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"At the end of the day, you need to do something": discourses on prioritization of stormwater solutions

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As urbanization continues to expand in the Puget Sound, Washington, USA region, stormwater management has wide ranging impacts to human and ecosystem health and is therefore fundamental to creating equitable and sustainable cities. This paper brings forward dominant discourses among stormwater experts in regard to which solutions should be implemented in the Puget Sound region and what outcomes would be most beneficial to this ecosystem. We used Q-methodology to investigate differences in prioritization of stormwater solutions currently being considered in the region and explore how emergent perspectives may affect decisions for stormwater management. We chose 29 stormwater solutions falling into three categories: source control, green infrastructure, and gray infrastructure, each leading to different co-benefits and environmental outcomes. The purpose of this study is to better understand which solutions lead to the most efficient and beneficial recovery of the Puget Sound ecosystem. Through centroid extraction analysis, we discovered three discourses that capture different themes, values, and beliefs held by stormwater experts. Within our 21 participants, each shared common stormwater goals: reducing the delivery of toxics to receiving waterways and reducing stormwater quantity. Even with these shared end goals, our participants disagreed on the prioritization and overall outcomes of solution types. Our findings are important to spark discussion between municipalities with differing worldviews and outcomes associated with stormwater management and to highlight multiple benefits associated with solutions and how they can be utilized to support environmental justice.

KEYWORDS

stormwater pollution, Q methodology, Puget Sound, green infrastructure (GI), environmental justice (EJ), sustainability, conservation

Introduction

Urbanization is a prevailing pattern across the globe (Tonne et al., 2021), with nearly 7 out of 10 people expected to inhabit cities by 2050 (Kiss et al., 2015). Indeed, McDonald and Beatley (2021), suggest that we have entered the "urban century"—a time when we must choose how we relate to and interact with cities. Urbanization can generate economic growth and vitality (Glaeser, 2012); however, expansion of urban landscapes generates cascading impacts on ecosystems and human health (e.g., Alberti, 2010; Seto et al., 2011; Bounoua et al., 2015; Bratman et al., 2019; Levin et al., 2020).

One of the most recognizable changes associated with urbanization is the removal of vegetation and replacement with impervious surfaces. This increases the volume and peak flow of surface runoff (Goonetilleke et al., 2005; Paule-Mercado et al., 2017), and as runoff travels over parking lots, roads, roofs, and other impervious surfaces, it picks up contaminants from residential neighborhoods, commercial and industrial areas, and roads before reaching receiving waters (Tsihrintzis and Hamid, 1997; Barbosa et al., 2012). This stormwater runoff, includes excess nutrients (Pitt et al., 1999; Davis et al., 2009), pesticides (Bucheli et al., 1998; Pitt et al., 1999), toxic metals (Davis et al., 2009; Mahbub et al., 2010), pathogens (Pitt et al., 1999; Davis et al., 2009), petroleum hydrocarbons (Pitt et al., 1999; Davis et al., 2009), and suspended solids (Davis et al., 2009; Hathaway and Hunt, 2011). These pollutants lead to significant adverse effects downstream (Walsh et al., 2005; Levin et al., 2020). In particular, urbanized waterways suffer from "urban syndrome"—a condition that results in low abundance and survival of sensitive aquatic and coastal species (Walsh et al., 2005). In addition, stormwater can have serious consequences for human health. For example, exposure to metals in stormwater increases risk of cancer, hypertension and renal dysfunction (Ma et al., 2016).

Addressing stormwater is thus a pressing issue in many urban and urbanizing regions (e.g., Keeler et al., 2019; Messager et al., 2021). Even so, there are dozens of approaches to stormwater mitigation[1] (Porse, 2013), and determining which management practices to adopt is a matter of much discussion. There are three major classes of stormwater solutions: gray infrastructure, green infrastructure and source control. Gray infrastructure for stormwater consists of storage structures and conveyances, frequently constructed of concrete and/or metal, which are used to contain and control stormwater (Svendsen et al., 2012; Dhakal and Chevalier, 2016). Green infrastructure includes human-made structures that use soil and plants to reduce stormwater flow and/or increase filtration of toxic substances from runoff (Svendsen et al., 2012; Ahmed et al., 2018; Steele et al., 2018). Source control refers to solutions that reduce stormwater flows by storage and use, reduce flow to impermeable areas, and those that place barriers between water sources and toxics and contaminants (Marsalek, 2001). Stormwater managers differ in their perspectives about the efficacy of these three classes of management actions. Some argue that gray infrastructure adequately reduces flooding but does not address other environmental problems associated with increased urbanization (Porse, 2013). Others advocate for green infrastructure because it can address stormwater issues while also providing numerous co-benefits (Andersson et al., 2014; Coutts and Hahn, 2015). While some managers promote source control because it is cost-effective, others note that spatial heterogeneity of sources and impacts may limit or complicate the effectiveness of source control (Marsalek, 2001).

The Puget Sound region in Washington is one of the fastest growing urban areas in the United States. With a population >4.5 million, the Puget Sound region has increased in population size by more than 500,000 since 2010 (Trimbach et al., 2022) and is projected to increase by another 2 million in the next 30 years (PSRC, 2020). Like many urban areas, a rise in the coverage of impervious surfaces has accompanied population growth (Hepinstall-Cymerman et al., 2013), with a concomitant increase in contaminants reaching urban streams and receiving waters (Tsihrintzis and Hamid, 1997; Gilbert and Clausen, 2006; Barbosa et al., 2012). These pollutants have had negative ecological effects in Puget Sound. Two highly publicized examples are: (1) Southern Resident Killer Whales (*Orcinus orca*) are exposed to high levels of contaminants including persistent organic pollutants (Mongillo et al., 2012) that cause health issues such as cancer, endocrine disruption, reproductive disruption, immunotoxicity, neurotoxicity, and neurobehavioral disruption (Mongillo et al., 2016); and, (2) runoff of the tire compound 6PPD-quinone from roads causes increased mortality of adult coho salmon (*Oncorhynchus kisutch*) prior to spawning (Tian et al., 2022).

