



## Green infrastructure in western Washington and Oregon: Perspectives from a regional summit



A.D. Jayakaran\*, K.B. Moffett, J.C. Padowski, P.A. Townsend, B. Gaolach

Washington State University, United States

### ARTICLE INFO

Handling Editor: Wendy Chen

#### Keywords:

Green infrastructure  
Pacific Northwest  
Stormwater  
Sustainable urban planning

### ABSTRACT

Green infrastructure (GI) has grown in acceptance as a sustainable means to manage stormwater in urbanizing landscapes, while providing a multitude of additional benefits that range from improving community health to protecting local ecosystems. The mandated use of GI for the management of stormwater is arguably more prevalent in the Pacific Northwest, where GI is a required practice per municipal stormwater regulations in western Washington State, and the City of Portland OR. However, adoption in the region has faced several challenges. A regional summit to elucidate some of these successes and challenges was organized in Oregon and drew attendees from western Oregon and Washington. Six challenges that impact GI adoption, and six themes that emerged as possible strategies to overcome these challenges, were identified. The six challenges that were identified were: the lack of coordination, traditionalism, site-specific scales, environmental costs, a lack of expertise, and little consideration for maintenance. The six emergent themes identified were: the need for adaptive design and maintenance, the placement of GI for maximum impact, the concept of collective impact, valuation of GI, equity and GI, and the intersection of GI and community health.

## 1. Introduction

### 1.1. Urban green infrastructure

The concept of “green infrastructure” (GI) to intentionally harness natural ecosystem processes to protect water resources and provide ecological services to human communities has seen increasing prevalence in the U.S. (Benedict and McMahon, 2006). The origins of GI lie in the field of landscape architecture as the interconnection of city parks (Teaford, 1987), an idea promoted in urban planning by John and Fredrick Olmsted as early as 1903 (Walmsley, 2006; Mell, 2014). Linking green spaces was specifically aimed to accrue benefits to the community, to the ecosystem, and to limit habitat fragmentation (Benedict and McMahon, 2006). Incorporated to a degree in urban planning since the early 1900’s, many cities around the world have embraced GI as an effective solution that harnesses natural hydrological and ecological processes to address a range of problems, from flooding to excessive heat (Brink et al., 2016).

Today, GI is a landscape planning approach connecting natural areas in and around a city to mitigate impacts from built infrastructure (Sandström, 2002; Benedict and McMahon, 2012). While GI can refer to many different eco-based solutions to urban problems, McPhillips and Matsler (2018) distinguish GI as greening aimed at offsetting

development impacts at spatial scales that range from a forest to individual trees. Whereas, Green Stormwater Infrastructure (GSI) and its synonym Low Impact Development (LID), are types of GI specifically designed to mitigate the harmful impacts of stormwater quantity and quality. GSI comprises discrete stormwater runoff-mitigating interventions that use natural ecohydrological processes to manage urban stormwater runoff quantity and quality in a spatially distributed manner close to the source of runoff generation (Arendt, 1996; Prince George’s County, 1999; Cook, 2007; Kloss et al., 2006; EPA, 2018). Through ecohydrological processes like infiltration, transpiration, biodegradation, and phytoremediation; GSI seeks to recreate the pre-urbanization physico-chemical characteristics of runoff. Typical types of GSI are green roofs, bioretention systems, permeable pavements, living walls, and other vegetated installations. While GSI is designed to provide similar flood abatement or water quality control services as “grey” (traditional) stormwater infrastructure, there are many ancillary benefits such as aesthetics, sustainability, community health, and green-space equity; benefits particularly important to urban communities (Young, 2011).

The umbrella term ‘ecosystem services’ (Costanza et al., 1997) is useful to characterize the many benefits of GI; where commonly accepted ecosystem services are provisioning services, regulation and maintenance services, and humanist or cultural services (Kopperoinen

\* Corresponding author at: Washington Stormwater Center, Washington State University, 2606 W Pioneer Ave, Puyallup, WA, 98371, USA  
E-mail address: [anand.jayakaran@wsu.edu](mailto:anand.jayakaran@wsu.edu) (A.D. Jayakaran).

et al., 2014). Provisioning services of GI describe any biomass (e.g., clippings for compost), food (e.g., yield from fruit trees), water (e.g., in rain barrels), or other materials that could be usefully harvested from a GI installation. Regulation and maintenance services encompass stormwater flow regulation, but also water and air quality mitigation, positive effects on air flow or water flow beyond just flood mitigation, as well as carbon sequestration, soil quality improvements, local climate regulation, habitat, and pollination. Cultural or humanist ecosystem services include human enjoyment of the GI for recreational or aesthetic value, human valuation of GI as a perceived symbol of neighborhood walkability or quality of life, GI utility to house community gatherings, and enhancing sense of place (e.g., as “mini-landscapes”) by plantings of native plant species, or by providing habitat for locally recognized animal species. The reader is directed to Hoover and Hopton (2019) for more on ecosystems services and GI. Today, the incorporation of GI into urban development is something closer to a national movement, with GI now viewed as ‘business as usual’ in some locations (Cortinovis and Geneletti, 2018). There are, however, several unintended social consequences that accompany unplanned GI implementation (Curran and Hamilton, 2012; Wolch et al., 2014) - environmental injustice (Baker et al., 2019), and green gentrification (Cole et al., 2017) are just two.

