Novel Nature-based Solutions for Climate Change Adaptation: Understanding and Expanding the Role of Community Perception and Everyday Landscape Experiences

by

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A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy
(Environment and Sustainability)
in the University of Michigan
2022

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Acknowledgements

First, I would like to thank my dissertation committee. I owe a debt of gratitude to my advisor, Prof. Joan Nassauer, for her guidance and support for this work. I appreciate her commitment to mentorship despite surprises and uncertainties during the pandemic. As a member of the Landscape Ecology, Perception, and Design Lab she leads, I also had the opportunity to participate in many projects that benefited this dissertation in various ways. I have learned much from her for contributing to positive landscape change through rigorous scholarship, enthusiasm, and hard work. I am also grateful to Prof. Stephanie Preston and Dr. Noah Webster for offering valuable insights from their disciplinary expertise in social sciences. I greatly appreciate Prof. Stephanie Preston's pertinent comments on my research and writing, as well as her insights for preparing manuscripts. I thank Dr. Noah Webster for his patient help and attention to detail in data analysis. I also want to thank Prof. Derek Van Berkel, who is always eager to listen and help. His advice and support greatly encouraged me to pursue my goals for this dissertation and a career in academia.

I must thank the landscape architecture faculty members at SEAS and guest studio instructors who have changed how I look at landscapes. Each of you has given of your time, energy, and expertise, and I am richer for it: Professor Emeritus Bob Grese, Associate Professor Emerita MaryCarol Hunter, Prof. Stan Jones, Prof. Mark Linquist, Kathy Poole, and Oliver Kiley.

I am so lucky to have my supportive families and friends. While they will not have a close read of this dissertation (with a 99% CI), I dedicate it to them. I thank my mother, Liying Yang, and my father, Zhenming Li, for their unconditional love and support. I thank my amazing grandmothers. The wisdom and perseverance I learned from them have helped me come through challenging times and will continue to guide me in the future. I greatly appreciate many friends and peers at SEAS and beyond. To Laís Petri, Akari Komura, Tiantong Gu, Yuanqiu Feng, Daniel Phillips, Chun Zheng, Sanaz Chamanara, and Divya Solomon, thank you for making the long and rough journey of pursuing a Ph.D. less lonely and more rewarding. To Shuyi Shen, Jiaolei Zhang, Yimei Feng, Dhara Mittal, Xiaomao Wang, Liwan Zhang, Ruoshui Liu, Hongling Lv, Rachel Leonard, Chen Zhang, Xinming Liu, and Runzi Wang, thank you for your thoughts, well-wishes, and being there when I needed a friend. Special thanks to Hao for his emotional support. He always reminds me that everything will be fine and that there is much to explore. I am proud of the world we have been building together and will continue to enrich.

This dissertation is impossible without support from the National Science Foundation: SCC-IRF 1737432, Overcoming Social and Technical Barriers for the Broad Adoption of Smart Stormwater Systems. My research and writing have also benefited greatly from funding from the Erb Family Foundation, the University of Michigan School for Environment and Sustainability, and the University of Michigan Rackham Graduate School. I hope my work proves that the money was well-spent.

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Abstract

Cities worldwide are exploring nature-based solutions (NBS) for climate change adaptation and sustainable development. To innovatively use nature to tackle societal challenges, thinking around NBS increasingly focuses on practices that integrate engineering and technological components with natural processes. Such novel NBS are especially relevant in urban contexts where land is limited and environmental stressors such as disturbance and pollution are present. This dissertation calls attention to a rarely considered implication of novel NBS: they may introduce noticeable yet unfamiliar changes and affect how people perceive everyday urban landscapes. These perceptions can influence local community members' well-being and support for NBS adoption. A deeper understanding of community members' perceptions of novel NBS can inform their design, implementation, and assessment to realize more reliable and sustained community co-benefits.

This dissertation presents three key chapters that are prepared as journal articles.

Chapter 2 identifies everyday landscape experiences as an essential cultural ecosystem service and connects them with the social impacts of and local communities' support for NBS. Focusing on NBS managed by smart systems, it speculates their potential negative influences on everyday urban nature experiences and how to address this issue in NBS development. This chapter lays the conceptual basis for this dissertation.

Chapter 3 investigates how microscale landscape elements may affect community members' perceptions of novel NBS through the example of retention ponds where smart systems manage stormwater storage. It examines both the effects of individual microscale elements on perceptions of smart ponds and the interacting effects of water level and other elements affected by design choices.

Chapter 4 applies "risk as feelings" to understand how people perceive visible stormwater dynamics in everyday urban landscapes, considering both uncontrolled localized flooding and intentional stormwater detention in novel vs. traditional NBS measures. It examines how experiences of localized flooding and other contextual and socio-demographic factors may affect perceived urban flood risks and the perceived safety of different NBS practices for stormwater management.

This dissertation connects different knowledge domains and employs quantitative social science methods to contribute to the understanding of public perception of novel NBS. It demonstrates that community members' perceptions can be affected by what is perceivable and manageable in the landscape, as well as their lived experiences and socio-demographic characteristics. This work has implications for the planning, design, and management of novel NBS to better address community members' experiences and gain broader societal support.

Chapter 1 Introduction

Nature-based solutions (NBS) broadly denotes actions that are "inspired by, supported by or copied from nature" (European Commission, 2015, p.5) to address complex societal challenges. They have gained tremendous attention in policy, practice, and research in recent years for potential application in climate change adaptation and sustainable development (Castellar et al., 2021; Hobbie & Grimm, 2020; Osaka et al., 2021; Seddon et al., 2020). Compared to previous concepts for managing ecosystems and natural processes to offer multiple social and ecological benefits, NBS embraces a much broader range of interventions and an explicit goal of addressing complex societal challenges (Dorst et al., 2019; Nesshover et al., 2017). While such a conceptualization has led to debates on what counts as "nature-based," it also allows transdisciplinary collaborations and invites "outside the box thinking" (Nesshover et al., 2017; Osaka et al., 2021).

Notably, there is a call for NBS supported by engineering and technological components that move away from a neat delineation between "green" and "grey", especially in urban contexts (Castellar et al., 2021; Eggermont et al., 2015; Hobbie & Grimm, 2020; Ossola & Lin, 2021; Seddon et al., 2020). Such integrated, novel solutions may provide targeted services in a smaller land footprint (Snep et al., 2020). They may also better cope with urban environmental stressors that are likely to be exacerbated by climate change, such as urban heat islands and concentration of stormwater runoff, than green or grey measures alone (Castellar et al., 2022; Ossola & Lin, 2021; Seddon et al., 2020). This dissertation defines novel NBS as practice employing innovative technology and engineering to actively manage plants, water, and soils in urban landscapes to address specific climate change impacts. Examples of novel NBS include street trees, green roofs, and stormwater retention ponds managed by "smart" systems (Goddard et al., 2021; Kerkez et al., 2016; Nitoslawski et al., 2019; Snep et al., 2020); and urban spaces that are specifically engineered to accommodate temporary inundation (Silva & Costa, 2018).

A topic that has received scant attention in the literature is how the general public and local community members perceive novel NBS practices proposed in everyday urban landscapes. Public perception is a critical dimension for NBS implementation and provision of co-benefits (Anderson & Renaud, 2021). People do not always welcome NBS in their communities, and resistance to adoption or tradeoffs among different benefits can occur when an NBS is perceived as unpleasant, unsafe, or harming sense of place (Frantzeskaki, 2019; Han & Kuhlicke, 2019; Silva & Costa, 2018).

This dissertation aims to address this knowledge gap, emphasizing the immediately perceivable landscape characteristics that can be affected by design, planning, and management. Landscape appearance offers a direct and meaningful way for people to experience and comprehend environmental phenomena and prompts affective responses, the rapid feelings of like or dislike, with implications for well-being and actions to change a landscape (Andersson et al., 2015; Dronova, 2019; Gobster et al., 2007).

Chapter 2 lays the conceptual foundation for this dissertation. It discusses the importance of pleasant everyday experiences of urban nature, connecting these experiences with the social impacts of novel NBS and local communities' support for their adoption. Drawing on various knowledge domains, including aesthetics, landscape architecture, environmental psychology, ecosystem services, and behavioral economics, this chapter describes what makes everyday experiences of urban nature pleasant and the potential well-being and social-cultural benefits of such experiences. It elucidates how landscape experiences depend on perceivable landscape characteristics that are only sometimes directly linked to environmental functions. Then it speculates how novel NBS that adopt smart management systems may noticeably and pervasively change urban landscapes, sometimes with unintended negative impacts on everyday urban nature experiences.

Building on ideas discussed in Chapter 2, Chapters 3 and 4 report two empirical studies on community members' perceptions of novel NBS, focusing on examples in urban stormwater management. These two studies analyzed data collected in a survey of three US cities to investigate how perceptions of novel NBS may relate to what is immediately perceivable in the landscape and community members' lived experiences and characteristics.

Chapter 3 examines the effects of microscale landscape elements on community members' perceptions of "smart" retention ponds. These ponds adopt smart systems that can manipulate water levels to enhance stormwater management functions. However, the different water level states may influence the pleasant experiences offered by ponds. At the same time, other microscale elements (i.e., land use context, basin slope, and surrounding plants) affected by landscape planning, design, and management choices may also influence perceptions of smart ponds. Therefore, three questions are addressed: 1) How does water level relate to smart ponds' perceived safety, attractiveness, and neatness? 2) How do other design elements relate to these perceptions? 3) Are the effects of water level on perceptions moderated by these design elements? Answers to these questions shed light on how the immediately noticeable characteristics of novel NBS, rather than their environmental functions, may affect community members' perceptions. They also offer insights into the landscape design and management of smart ponds and other NBS practices to better address community members' experiences.