Here, we investigate these diverse discourses on management practices for stormwater in the Puget Sound region. Building on lessons from Puget Sound, our objective was to illuminate perspectives on the stormwater mitigation held by actors engaged in stormwater issues. Specifically, we asked stormwater experts to prioritize a variety of stormwater solutions currently being proposed in the region and considered how emergent perspectives may affect decisions for stormwater management. Using Q methodology (Zabala et al., 2018), we determined whether specific discourses emerged that inform the prioritizations by experts and explored the ways in which such discourses may reflect the experience, concerns and objectives of stormwater actors.

Methods

Q methodology

Q Methodology is a structured approach for discourse analysis that uses both qualitative and quantitative techniques to reveal dominant discourses, as well as consensus and divergent perspectives using a rank ordering activity and factor analysis (Brown, 1980; Webler et al., 2009; Zabala et al., 2018). A discourse is defined as the way an individual views, or forms conceptions of, the world (Barry and Proops, 1999), and can be elicited by discussion and the rank ordering activity. Q Methodology initially was implemented in psychological research (Watts and Stenner, 2005; Webler et al., 2009), but has more recently been used to study environmental and resource management issues (e.g., Gruber, 2011; Nelson et al., 2022) and stormwater governance (Arik, 2022). Because Q methodology aims to understand the internal frame of reference of individuals (rather than extrapolating to populations), Q studies can be successful with sample sizes between 10 and 40 participants (e.g., Cairns, 2012; Sandbrook et al., 2013) and does not require random sampling (Zabala et al., 2018). Our sample size ($n = 21$) is within the typical range of Q sort and captured a diversity of experiences (Watts and Stenner, 2005).

We used Q Methodology to investigate perspectives of stormwater experts in the Puget Sound region of Washington, U.S.A. Specifically, we focused on perspectives of experts regarding the efficacy and priority of a diverse suite of potential solutions to address stormwater and associated pollution. The workflow of our Q study consisted of 4 steps: (1) creation of the Q set (or the list of statements to be ranked) and P set (or the study

1 https://www.epa.gov/npdes/national-menu-best-management-practices-bmps-stormwater

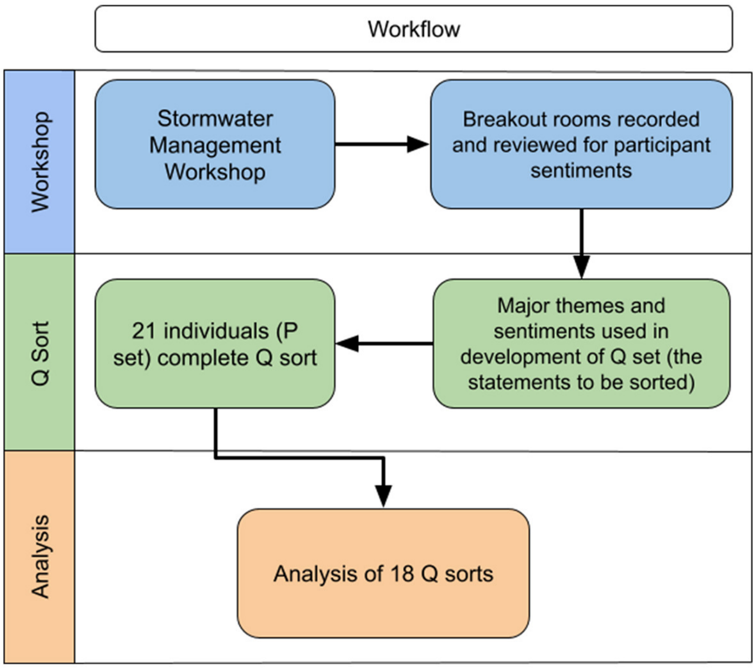

FIGURE 1
Description of project workflow.

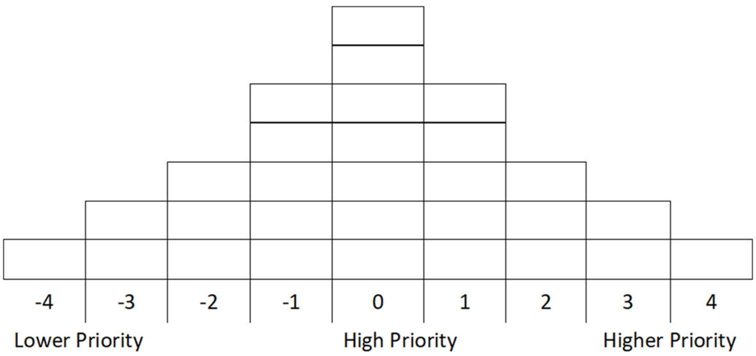

FIGURE 2
Blank Q board distribution onto which participants sorted the 29 solutions. Column 4 is the highest priority while −4 represents the lowest. Boxes within the same column had the same level of priority.

participants); (2) ranking of the Q set (creating a "Q sort"); (3) factor analysis of Q sorts; (4) interpretation of factor analysis (Figure 1) (Brown et al., 1999). Thus in this study, the Q set were stormwater solutions which were ranked and sorted by regional stormwater experts, the P set. To sort the Q Set, participants were tasked with placing the statements into a predetermined semi-normal distribution along a spectrum of lower priority to higher priority, which we refer to as the Q board (Figure 2) (Watts and Stenner, 2005; Webler et al., 2009). As illustrated by Figure 2, participants were able to place a single statement on the Q board as their highest priority, two statements as their second highest priority, and so on. Factor analysis of the completed Q sorts reduced dimensionality of the data and created idealized Q sorts for each group of individuals. Idealized Q sorts disclose common viewpoints regarding stormwater solutions held by group members. Below we provide additional details regarding Q Methodology.