### 1.2. GI growth in western Washington and Oregon

The use of GI for the management of stormwater is very prevalent in the Pacific Northwest (McPhillips and Matsler, 2018; Baker et al., 2019). This use is intrinsically linked to how the municipal stormwater permits are implemented in the region. The U.S. Environmental Protection Agency (USEPA) issues municipal stormwater permits to regulate discharges from municipal separate storm sewer systems across the nation, however, the manner the permit is implemented varies by state. Washington was the first state in the nation to require the use of GSI. In the Stormwater Management Manual for Western Washington (SWMMWW, 2014) and the City of Portland’s stormwater manual (BES, 2016), GSI is required where feasible when an area of landscape above a certain threshold is developed or retrofitted. However, a recent report by the American Society of Civil Engineers gave Washington State’s stormwater infrastructure a D + rating, the lowest of all types of civil infrastructure evaluated in the state (ASCE, 2019). Suggestions to raise the grade involved better asset management to track service gaps, better education resources, and improved leveraging of existing funding to tackle stormwater issues. On the other hand, Portland, OR has been installing large amounts of green infrastructure for over a decade and continues to do so. These examples provide a sense of some of the regional Pacific Northwest (PNW) opportunities and contrasts. The following six issues provide context for the wide acceptance and increasingly rapid integration of GI in PNW.

- 1 Climate and topography** – The western PNW maritime climate is characterized by frequent low intensity events with 95 % of the rainfall intensity less than 4 mm/hour (Williams et al., 1998). However, this region is also subject to less frequent but extremely heavy rainfall when moisture-laden atmospheric rivers encounter the Cascades mountain range (Warner et al., 2012). The prolonged wet season, and the need to handle periodic large precipitation events coming from urbanizing landscapes rendered the business of effective stormwater management a critical component of sustainable land development in the PNW.
- 2 Rapid growth** – The expanding development in the region (Franczyk and Chang, 2009; Nelson and Booth, 2002; VanMetre et al., 2015) associated with a growing economy (PSRC, 2017) was directly responsible for increasing populations (U.S. Census, 2015) and impervious areas (Pivo, 1996). The modification of extant drainage systems, increasing vehicular traffic (PSRC, 2008, 2018) created a paucity of space for stormwater management,

necessitating creative and newer technologies such as GI.

- 3 Iconic and endangered species** – The strong connection between water quality in PNW streams and estuaries, and the health of key species like orcas and salmon motivates public interest (Spromberg et al., 2016; Schindler et al., 2003; Poole et al., 2004; Larson and Ferrell, 2007). Both freshwater and saltwater fishing rights are critical aspects of tribal treaties, emphasizing the bond between peoples of the PNW and the environment (Gibbs and McClellan, 1967; Zaferatos, 2004). While the toxic effects of stormwater on coho salmon in the PNW (Feist et al., 2011; Scholz et al., 2011) is well documented, recent work has demonstrated the importance of GI in limiting these toxic effects (Spromberg et al., 2016).
- 4 Keen environmental attitude** - While this issue is intrinsically linked to the previous (iconic species), Ellis and Thompson (1997) showed that there exists a strong regional bias toward outdoor activities and environmental enthusiasm in the PNW. This broad environmentalism translates to a willingness to work with nature to limit some of the pitfalls of urbanization, through the implementation of GI.
- 5 Regulations** – Combined Sewer Overflow (CSO) consent decrees, USEPA total maximum daily loads (TMDL) requirements and municipal separated stormwater sewer systems (MS4) permits, and anticipated stormwater retrofit requirements are very large drivers for GSI adoption in the PNW. In western Washington, the municipal stormwater permit encouraged the use of GSI in 2005, and in 2012 required GSI where feasible (SWMMWW, 2014). Most Phase 2 jurisdictions and all Phase 1 jurisdictions in western Washington are required, as of today, to implement GSI when developing land above a certain parcel size. Currently in western Oregon, only Phase 1 jurisdictions are required to *consider* GSI, but not required to. However, the City of Portland does require GSI (BES 2104) where feasible.
- 6 Funding** – Public and elected officials in the PNW have become expected to put forward “green” projects and prioritize them more highly than typical grey infrastructure (Babstiste et al. 2015). With recent emphases to meet equity and environmental justice goals through city/municipal projects (Haughton, 1999; Long, 2016), the more comprehensive and multifaceted a GI project is, the larger the funding pool, and the more likely it will meet additional environmental, social, or health regulations in a way that traditional grey infrastructure cannot.

### 1.3. Land Grant University leadership of the regional green infrastructure summit

Designing GI that meets environmental, site, and fiscal constraints, and achieves the desires of the local stakeholders is still not a common practice. Reasons for installation more often favor what are perceived as more “practical needs” over community “desires.” This perception is changing, however, with growing realization that the imposition of standard practices can marginalize voices that speak for community. This increasing recognition of the need to engage communities in GI development, even as the science and practice of GI continue to evolve, makes these projects a particularly relevant area of focus for land grant universities (LGUs). LGUs have a unique role among U.S. universities; the combination of Congress’ Morrill, Hatch, and Smith-Lever Acts created a mission of knowledge creation (research) coupled to dissemination and implementation of that knowledge for communities and individuals (via the Cooperative Extension System, CES). To begin elucidating some of these issues associated with GI adoption in PNW, an Urban Green Infrastructure Summit was held in the Portland, OR suburb of Tigard in February 2018. The convened Urban Green Infrastructure Summit aimed to test a new model, to take advantage of the LGU Extension network and its capacity and expertise in connecting researchers and practitioners in the PNW. The summit was organized with a regional focus on western Oregon and Washington, at a size

practical for a first effort, and to foster a commonality of purpose within the common regional maritime climate (Bailey, 1980) and physiographic setting of the Puget-Willamette basin.