Chapter 4 investigates how experiences of localized flooding and other contextual and socio-demographic factors may affect community members' perceptions of urban flood risks and the perceived safety of different NBS practices. Using "risk as feelings" as an organizing framework, it considers how people may associate standing water in everyday urban landscapes with negative affective responses based on their lived experiences, whether such visible stormwater dynamics result from overwhelmed drainage systems or intentional stormwater detention in NBS. Specifically, to examine NBS practices with novel vs. familiar appearance, it compares floodable sites, a novel NBS practice that temporarily inundates urban spaces under the storm condition, with retention ponds, a familiar NBS practice that holds an excess amount of water under the storm condition. This chapter provides evidence on how people may intuitively perceive risks related to urban flooding and its management as well as what factors may shape their perceptions. The findings are especially relevant to developing novel NBS to enhance urban flood resilience.

The successful development of NBS relies on positive public perception. This dissertation further elucidates that what people immediately notice and experience in their everyday landscape surroundings can shape their perceptions of NBS. Chapter 2 discusses the characteristics and value of everyday landscape experiences and their implications for ecosystem services and co-benefits that novel NBS aims to provide. Chapter 3 and Chapter 4 provide evidence on how noticeable yet unfamiliar dynamics introduced by novel NBS may undermine community members' experiences and what landscape and individual characteristics may also affect perceptions. Together, these three chapters help close the knowledge gap regarding how people perceive novel NBS that will look differently from more familiar types of urban greenspace. Findings from this research can also inform the design, planning, and management of novel NBS to align better what people value in everyday landscape experiences and goals for climate change adaptation.

While everyday landscapes may not appear significant if measured by intense experiences of beauty, awe, or novelty, they are a product of people "pragmatically using what they know to make a living, to take care of what they own, or to manage the quality of life in their communities" (Nassauer, 2012, p.223). Everyday landscapes constitute an essential context where human behaviors are 'encultured' and 'enearthed' (Schill et al., 2019). From sustaining verdant neighborhoods in a desert to objecting to offshore wind turbines, a deeper understanding of why people decide to act upon their surrounding environment in specific ways can be gained through the lens of everyday landscape experiences. Everyday landscapes thus form fertile ground for human behavioral shifts on an aggregate scale, including pervasively developing nature-based and integrated solutions for climate change adaptation.

References

Anderson, C. C., & Renaud, F. G. (2021). A review of public acceptance of nature-based solutions: The 'why', 'when', and 'how' of success for disaster risk reduction measures. *Ambio*, *50*(8), 1552–1573.

Andersson, E., Tengö, M., McPhearson, T., & Kremer, P. (2015). Cultural ecosystem services as a gateway for improving urban sustainability. *Ecosystem Services*, *12*, 165–168.

Castellar, J. A. C., Popartan, L. A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Säumel, I., Corominas, L., Comas, J., & Acuña, V. (2021). Nature-based solutions in the urban context: Terminology, classification and scoring for urban challenges and ecosystem services. *Science of The Total Environment*, *779*, 146237.

European Commission, Directorate-General for Research and Innovation. (2015). *Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-Naturing Cities: Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities'*: (full version), Publications Office.

Dorst, H., van der Jagt, A., Raven, R., & Runhaar, H. (2019). Urban greening through nature-based solutions–Key characteristics of an emerging concept. *Sustainable Cities and Society*, *49*, 101620.

Dronova, I. (2019). Landscape beauty: A wicked problem in sustainable ecosystem management? *Science of the Total Environment*, *688*, 584–591.

Eggermont, H., Balian, E., Azevedo, J. M. N., Beumer, V., Brodin, T., Claudet, J., Fady, B., Grube, M., Keune, H., Lamarque, P., Reuter, K., Smith, M., van Ham, C., Weisser, W. W., & Le Roux, X. (2015). Nature-based Solutions: New Influence for Environmental Management and Research in Europe. *GAIA - Ecological Perspectives for Science and Society*, *24*(4), 243–248.

Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy*, *93*, 101–111.

Gobster, P. H., Nassauer, J. I., Daniel, T. C., & Fry, G. (2007). The shared landscape: What does aesthetics have to do with ecology? *Landscape Ecology*, *22*(7), 959–972.

Goddard, M. A., Davies, Z. G., Guenat, S., Ferguson, M. J., Fisher, J. C., Akanni, A., Ahjokoski, T., Anderson, P. M. L., Angeoletto, F., Antoniou, C., Bates, A. J., Barkwith, A., Berland, A., Bouch, C. J., Rega-Brodsky, C. C., Byrne, L. B., Cameron, D., Canavan, R., Chapman, T., … Dallimer, M. (2021). A global horizon scan of the future impacts of robotics and autonomous systems on urban ecosystems. *Nature Ecology & Evolution*, *5*(2), 219–230.

Han, S., & Kuhlicke, C. (2019). Reducing Hydro-Meteorological Risk by Nature-Based Solutions: What Do We Know about People's Perceptions? *Water*, *11*(12), 2599.

Hobbie, S. E., & Grimm, N. B. (2020). Nature-based approaches to managing climate change impacts in cities. *Philosophical Transactions of the Royal Society B*, *375*(1794), 20190124.

Keeler, B. L., Hamel, P., McPhearson, T., Hamann, M. H., Donahue, M. L., Prado, K. A. M., Arkema, K. K., Bratman, G. N., Brauman, K. A., & Finlay, J. C. (2019). Social-ecological and technological factors moderate the value of urban nature. *Nature Sustainability*, *2*(1), 29–38.

Kerkez, B., Gruden, C., Lewis, M., Montestruque, L., Quigley, M., Wong, B., Bedig, A., Kertesz, R., Braun, T., Cadwalader, O., Poresky, A., & Pak, C. (2016). Smarter Stormwater Systems. *Science of The Total Environment*, *50*(14), 7267–7273.

Nassauer, J. I. (2012). Landscape as medium and method for synthesis in urban ecological design. *Landscape and Urban Planning, 106*(3), 221-229.

Nesshover, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., Haase, D., Jones-Walters, L., Keune, H., Kovacs, E., Krauze, K., Kulvik, M., Rey, F., van Dijk, J., Vistad, O. I., Wilkinson, M. E., & Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of The Total Environment*, *579*, 1215–1227.

Nitoslawski, S. A., Galle, N. J., Van Den Bosch, C. K., & Steenberg, J. W. N. (2019). Smarter ecosystems for smarter cities? A review of trends, technologies, and turning points for smart urban forestry. *Sustainable Cities and Society*, *51*, 101770.

Osaka, S., Bellamy, R., & Castree, N. (2021). Framing "nature-based" solutions to climate change. *WIREs Climate Change*, *12*(5).

Ossola, A., & Lin, B. B. (2021). Making nature-based solutions climate-ready for the 50 °C world. *Environmental Science & Policy*, *123*, 151–159.

Schill, C., Anderies, J. M., Lindahl, T., Folke, C., Polasky, S., Cárdenas, J. C., Crépin, A.-S., Janssen, M. A., Norberg, J., & Schlüter, M. (2019). A more dynamic understanding of human behaviour for the Anthropocene. *Nature Sustainability*, *2*(12), 1075–1082.

Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1794), 20190120.

Silva, M. M., & Costa, J. P. (2018). Urban floods and climate change adaptation: The potential of public space design when accommodating natural processes. *Water*, *10*(2), 180.

Snep, R. P., Voeten, J. G., Mol, G., & Van Hattum, T. (2020). Nature Based Solutions for Urban Resilience: A Distinction Between No-Tech, Low-Tech and High-Tech Solutions. *Frontiers in Environmental Science*, *8*.

Chapter 2 Technology in Support of Nature-Based Solutions Requires Understanding Everyday Experiences

Abstract

Nature-based solutions that incorporate "smart" technologies to enhance ecosystem services delivery may change the way people experience urban nature in their everyday lives. We lay out a conceptual basis for considering such changes and their social impacts. Cities are increasingly recognized as complex social-ecological-technological systems in which sustainability and climate resilience require environmental function to be paired with innovative technology. Smart technologies for real-time monitoring and autonomous operation promise innovations in urban landscape management. However, this promise can be fully realized only with adequate consideration of social impacts. Drawing on literature in landscape studies, environmental psychology, behavioral economics, public health, and aesthetics, we initiate a discussion connecting everyday experiences of urban nature with the social impacts of smart nature-based solutions and with local communities' support for their implementation. We describe what makes pleasant everyday experiences of urban nature and their related well-being benefits and social and cultural values, and we elucidate how these experiences depend on perceivable landscape characteristics that are only sometimes directly linked to environmental functions. Then, based on this literature, we speculate about how adopting smart technologies to manage nature-based solutions may noticeably change the landscape in novel ways and have unintended negative impacts on everyday experiences of urban nature. We illustrate this with an example: smart stormwater management of retention ponds. We conclude that the risk of degraded everyday experiences of nature must be considered and addressed in the development of smart nature-based solutions. If pleasant everyday experiences are ensured through appropriate design, smart nature-based solutions may not only realize societal co-benefits, but also gain acceptance and continued support from the public for the whole set of ecosystem services they deliver.

