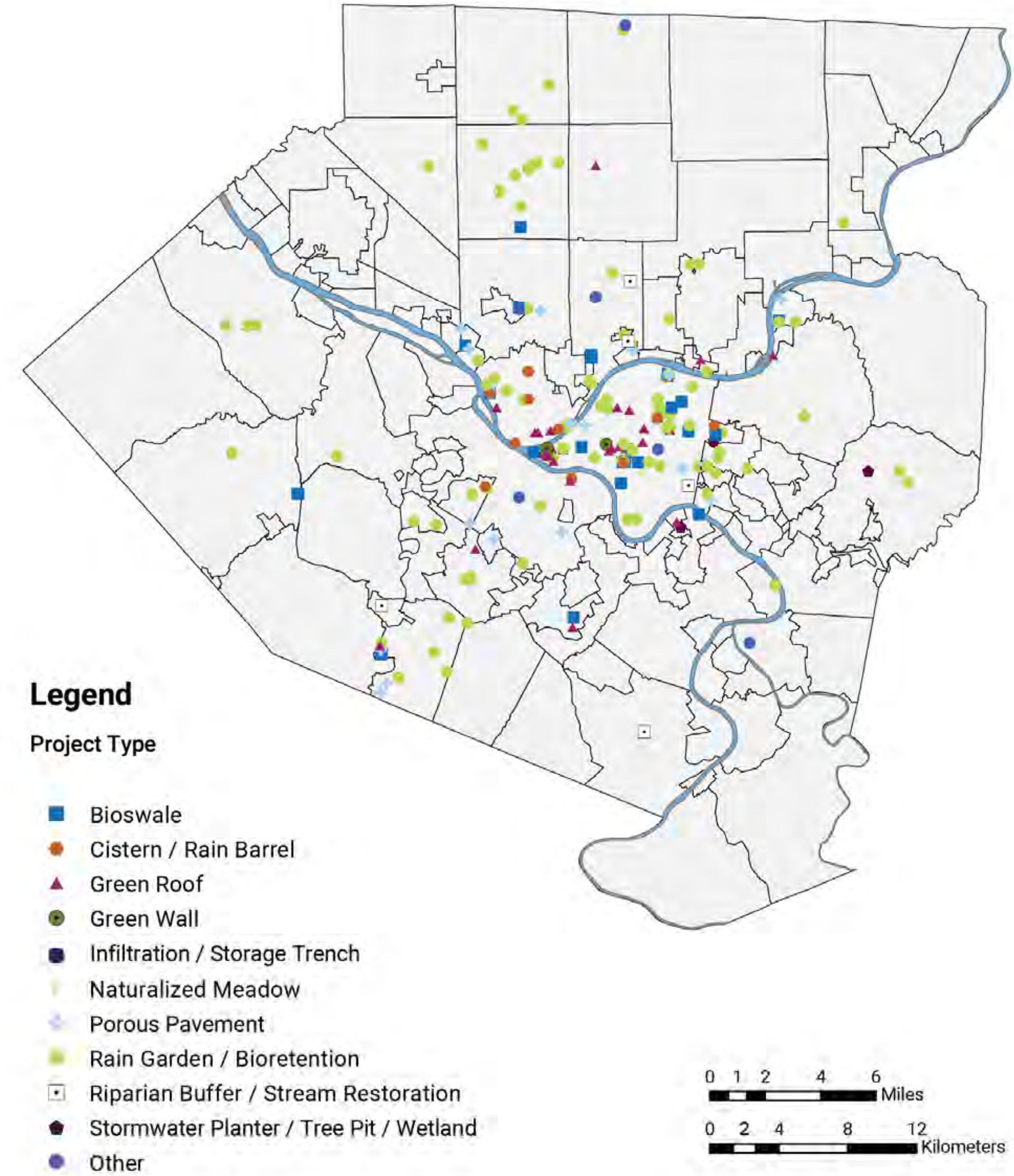

Figure 2. *Green infrastructure projects installed in Allegheny County according to Three Rivers Wet Weather Green Infrastructure Atlas < http://www.3riverswetweather.org/green/green-infrastructure-atlas>.*