Q set

In developing our Q set, we heeded the advice of Stephenson (1953) to be inclusive of a broad range of perspectives. To accomplish this, we hosted a workshop in partnership with The Water 100 Project[2]—a collaboration between The Nature Conservancy and Puget Sound Partnership that details the 100 most impactful solutions for a clean and resilient Puget Sound. The workshop was attended by experts in stormwater infrastructure,

2 water100project.org

planning, and research. Workshop attendees were employed by tribes, city or state agencies, NGOs, and universities. The workshop took place in Winter of 2021 was conducted virtually due to the COVID pandemic. We used key concepts and sentiments expressed at the workshop about stormwater solutions with language used by the Water 100 Project to create the final Q Set of 29 statements: 13 Green Infrastructure solutions, 8 Gray Infrastructure solutions, and 8 Source Control solutions (Table 1). These concepts and sentiments helped us narrow down our Q set from the 100 solutions listed in the Water 100 Project. The Q Set was developed and finalized prior to participant recruitment for the P Set.

We categorized our Q Set based on both U.S. Environmental Protection Agency (EPA) definitions, and sentiments from participants expressed in our workshop. Green Infrastructure definitions can vary, the EPA describes it as "the range of measures that use plant or soil systems, permeable pavement or other permeable surfaces or substrates, stormwater harvest and reuse, or landscaping to store, infiltrate, or evapotranspirate stormwater and reduce flows to sewer systems or to surface waters". Individuals who attended the stormwater workshop defined Green Infrastructure more narrowly, focusing on the plant and soil systems mentioned in the EPA description. Therefore, for the purpose of this study we chose to define green infrastructure as solutions that are nature-based (i.e., they incorporate plants and soil into their design.) This excludes solutions such as permeable pavement and stormwater harvesting which we defined as gray infrastructure, because they use composite concrete and rain barrels or cisterns, respectively.

P set

Following the guidance of Webler et al. (2009), we recruited participants for the Q study (the P set) who represented a variety of opinions and perspectives of those involved in stormwater management. Our participants consisted of stormwater experts which we defined as someone who is professionally involved in stormwater policy, science or management. The participant pool consisted of individuals in city, county, and state level of governments, environmental non-profit planners, and private sector green-stormwater infrastructure CEOs. 43% of our participants were government employees and 57% were employed by NGOs, offering us a wide breadth of opinions from main interest groups regarding stormwater management. Many of these individuals participated in county sponsored regional stormwater technical workshops, urban water solutions workshop, and other Puget Sound focused stormwater toxics workshops. We used stratified chain referral (Biernacki and Waldorf, 1981) to enlist participants. Twenty-one individuals participated in the study—a sample size within the typical range of Q studies that meaningfully captures a diversity of views (Watts and Stenner, 2005). Participation was voluntary and no money or goods were exchanged.

We performed the interviews and Q sort using virtual video conferencing. After receiving consent from 20 of the 21 participants, we recorded and later transcribed the interviews to capture explanations and the thought process used by participants during the exercise. Prior to conducting the Q sort, we asked each participant basic demographic questions and to self-identify as a scientist, practitioner, manager or something else. Participants were also asked to describe their area of stormwater expertise.

Q sort and interview

Next, we guided each participant through the Q sort using the online platform, Q Method Software. Participants were given the prompt, "Consider each of the stormwater solutions identified in each of the 29 statements and rank them as lower, high, and highest priority for implementation". We chose to use the language "lower, high, and highest" rather than "lower, medium, and high" because pilot Q sorts revealed that stormwater experts tended to prioritize solutions as low or high, and thus the use of "highest" forced individuals to identify those solutions that should receive highest priority. Experts first performed a preliminary sort where each of the stormwater solutions were ranked as lower, high, or highest priority. This was followed by a detailed sort where participants placed the pre-sorted statements onto a Q board where −4 represented their lowest ranked and +4 represented their highest ranked solutions (Figure 2). Statements placed in the same column were treated as the same rank (i.e., all statements in the −2 column were of the same prioritization) (Figure 2). Throughout the exercise, we prompted participants to explain their rationale for their sorting choices—the details of which were transcribed from the recordings.

Following the completion of the Q sort activity, we asked participants a series of questions to get them to articulate the ecological or human outcomes that they considered during their sort. We also asked whether there was anything especially challenging during this process. The average total duration of the Q sort activity and interview was 42 min.

Factor analysis

Q sorts ($n = 21$) were analyzed using the Q Method Software[3] (Lutfallah and Buchanan, 2019). We used Centroid Extraction (CE) factor analysis to reduce the data into factors which were then subjected to varimax rotation to associate each individual with only one factor. Based on the amount of variability explained, inspection of scree plots, eigenvalues, and the interpretability and theoretical significance of the factors (Brown et al., 1999; Watts and Stenner, 2005), we extracted three factors (Appendix 1: Supplementary Figure A1).

The factors represent idealized Q sorts reflecting the dominant discourse of the group. Each statement has a z-score which represents the weighted average of the scores that similar respondents gave to the statement (Zabala et al., 2018), as well as an integer that represents where the statement was placed in the idealized Q Sorts. Each individual participant also has a factor loading score indicating how closely they associated with the idealized Q sorts (Zabala et al., 2018). Our analysis also identified

3 qmethodsoftware.com

TABLE 1 Q Set statements, or stormwater solution/intervention, and associated solution classification.