Keywords: aesthetics; cultural ecosystem services; green infrastructure; landscape design; urban greenspace

2.1 Introduction: technology in nature-based solutions and experiences of urban nature

Cities are increasingly understood as complex social-ecological-technological systems, with both environmental function and technology driving transformations necessary for sustainability (Grimm, Cook, Hale, & Iwaniec, 2015; McPhearson et al., 2021; Tan et al., 2020). Technological advances, notably in computation, information and communication technology, Internet of Things, and robotics and autonomous systems, have prompted exploration of how urban systems might be transformed into “smart cities” (Albino, Berardi, & Dangelico, 2015; Martin, Evans, & Karvonen, 2018). This includes adopting “smart” technologies to monitor and manage urban green infrastructure and nature-based solutions (NBS) to deliver ecosystem services in a more adaptive manner and help cities respond to climate change (Arts, van der Wal, & Adams, 2015; Goddard et al., 2021; Gulsrud et al., 2018; Nitoslawski, Galle, Van Den Bosch, & Steenberg, 2019). For example, experiments have been conducted with real-time monitoring of soil moisture and automated irrigation to decrease mortality of urban trees under extreme drought and heat (Nitoslawski et al., 2019), and with holistic regulation of urban stormwater flows at the watershed scale to mitigate flooding risk and improve water quality (Bartos, Wong, & Kerkez, 2018; Shishegar, Duchesne, Pelletier, & Ghorbani, 2021).

However, unlike adopting smart technologies to operate only built infrastructure, e.g., transportation or energy systems, incorporating smart technologies in urban ecosystems may cause noticeable landscape change, which may consequently change the way people experience urban nature. Such change is likely to be novel in appearance and ubiquitous in extent. Smart systems employ pervasive networks of computing devices to collect, process, and communicate data in real time. Although this can adapt relatively stable management regimes to be more responsive to climate change impacts, it may introduce unfamiliar dynamics into urban landscapes. For example, neighborhood parks and streets may have a novel appearance because they are employed to temporarily store stormwater (Lund et al., 2019). Even familiar landscape dynamics might change in frequency and magnitude: smart systems adopted in stormwater ponds can rapidly draw water levels up or down when controlling stormwater flow and storage (Mullapudi, Bartos, Wong, & Kerkez, 2017). To further enhance resulting regulating services, these landscape changes will often be systematic and ubiquitous, affecting both new and retrofitted urban infrastructure. This could change commonplace urban landscapes such as streets, neighborhoods, and greenspaces, affecting everyday experience of the urban landscape. Because of these likely novel and ubiquitous landscape effects, we raise the question of attendant qualitative changes in people's everyday experiences of urban nature. Will interventions informed by smart technologies bring urban residents pleasant nature experiences and greater well-being or degrade their experiences of urban nature?

In this paper, we hope to shed light on this question and offer conceptual insights about the social implications of incorporating smart technologies in nature-based solutions. A comprehensive understanding of how the uptake of smart technology might impact human–ecosystem interactions is not yet established (Goddard et al., 2021). To date, scattered discussions have identified both opportunities and unintended consequences including implications for stakeholder engagement, environmental justice, citizen empowerment, traditional biocultural and place-based knowledge, environmental education, environmental awareness, and nature contact, pointing to the urgent need for addressing long-term social considerations (Galle, Nitoslawski, & Pilla, 2019; Goddard et al., 2021; Gulsrud et al. 2018; Martin et al., 2018; Nitoslawski et al. 2019). We add to these propositions that how people experience urban nature in their everyday lives has fundamental social impacts, and we suggest that smart technologies might affect these experiences by noticeably changing urban landscapes in novel and unfamiliar ways.

To examine adoption of smart technologies in managing urban ecosystems, we focus specifically on "smart" nature-based solutions (sNBS), i.e., employing technological innovations broadly based on computation, information and communication technology, sensor networks, artificial intelligence, and robotics and autonomous systems to enhance certain ecosystem services. Others, in different topical contexts, have framed related terms and concepts such as digital conservation, green infrastructure automation, smart urban forests, or the "Internet of Nature" (Arts et al., 2015; Galle et al., 2019; Gulsrud et al. 2018; Nitoslawski et al., 2019). We focus on sNBS because NBS has been defined around a recognition of critical natural capital while also addressing societal challenges and providing co-benefits through innovative design and management of urban landscapes (Dorst, van der Jagt, Raven, & Runhaar, 2019; European Commission 2015; Nesshöver et al., 2017; Pauleit et al., 2017). Smart technologies are not inherently pro-environmental; if they are implemented to meet narrowly defined societal objectives, such technologies may actually undermine sustainability (Goddard et al., 2021; Gulsrud et al., 2018; McPhearson et al., 2021). For example, robotic lawn mowers may reduce human labor costs and encourage more extensive or frequent mowing in greenspaces, reinforcing norms for an intensively manicured landscape that may not support biodiversity. This paper focuses on scenarios where the adoption of smart technologies is explicitly intended to support sustainability and climate resilience.

In this paper, we use "urban nature" as an inclusive term to describe various outdoor biotic, e.g., plants, and abiotic, e.g., water, features that compose urban landscapes ranging from playing fields to nature reserves. Urban nature that city dwellers can regularly encounter in their everyday lives sometimes constitutes their only opportunity to interact with nature, and can be pivotal to well-being if associated with a feeling of pleasure (Andersson et al., 2014; Soga & Gaston 2016). The pandemic world makes this vividly apparent: many of us now know well the pleasure of walking down neighborhood streets while appreciating trees and home gardens, or even just getting some fresh air, and how much we yearn for such pleasure and the relief and relaxation it can offer (Corley et al., 2020; Kleinschroth & Kowarik 2020).

Strong evidence suggests that pleasant everyday experiences of urban nature can potentially enhance mental, physical, and social well-being (Bratman et al., 2019; Markevych et al., 2017,), motivate pro-environmental decision and behavior (Alcock et al., 2020), and nurture a general connectedness to nature that may contribute to more sustainable lifestyles and culture (Giusti, Wang, & Marriott, 2020; Lumber, Richardson, & Sheffield, 2017). In this sense, pleasant everyday experiences of urban nature constitute cultural ecosystem services that potentially provide well-being benefits co-produced by people and the biophysical domain (Andersson, Tengö, McPhearson, & Kremer, 2015; Daniel et al. 2012).

In contrast, landscapes that fail to provoke pleasant everyday experiences of urban nature may not support well-being, or may even result in "disservices" if the landscape is perceived as unsafe or unpleasant (Dronova, 2019, Keeler et al., 2019).

In the following sections, we conceptualize everyday experiences of urban nature and describe how cultural and social values underlie pleasant everyday experiences that contribute to well- being. We elucidate that increased provision of ecosystem services does not necessarily ensure pleasant everyday experiences. Rather, human experiences must be examined and managed differently from environmental processes. Based on these ideas, we discuss how smart technologies may noticeably change the landscape in novel and unfamiliar ways that affect everyday experiences of urban nature. To identify potential social challenges for sNBS development, we highlight how implementation of smart technologies could create trade-offs between pleasant everyday experiences and environmental benefits, if sNBS are designed without adequate consideration of human experiences. Last, we illustrate the implications of implementation choices with an example: stormwater retention ponds managed by a smart system. We argue that, as pervasive adoption of smart systems in urban ecosystems accelerates, the potential effects of sNBS on everyday experiences of nature must be anticipated and addressed.

2.2 Pleasant everyday experiences of urban nature have far-reaching benefits and values

Everyday experiences of urban nature are characterized by their regular and frequent occurrence, by the familiarity of the landscapes where they occur, and by their typical and ordinary experiential quality. What counts as everyday experiences of urban nature is context-dependent, but for many people, such experiences may take place in commonplace landscapes such as residential yards, streets, nearby parks, and the open spaces in between buildings. In contrast, more infrequent, unusual experiences of urban nature may be intentionally planned for and accessible only after travel, for example, in nature reserves, along shorelines, or in downtown parks and greenways that are distant from a neighborhood (Samuelsson et al., 2018).

We define "pleasant" experiences of urban nature as characterized by a feeling of pleasure in response to immediately noticeable characteristics of urban nature. Studies in aesthetics identify "immediately noticeable characteristics" as sensuous qualities and intrinsic properties of any object, phenomenon, and event, including landscapes (Eaton, 1997; Gobster, Nassauer, Daniel, & Fry, 2007; Saito, 2007). Pleasant experiences of urban nature involve all senses. For example, smell and sound contribute to landscape aesthetic experiences (Franco, Shanahan, & Fuller, 2017; Jeon & Jo, 2020). In this paper, we focus on visual characteristics to initiate discussion about how sNBS may affect everyday experiences of urban nature.

The feeling of pleasure ultimately involves affective processes in which the feeling of pleasure arises directly and rapidly; at least it feels so to people who are experiencing it (Kaplan, 1987). We recognize that pleasant experiences of the landscape involve complex underlying psychological processes that involve learning and cognition in varying ways and contexts. For example, many have described how environmental knowledge can and should affect pleasant landscape experiences (e.g., Carlson, 2010). Yet we also note that there is little evidence to suggest that the general public attentively acquires environmental knowledge, especially about complex or unseen environmental processes, and further, employs this knowledge when casually interacting with urban nature in everyday life. People more easily learn from firsthand experiences of environmental phenomena and the effects of learning are subject to the quality of their experiences (Kuang & Liao, 2020).

Further, pleasant everyday experiences of urban nature are structured in large part by social norms and cultural traditions. These experiences can elicit positive feelings by providing familiarity, stability, comfort, safety, and reassurance that are necessary and appreciated in daily life (Saito, 2017). Unlike aesthetic experiences associated with the wilderness or the scenic beauty of nature reserves, or the design of iconic public space projects, the feeling of pleasure arising from everyday experiences of urban nature may depend on more basic and commonly valued noticeable landscape qualities such as being orderly, under control, and well-kept (Nassauer, 1995a; Saito, 2007), or by a sense of place and attachment associated with a city or neighborhood (Dronova, 2019; Gobster et al., 2007). This does not mean that pleasant everyday experiences of urban nature are not associated with scenic or well-designed places, or that aesthetic characteristics of urban nature are not surprising or fascinating. Many have suggested that ephemeral nature phenomena, notably seasonal and meteorological events, offer wonderful aesthetic surprises and discoveries in everyday experience, and that such experiences can benefit well-being (Beery et al., 2017). We note the "effortless attention" engaged by such phenomena, and the familiar and ordinary surroundings that allow such pleasures of fascination and surprise to emerge.