The objectives of the summit were to:

- a) Characterize PNW challenges and opportunities in the implementation of GI.
- b) Elucidate next steps for research, coordination, and extension needed by PNW practitioners.
- c) Determine avenues for regional collaboration for maximum human/ecosystems benefit.

## 2. Summit design (methods)

The Summit was planned by a core committee of research and extension faculty with expertise in GI and/or outreach and engagement and representatives from PNW cities' GI or GSI-related departments. Desired outcomes for the summit were (a) to connect communities, academic researchers, and extension faculty, (b) to share existing resources, (c) to inform education and research priorities, and (d) to build new collaborative, problem-solving networks. For more detailed information on presentations, participants and other information from the Summit readers can visit: <https://metroextension.wsu.edu/2017/10/10/gisummit/>. This paper distills the ideas shared and outcomes developed from this event, and represents voices from a wide spectrum of local governments, university researchers, non-profit organizations, and environmental consultants from Washington, Oregon, and beyond. The results below reflect the views of these participants and as such provide a perspective on GI for the wider PNW region.

## 3. Results

The summit highlighted the breadth of GI work occurring around the western PNW region and illuminated a set of emerging themes and challenges researchers and practitioners face as they continue to expand the practice and science of GI. While the challenges listed below were voiced by attendees of this regional conference, many resonate with other published studies in the US and Europe (e.g., Dhakal and Chevalier, 2017; Hoang and Fenner, 2016; Chaffin et al., 2016; O'Donnell et al., 2017; Meerow and Newell, 2017). The summit's resulting "GI Implementation in the PNW - opportunities for growth" while regionally specific, may also provide inspiration for other regions.

### 3.1. Challenges to GI expansion in the PNW

#### 3.1.1. Lack of coordination

The "silo effect" or the lack of communication and coordination across institutional domains remains a major and persistent challenge for holistic GI management in the PNW. GI design, construction, and maintenance are often implemented by a varied cast of characters, including city departments, non-profit groups, or state agencies. The work is performed with varying goals, and occasionally co-located within the same jurisdiction or even neighborhood, e.g., street trees may be planted by a city Department of Transportation while adjacent park trees are planted by a Department of Parks and Recreation. The lack of communication among entities that implement GI on the landscape was a recurrent theme among the summit attendees. The absence of coordination from policy, to regulation and enforcement, to construction and maintenance, was presented as a significant shortcoming.

#### 3.1.2. Inertia and traditionalism

A frequent theme among participants was difficulty in gaining acceptance from neighborhood residents, or finding the appetite for new GI practices amongst traditionally-minded municipal directors/engineers. In addition to ensuring that GI designs address local landscape, ecology, and climate constraints, public appreciation of GI is also a

critical part of success. It takes a long time to increase understanding, develop trust and relationships, necessitating consistent language for engaging people about how these systems work, and their importance. For example, some believe that parks and green spaces in lower income neighborhoods attract crime despite evidence to the contrary (Bogar and Beyer, 2016; Sreetheran and Van Den Bosch, 2014; Kuo and Sullivan, 2001). Others expressed fear that greenspace installation will lead to gentrification and pricing-out from the neighborhood, or that curbside bioswales will take the place of scarce street parking spaces.

#### 3.1.3. Site-scale focus

Municipalities and organizations participating in the summit focus primarily at the scale of individual sites and projects, particularly small plots within parcels, e.g., individual street corners for bioswales, or stormwater planters, or site-based mitigation of redevelopment runoff. Yet, most summit participants aspired to a more comprehensive and integrated watershed-scale mindset supported by concomitant policies, funding, and prioritization. The sentiment was that this watershed-scale mindset is necessary to achieve cumulative benefits at the watershed scale from multiple small projects, to understand how GI investments and benefits can best be spatially and equitably distributed, and how disparate watershed-relevant funding sources can be brought to bear on common issues.

#### 3.1.4. Externalizing environmental costs

The typical approach to stormwater quality and quantity issues has been to externalize them – manage them away from their sources by collecting the stormwater, conveying it to a detention pond or a treatment facility, and either actively treating or passively letting infiltration, evaporation, dilution, or opportunistic bioremediation hopefully mitigate the problem. This common approach also isolates the cost, making stormwater management appear as a seemingly additional line-item above the "normal" costs of road, parking lot, or building construction, or even as "someone else's problem," i.e., the water quality steward or municipal sewer authority.

#### 3.1.5. Lack of expertise or money

Green infrastructure melds biophysical processes and social land use, ideally achieving nuanced integration of local community, hydrology, and ecology compared to the less site-customized design and installation of traditional "grey" infrastructure (Young et al., 2014). Many engineering and construction firms lack trained GI designers, installers, and maintenance personnel. Construction and land costs in most cities of the PNW make GI installations and GSI retrofits appear expensive (see *Externalizing costs*, above). This was noted to be a challenge specifically for smaller towns with limited available resources for hiring additional experts if expertise does not already exist in-house. In addition, funding or regulatory policies do not always align with ecosystem needs.

#### 3.1.6. Maintenance as an afterthought

The cost of GI maintenance was perhaps the most-repeated challenge for summit attendees. Although generally GI enthusiasts, participants still often noted that GI can be a "maintenance nightmare," both to maintain and to fund maintenance. In some cases, this tips the scales enough that GI is avoided. Another major challenge is the question of jurisdictional responsibility for the inspection and monitoring of installed GI facilities, which can vary by facility type and over time. For example, due to dry summers, Portland may pay for and conduct watering and pruning of new street trees for the first 1–3 years, after which the tree is the adjacent landowner's responsibility. Meanwhile, curbside bioswales may be maintained entirely by the city indefinitely. Or, in some cases, well-meaning homeowners may take responsibility to clean and maintain bioswales on their street but may inadvertently plant unhelpful or non-native vegetation in an effort to further beautify the facility.