	Statement	Solution type
1	Implement neighborhood stormwater facilities—utilizing nature-based stormwater retention and treatment systems.	Gray infrastructure
2	Implement blue-green roadside bio swales—channels with gently sloped sides that often utilize wetland type plants and rocks or other elements to slow water movement to allow for stormwater infiltration and treatment.	Green infrastructure
3	Research and implement permeable pavement—Removing unnecessary pavement or converting impervious surfaces to porous pavement.	Gray infrastructure
4	Implement green clean bridges—using private land adjacent to bridges and elevated highways to treat community road pollution at a district or neighborhood scale.	Green infrastructure
5	Implement green roofs/walls—Green walls- free standing walls for pollution barriers treatment facility, improves infiltration, source control, grabs pollutants from air before getting to paved surfaces.	Green infrastructure
6	Invest in and increase pipeline and outfall cleaning—A one-time cleaning of stormwater pipes provides a safe and contained means of removing years of chemical build-up.	Source control
7	Increase rainwater harvesting—from rooftops or paved surfaces.	Gray infrastructure
8	Increase street sweeping—Street sweeping vehicles can remove pollution, dust and debris that collects on streets before it enters stormwater systems or enters local waterways.	Gray infrastructure
9	Invest in urban soil building—restores these soils into a life-giving substrate and effective flood control urban asset, while microbes help to break down pollutants in runoff.	Green infrastructure
10	Invest in eelgrass restoration.	Green infrastructure
11	Invest in industrial area source control—Putting roofs over activities that have a high potential to result in polluted runoff.	Source control
12	Increase space for urban agriculture—Urban agriculture brings the source of food closer to the demand reducing the need for transportation and help generate rich soils that can replace impervious surfaces, providing infiltration and treatment of stormwater.	Green infrastructure
13	Research and invest in advanced brake pads/tires–Copper is used in vehicle brake pads to dissipate heat, however particles of copper in break dust poses significant health risks to aquatic life.	Source control
14	Increase voluntary buyouts – of repeatedly flooded properties to reduce future private property losses and injury while returning land to open space or wetland habitat.	Green infrastructure
15	Increase/implement Wastewater treatment wetlands—nature-based treatment approach reduces the use of chemicals and energy required for water treatment.	Green infrastructure
16	Increase the number of Stormwater ponds—ponds can be optimized to empty before storm events and reduce the burden on streams, combined sewer overflows, and offer initial filtration of water.	Gray infrastructure
17	Implement Groundwater recharge areas—engineered filtration systems using pipes and permeable gravels to help manage high spring/winter flows and store and then augment available water during the rest of the year.	Green infrastructure
18	Increase awareness of household best practices—for example Hazardous Waste Community Collection Sites.	Source control
19	Invest in Pharmaceutical management—proper disposal of household pharmaceutical products.	Source control
20	Implement Gray infrastructure—separating combined systems and emergency power backup and fail-safe equipment for combined sewage overflow control.	Gray infrastructure
21	Invest in Red List free materials – worst in class materials and chemicals that are too often used in the construction industry.	Source control
22	Increase Stream Restoration	Green infrastructure
23	Increase Tree planting—filtering inorganic nutrients and shading the stream.	Green infrastructure
24	Research and implement fish safe culverts.	Gray infrastructure
25	Increase use of Manure control and nutrient management	Source control
26	Research and implement Floodable parks and outdoor flex space.	Green infrastructure
27	Implement Soft shorelines—filter and slow runoff before reaching the ocean, help to restore natural processes in the Sound, and promote ecological exchange between terrestrial and aquatic systems.	Green infrastructure
28	Research and implement Regenerative fish farming, agriculture, carbon farming – Integrated multi-trophic aquaculture. Agriculture—holistic practices that build soil health, increase biodiversity, improve watersheds, and support ecosystem services. Carbon Farming – mimics the migratory behavior of large herbivores to build soil health and capture carbon in the soil using native grasses with deep root systems.	Source control
29	Implement Smart sensors—real-time and low-cost monitoring of water characteristics enabling improved management of water flow, identification and elimination of water pollution.	Gray infrastructure

distinguishing and consensus statements—statements that are statistically different ($p \leq 0.05$) or similar to other perspectives, respectively. We interpreted discourses by comparing the ranking of statements among factors, overlapping distinguishing and consensus statements among the factors, and qualitative analysis of the transcribed interviews.

Results

Of the 21 Q sorts, 18 loaded significantly onto one of the three factors, while three did not align with any of the emergent groupings. The three factors represent the common discourses held by the stormwater experts we interviewed, and we refer to these discourses as follows: (1) Green Action Now, (2) First Things First, and (3) Don't Forget the Urban Fringe. The discourses are described in the following sections and the distribution of statements for each idealized Q sort are shown in Figure 3. A complete list of statements with associated factor scores and consensus or distinguishing status can be found in Appendix 1.

Discourse analysis

Factor A: green action now

The first discourse, "Green Action Now", is defined by the prioritization of green infrastructure that not only mitigates stormwater toxicity and high flow rates, but also provides co-benefits to human health (Table 2, Figure 3). This group had a higher proportion of individuals employed by NGOs (62.5%) with more interdisciplinary jobs than the other groups (12.5% in "First Things First", 50% in "Don't Forget the Urban Fringe"). This group also prioritized more recently developed stormwater solutions and technologies (e.g., smart sensors, floodable parks, and neighborhood scale stormwater facilities) that the experts believed could have an immediate positive impact on stormwater metrics and human health once implemented. Participants in this discourse ranked some contaminant removal techniques, such as street sweeping, lower than other forms of contaminant removal, such as roadside bioswales, which provide multiple benefits (Hansen and Pauleit, 2014; Coutts and Hahn, 2015). One participant summed up the prioritization of multi-benefit solutions by this group as follows:

> *"I think it was multi-benefit outcomes, so one of the things my agency works on is the ecosystem recovery plan for Puget Sound which looks at habitats across all landscapes across all watersheds and looks at habitat recovery, human wellbeing, equity, and salmon recovery. So, as we do all that planning, and we are aware of the limited amount of resources there are available for restoration and recovery and protection. It's really trying to find those things that have that multi-benefit impact... something like stream restoration well that's everything, that's clean water, that's salmon, you know, healthy drinking water for people, that's connected habitat, so that ends up getting much higher [ranking]."*

This discourse also prioritized nature-based solutions that had positive effects on adjacent and downstream ecosystems, such as streams and eelgrass beds, rather than reducing toxics at their source. In addition, these nature-based stormwater solutions provide benefits to humans living in urban rather than rural areas. They prioritize solutions that will green cities and enhance the delivery of ecosystem services to city dwellers.