Moreover, whether noticeable characteristics of urban nature can elicit pleasant everyday experiences is contingent upon shared expectations of how a landscape should look in a specific context (Gobster et al., 2007; Nassauer, 1992). The appearance of urban landscapes connotes social norms and cultural traditions, and is strongly shaped by vernacular practices that may be specific to a locale (Jackson, 1984; Nassauer, 1995b). A dense woodland may be perceived as pleasantly wild in a nature reserve but as forbiddingly wild in a neighborhood park. "Floodable" city parks and streets may be perceived as incompatible with public expectations that urban areas should stay dry and free from inundation (Liao, 2012). Further, meeting such expectations for landscape appearance has moral implications (Nassauer, 1995b; Saito, 2007). For example, uniform and weed-free lawns in American home yards are often associated with good neighbors who take pride in their homes and communities (Larson & Brumand, 2014; Nassauer, 1995b). In this sense, everyday experiences of urban nature can reflect normative relationships within human communities, and between people and nature, bearing relational values that broadly contribute to a good, meaningful life (Chan et al., 2016).

Everyday experiences of urban nature have been shown to make important contributions to the mental, physical, and social health of city dwellers, presenting critical opportunities for urban ecosystems to deliver well-being benefits. Accumulating evidence has linked potential well-being benefits to more exposure to urban nature (Bratman et al., 2019; Ekkel & de Vries, 2017; Markevych et al., 2017; Mossabir, Froggatt, & Milligan, 2021). For many people, indirect and incidental experiences of urban nature in everyday life—for example, views from homes, offices, and classrooms, or nature encounters during commuting—constitute the majority of regular nature experiences, occurring much more often than intentional visits to gardens and public parks (Cox et al., 2017). Pleasant experiences of urban nature may help reduce stress and restore attention fatigue (Bratman et al., 2019; Markevych et al., 2017). Further, the quality of everyday experiences may moderate well-being benefits, affecting the frequency of peoples' interactions with nature. For example, Beery et al. (2017) discussed how design choices in urban greenspaces, such as an appealing plant palette with species of different textures and seasonal color changes, may evoke pleasant experiences of urban nature, thereby "nudging" people to use greenspaces more often, and, as a result, receive potentially greater well-being benefits.

2.3 Increased provision of ecosystem services does not ensure pleasant everyday experiences

In everyday life, what people enjoy in or expect from a landscape may or may not align with its environmental benefits (Nassauer, 1992). On the fundamental level of human perception, environmental phenomena may occur at spatial scales where humans cannot directly perceive or notice them, whereas people experience urban nature through the immediately noticeable landscape characteristics of vegetation, water, topography, and built structures in the "perceptible realm" (Gobster et al., 2007). Pleasant experiences are related to environmental processes by landscape perception, which is shaped by social and cultural phenomena and arises from psychological processes rather than from scientific assessments of ecosystem services (Andersson et al., 2014; Gobster et al., 2007). Consequently, comparing ecosystem services with aesthetic experiences, “what is good may not look good” (Nassauer, 1995b, p.161).

Moreover, everyday experiences of urban nature are closely related to pragmatic considerations such as property management that can powerfully motivate people’s attitudes and behaviors toward the landscape (Saito, 2017). For example, vegetation maintenance norms for neighborhoods (Cook et al., 2012) and urban nature in views from a home (Sander & Haight, 2012) can be decisive factors for property value. Pro-environmental interventions in familiar landscapes, such as street trees, neighborhood stormwater controls and greenspaces, workplace green roofs, or home yards, are likely to be subject to normative community expectations for landscape appearance, as we discussed in the previous section. Consequently, people living in a neighborhood dominated by manicured lawns may apply lawn chemicals regardless of what they know about impacts on water quality. Also, residents may object to adding shrubs and grasses to neighborhood stormwater ponds, despite knowing related water quality benefits, because they worry that taller plants could block views to water and degrade aesthetic experiences (Monaghan et al., 2016).

The distinction between pleasant everyday experiences and environmental benefits has been noted in recent studies that address potential trade-offs between cultural and other ecosystem services and challenges for ensuring multiple benefits and values of urban nature (Dronova, 2019; Keeler et al. 2019). It also has implications for equity and environmental justice (Anguelovski et al., 2019; Dronova 2019). Landscape interventions that appear to degrade everyday experiences may be unwanted in many communities and sited in disempowered ones (Wilson, 2009). Even interventions that are developed to benefit communities where residents suffer from disproportionately distributed environmental stressors may not fully support health equity if they do not ensure pleasant everyday experiences (Woolf, 2017). For example, residents may object to planting of trees near their home because they perceive trees as a maintenance burden or a threat to personal safety, even though urban trees can moderate human experience of extreme heat (Carmichael a& McDonough, 2018; Nassauer, Webster, Sampson, & Li, 2021).

Improving the attractiveness of urban environments and enhancing human well-being are among the principal goals for developing NBS in cities (European Commission 2015; Raymond at el., 2017). These benefits should not be assumed when NBS are implemented, however. Rather, various impacts of NBS, both positive and negative, must be anticipated and investigated from social, ecological, and technological perspectives (Kabisch et al., 2016; Keeler et al., 2019; Nesshöver et al., 2017). This is particularly relevant for urban sNBS that employ smart technologies to pervasively intervene in environmental processes and functions in a novel manner. Unless sNBS are developed with attention to noticeable landscape characteristics, they may fail to offer pleasant everyday experiences and related well-being benefits. In contrast, if urban landscapes affected by sNBS are perceived as pleasant, they are more likely to be culturally sustainable: accepted and embraced over time (Dronova, 2019; Nassauer, 1997).

2.4 Smart NBS may pervasively and noticeably change urban landscapes in novel ways

Smart technologies may help cities more efficiently and effectively manage NBS to provide ecosystem services such as stormwater management and microclimate regulation in response to climate change (Goddard et al., 2021; Gulsrud et al., 2018; Nitoslawski et al., 2019). The very effectiveness of these technologies in enhancing the regulating ecosystem services of both new and retrofitted urban systems could lead to their rapid and ubiquitous adoption (Goddard et al., 2021). This could pervasively and noticeably change urban landscapes in ways that are novel and unfamiliar to residents, unintentionally affecting their everyday experiences of urban nature (Table 2.1) and creating public resistance to sNBS, even if smart systems enhance ecosystem services.

Table 2.1 ***Table 2.1*** *Examples of ways smart technologies might be employed in NBS and their potential effects on everyday experience.*
Note that these examples are speculative; we do not intend to review existing practices or predict future trends here.

		NBS and related smart technologies		
		Street trees/green roofs *Automated irrigation based on monitoring and forecasting data for soil moisture and weather*	**Stormwater controls** *Real-time monitoring and control of stormwater flow among retention/detention sites, including temporary storage in built areas*	**Urban greenspaces** *Restoration, conservation, or creation of high-quality habitats with minimal human influence*
Intended and unintended impacts	**Ecosystem services delivery objective**	Provisioning of water resources in arid cities	More effectively improve water quality and mitigate flood risk	Biodiversity support and supporting services
	Noticeable change in the landscape	Yellow and brown, or withering plants during hot and drought seasons	Temporarily flooded streets, lawns, or parking area; drained ponds with little water and revealed sediments	Unmaintained, spontaneous plants that look wild or "weedy"; presence of wildlife that elicits little affection, but unpleasantness or even danger (e.g., insects, snakes)
	Potential degradation in everyday experiences	Undermined "green" image and aesthetic value; perceived unhealthy or/and lack of care	Perceived flooding risk and safety hazard; messiness and unpleasant odor; undermined aesthetic value	Lack of legibility or culturally and socially familiar cues; decreased perceived safety; loss of opportunities for stewardship and taking care of "nature"

Smart technologies that allow real-time monitoring and control can transform NBS from passively relying on embodied environmental processes to actively interacting and intervening with these processes to deliver more ecosystem services. This may help NBS to better respond and adapt to constantly changing and increasingly unpredictable environmental stressors. However, at the same time, it may introduce noticeable and unfamiliar changes in landscapes dynamics. Although people often enjoy the beauty of ephemeral and regularly changing nature phenomena such as seasonal transitions, sunsets, and rainbows, “surprises” resulting from real-time control like flooded streets or drained ponds are not familiar landscape changes. Such novel dynamics in noticeable landscape characteristics may seem unrecognizable and incomprehensible, and challenge expectations and preferences for a relatively static look of the landscape in daily life (Mozingo, 1997).

Moreover, smart technologies may drive innovations in NBS design and management decision making, especially regarding maintenance. Smart systems enable previously unavailable forms of data collection and modeling, which promote autonomous systems that require less human agency. For example, rather than being determined by maintenance staffs’ experience and knowledge, irrigation of urban street trees and plants can be automated based on real-time monitoring as well as forecasting of soil moisture and weather events. Such an approach may promise more efficient water use and lower plant mortality, while potentially altering the noticeable characteristics of plants (e.g., leaf color, species evenness). There are even discussions about completely removing human perception and control from ecological restoration, and instead using robotics and autonomous systems instead to rewild landscapes and support biodiversity (Cantrell, Martin, & Ellis, 2017; Goddard et al., 2021).