### 3.2. GI Implementation in the PNW - opportunities for growth

Despite the challenges described by the summit participants, six opportunities for growth were also identified. These opportunities build from the challenges discussed above, and represent efforts that practitioners, academics, and Extension might collectively tackle to improve the efficiency and acceptance of GI in PNW communities.

#### 3.2.1. Adaptive design and maintenance of GI

Wider acceptance and implementation of GI has meant that practitioners and researchers in the PNW are looking for new ways to use science, technology, and people to improve operations. Currently, resources for designing and maintaining GI consist mainly of technical documents. While useful to those siting and installing GI, such documents lack information about other issues and challenges experienced by users. In particular, summit attendees expressed a need for more flexible and adaptable guidance around: 1) designs for complicated or novel sites; 2) retrofits for sites that were not installed properly, or are not functioning as expected; and 3) maintaining or reducing the maintenance load for existing and future projects, such as by more detailed assessment of vegetation types and their benefits (or lack thereof) than is presently available in literature or practice. As new locations for GI continue to be developed, new challenges emerge. Creative solutions, developed through practitioner and university engagement facilitated by LGU Cooperative Extension, could help in areas where standard GI solutions do not align well with site conditions, or where monitoring is currently lacking but needed. Development of new infiltration media, smart sensors, or protocols for initiating citizen science efforts could all potentially help resolve some of the design and maintenance issues associated with current GI practices.

#### 3.2.2. Placing GI for maximum cumulative watershed impact

While the vision for “large scale” GI management for maximum impact requires a clearer understanding of how best to design and monitor individual installations, it also brings into question how we design and monitor across scales, e.g., for networks of distributed or mutually reinforcing facilities. Participants discussed the narrow site-scale focus of most GI implementation, where siting is done on a case-by-case basis with primary attention to the site itself and less on watershed context. A more holistic approach was greatly desired by summit participants, wherein suites of GI installations would be located in the larger landscape to offer mutually-reinforcing, cumulative, maximum stormwater (e.g. [Martin-Mikle et al., 2015](#)), heat reduction ([Whitford et al., 2001](#); [Declet-Barreto et al., 2016](#)), ecosystem ([Marull et al., 2007](#); [Opdam et al., 2006](#)), and environmental/social/health equity benefits. This will become even more important as communities adapt (or fail) along climate change-impacted pathways for the future. More research is needed to identify what co-benefits different types of GI offer, at what scales in a distributed landscape, and how to place them to diversify or maximize benefits.

#### 3.2.3. GI through collective impact

The idea of “collective impact” as a mechanism for encouraging and maintaining GI was a major topic of interest for practitioners at the summit. Used frequently by NGOs, commercial, and industry organizations, the Collective Impact framework formalizes a social process that reduces friction and coordinates diverse collaborators toward a common goal ([Christens and Inzeo, 2015](#)). Concomitant with the issues related to GI-adoption identified by the summit participants, was a keen interest to ensure that not only environmental benefits were met, but also human ones. Community engagement could help local and regional GI portfolios work toward environmental equity and social justice, provide innovative ideas and approaches for addressing GI challenges, and potentially alleviate some of the regulatory (e.g., compliance) and workforce (e.g., maintenance, monitoring) challenges now hindering persistent and widespread success, sustainability, and

adoption of GI. Community engagement with GI and their watershed can theoretically also lead to more community volunteerism in green-spaces, more attention to private landscaping and native plants, and more social cohesion and intra-community support in general.

#### 3.2.4. Market and non-market valuation of GI

Perhaps the least studied and certainly among the most important aspects of successful GI implementation in the PNW is the economics of GI adoption ([Voicu and Been, 2008](#)). Many PNW communities highly value walkable, bikeable, green neighborhoods. Some PNW neighborhoods have found that implementing curbside bioswale GI helps achieve these “better streets” by reducing parking space (dissuading driving), slowing traffic (improving safety), and increasing community engagement (more attractive to visit and spend time). Despite less parking, some communities have experienced benefits to local businesses from neighborhood center revitalizations, even from just a few, nicely constructed bioswales or stormwater planters in a few former parking spots. Among researchers, Extension specialists, agency, and city attendees at the conference, there was a palpable sense that more complete lifecycle-based assessments of economic, ecological, human, and social costs and benefits associated with GI are critically needed in the PNW, and beyond. Concepts such as demand analysis and price elasticity that relate cost of a certain GI practice to the demand were discussed, as were strategies for estimating the value of GI (e.g., improved air and water quality, urban cooling), in comparison to benefits of grey infrastructure (e.g., below-ground ‘invisibility’, traditional practice and knowledge base). Summit participants clearly enunciated a host of additional GI values, such as habitat provisioning for birds and pollinators, soil remediation over time, greenery contributions to recreation and mental health, and expanded “space for nature” amid developed lands. However, in some cases these same values can present challenges, e.g., habitat for undesirable rodents, ponding as mosquito habitats, and perception of untidy greenery “overgrowth.” These additional benefits/costs from GI remain, at the moment, largely anecdotal, and so pose as untested hypotheses that require further research to understand their significance and variability.