Factor B: first things first

The second discourse, "First Things First", is characterized by experts that favored solutions that address stormwater and associated contaminants at the source and have been demonstrated to be effective (Sutherland and Jelen, 1997; Pitt et al., 2004) (Table 3, Figure 3). This discourse had a higher proportion of Governmental employees (87.5%) than the other two discourses (37.5% in Green Action Now, 50% in Don't Forget the Urban Fringe). More often than the other two discourses, these individuals advocated addressing stormwater issues at their root before implementing new or potentially more expensive green solutions. This group reasoned that "end of the pipe" solutions, such as restoration efforts including stream restoration and soft shorelines, are ineffective unless toxic reduction and flow control are addressed first. The attitude of this discourse was concisely expressed by one participant who said the key question to ask is:

> *"What is the most important thing you can do with the resources that you've got?".*

This discourse focused on maximizing return on investment and minimizing uncertainty in the effectiveness of the solution and associated outcomes. They were more concerned with operations and maintenance costs for green infrastructure solutions that had not been heavily studied or widely implemented. For example, those in the First Things First discourse collectively ranked eelgrass restoration, wastewater treatment wetlands, and regenerative fish farming, agriculture and carbon farming low. While these solutions can mitigate the impacts of stormwater, their effect is indirect, and the return on investment is less clear than solutions that focus on controlling sources of stormwater toxicity. Instead, this group ranked street sweeping, smart sensors, and industrial area source control as their top three solutions. The stormwater management effectiveness of these solutions have been more rigorously studied than the previously listed nature-based solutions. This groups prioritization of gray infrastructure solutions shows the importance of reducing the uncertainty surrounding the effectiveness of the solutions. This preference is highlighted by a participant who stated that we should focus on the

> *"...known impact of actions versus researching innovative technologies. I think there's an urgency to doing this work and we ought to be doing the things that we know work..."*

This participant as well as the others in this group felt that we need to act now with the solutions we know work to address the stormwater problem in Puget Sound. Some participants did state that if nature-based solutions had adequate research showing their success and return on investment, they would have ranked them higher during the Q sort. Participants expressed that they valued green space and agreed that there were benefits to those solutions, but ultimately decided that known and immediately implementable solutions are the ones that we should be focusing on first.