Current scholarship about sNBS development may assume that people welcome accompanying landscape change because such change may make environmental processes and dynamics more apparent in urban landscapes. Or, that sufficient community engagement or new knowledge will easily nurture a positive attitude toward novel changes happening in their everyday landscape surroundings (Lund et al., 2019). However, strong community objections against pro-environmental landscape interventions, including constructed wetlands, wind turbines, and solar farms, have occurred in the past, and such objections have not been easily resolved by educating the community about their environmental benefits (Sánchez-Pantoja, Vidal, & Pastor, 2018; Vlami et al., 2020). Such interventions introducing noticeable unfamiliar processes or novel structures into the landscape were met with skepticism, disapproval, or fear by residents.

As we have described above, local residents may share expectations for everyday experiences of urban nature that derive from vernacular practices, social norms, and cultural traditions. Along with formal regulations and institutional characteristics of municipal government such as disciplinary silos (Nitoslawski et al., 2019), these expectations constitute the broader institutional context that prevents or encourages cities from incorporating smart technologies in NBS (Kiparsky, Sedlak, Thompson, & Truffer, 2013). We suggest that, where local communities are concerned about the unfamiliar appearance of landscapes affected by sNBS, institutional drag on adoption may be amplified, even to the point of preventing adoption of environmentally beneficial technologies.

Invisible or remote environmental functions or ecosystem services are unlikely to compensate for potential degradation of pleasant experiences, a key cultural ecosystem service, in sNBS. The human tendency for status quo bias and loss aversion implies a strong resistance to exchanging palpable loss of pleasant experiences for an intangible gain in environmental benefits (Samuelson & Zeckhauser 1988; Schill et al. 2019; Tversky &Kahneman, 1991). Sustainability and resilience challenges that sNBS address can seem so distant and unrelated to everyday life that people may lack motivation to change their attitude and behavior unless they have impactful personal experiences, for instance, experience with extreme events like wildfires and flooding (Kunreuther et al., 2014). "Humans are not optimization algorithms" (Schill et al., 2019, p.1076). Rather, people act within socio-cultural contexts, and under uncertainty tend not to favor decisions with long-term benefits. As a result, people may not favor sNBS that promote environmental functions and related ecosystem services if sNBS rob a landscape of socially and culturally familiar characteristics (Nassauer, 1995b) or make it appear confusingly illegible or even unsafe (Kaplan, 1987; Monzingo, 1997). Rather, sNBS that degrade everyday experiences of urban nature may be rejected or ultimately altered amid community backlash.

Urban landscapes affected by sNBS embody environmental processes and ecological functions. At the same time, they are also visible entities that different people, who may or may not have environmental knowledge, notice and respond to (Nassauer, 1992; Termorshuizen & Opdam 2009). Because the appearance of sNBS will affect people's everyday experiences of urban nature and, consequently, their support for sNBS, understanding everyday experiences of sNBS is necessary to the sustainable and equitable delivery of ecosystem services by sNBS.

2.5 An illustrative case: smart stormwater ponds in social-ecological-technological systems

We illustrate ideas discussed in previous sections by examining urban stormwater controls, a common focus in NBS (Keeler et al., 2019) that incorporates smart technologies in stormwater management. Advances in sensing, computation, and wireless communication technologies have inspired development of smart stormwater ponds that are monitored in real time and controlled across a watershed as a whole system (Bartos et al., 2018; Lund et al., 2019). Such a sNBS presents opportunities to regulate urban stormwater to more effectively and strategically address extreme precipitation events under climate change. Specifically, individual ponds at different locations can be remotely operated to drain water before storms to free up storage capacity and to retain water longer to reduce peak flows into stormwater infrastructure after storms (Bartos et al., 2018; Shishegar et al., 2021). However, these operations can introduce noticeable unfamiliar landscape change into residential neighborhoods, parks, or commercial plazas that contain ponds. For example, draining ponds before a storm may reveal accumulated sediment, and retaining more water for a longer time after storms may raise water levels, resembling flood conditions. These changes have implications for everyday experiences of urban nature.

Stormwater retention ponds characterized by perennial open water are widely recognized as an amenity that offers pleasant everyday experiences to nearby residents (Bastien, Arthur, & McLoughlin, 2012; Lähde, Khadka, Tahvonen, & Kokkonen, 2019). Surface water with good clarity is a highly preferred landscape feature and is often perceived as natural, beautiful, and relaxing (Herzog 1985, White et al. 2010) with potential for enhancing well-being (McDougall, Quilliam, Hanley, & Oliver, 2020; Völker & Kistemann 2011). Moreover, compared with other stormwater controls that do not have perennial open water, retention ponds may be associated with higher home prices nearby (Sohn et al. 2020). However, fluctuations of water level and surface extent caused by smart technologies could raise community concerns about safety, aesthetics, and public health. High water concerns may be related to localized flooding, drowning hazards, or physical contact with polluted water (Jarvie, Arthur, & Beevers, 2017; Williams et al., 2019). Low water concerns may be about revealed sediments looking dirty and unattractive (Cottet, Piégay, & Bornette, 2013; Herzog, 1985).

Drawing on work from our ongoing investigation of smart stormwater management in three American cities (Ann Arbor, Michigan; South Bend, Indiana; and Knoxville, Tennessee), we illustrate how smart technologies might affect everyday experiences associated with stormwater ponds. We developed digital visualizations of ponds for which water levels could be manipulated by smart stormwater management systems to adapt to extreme storm events, as shown in Figure 2.1. Then, we employed these visualizations in mail surveys of residents of each city. Respondents ($n = 977$) rated pond landscapes on a 5-point Likert scale on three dimensions of everyday experiences: attractiveness, neatness, and safety. Below, for the purposes of illustrating the implications of our argument for consideration of everyday experiences of sNBS, we report from our survey data.

__Figure 2.1__ An example of sNBS: a retention pond in a residential area that is managed by a smart stormwater system.
The pond was depicted with different water levels: 1) typical, 2) low, as if the pond were drained 24 hours before a storm to free up storage capacity, and 3) high, as if water were retained at a higher than the typical level for as long as 48 hours after a storm (visualizations by Yiiran Shen and Yuanqiu Feng).

Our data suggest that different pond water levels, manipulated by smart technology, were associated with different everyday experiences. For the pond shown in Figure 2.1, although ratings for attractiveness, neatness, and safety of both high and low water levels were lower than for the typical water level, the high water level tended to be rated as least safe, and the lower water condition tended to be rated as least attractive. Survey visualizations also included ponds located in parks and commercial areas, and with other shoreline configurations and plants. For another pond, which was depicted in a park and with wetland plants along the shore, everyday experiences associated with the high water level were similar to those associated with the typical water level, whereas the low water level was perceived as far less attractive and safe than the typical water level.

These experiences of high and low water levels, compared to the typical water level, are particularly relevant for considering how everyday experiences of a pond may relate to its stormwater regulation services. Both pre-storm draining and after-storm extra retention regulate flows, contributing to downstream water quality and flood prevention. Yet the appearance of the pond associated with each of these operations elicited different experiences. Knowing about residents' likely perceptions, local managers might opt to design or locate ponds differently. For instance, having a steeper basin that can contain increased volumes of water within a smaller surface extent, or draining ponds only within a few hours of an expected storm might reduce degradation of everyday landscape experience. Further, other design variables, like shoreline vegetation and land use context, might be used to further reduce degradation or even enhance everyday experiences of stormwater pond landscapes.

This example illustrates how provision of some ecosystem services by sNBS raises questions about the provision of what we assert is an essential cultural ecosystem service, pleasant everyday experiences of urban nature. At the "human scale," pleasant everyday experiences require attention to the noticeable characteristics of urban nature. These everyday experiences cannot be directly inferred from analyzing environmental functions that may depend on unperceivable environmental processes. Rather, sNBS must be intentionally designed to ensure pleasant everyday experiences. By gaining a better understanding of how people will perceive and experience urban landscapes affected by smart technologies, adoption of sNBS may avoid or at least minimize loss of cultural ecosystem services while it also eases the pathway for more widespread adoption.

2.6 Conclusion

Cities may increasingly employ smart technologies to facilitate how nature-based solutions are conceived and managed to address sustainability and climate resilience. However, how smart technologies may affect people's everyday experiences of urban nature also deserves attention. In this paper, we elucidate how smart NBS may degrade everyday experiences of urban nature when they introduce noticeable landscape change, particularly unfamiliar landscape dynamics. Loss of pleasant experiences of urban nature could undermine the well-being of residents and have negative impacts on community identity, property management, and health equity. Further, objections from residents who perceive unfamiliar changes as degrading their everyday experiences of local landscapes, coupled with managers' responses to these objections, may hinder the systematic adoption and long-term success of sNBS for delivering overall ecosystem services.

Pleasant everyday experiences of urban nature subtly connote basic human needs, deep-rooted cultural values, and powerful social norms. These connotations of landscape appearance can change: the history of landscape aesthetics suggests that both individuals and societies sometimes learn to attach these connotations to different landscape characteristics over time. Yet we caution that attempts to force change in deep-seated perceptual responses to everyday surroundings may have disappointing or damaging results. Although it is possible that more knowledge of environmental functions underlying unfamiliar landscape changes may lead to greater acceptance, we assert that people are more likely to appreciate unfamiliar landscape characteristics through lived experiences that they find pleasant and valuable. Pleasant everyday experiences should be evident for sNBS to gain societal legitimacy (Harris-Lovett et al. 2015) or for evolution to a new aesthetic norm for highly functioning urban nature (Meyer, 2008; Nassauer, 1992). By directly connecting people to environmental phenomena in their daily life, pleasant everyday experiences of urban nature may serve as a nudge to help accelerate the societal transformation urgently needed to respond to environmental crises, guiding people to accept and support sNBS that they might otherwise reject (Beery et al., 2017; Nassauer, 2011).