- Who will administer and curate the database? Effective databases are a great deal of work. The existence and benefit has to be advertised almost continuously as interested parties move in and out of the area. Changes in data needs require alterations to data structures. And data input tools have to be robust and maintained.
    - There are recognized data authorities in the area (e.g., the Western Pennsylvania Regional Data Center) that are capable of this task, but operation and maintenance costs are needed to sustain efforts in these bodies.
    - For static data sets, there generally are tools that can reliably serve data (e.g., Three Rivers Second Nature (**https://3r2n.collinsandgoto.com/**) continues to provide a crucial snapshot of river conditions). However, these examples generally are not a living database that grows as additional green infrastructure is implemented. Moreover, they are likely exceptions. For example, one of the most ambitious recent national GI database efforts was the National River Restoration Science Synthesis database. This effort is sunsetted and now only hosted at a GitHub site (**https://github.com/khondula/nrrss**). This arrangement, while workable for sophisticated data users, does not provide friendly user interfaces with search functionality that was likely envisioned by participants.
    - There are national data structures that provide another potential means to host, curate, and distribute data. Community data structures such as CUAHSI's hydrologic information system (**https://www.cuahsi.org/data-models/publication**) may provide a framework flexible enough to allow for the sharing of specific kinds of green infrastructure data. This outlet will still require curation and advertising, but may offer sophisticated enough data structures to serve the green infrastructure community in southwestern Pennsylvania.

3.2 What Do We Monitor?

The broad range of potential data necessary for the assessment of green infrastructure is likely not feasible as a uniform set of parameters to track. Potential information ranges from water quantity to water quality to frequency and cost of basic maintenance such as mowing or watering of plantings to the long-term, cost and frequency of ongoing maintenance such as infrastructure repair/replacement.

While a broadly comprehensive dataset is the best way to ensure an ability to answer unexpected questions, monitoring is expensive. Design and implementation of a broadly comprehensive set of monitoring parameters can create tradeoffs and diminish the amount of GI implemented. The identification of a minimal dataset is a difficult but essential challenge for the GI community.

The most fundamental question for database architecture and functionality relates to what questions the database should definitively be able to answer. The realities created by the sewer overflow challenges dictate that utilities monitor flow and quantify reductions in stormwater flow to the sewer system. Other organizations such as watershed associations and environmental councils that pursue funding from a broader array of sources are interested in a broader parameter set that includes water quality improvements, urban tree health, aquatic ecology, and soil quality. The triple bottom line benefits such as green jobs and human health improvements require an even broader and more complicated data set.

There is a set of principles that will need to be addressed in designing an effective set of data to be included in a database. For example:

- All data producers who will use the database need to agree to collect and report a minimal set of data. This data consistency is absolutely critical to enable cross-project comparisons.

- This minimal data set has to be feasible financially and therefore important funding providers need to buy in to this data requirement. Otherwise, funding of this activity will continue to be an afterthought or oversight.

- Data characterizing both pre- and post-installation conditions are required to adequately assess a GI project.

- The data requires sufficient information about the data (i.e., metadata) to allow evaluation of the data and comparison of data collected in unique situations with data collected from more typical situations.

- Participants identified cost estimates, in terms of installation, operations and maintenance, as particularly important data components given the emergent nature of GI in the Pittsburgh region. This type of financial data will require separate discussion as they create additional challenges in terms of availability (some of the data are likely proprietary).

3.3 Comprehensive Evaluation of Green Infrastructure

The co-benefits of GI are a vital part of arguments for green first approaches. However, the case for these benefits is particularly hard to make in Pittsburgh. While there are at least limited data sets regarding GI function in terms of quality and quantity, comprehensive datasets regarding economic and social impacts are rarer.