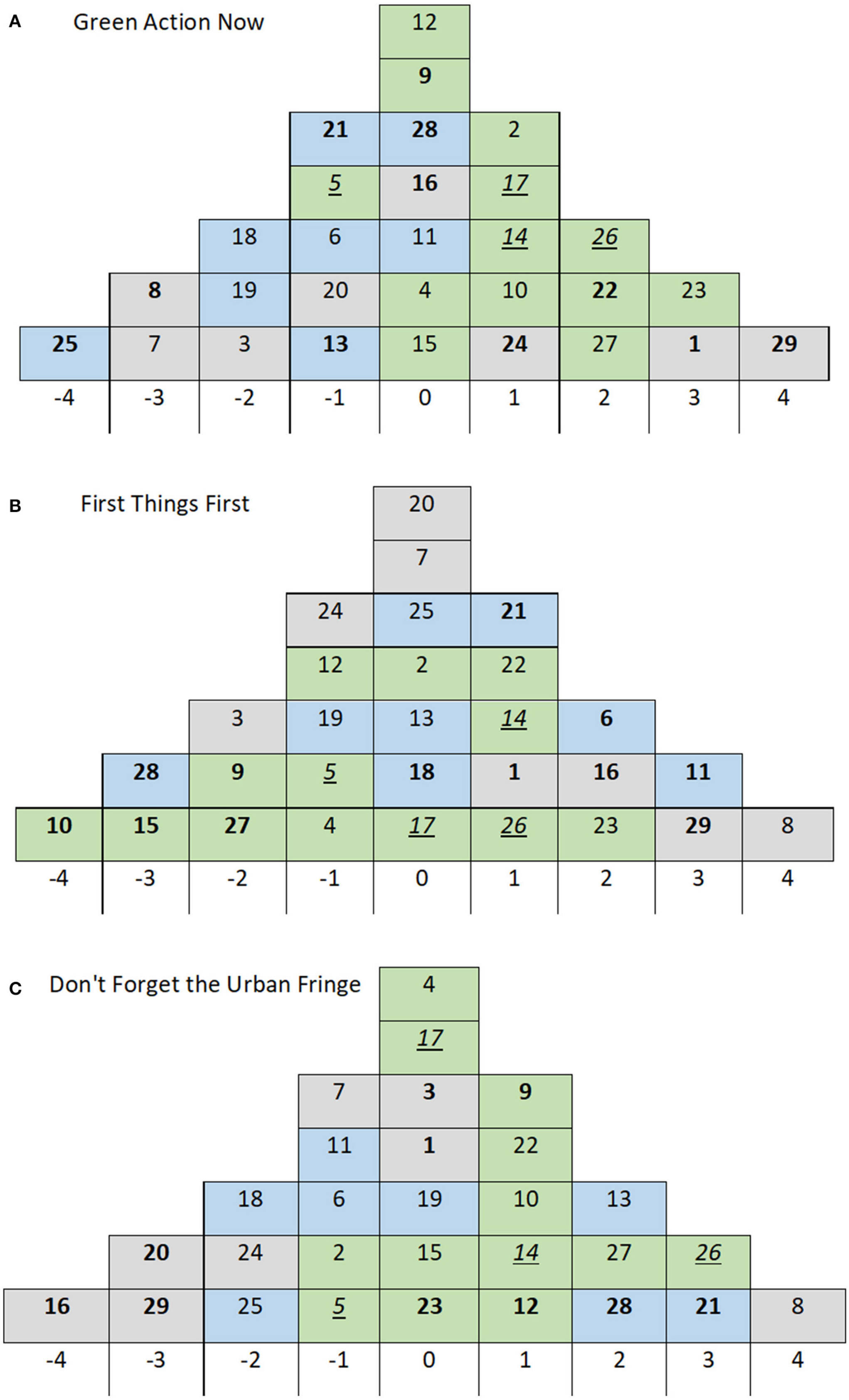

FIGURE 3
Distribution of statements for the three discourses: **(A)** Green Action Now, **(B)** First Things First, and **(C)** Don't Forget the Urban Fringe. Numbers in bold are distinguishing statements, numbers italicized and underlined are consensus statements. Green boxes represent green infrastructure solutions, gray boxes represent gray infrastructure solutions, and blue boxes represent source control solutions.

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TABLE 2 Group characteristics for factor A "green action now".

Name	Loading Q sorts	% variance explained	Eigenvalues	Work sectors
Green action now	8	22	4.6	Government, NGO, private sector
Top 3 priorities				Z-Scores
Implement smart sensors				2.101
Implement neighborhood stormwater facilities				1.483
Increase tree planting				1.472

TABLE 3 Group characteristics for factor B "first things first".

Name	Loading Q sorts	% variance explained	Eigenvalues	Work sectors
First things first	8	13	2.7	Government, NGO
Top 3 priorities				Z-Scores
Increase street sweeping				1.583
Implement smart sensors				1.506
Invest in industrial area source control				1.241

TABLE 4 Group characteristics for factor C "don't forget the urban fringe".

Name	Loading Q sorts	% variance explained	Eigenvalues	Work sectors
Don't forget the urban fringe	2	9	1.8	Government, NGO
Top 3 priorities				Z-Scores
Increase street sweeping				1.901
Invest in redlist free materials				1.825
Research and implement Regenerative fish farming, agriculture, carbon farming				1.216

Factor C: don't forget the urban fringe

Experts included in the "Don't Forget the Urban Fringe" discourse prioritized solutions with benefits that cross the urban-rural interface. Only two participants loaded onto this discourse but their views regarding the urban-rural divide were not reflected in any other discourse (Table 4, Figure 3). "Don't Forget the Urban Fringe" puts more emphasis on space for urban agriculture and urban soil health than "Green Action Now" and "First Things First". This group placed their focus on the relationship and connection between individuals living in urban areas and those living in rural areas. Stormwater infrastructure and solutions typically focus on urban areas due to the higher concentrations of contaminants and impervious surfaces. While "Don't Forget the Urban Fringe" still prioritized known contaminant removal practices that are effective in urban areas, such as street sweeping (top rank), they also prioritized source control methods that focused on rural areas, such as regenerative agriculture, higher than the other groups. When discussing the urban-rural divide, one participant in this group said,

> *"...when you talk about multiple benefits the cultural urban-rural divide is this really big scary issue that we've got nationally and for folks to start collaborating across that geography and for urban communities to understand rural communities better and vice versa and to work together and collaborate... There's this rural stormwater conversation that I think has a lot of potential to start bridging some of those cultural gaps that are tearing us apart."*

Experts in this group did not prioritize gray infrastructure as highly as the other two discourses – four of the bottom six solutions were in the gray infrastructure category. Smart sensors ranked near the bottom in the "Don't Forget the Urban Fringe" discourse, while it ranked first in the other two groups. This general lack of interest in gray infrastructure reflects a desire to protect the rural-urban fringe from expanding urbanization and greater coverage of impervious surfaces. This perspective is further highlighted by the prioritization of green infrastructure by this group.

Consensus views

In addition to identifying statements that distinguish each factor, we identified consensus statements—statements that were common across discourses. Out of the 29 statements, four were identified as statistical points of consensus among all three discourses (Table A3). These four consensus statements were all types of green infrastructure: Green roofs and walls, Increase voluntary buyouts of repeatedly flooded properties, Implement groundwater recharge areas, and Floodable parks and flex space

(Table 1, Table A3). Of the four consensus statements, Floodable parks and flex space ranked the highest while Green roofs and walls ranked the lowest (Figure 3, Table A3). It is important to note that all four consensus statements fell in the moderate priority range. No statements falling in the extreme ends of the Q Board were agreed upon across the three discourses.

Discussion

People are drawn to coastal cities for utility, leisure and necessity; however, when our cities were built, the health of coastal ecosystems was not often considered in urban planning and policies. As we urbanize our coast lines, we turn rainfall from a resource into a vehicle for pollution. While there is a diverse array of solutions to the stormwater problem, prioritization of one solution over another requires weighing multiple factors including cost, landscape and land availability, sources of pollution, and desired outcomes. We used Q methodology to investigate how a group of stormwater experts in Puget Sound prioritized stormwater solutions. Our research revealed three distinct discourses about stormwater solutions. Some experts focused on the need for green and nature-based solutions, while others highlighted regulation and known effective solutions, and still others emphasized the protection of the urban fringe with its unique opportunities and natural habitats. The diversity of perspectives illustrated by these discourses emerged from a group of experts working toward overlapping regional stormwater goals, revealing important differences in an effort to reduce conflict so that fruitful environmental management can proceed (Levin et al., 2021).