#### 3.2.5. GI through an equity lens

In many communities, GI is seen as a desirable addition, adding “greenness” and a “park-like” feel to a neighborhood or area. However, there is a pronounced risk of “green gentrification” and displacement ([Wolch et al., 2014](#)) in areas that have been made, or are perceived to have been made, more “livable” by GI, whether by curbside bioswale gardens, street tree planting, or other such initiatives. Although individual practitioners and community outreach specialists already think deeply about this topic, it does not yet seem to be ever-present in the minds of GI-related personnel, as it deserves to be. There does not seem to be a general practice of having housing equity and property value on the table for discussion before (or even after) GI siting, design, and implementation. It is also not yet clear if there are examples of effective mitigation of the gentrification/displacement housing problem in the PNW, nor clear research explaining any role GI may be playing in it overall. Some studies have shown that greener neighborhoods tend to be correlated with higher income areas ([Jenerette et al., 2013, 2011](#); [Markevych et al., 2017](#); [Astell-Burt et al., 2014](#)), but more study is needed to determine if there is a causal relationship between GI greening and displacement.

#### 3.2.6. Intersections of GI and community health

A key future area of growth for GI, in terms of both valuation and funding support, may be to align GI with the missions of community health organizations and nonprofits, as well as major health providers invested in preventative care (e.g., Willamette Partnership and the Oregon Public Health Institute; [Cochran et al., 2018](#)). Examples of a nexus between community health and GI are the “prescription trails ([Prescription Trails, 2019](#))” championed by the New Mexico Health Care

Authority Takes on Diabetes effort, and the “Green Infrastructure and Health Guide” produced by the [Oregon Health and Outdoors Initiative \(2018\)](#). A challenge in this area, however, is that building a city-wide or perhaps even a regional network of cooperation around outdoor environmental health, GI, and human health would have to overcome potential inter-provider competition, as well as the challenges of quantitative or controlled studies in a setting that properly safeguards patient information. Still, the potential synergy by broadly, and hopefully equitably, creating shadier or greener streetscapes, slowing traffic, adding recreational paths, reducing flood/road hazards, improving air quality, and promoting biking and walking could have immense physical and mental health benefits across communities.

One idea for building on this intersection of GI and community health raised by summit participants was to consider seeking a more explicit coalescence of GI, community gardens, and community orchards under a shared umbrella. This may have the added benefit of helping to translate what may seem like a somewhat abstract and utilitarian notion of GI into a more accessible and proximal notion of personal and community food provisioning and nutrition. This is another natural junction for cooperation among community, practitioners, Cooperative Extension (4H, urban farming), and academics (research quantifying green services). By merging consideration of urban farming and gardening with planning for stormwater control and other GI benefits, additional funding streams for the former may also be accessed, at possible benefit to the latter as climates become more extreme and unpredictable.

#### 4. Conclusions

The top two goals for attendance of a summit dedicated to advancing GI in the PNW, based on a pre-summit survey of potential summit attendees, were:

- 1 Improved understanding of GI facilities and implementation in the PNW region,
- 2 Improved connections with professionals that have varied GI expertise.

The top three priorities for future work identified by a post-summit survey were:

- 1 Foster new research to answer important questions on specific GI topics, e.g. economics, ecosystem services, vegetative functions, community health, etc.
- 2 Plan another regional or western GI Summit.
- 3 Use an email distribution list from the summit to disseminate the latest publications, studies, and grant opportunities.

Key challenges for GI in the PNW and broadly, remain: finding the most effective means to foster new, novel, and innovative partnerships to advance GI from site to national scales; quantifying the designs, uses, costs, and values of GI, and seeking and ensuring equity in GI at all levels from first discussions and ideation through participation, planning, installations, outreach, and related jobs and activities. Still, these challenges are also inspirations to continue efforts to bring together municipal, Extension, research, utility, and community participants, and disciplines that have not historically worked together.

The Pacific Northwest is clearly at a critical stage where many scientific advances from around the world have demonstrated the promise of GI as a viable means to preserve and protect ecosystems services while meeting strong PNW regulatory concerns of adequate stormwater and water pollution management. Reasons for these advances point towards its distinctive history, climate, topography, and people. The city-wide and state-wide requirements for GSI in many areas of the PNW are immensely strong regional drivers in this field. Despite these advances and requirements, fundamental adoption of GI as a means to

manage growing populations and ecosystem needs is still lagging. Information gleaned from academics, professionals, and Extension specialists in the region suggest that the lack of widespread adoption is related to several possible reasons that range from a narrow spatial focus of GI implementation, to the lack of funding.

Key emergent themes to move GI forward include a more adaptive, ecosystems-based, and watershed-scale approach to designing and siting GI practices. Including community and equity of gender, race, income, and opportunity into planning, design, and maintenance of GI was recognized as paramount. The nexus of GI, economic, and community health was seen as an exciting and necessary frontier for further inquiry. The existing nation-wide resource provided by LGUs and their Cooperative Extension staff, already highly experienced in such site-to-watershed, community well-being and equity, and education and innovation concerns, was recognized at this summit as a huge, but under-utilized potential for GI in the U.S. Addressing GI benefits beyond stormwater requires the melding of environment with health, behavior, policy, finance, equity, and community, with the ultimate goal of healthy humans living in healthy landscapes (Sullivan et al., 2014).

#### CRedit authorship contribution statement

**A.D. Jayakaran:** Supervision, Methodology, Writing - original draft, Writing - review & editing. **K.B. Moffett:** Methodology, Writing - original draft. **J.C. Padowski:** Methodology, Writing - original draft, Writing - review & editing. **P.A. Townsend:** Methodology, Writing - original draft. **B. Gaolach:** Conceptualization, Writing - original draft, Methodology.

#### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

#### Acknowledgments

We wish to thank the speakers who shared their time and insights with us: Scott Altenhoff, City of Eugene; Joseph Cook, Washington State University; Rosana Da Silva, Rutgers Cooperative Extension; Doug Howie, Washington Department of Ecology; Jennifer Karpis, City of Portland; Yekang Ko, University of Oregon; Sarah Medary, City of Eugene; Christopher Obropta, Rutgers Cooperative Extension; Bruce Roll, Clean Water Services; Carrie Sanneman, Willamette Partnership; Vivek Shandas, Portland State University; Bob Simmons, Washington State University Extension; and Sarah Whitney, Long Tom Watershed Council. Funding for this summit was provided by the Western Center for Metropolitan Extension and Research with additional support from the Washington State University Metropolitan Center for Applied Research and Extension; Oregon State University Extension Service, Washington County; Clean Water Services; and Washington State University Clark County Extension. We are also grateful to steering committee members: Scott Altenhoff, Fred Lockhart, Maria Anguiano, Andy Meyer, Vicki Campbell, Derek Goodwin, Patrick Proden, and Josh Gunn. Finally, we wish to thank all the summit attendees who braved a rare February snowstorm to participate.

#### Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:<https://doi.org/10.1016/j.ufug.2020.126654>.

#### References

- Arendt, R., 1996. *Conservation Design for Subdivisions*. Island Press, Covelo, CA.  
ASCE, 2019. Washington Infrastructure Report Card, 2019. American Society of Civil