As with physical design of the GI, local conditions in Pittsburgh will impact the broader economic and social impacts of the GI, and hence these broader impacts are an important part of the evaluation process. For example, generic estimates of infiltration benefits likely do not examine the potential negative impact of wetter basements down gradient of infiltration systems. Further, the fragmented nature of the local governance structure likely makes the administration of mechanisms to develop green jobs less efficient and therefore often less effective.

One popular idea identified by the stakeholders was the design of GI projects that could incorporate citizen volunteers in both monitoring and maintenance. There are local program models that suggest a capacity for important volunteer roles, particularly the Urban Ecosteward program (**https://www.pittsburghparks.org/urban-ecostewards**). However, the difference in task sophistication and duty cycles will require careful consideration. It is likely that this type of volunteer maintenance activity could address chronic problems (e.g., invasives in bioswales) but not acute problems (e.g., clogged water conveyances during major storms).

In addition, the valuation of these potentially important benefits can be hindered by relatively limited data sources. For example, estimates of tree interception (e.g., **https://www.fs.fed.us/psw/topics/urban_forestry/products/2 cufr_626_gtr199_midwest_tree_guide_corrected.pdf**) are based on surprisingly small sample sizes. While efforts to estimate value clearly use the best available data, sometimes the best available data is not good enough. Particularly, as we move toward design that emphasizes sustained benefits and resilience after disturbance, data sufficient for clear evaluation of potential uncertainties is paramount.

Potentially most important, if faulty decisions are made based on assumed co-benefits and the assumptions are themselves are wrong, decisions made as part of planned large-scale implementation have the potential to reinforce or increase existing inequities across the region.

Given the importance of co-benefits to the discussions about green infrastructure in the region, careful examination of the underlying assumptions and information are vital to ensure this massive re-investment in infrastructure is done as effectively as possible. This is a case where the scientific and engineering academic expertise being brought to the table needs to be broadened to tap the substantial expertise in social and economic processes.

Voting results summarized in Section 2 are the consensus needs and approaches identified by the group that attended the meeting in November 2018. These include the need for data collection and distribution, a broader agreement on the types and extent of monitoring, and the placement of GI planning in a strategic, comprehensive context. There are several immediate action items these results point toward.

4.0 Recommendations and Future Directions

4.1 Forge a Regional GI Data Strategy

- **Database:** The development and maintenance of a regional database of GI data ranging from construction to maintenance to monitoring is necessary. Past experience with databases suggests that this task, while useful, will require substantial effort to both initiate and sustain the database.
    - This database will need to have buy-in from major data generators in addition to all of the smaller organizations championing GI.
    - A home for the database must be identified and resources to sustain and maintain the database need to be identified. If existing national structures are chosen, the means to sustain the resource will still need to be identified.
- The building of this database could be strongly informed by the collection and organization of existing small data sets held across the local GI community. This exercise will encourage several important decisions:
    - What data need to be stored?
    - How should raw/analyzed data should be reported?
    - How will data be transferred to the database? Will it be mediated or direct?
    - What are the barriers to the use of existing data tools?
    - How will the data be served back to the community (e.g., static snapshots or a dynamic user interface)?
    - What mechanisms are necessary to ensure data is transferred to the database?
    - How can we ensure the inclusion of poorly functioning cases, so the database is not biased toward successes?
- This process will likely need to be driven by a group of individuals that represent the breadth of the local GI community. Continued efforts will require support from large institutional organizations (e.g., ALCOSAN, PWSA) given the important role they play in GI projects. Without all viable stakeholders contributing data, it is likely that the effort would not be sustainable.