Urban versus rural solutions

An important focus of the emergent discourses was the distinct needs of urban and rural locales. Urban areas often dominate the discussion surrounding stormwater management because of the volume of surface runoff from impervious surfaces and larger populations compared to rural areas (Goonetilleke et al., 2005; Walsh et al., 2005; Cousins, 2017); however, there is still the need for stormwater solutions in rural areas. Priorities for stormwater management differ between urban and rural areas because of differences in land use practices (Paule-Mercado et al., 2017). In rural areas there is less impervious surface, lower population density and associated traffic pollution than urban regions (Messager et al., 2021), but rural, agricultural landscapes generate nutrients and pesticides in stormwater runoff that need to be addressed (Zhang and Zhang, 2011). These differences in pollution sources require different stormwater solutions. Solutions such as street sweeping that can effectively remove pollutants from roadways (e.g., Järlskog et al., 2020) do not have the same impact in rural areas compared to urban areas because there are fewer cars contributing to vehicle pollution. Thus, stormwater solutions favored by experts with urban expertise may not translate well to more rural areas. This point was emphasized by one of our interviewees:

> *"Doing [street sweeping] in highly urbanized areas where you're getting a lot of pollutants and pollutants are your main cause of impairments makes sense and has high value. [Doing it in] more rural agricultural areas, the value goes down depending upon the sources of pollutants and areas that are draining directly to a stream… Doing it on a country road that is surrounded by pastures, I'd really struggle to defend the value of that."*

In contrast to urban areas, rural areas focus on implementation of roadside bioswales to effectively treat roadway stormwater runoff (AECOM, 2020). While both street sweeping and roadside bioswales remove roadway contaminants, street sweeping focuses on vehicle related contaminants including PAHs, inhalable particles, and metals (Järlskog et al., 2020) while roadside vegetated bioswales have been utilized to remove pesticides in agricultural runoff (Cooper et al., 2004; Zhang and Zhang, 2011).

These examples highlight a common theme found in all three of our discourses; the specific stormwater intervention should be selected with specific goals in mind. There is no "one size fits all" solution that can be implemented in any situation to provide immediate and effective benefits to water quality. The context-specific nature of stormwater solutions can make prioritization decisions difficult, even for stormwater experts, and motivates the need to expose underlying assumptions and unconscious biases.

Solution trade offs

Our results reveal that even stormwater experts with many years of experience have difficulty choosing which solutions to prioritize. All stormwater solutions are important for different reasons and can be more or less efficient in different settings. The difficulty is in deciding which solutions to implement, where to implement it, and for what purpose or goal in mind. Source controls, such as pharmaceutical management and household best practices, prevent specific pollutants that have known adverse effects from entering the environment. However, while source control can be effective, study participants diverged in their opinions of this class of solutions because there are many different compounds stemming from different sources that vary widely in their impacts (Pitt et al., 1999; Davis et al., 2009). For instance, the tire rubber-derived compound 6PPD-quinone has been demonstrated to be acutely toxic in coho salmon (*O. kisutch*) (Tian et al., 2021) resulting in mortality of adult fish prior to spawning. However, the impact of this compound is heterogenous, and its toxicity may be less in some other species (e.g., McIntyre et al., 2021; Brinkmann et al., 2022). Given its ubiquity and toxicity (Tian et al., 2022), it is rational to remove this pollutant at its source; however, with more than 5,000 different unique pollutants entering Puget Sound annually (Peter et al., 2018; Saifur and Gardner, 2021; Tian et al., 2022), some of the participants in our study noted that it can be difficult to decide on which pollutant to focus on first and why.

How do managers decide between solutions that provide known ecological protection versus solutions that protect humans from environmental contaminant exposure and improve human wellbeing? In this study we found two divergent views on this question; "Green Action Now" prioritized stormwater solutions with nature-based components because they have co-benefits related to human health and environmental justice, while "First Things First" prioritized solutions that prevented contaminants with adverse ecological and human health effects from entering the environment. There is no objectively correct answer or viewpoint because both achieve stormwater quality improvements that provide ecological and human health benefits. The ways in which solutions go about achieving these outcomes is where the discourses surrounding this decision diverge.

One of the tensions that arose in our interviews of stormwater experts was between "proven" solutions such as gray infrastructure and source control vs. non-traditional, nature-based green infrastructure solutions. A typical perspective by experts who favored green infrastructure is expressed by this interviewee:

> *"…we are aware of the limited amount of resources available for restoration and recovery and protection. It's really trying to find those things that have that multi-benefit impact. Something like putting roofs over the industrial area of– certainly that does benefit multiple things but it's kind of you have to go down your logic chain a bit vs. something like stream restoration well that's everything, that's clean water, that's salmon you know healthy drinking water for people, that's connected habitat so that ends up [ranking] much higher."*

This participant and the "Green Action Now" group felt that green infrastructure solutions would result in the greatest overall ecosystem improvement because of the broad ranging benefits provided by natural systems and ecosystem services (Coutts and Hahn, 2015). Thus, the group felt that green infrastructure should be higher priority than solutions focusing specifically on the quality of the stormwater. These experts acknowledge that while solutions like industrial area source control are necessary and important to include in stormwater management plans, it is important to look beyond the immediate outcome and take into account objectives that may be further removed from the solution.

Another participant takes a different stance in favor of source control and gray infrastructure solutions stating:

> *"Nature based treatment approaches are great, but you know, at the end of the day you need something- and these are all engineered of course- that's engineered to do the job that you need it to do."*

This participant put more value on the knowledge that a solution is going to produce known and measurable results rather than risk implementing a nature-based solution that may not be as effective at doing the same thing for stormwater. Some stormwater managers believe that evidence supporting the efficiency of green infrastructure and its longevity is insufficient to advocate for its implementation (Copeland, 2014). The question therefore becomes, do the co-benefits associated with green infrastructure outweigh their potential inefficiencies or should gray infrastructures and source control solutions that produce known measurable effects without co-benefits be prioritized? More research comparing the stormwater mitigation capabilities of green infrastructure to traditional source control and gray infrastructure solutions could help to answer this question.