For sNBS to provide both pleasant everyday experiences and other ecosystem services, consideration of the relationship between their noticeable characteristics and local residents' landscape perceptions must be integral to their development. This demands simultaneous attention to both the noticeable characteristics of sNBS that are inherent to their environmental functions and to noticeable characteristics that make for pleasant everyday experiences. Recognizing pleasant everyday experiences of urban nature as cultural ecosystem services that occur at the human scale should suggest that design, evaluation, and assessment of sNBS must include these dimensions (Raymond et al., 2017). Further, contradictions between these dimensions may sometimes be amenable to resolution by design and planning. Specifically, co-design and co-creation processes that engage researchers and design professionals with local residents may help to integrate expert knowledge and local perspectives (Frantzeskaki, 2019; Kabisch et al., 2016).

Will the adoption of smart technologies in NBS offer pleasant everyday experiences of urban nature and open new pathways to enhance the well-being of urban residents? We conclude that sNBS may noticeably change commonplace urban landscapes in novel and unfamiliar ways, leading to unintended loss of pleasant everyday experiences. Attention to such potential impacts of noticeable landscape characteristics—anticipating community resistance and avoiding harm—may be essential to the success of smart sustainability efforts. Furthermore, because everyday experiences of urban nature can powerfully motivate attitudes and behavior, sNBS that are designed to ensure pleasant experiences could elevate public appreciation for landscape change that supports ecosystem services. Effective sNBS intervention will require holistic understanding of social-ecological-technological interactions. Along with investigation of the technological, ecological, and governance dimensions of sNBS, it is critical to address how sNBS may affect everyday experiences of urban nature. These experiences have far-reaching implications for well-being and behavior, and can fundamentally affect societal response to innovation. Managing urban landscapes to be cherished and celebrated in everyday life is not trivial or extraneous to building sustainable and resilient cities. Rather, it suggests a pathway to such a future.

References

Albino, V., Berardi, U., & Dangelico, R. M. (2015). Smart cities: Definitions, dimensions, performance, and initiatives. *Journal of urban technology*, 22(1), 3-21.

Alcock, I., White, M. P., Pahl, S., Duarte-Davidson, R., & Fleming, L. E. (2020). Associations between pro-environmental behaviour and neighbourhood nature, nature visit frequency and nature appreciation: Evidence from a nationally representative survey in England. *Environment international*, 136, 105441.

Andersson, E., Barthel, S., Borgström, S., Colding, J., Elmqvist, T., Folke, C., & Gren, Å. (2014). Reconnecting cities to the biosphere: stewardship of green infrastructure and urban ecosystem services. *Ambio*, 43(4), 445-453.

Andersson, E., Tengö, M., McPhearson, T., & Kremer, P. (2015). Cultural ecosystem services as a gateway for improving urban sustainability. *Ecosystem Services*, 12, 165-168.

Anguelovski, I., Connolly, J. J. T., Garcia-Lamarca, M., Cole, H., & Pearsall, H. (2019). New scholarly pathways on green gentrification: What does the urban 'green turn'mean and where is it going? *Progress in human geography*, 43(6), 1064-1086.

Arts, K., van der Wal, R., & Adams, W. M. (2015). Digital technology and the conservation of nature. *Ambio*, 44(4), 661-673.

Bartos, M., Wong, B., & Kerkez, B. (2018). Open storm: a complete framework for sensing and control of urban watersheds. *Environmental Science: Water Research & Technology*, 4(3), 346-358.

Bastien, N. R. P., Arthur, S., & McLoughlin, M. J. (2012). Valuing amenity: public perceptions of sustainable drainage systems ponds. *Water and Environment Journal*, 26(1), 19-29.

Beery, T. H., Raymond, C. M., Kytta, M., Olafsson, A. S., Plieninger, T., Sandberg, M., . . . Jonsson, K. I. (2017). Fostering incidental experiences of nature through green infrastructure planning. *Ambio*, 46(7), 717-730.

Bratman, G. N., Anderson, C. B., Berman, M. G., Cochran, B., De Vries, S., Flanders, J., . . . Hartig, T. (2019). Nature and mental health: An ecosystem service perspective. *Science advances*, 5(7), eaax0903.

Cantrell, B., Martin, L. J., & Ellis, E. C. (2017). Designing autonomy: Opportunities for new wildness in the Anthropocene. *Trends in Ecology & Evolution*, 32(3), 156-166.

Carlson, A. (2010). Contemporary environmental aesthetics and the requirements of environmentalism. *Environmental Values*, 19(3), 289-314.

Carmichael, C. E., & McDonough, M. H. (2019). Community stories: Explaining resistance to street tree-planting programs in Detroit, Michigan, USA. *Society & Natural Resources*, 32(5), 588-605.

Chan, K. M., Balvanera, P., Benessaiah, K., Chapman, M., Díaz, S., Gómez-Baggethun, E., . . . Klain, S. (2016). Opinion: Why protect nature? Rethinking values and the environment. *Proceedings of the National Academy of Sciences*, 113(6), 1462-1465.

Cook, E. M., Hall, S. J., & Larson, K. L. (2012). Residential landscapes as social-ecological systems: a synthesis of multi-scalar interactions between people and their home environment. *Urban Ecosystems*, 15(1), 19-52.

Corley, J., Okely, J. A., Taylor, A. M., Page, D., Welstead, M., Skarabela, B., . . . Russ, T. C. (2020). Home garden use during COVID-19: associations with physical and mental wellbeing in older adults. *Journal of Environmental Psychology*, 101545.
Cottet, M., Piégay, H., & Bornette, G. (2013). Does human perception of wetland aesthetics and healthiness relate to ecological functioning? *Journal of Environmental Management*, 128, 1012-1022.
Cox, D. T. C., Hudson, H. L., Shanahan, D. F., Fuller, R. A., & Gaston, K. J. (2017). The rarity of direct experiences of nature in an urban population. *Landscape and Urban Planning*, 160, 79-84.
Daniel, T. C., Muhar, A., Arnberger, A., Aznar, O., Boyd, J. W., Chan, K. M. A., . . . von der Dunk, A. (2012). Contributions of cultural services to the ecosystem services agenda. *Proceedings of the National Academy of Sciences of the United States of America*, 109(23), 8812-8819.
Dorst, H., van der Jagt, A., Raven, R., & Runhaar, H. (2019). Urban greening through nature-based solutions–Key characteristics of an emerging concept. *Sustainable Cities and Society*, 49, 101620.
Dronova, I. (2019). Landscape beauty: A wicked problem in sustainable ecosystem management? *Science of the Total Environment*, 688, 584-591.
Eaton, M. M. (1997). The beauty that requires health. In J. I. Nassauer (Ed.), *Placing nature: Culture and landscape ecology* (pp. 85-106). Washington, DC: Island Press.
Ekkel, E. D., & de Vries, S. (2017). Nearby green space and human health: Evaluating accessibility metrics. *Landscape and Urban Planning*, 157, 214-220.
European Commission, Directorate-General for Research and Innovation. (2015). *Towards an EU Research and Innovation Policy Agenda for Nature-Based Solutions & Re-Naturing Cities: Final Report of the Horizon 2020 Expert Group on 'Nature-Based Solutions and Re-Naturing Cities'*: (full version), Publications Office.
Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy*, 93, 101-111.
Franco, L. S., Shanahan, D. F., & Fuller, R. A. (2017). A review of the benefits of nature experiences: more than meets the eye. *International journal of environmental research and public health*, 14(8), 864.
Galle, N. J., Nitoslawski, S. A., & Pilla, F. (2019). The Internet of Nature: How taking nature online can shape urban ecosystems. *The Anthropocene Review*, 6(3), 279-287.
Giusti, M., Wang, W., & Marriott, T. (2020). Connecting land. A transdisciplinary workshop to envision a nature-connecting human habitat. *Cities & Health*, 1-8.
Gobster, P. H., Nassauer, J. I., Daniel, T. C., & Fry, G. (2007). The shared landscape: what does aesthetics have to do with ecology? *Landscape Ecology*, 22(7), 959-972.
Goddard, M. A., Davies, Z. G., Guenat, S., Ferguson, M. J., Fisher, J. C., Akanni, A., . . . Dallimer, M. (2021). A global horizon scan of the future impacts of robotics and autonomous systems on urban ecosystems. *Nature Ecology & Evolution*, 5(2), 219-230.
Grimm, N. B., Cook, E. M., Hale, R. L., & Iwaniec, D. M. (2015). A broader framing of ecosystem services in cities: Benefits and challenges of built, natural or hybrid system function. In *The Routledge handbook of urbanization and global environmental change* (pp. 227-236). Routledge.