4.2 Define a Realistic and Effective Monitoring Agenda

Regardless of whether or not a comprehensive database is ultimately adopted, given the wide variety of potential questions the GI community would like to answer, a minimal comprehensive set of data should be agreed upon to effectively answer these community questions. Questions can be loosely grouped into the following subjects:

- **Water quantity.** In particular, how much water does the GI remove from the combined system?
- **Water quality.** This is particularly urgent for sewer managers as the potential for individual GI components imminently subject to MS4 regulations may require substantial additional infrastructure.
- **Ecological Health.** How do surrounding soils/animals/plants change or benefit from the GI?
- **GI installation/operation/maintenance.** What are the costs and best practices?
- **Multiple bottom line considerations.** What are the social and economic impacts of the GI?

A monitoring program that is capable of answering all of these questions is not feasible given available resources (or, the monitoring costs would be large enough to preclude the completion of some projects).

While water quantity and quality questions are generally driven by concrete regulatory needs, these regulatory systems have spurred development of community standard methods to measure quantity and quality. As one moves down the list of potential questions above, the influence of both regulations and the resulting sophistication in measurement wanes. Without a consistent effort to hone and expand the questions that are asked as part of GI management, the data collected will not be capable of answering all of these questions (e.g., it will meet ALCOSAN GROW requirements and no more). Fleshing out and refining these questions is an essential next step in the management process. Otherwise, as emerging change continues (e.g., bigger, more intense precipitation with changing climate), repeat reinvestment in infrastructure will be required.

4.3 Push Toward a Comprehensive Approach to GI

GI is advantageous compared to grey solutions because of environmental, social, and economic co-benefits. Given the importance of these benefits, a clearer understanding of co-benefits will likely be important to the continued success of a GI-centered strategy to the region's stormwater challenges.

One of the fundamental gaps in this conversation is the impact of these co-benefits in other cities. How many green jobs has the GI in Portland, OR or Philadelphia, PA spawned, and more importantly, sustained? How has GI changed inequities in access to greenspace? As the region embarks on large scale GI planning, it seems wise to carefully consider the experiences other locations have had with co-benefits.

In addition, as with any regional management challenge, the implementation of GI has to deal with the fragmented nature of regional governance. Transfer of storm water to adjacent areas can resolve responsibilities for a particular jurisdiction in an upstream region, but that same transfer can exacerbate stormwater challenges in downstream areas. These dis-services, given the spatial arrangement, can and will contribute to regional inequity and need to be acknowledged and quantified as part of the triple bottom line accounting.

Finally, the need to engage citizens is an important part of identifying and filling knowledge gaps. Creation of strategies and programs to harness this resource is an important part of a successful long-term GI strategy.

5.0 Acknowledgements

The Pittsburgh Collaboratory for Water Research, Education, and Outreach thanks all working group participants for their time and generous sharing of experiences and ideas. We thank the Heinz Endowments for their support of the Collaboratory.

This document was reviewed by Brenda Smith and Maureen Copeland from the Nine Mile Run Watershed Association and Joe Fedor at ALCOSAN. We appreciate their careful reading and helpful feedback. We also thank Krissy Hopkins for her contribution of photographs.

Appendix 1: Working Group Participants

Participant	Organization
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Neil Brown	(none)
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Marja Copeland	University of Pittsburgh
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Marion Divers	Ethos Collaborative
Beth Dutton	3 Rivers Wet Weather
Matt Erb	Tree Pittsburgh
Joe Fedor	ALCOSAN
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Memphis Hill	University of Pittsburgh
Stan Kabala	3 Rivers Quest
Barton Kirk	Ethos Collaborative
Matt Mehalik	Breathe Project
Molly Mehling	Heinz Family Foundations
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Carla Ng	University of Pittsburgh
Maureen Olinzock	Pittsburgh Parks Conservancy
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Tim Prevost	ALCOSAN
Ryan Quinn	PWSA
Lou Reynolds	US Environmental Protection Agency
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Scott Swansinger	US Army Corps of Engineers
Jack Ubinger	Pennsylvania Environmental Council
Natalie Uscher-Arroyo	Lower Chartiers Watershed Association
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