Multiple benefits of green infrastructure solutions

Policies for conservation, sustainability and land management often seek to achieve multiple objectives (e.g., Feng et al., 2004; Stagnari et al., 2017; Gardali et al., 2021). Multiple Benefit Conservation is an emerging approach in conservation that measures success by evaluating outcomes against multiple predetermined ecological and societal objectives (Gardali et al., 2021). Conservation efforts that promote and focus on multiple benefits can generate opportunities for inclusivity of those with diverse cultures, values and worldviews (Gould et al., 2018; Gardali et al., 2021). Categorizing stormwater solutions as Multiple Benefit Conservation is yet to be discussed in depth, but the inclusion of more holistic goals and outcomes for stormwater solutions is gaining traction (Wang et al., 2016; Jessup et al., 2021). Stormwater solutions that benefit receiving waters but also produce multiple benefits that address other ecological and human wellbeing outcomes may provide opportunities for additional federal, state, and local funding opportunities. Indeed, policies that benefit human health, or environmental justice may have larger budgets than those only promoting green infrastructure stormwater action (Copeland, 2014). Instead of focusing on stormwater as the center for the solution, what if these solutions are framed with the intent of promoting human and community wellbeing and have co-benefits to stormwater quality and quantity? This is an example of diversifying the funding and resource allocation for stormwater solutions to be implemented. Currently there is no federal funding specifically toward green infrastructure projects, typically smaller municipalities offer incentives for private landowners to implement green infrastructures (Kirschbaum and Lowry, 2012; Copeland, 2014). Our Q sort transcribed interviews revealed that financial and political feasibility are common factors in stormwater management decision making.

Green infrastructure solutions offer a plethora of benefits to human health, community strength, and climate change mitigation (Copeland, 2014; Jessup et al., 2021). Solutions that increase green space such as floodable parks, tree planting, and neighborhood stormwater facilities not only aid in stormwater filtration and carbon uptake, but they also aid in physical and mental human health (Mackenzie and McIntyre, 2018). Increased greening is also linked to improvements in standardized test scores, concentration in children with ADHD, hospital recovery time, and physical activity in residents (Mackenzie and McIntyre, 2018). Not only does green infrastructure implementation provide benefits to biodiversity, increased green space has also been linked to lowered crime rates and an increased sense of community (Dunn, 2010). One participant from "Green Action Now" stated the following about the link between green space and community strength:

> *"I think a lot about community-based solutions and those that will also incentivize the people who live in those areas to invest in it and to help manage it just because it benefits them,*

> *so you know things like urban soil, and rainwater harvesting. Especially things that end up contributing to community gardens, you know, that build incentive to work on it locally and support it locally."*

Studies have shown that neighborhoods with higher occupancy of people of color and lower socioeconomic status have less access to green space (Wolch et al., 2014; Voelkel et al., 2018), more exposure to environmental hazards and pollutants (Adamkiewicz et al., 2011; Tessum et al., 2019; Schell et al., 2020), and increased incidence of negative effects associated with urban heat islands (Jenerette et al., 2011; Jesdale et al., 2013; Mitchell and Chakraborty, 2015; Schell et al., 2020). Additionally, access to safe greenspace in low income and non-white communities is lower than in more affluent white neighborhoods (Day, 2006; Williams et al., 2020). There is potential to alleviate the uneven distribution of stressors to these disadvantaged communities by implementing nature-based green infrastructure stormwater solutions. Solutions such as floodable parks, green roofs and walls, and tree planting can increase green space, remove impervious surfaces and increase urban canopy cover thereby reducing the urban heat island effect and increasing carbon sequestration (Dunn, 2010; Foster et al., 2011; Block et al., 2012; Balany et al., 2020; Jessup et al., 2021). These solutions are designed to reduce stormwater peak flows and reduce contaminants by natural infiltration but can also alleviate climate-related inequalities to disadvantaged communities. The implementation of specific stormwater solutions that have a multiple benefit conservation framework can simultaneously benefit stormwater, human health, and promote environmental justice by providing underrepresented low income and non-white communities with the multiple benefits associated with green stormwater infrastructures.

Conclusions

Q studies, such as this one, should not be extrapolated since the small sample size and non-random participant selection mean perspectives found in this study may not encompass all perspectives and worldviews (Brown et al., 1999). However, Q methodology can highlight minority perspectives within a group (Watts and Stenner, 2005); this is useful in uplifting underrepresented voices in the stormwater realm. In our work this is particularly evident for those participants who linked solutions to human health and wellbeing. Future studies focused on individuals from different sectors (e.g., human health, urban planning, transportation) or other roles (e.g., policy makers and elected officials) may provide additional insight about prioritization of stormwater solutions. Such additional perspectives could help provide further insight about tradeoffs and the multiple benefits associated with green infrastructure (Andersson et al., 2014; Copeland, 2014; Coutts and Hahn, 2015).

Solving the stormwater problem is clearly a difficult task, with obstacles at all levels of implementation from designers and land managers to policy decision makers (Qiao et al., 2018). Embracing diverse discourses will help to spark discussion, clarify foundational areas of disagreement, and can sharpen focus on the shared goals for stormwater mitigation. While there are many perspectives and opinions on specific solutions, the ultimate goal for stormwater management is shared: equitably improve water quality for both nature and people. Given the rapid urbanization of the globe and the accompanying increase in stormwater contamination, the integrity of coastal ecosystems depends on learning from diverse perspectives, and then, as one participant urged, "doing something."

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by the University of Washington Human Subjects Division. The patients/participants provided their written informed consent to participate in this study.

Author contributions

PL, RL, DS, and JI designed and conceived the study. RL, PL, and DS performed analysis. RL, PL, DS, CM, and JI wrote and revised the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsc.2023.1134126/full#supplementary-material

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