- Engineers Seattle, Tacoma-Olympia, and Inland Empire Sections. <https://www.infrastructurereportcard.org/state-item/washington/>.
- Astell-Burt, T., Feng, X., Mavoia, S., Badland, H.M., Giles-Corti, B., 2014. Do low-income neighbourhoods have the least green space? A cross-sectional study of Australia's most populous cities. *BMC Public Health* 14 (1), 292.
- Bailey, R.G., 1980. Description of the Ecoregions of the United States. No. 1391. US Department of Agriculture, Forest Service 1980.
- Baker, A., Breneman, E., Chang, H., McPhillips, L., Matsler, M., 2019. Spatial analysis of landscape and sociodemographic factors associated with green stormwater infrastructure distribution in Baltimore, Maryland and Portland, Oregon. *Sci. Total Environ.* 664, 461–473.
- Benedict, M.A., McMahon, E.T., 2006. *Green Infrastructure*. Island Press, Washington, DC.
- Benedict, M.A., McMahon, E.T., 2012. *Green Infrastructure: Linking Landscapes and Communities*. Island Press.
- BES, 2016. Bureau of Environmental Services, City of Portland Stormwater Management Manual, Portland OR.
- Bogar, S., Beyer, K.M., 2016. Green space, violence, and crime: a systematic review. *Trauma Violence Abuse* 17 (2), 160–171.
- Brink, E., Aalders, T., Ádám, D., Feller, R., Henselek, Y., Hoffmann, A., Ibe, K., Matthey-Doret, A., Meyer, M., Negrut, N.L., Rau, A.L., 2016. Cascades of green: a review of ecosystem-based adaptation in urban areas. *Glob. Environ. Chang. Part A* 36, 111–123.
- Chaffin, B.C., Shuster, W.D., Garmestani, A.S., Furio, B., Albro, S.L., Gardiner, M., Spring, M., Green, O.O., 2016. A tale of two rain gardens: barriers and bridges to adaptive management of urban stormwater in Cleveland, Ohio. *J. Environ. Manage.* 183, 431–441.
- Christens, B.D., Inzeo, P.T., 2015. Widening the view: situating collective impact among frameworks for community-led change. *Community Dev.* 46 (4), 420–435.
- Cochran, B., Robison, B., Henke, E., 2018. *Green Infrastructure & Health Guide*. Technical Report, Willamette Partnership and Oregon Public Health Institute.
- Cole, H.V., Lamarca, M.G., Connolly, J.J., Anguelovski, I., 2017. Are green cities healthy and equitable? Unpacking the relationship between health, green space and gentrification. *J. Epidemiol. Community Health* 71 (11), 1118–1121.
- Cook, E.A., 2007. Green site design: strategies for storm water management. *J. Green Build.* 2 (4), 46–56.
- Cortinovis, C., Geneletti, D., 2018. Ecosystem services in urban plans: what is there, and what is still needed for better decisions. *Land Use Policy* 70, 298–312.
- Costanza, R., d'Arge, R., De Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R.V., Paruelo, J., Raskin, R.G., 1997. The value of the world's ecosystem services and natural capital. *Nature* 387 (6630), 253–260.
- Curran, W., Hamilton, T., 2012. Just green enough: Contesting environmental gentrification in Greenpoint, Brooklyn. *Local Environ.* 17 (9), 1027–1042.
- Declet-Barreto, J., Knowlton, K., Jenerette, G.D., Buyantuev, A., 2016. Effects of urban vegetation on mitigating exposure of vulnerable populations to excessive heat in Cleveland, Ohio. *Weather. Clim. Soc.* 8 (4), 507–524.
- Dhakal, K.P., Chevalier, L.R., 2017. Managing urban stormwater for urban sustainability: barriers and policy solutions for green infrastructure application. *J. Environ. Manage.* 203, 171–181.
- Ellis, R.J., Thompson, F., 1997. Culture and the environment in the Pacific Northwest. *Am. Polit. Sci. Rev.* 91 (4), 885–897.
- EPA, 2018. *Stormwater Management and Green Infrastructure Research*. [online]. <https://www.epa.gov/water-research/stormwater-management-and-green-infrastructure-research>.
- Feist, B.E., Buhle, E.R., Arnold, P., Davis, J.W., Scholz, N.L., 2011. Landscape ecotoxicology of coho salmon spawner mortality in urban streams. *PLoS One* 6 (8).
- Franczyk, J., Chang, H., 2009. The effects of climate change and urbanization on the runoff of the Rock Creek basin in the Portland metropolitan area, Oregon, USA. *Hydrol. Process.* 23 (6), 805–815.
- Gibbs, G., McClellan, G.B., 1967. *Indian Tribes of Washington Territory*. Galleon Press.
- Houghton, G., 1999. Environmental justice and the sustainable city. *J. Plan. Educ. Res.* 18 (3), 233–243.
- Hoang, L., Fenner, R.A., 2016. System interactions of stormwater management using sustainable urban drainage systems and green infrastructure. *Urban Water J.* 13 (7), 739–758.
- Hoover, F.A., Hopton, M.E., 2019. Developing a framework for stormwater management: leveraging ancillary benefits from urban greenspace. *Urban Ecosyst.* 22 (6), 1139–1148.
- Jenerette, G.D., Harlan, S.L., Stefanov, W.L., Martin, C.A., 2011. Ecosystem services and urban heat risk: moderation: water, green spaces, and social inequality in Phoenix, USA. *Ecol. Appl.* 21 (7), 2637–2651.
- Jenerette, G.D., Miller, G., Buyantuev, A., Pataki, D.E., Gillespie, T.W., Pincetl, S., 2013. Urban vegetation and income segregation in drylands: a synthesis of seven metropolitan regions in the southwestern United States. *Environ. Res. Lett.* 8 (4), 044001.
- Kloss, C., Calaruse, C., Stoner, N., 2006. *Rooftops to Rivers: Green Strategies for Controlling Stormwater and Combined Sewer Overflows*. [online] URL: <https://www.nrdc.org/resources/rooftops-rivers-green-strategies-controlling-stormwater-and-combined-sewer-overflows>.
- Kopperoinen, L., Itkonen, P., Niemelä, J., 2014. Using expert knowledge in combining green infrastructure and ecosystem services in land use planning: an insight into a new place-based methodology. *Landscape Ecol.* 29 (8), 1361–1375.
- Kuo, F.E., Sullivan, W.C., 2001. Environment and crime in the inner city: Does vegetation reduce crime? *Environ. Behav.* 33 (3), 343–367.
- Larson, L.R., Ferrell, J., 2007. *Orcinus* and *Oncorhynchus*: Will Saving Puget Sound Orcas and Salmon Save an Ecosystem? *J. Pengelolaan Sumberd. Alam Dan Lingkung.* 22 (2), 26–58.
- Long, J., 2016. Constructing the narrative of the sustainability fix: Sustainability, social justice and representation in Austin, TX. *Urban Stud.* 53 (1), 149–172.
- Markevych, I., Maier, W., Fuertes, E., Lehmann, I., von Berg, A., Bauer, C.P., Koletzko, S., Berdel, D., Sugiri, D., Standl, M., Heinrich, J., 2017. Neighbourhood greenness and income of occupants in four German areas: GINplus and LISplus. *Urban For. Urban Green.* 21, 88–95.