Gulsrud, N. M., Raymond, C. M., Rutt, R. L., Olafsson, A. S., Plieninger, T., Sandberg, M., . . . Jönsson, K. I. (2018). 'Rage against the machine'? The opportunities and risks concerning the automation of urban green infrastructure. *Landscape and Urban Planning*, 180, 85-92.
Harris-Lovett, S. R., Binz, C., Sedlak, D. L., Kiparsky, M., & Truffer, B. (2015). Beyond User Acceptance: A Legitimacy Framework for Potable Water Reuse in California. *Environmental Science & Technology*, 49(13), 7552-7561.
Herzog, T. R. (1985). A cognitive analysis of preference for waterscapes. *Journal of Environmental Psychology*, 5(3), 225-241.
Jackson, J. B. (1984). *Discovering the vernacular landscape*. Yale University Press.
Jarvie, J., Arthur, S., & Beevers, L. (2017). Valuing multiple benefits, and the public perception of SUDS ponds. *Water*, 9(2), 128.
Jeon, J. Y., & Jo, H. I. (2020). Effects of audio-visual interactions on soundscape and landscape perception and their influence on satisfaction with the urban environment. *Building and Environment*, 169, 106544.
Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., . . . Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society*, 21(2).
Kaplan, S. (1987). Aesthetics, affect, and cognition: Environmental preference from an evolutionary perspective. *Environment and behavior*, 19(1), 3-32.
Keeler, B. L., Hamel, P., McPhearson, T., Hamann, M. H., Donahue, M. L., Prado, K. A. M., . . . Finlay, J. C. (2019). Social-ecological and technological factors moderate the value of urban nature. *Nature Sustainability*, 2(1), 29-38.
Kiparsky, M., Sedlak, D. L., Thompson, B. H., & Truffer, B. (2013). The Innovation Deficit in Urban Water: The Need for an Integrated Perspective on Institutions, Organizations, and Technology. *Environmental Engineering Science*, 30(8), 395-408.
Kleinschroth, F., & Kowarik, I. (2020). COVID-19 crisis demonstrates the urgent need for urban greenspaces. *Frontiers in Ecology and the Environment*, 18(6), 318.
Kuang, D., & Liao, K.-H. (2020). Learning from Floods: Linking flood experience and flood resilience. *Journal of Environmental Management*, 271, 111025.
Kunreuther, H., Gupta, S., Bosetti, V., Cooke, R., Dutt, V., Ha-Duong, M., . . . Shittu, E. (2014). Integrated risk and uncertainty assessment of climate change response policies. In *Climate Change 2014: Mitigation of Climate Change: Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 151-206). Cambridge University Press.
Lähde, E., Khadka, A., Tahvonen, O., & Kokkonen, T. (2019). Can we really have it all?—Designing multifunctionality with sustainable urban drainage system elements. *Sustainability*, 11(7), 1854.
Liao, K.-H. (2012). A theory on urban resilience to floods—a basis for alternative planning practices. *Ecology and Society*, 17(4).
Lumber, R., Richardson, M., & Sheffield, D. (2017). Beyond knowing nature: Contact, emotion, compassion, meaning, and beauty are pathways to nature connection. *PloS one*, 12(5), e0177186.

Lund, N. S. V., Borup, M., Madsen, H., Mark, O., Arnbjerg-Nielsen, K., & Mikkelsen, P. S. (2019). Integrated stormwater inflow control for sewers and green structures in urban landscapes. *Nature Sustainability*, 2(11), 1003-1010.

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., . . . Nieuwenhuijsen, M. J. (2017). Exploring pathways linking greenspace to health: theoretical and methodological guidance. *Environmental Research*, 158, 301-317.

Martin, C. J., Evans, J., & Karvonen, A. (2018). Smart and sustainable? Five tensions in the visions and practices of the smart-sustainable city in Europe and North America. *Technological Forecasting and Social Change*, 133, 269-278.

McDougall, C. W., Quilliam, R. S., Hanley, N., & Oliver, D. M. (2020). Freshwater blue space and population health: An emerging research agenda. *Science of the Total Environment*, 737, 140196.

McPhearson, T., M. Raymond, C., Gulsrud, N., Albert, C., Coles, N., Fagerholm, N., . . . Vierikko, K. (2021). Radical changes are needed for transformations to a good Anthropocene. *npj Urban Sustainability*, 1(1).

Meyer, E. K. (2008). Sustaining beauty. The performance of appearance. *Journal of Landscape Architecture*, 3(1), 6-23.

Monaghan, P., Hu, S., Hansen, G., Ott, E., Nealis, C., & Morera, M. (2016). Balancing the Ecological Function of Residential Stormwater Ponds with Homeowner Landscaping Practices. *Environmental Management*, 58(5), 843-856.

Mossabir, R., Froggatt, K., & Milligan, C. (2021). Therapeutic Landscape experiences of everyday geographies within the wider community: A scoping review. *Social Science & Medicine*, 113980.

Mozingo, L. A. (1997). The aesthetics of ecological design: seeing science as culture. *Landscape journal*, 16(1), 46-59.

Mullapudi, A., Bartos, M., Wong, B., & Kerkez, B. (2018). Shaping Streamflow Using a Real-Time Stormwater Control Network. *Sensors*, 18(7), 2259.

Nassauer, J. I. (1992). The appearance of ecological systems as a matter of policy. *Landscape Ecology*, 6(4), 239-250.

Nassauer, J. I. (1995a). Culture and changing landscape structure. *Landscape Ecology*, 10(4), 229-237.

Nassauer, J. I. (1995b). Messy ecosystems, orderly frames. *Landscape journal*, 14(2), 161-170.

Nassauer, J. I. (1997). Cultural sustainability: aligning aesthetics and ecology. In J. I. Nassauer (Ed.), *Placing nature: Culture and landscape ecology* (pp. 65-83). Washington, DC: Island Press.

Nassauer, J. I. (2011). Care and stewardship: From home to planet. *Landscape and Urban Planning*, 100(4), 321-323.

Nassauer, J. I., Webster, N. J., Sampson, N., & Li, J. (2021). Care and safety in neighborhood preferences for vacant lot greenspace in legacy cities. *Landscape and Urban Planning*, 214, 104156.

Nesshöver, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., . . . Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Science of the Total Environment*, 579, 1215-1227.

Nitoslawski, S. A., Galle, N. J., Van Den Bosch, C. K., & Steenberg, J. W. N. (2019). Smarter ecosystems for smarter cities? A review of trends, technologies, and turning points for smart urban forestry. *Sustainable Cities and Society*, 51, 101770.

Pauleit, S., Zölch, T., Hansen, R., Randrup, T. B., & Konijnendijk van den Bosch, C. (2017). Nature-based solutions and climate change–four shades of green. In *Nature-Based solutions to climate change adaptation in urban areas* (pp. 29-49). Springer, Cham.

Raymond, C. M., Breil, M., Nita, M. R., Kabisch, N., de Bel, M., Enzi, V., . . . Cardinaletti, M. (2017). *An impact evaluation framework to support planning and evaluation of nature-based solutions projects*. Report prepared by the EKLIPSE Expert Working Group on Nature-Based Solutions to Promote Climate Resilience in Urban Areas. Centre for Ecology and Hydrology.

Saito, Y. (2007). *Everyday aesthetics*. Oxford University Press.

Saito, Y. (2017). *Aesthetics of the familiar: Everyday life and world-making*. Oxford University Press.

Samuelson, W., & Zeckhauser, R. (1988). Status quo bias in decision making. *Journal of risk and uncertainty*, 1(1), 7-59.

Samuelsson, K., Giusti, M., Peterson, G. D., Legeby, A., Brandt, S. A., & Barthel, S. (2018). Impact of environment on people's everyday experiences in Stockholm. *Landscape and Urban Planning*, 171, 7-17.

Sánchez-Pantoja, N., Vidal, R., & Pastor, M. C. (2018). Aesthetic impact of solar energy systems. *Renewable and Sustainable Energy Reviews*, 98, 227-238.

Schill, C., Anderies, J. M., Lindahl, T., Folke, C., Polasky, S., Cárdenas, J. C., . . . Schlüter, M. (2019). A more dynamic understanding of human behaviour for the Anthropocene. *Nature Sustainability*, 2(12), 1075-1082.

Sander, H. A., & Haight, R. G. (2012). Estimating the economic value of cultural ecosystem services in an urbanizing area using hedonic pricing. *Journal of environmental management*, 113, 194-205.

Shishegar, S., Duchesne, S., Pelletier, G., & Ghorbani, R. (2021). A smart predictive framework for system-level stormwater management optimization. *Journal of Environmental Management*, 278(Pt 1), 111505.

Soga, M., & Gaston, K. J. (2016). Extinction of experience: the loss of human–nature interactions. *Frontiers in Ecology and the Environment*, 14(2), 94-101.

Sohn, W., Kim, H. W., Kim, J.-H., & Li, M.-H. (2020). The capitalized amenity of green infrastructure in single-family housing values: An application of the spatial hedonic pricing method. *Urban Forestry & Urban Greening*, 126643.

Tan, P. Y., Zhang, J., Masoudi, M., Alemu, J. B., Edwards, P. J., Grêt-Regamey, A., . . . Wong, L. W. (2020). A conceptual framework to untangle the concept of urban ecosystem services. *Landscape and Urban Planning*, 200, 103837.

Termorshuizen, J. W., & Opdam, P. (2009). Landscape services as a bridge between landscape ecology and sustainable development. *Landscape Ecology*, 24(8), 1037-1052.

Tversky, A., & Kahneman, D. (1991). Loss aversion in riskless choice: A reference-dependent model. *Quarterly Journal of Economics*, 106(4), 1039-1061.

Vlami, V., Danek, J., Zogaris, S., Gallou, E., Kokkoris, I. P., Kehayias, G., & Dimopoulos, P. (2020). Residents' Views on Landscape and Ecosystem Services during a Wind Farm Proposal in an Island Protected Area. *Sustainability*, 12(6), 2442.

Völker, S., & Kistemann, T. (2011). The impact of blue space on human health and well-being–Salutogenetic health effects of inland surface waters: A review. *International Journal of Hygiene and Environmental Health*, 214(6), 449-460.

White, M., Smith, A., Humphryes, K., Pahl, S., Snelling, D., & Depledge, M. (2010). Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes. *Journal of Environmental Psychology*, 30(4), 482-493.

Williams, J. B., Jose, R., Moobela, C., Hutchinson, D. J., Wise, R., & Gaterell, M. (2019). Residents' perceptions of sustainable drainage systems as highly functional blue green infrastructure. *Landscape and Urban Planning*, 190.

Wilson, S. M. (2009). An ecologic framework to study and address environmental justice and community health issues. *Environmental Justice*, 2(1), 15-24.