- Martin-Mikle, C.J., de Beurs, K.M., Julian, J.P., Mayer, P.M., 2015. Identifying priority sites for low impact development (LID) in a mixed-use watershed. *Landscape Urban Plan.* 140, 29–41.
- Marull, J., Pino, J., Mallarach, J.M., Cordobilla, M.J., 2007. A land suitability index for strategic environmental assessment in metropolitan areas. *Landscape Urban Plan.* 81 (3), 200–212.
- McPhillips, L.E., Matsler, A.M., 2018. Temporal evolution of green stormwater infrastructure strategies in three US cities. *Front. Built Environ.* 4, 26.
- Meerow, S., Newell, J.P., 2017. Spatial planning for multifunctional green infrastructure: growing resilience in Detroit. *Landscape Urban Plan.* 159, 62–75.
- Mell, I.C., 2014. Aligning fragmented planning structures through a green infrastructure approach to urban development in the UK and USA. *Urban For. Urban Greening* 13 (4), 612–620.
- Nelson, E.J., Booth, D.B., 2002. Sediment sources in an urbanizing, mixed land-use watershed. *J. Hydrol. (Amst)* 264 (1–4), 51–68.
- O'Donnell, E.C., Lamond, J.E., Thorne, C.R., 2017. Recognizing barriers to implementation of Blue-Green Infrastructure: a Newcastle case study. *Urban Water J.* 14 (9), 964–971.
- Opdam, P., Steingröver, E., Van Rooij, S., 2006. Ecological networks: a spatial concept for multi-actor planning of sustainable landscapes. *Landscape Urban Plan.* 75 (3–4), 322–332.
- Oregon Health and Outdoors Initiative, 2018. *Green Infrastructure and Health Guide* – Version 1, July 10, 2018. [online] URL: <https://willamettepartnership.org/green-infrastructure-health-guide/>.
- Pivo, G., 1996. Toward sustainable urbanization on Mainstreet Cascadia. *Cities* 13 (5), 339–354.
- Poole, G.C., Dunham, J.B., Keenan, D.M., Sauter, S.T., McCullough, D.A., Mebane, C., Lockwood, J.C., Essig, D.A., Hicks, M.P., Sturdevant, D.J., Materna, E.J., 2004. The case for regime-based water quality standards. *BioScience* 54 (2), 155–161.
- Prescription Trails, 2019. *New Mexico Health Care Takes On Diabetes*. [online] URL: <https://prescriptiontrails.org/>.
- Prince George's County, 1999. *Low-impact Development Design Strategies, an Integrated Design Approach*. Department of Environmental Resources, Programs and Planning Division, Prince George's County, Maryland.
- PSRC, 2008. *Traffic Choices Study – Final Report*. April 2008. Puget Sound Regional Council, Seattle, WA. [online] URL: <https://www.psrc.org/sites/default/files/traffic-choices.pdf>.
- PSRC, 2017. *May 2017 Puget Sound Trends*. Puget Sound Regional Council, Seattle, WA. [online] URL: <https://www.psrc.org/sites/default/files/trend-jobs-201705.pdf>.
- PSRC, 2018. *August 2018 Puget Sound Trends*. Puget Sound Regional Council, Seattle, WA. [online] URL: <https://www.psrc.org/sites/default/files/trend-vehiclemiletraveled-201809.pdf>.
- Sandström, U.F., 2002. Green Infrastructure planning in urban sweden. *Plan. Pract. Res.* 17 (4), 373–385.
- Schindler, D.E., Scheuerell, M.D., Moore, J.W., Gende, S.M., Francis, T.B., Palen, W.J., 2003. Pacific salmon and the ecology of coastal ecosystems. *Front. Ecol. Environ.* 1 (1), 31–37.
- Scholz, N.L., Myers, M.S., McCarthy, S.G., Labenia, J.S., McIntyre, J.K., Ylitalo, G.M., Rhodes, L.D., Laetz, C.A., Stehr, C.M., French, B.L., McMillan, B., 2011. Recurrent die-offs of adult coho salmon returning to spawn in Puget Sound lowland urban streams. *PLoS One* 6 (12).
- Sprongberg, J.A., Baldwin, D.H., Damm, S.E., McIntyre, J.K., Huff, M., Sloan, C.A., Anulacion, B.F., Davis, J.W., Scholz, N.L., 2016. Coho salmon spawner mortality in western US urban watersheds: bioinfiltration prevents lethal storm water impacts. *J. Appl. Ecol.* 53 (2), 398–407.
- Sreetheran, M., Van Den Bosch, C.C.K., 2014. A socio-ecological exploration of fear of crime in urban green spaces: a systematic review. *Urban For. Urban Green.* 13 (1), 1–18.
- Sullivan, W.C., Frumkin, H., Jackson, R.J., Chang, C.Y., 2014. Gaia meets Asclepius: creating healthy places. *Landscape Urban Plann.* 127, 182–184.
- Stormwater Management Manual for Western Washington (SWMWW), 2014. Washington State Department of Ecology: Publication Number 14-10-055. Lacey, WA, USA. [online] URL: <https://fortress.wa.gov/ecy/madcap/wq/2014SWMWWWinteractive/Content/Resources/DocsForDownload/2014SWMWW.pdf>.
- Teaford, J.C., 1987. *Landscape America*. *Rev. Am. Hist.* 15 (4), 656–661.
- U.S. Census, 2015. *Population Data for King County*. [online] URL: <https://www.census.gov/quickfacts/fact/table/kingcountywashington/WA/PS045216Ret>.
- VanMetre, P.C., Morace, J.L., Sheibley, R., 2015. The Pacific northwest stream quality assessment. *US Geol. Survey Fact Sheet* 3020 (2).
- Voicu, I., Been, V., 2008. The effect of community gardens on neighboring property values. *Real Estate Econ.* 36 (2), 241–283.
- Walmsley, A., 2006. Greenways: multiplying and diversifying in the 21<sup>st</sup> century. *Landscape Urban Plan.* 76 (1–4), 252–290.
- Warner, M.D., Mass, C.F., Salathé Jr., E.P., 2012. Wintertime extreme precipitation events along the Pacific Northwest coast: Climatology and Synoptic Evolution. *Mon. Weather Rev.* 140 (7), 2021–2043.
- Whitford, V., Ennos, A.R., Handley, J.F., 2001. "City form and natural

- process”—indicators for the ecological performance of urban areas and their application to Merseyside, UK. *Landscape Urban Plann.* 57 (2), 91–103.
- Williams, J.D., Wilkins, D.E., McCool, D.K., Baarstad, L.L., Klepper, B.L., Papendick, R.I., 1998. A new rainfall simulator for use in low-energy rainfall areas. *Appl. Eng. Agric.* 14 (3), 243–247.
- Wolch, J.R., Byrne, J., Newell, J.P., 2014. Urban green space, public health, and environmental justice: The challenge of making cities “just green enough”. *Landsc. Urban Plan.* 125, 234–244.
- Young, R.F., 2011. Planting the living city: best practices in planning green infrastructure: results from major US cities. *J. Am. Plan. Assoc.* 77 (4), 368–381.
- Young, R., Zanders, J., Lieberknecht, K., Fassman-Beck, E., 2014. A comprehensive typology for mainstreaming urban green infrastructure. *J. Hydrol. (Amst)* 519, 2571–2583.
- Zaferatos, N.C., 2004. Tribal Nations, local governments, and regional pluralism in Washington state: the Swinomish approach in the Skagit valley. *J. Am. Plan. Assoc.* 70 (1), 81–96.