Woolf, S. H. (2017). Progress in achieving health equity requires attention to root causes. *Health Affairs*, 36(6), 984-991.

Chapter 3 Landscape Elements Affect Public Perception of Nature-based Solutions Managed by Smart Systems

Abstract

Smart technologies promise innovative approaches to manage nature-based solutions (NBS) for more effective regulating functions under climate change. However, smart systems may also affect people's experiences of NBS by introducing noticeable changes in urban landscapes. This study investigated public perception of "smart" retention ponds that had changing water level as controlled by smart systems and varied in the following microscale landscape elements determined by planning and design choices: land use context, basin slope, and surrounding plants. Using visualizations that showed pond design alternatives at typical, low (draining water), and high (retaining water) water levels, we surveyed residents in three American cities for their perceptions of smart ponds (n = 974). Our results suggest that water level manipulation by smart systems negatively affects perceptions of stormwater ponds; both low and high water were perceived as significantly less attractive, neat, and safe than the typical water level condition. Furthermore, these effects of water level were moderated by other design elements. Perceptions of high water level were more positive for ponds in greenspace than in residential or commercial contexts. Perceptions of low water level were more positive for ponds in residential contexts than in greenspace or commercial contexts, as well as for ponds surrounded by woody or unmaintained plants than those surrounded by mown turf edge. In both high and low water conditions, ponds with steep slopes were perceived more positively than those with shallow slopes. These findings can support successful planning, design, and management of smart NBS.

Keywords: aesthetics; cultural ecosystem services; green infrastructure; landscape design; nature-based solutions; resilience

3.1 Introduction

The concept of "smart cites" and related technological innovations present novel approaches for managing urban ecosystems and the services they provide (Arts, van der Wal, & Adams, 2015; Goddard et al., 2021; Gulsrud et al., 2018; Nitoslawski, Galle, Van Den Bosch, & Steenberg, 2019). A widely considered application is smart stormwater systems that integrate technologies such as information and communication technology, sensors, and autonomous systems into nature-based solutions (NBS) for urban stormwater management (Bartos, Wong, & Kerkez, 2018; Lund et al., 2019; Meng & Hsu, 2019; Shishegar, Duchesne, Pelletier, & Ghorbani, 2021). Smart systems can monitor multiple NBS sites in real time and evaluate their systematic performances, providing new insights for management decisions (Kerkez et al., 2016; Meng & Hsu, 2019). Moreover, smart systems can actively control detention and retention processes to better respond to stressors from climate change, aging infrastructure, and land use change (Kerkez et al., 2016; Lund et al., 2019).

However, despite rapidly advancing technological capacity, how the public may respond to the visible effects of implementing smart stormwater systems has not been adequately considered. Smart systems can noticeably change the appearance of NBS by intentionally storing water in neighborhood streets or draining retention ponds. Such unfamiliar landscape appearances may degrade people's everyday experiences of urban nature, a cultural ecosystem service with implications for both urban residents' well-being and public support for smart system adoption (Li & Nassauer, 2021). Landscape experiences are a product of human perception and cognition, and may not align with environmental processes and functions (Andersson, Tengö, McPhearson, & Kremer, 2015; Daniel et al., 2012; Dronova, 2019; Gobster, Nassauer, Daniel, & Fry, 2007). Smart stormwater systems manage processes that occur at various spatial scales, some of which are not perceivable. In contrast, people immediately notice microscale landscape elements – the fine-grained characteristics of water, plants, landforms, and structural elements that are immediately perceptible – at the scale of streets and sites (Nassauer, Webster, Sampson, & Li, 2021; Raymond et al., 2017).

This paper reports on our investigation of urban residents' perceptions of microscale landscape elements of NBS managed by smart systems. Specifically, we focused on "smart ponds", i.e., stormwater retention ponds in which sensors, actuators, and wireless communication devices are deployed to monitor weather and stormwater quantity and quality metrics and dynamically control flows across multiple sites in real time (Kerkez et al., 2016; Mullapudi, Bartos, Wong, & Kerkez, 2018). For many decades, stormwater retention ponds have been widely implemented in the US and many other countries in residential neighborhoods, greenspace, and commercial developments to collect and treat stormwater runoff (Eckart, McPhee, & Bolisetti, 2017; Fletcher et al., 2014; Hassall, 2014). Studies on public perceptions of stormwater ponds consistently highlight their amenity values, reporting that nearby residents often see safe and neatly kept pond landscapes as offering aesthetic experiences, including viewing birds and other wildlife (Bastien, Arthur, & McLoughlin, 2012; Eckart et al., 2017; Lamond & Everett, 2019; Moore & Hunt, 2012; Rooney et al., 2015; Williams et al., 2019).

The adaptation of stormwater ponds by smart systems, through both retrofitting and new construction, could enhance stormwater regulating functions and allow more flexible and responsive management regimes in response to climate change (Bartos et al., 2018; Goddard et al., 2021; Lund et al., 2019). Smart systems can drain ponds before an intense storm to free up storage space and retain more water during and after the storm to more effectively mitigate flooding risk and water quality impairment (Mullapudi et al., 2018; Shishegar et al., 2021). However, such manipulations of pond water level can result in visible landscape changes. Draining water can result in unusually low water levels, sometimes exposing sediments. Retaining water after storms at a higher than usual level can resemble flooding conditions. To our knowledge, no study has investigated how water level may affect people's perceptions of stormwater ponds, especially under the novel regime of smart systems where water level is managed through a highly engineered process and can change rapidly.

Given the different decision-making mechanisms that shape microscale landscape elements of smart ponds, we conceptualized these elements into two categories: pond water, which is inherently related to stormwater management functions and controlled by smart systems; and other "design elements" such as plants, landform, and adjacent buildings and structures, which depend on planning and design choices and maintenance regimes and will appear as more stable than pond water level. While these design elements are not directly controlled by smart systems, they constitute the overall smart pond landscape that people immediately perceive and experience. Based on our conceptualization of microscale elements, we draw from existing knowledge to consider pond water level as related to perception and to identify design elements that might affect perception.

Open water is critical for everyday aesthetic experiences offered by stormwater ponds. It is often associated with high landscape preference, aesthetic pleasure, and relaxation and restoration (Herzog, 1985; Kaplan & Kaplan, 1989; Völker, Matros, & Claßen, 2016; White et al., 2010). But the visual qualities of water such as transparency and color may also profoundly affect how people perceive it (Flotemersch & Aho, 2021). Studies of natural wetlands noted that absence of visible water (Dobbie, 2013) or presence of sediments (Cottet, Piégay, & Bornette, 2013) may significantly undermine aesthetic experiences. Aesthetic preferences for rivers have been reported to be greatest at medium water flow, with both high and low flows less preferred – possibly due to suspended debris and exposed channel beds (Brown & Daniel, 1991; Pflüger, Rackham, & Larned, 2010; Yamashita, 2002). For stormwater detention areas, temporary flooding in neighborhoods may raise safety concerns when residents are not aware of the intention and mechanism of stormwater management (Williams et al., 2019).

As design elements, characteristics of plants growing in and around ponds have been reported to affect both aesthetic appeal and neatness. Orderly-looking plants and regular mowing can signal ongoing maintenance, care, and conform to social norms, especially in residential areas (Li & Nassauer, 2020; Nassauer, 2004; O'Donnell, Maskrey, Everett, & Lamond, 2020; Taguchi et al., 2020). Mature canopy trees may also contribute to greater landscape preferences in some contexts (Dobbie, 2013; Lund et al., 2019; Suppakittpaisarn, Larsen, & Sullivan, 2019). In contrast, submergent plants and densely growing tall grasses are often noted as view-blocking, messy, and unpleasant (Flotemersch & Aho, 2021; Jarvie, Arthur, & Beevers, 2017; Taguchi et al., 2020). Messy-looking plants can also prompt concerns about safety; residents may associate these plants with dangerous and dirty breeding grounds for mosquitos and rats, especially when the extent of water is small (Jarvie et al., 2017; Monaghan et al., 2016; Taguchi et al., 2020; Williams et al., 2019). Moreover, low gradient basin slope is often mandated in stormwater pond construction to minimize drowning hazard, a safety concern people commonly raise (Bastien et al., 2012; Jones, Guo, Urbonas, & Pittinger, 2016). Besides, the basin slope of a pond affects the extent and shape of visible water, which may affect landscape perception (Dobbie & Green, 2013).

Further, land use context can prompt people to have certain expectations for landscape appearance, influencing how people perceive a landscape (Flotemersch, Shattuck, Aho, Cox, & Cairns, 2019; Gobster et al., 2007). For the purposes of this study, we operationalize land use context as a microscale design element because it affects what built structures and landcovers may exist adjacent to ponds. Previous studies on public perceptions of retention ponds that surveyed multiple sites in different land uses commented on substantial variations among sites, but did not explicitly examine the effects of land use context (Jarvie et al., 2017; Williams et al., 2019). Studies of other aquatic systems have noted that, for example, people may have greater preferences for restored wetlands that are located in a natural context (e.g., nature reserve) (Nassauer, 2004).

Building on this literature, we investigated how water level manipulations by smart systems affect the perceived attractiveness, neatness, and safety of pond landscapes. We also considered if and how the effects of water level on perceptions are moderated by design elements. We specifically addressed the following three research questions:

1. How does water level relate to perceived safety, attractiveness, and neatness of smart ponds?

2. How do design elements (i.e., land use context, basin slope, and surrounding plants) relate to perceived safety, attractiveness, and neatness of smart pond landscapes?

3. Are the effects of water level on perceptions of smart ponds moderated by these design elements?

3.2 Method

3.2.1 Study location and smart pond design alternatives

3.2.1.1 Study cities

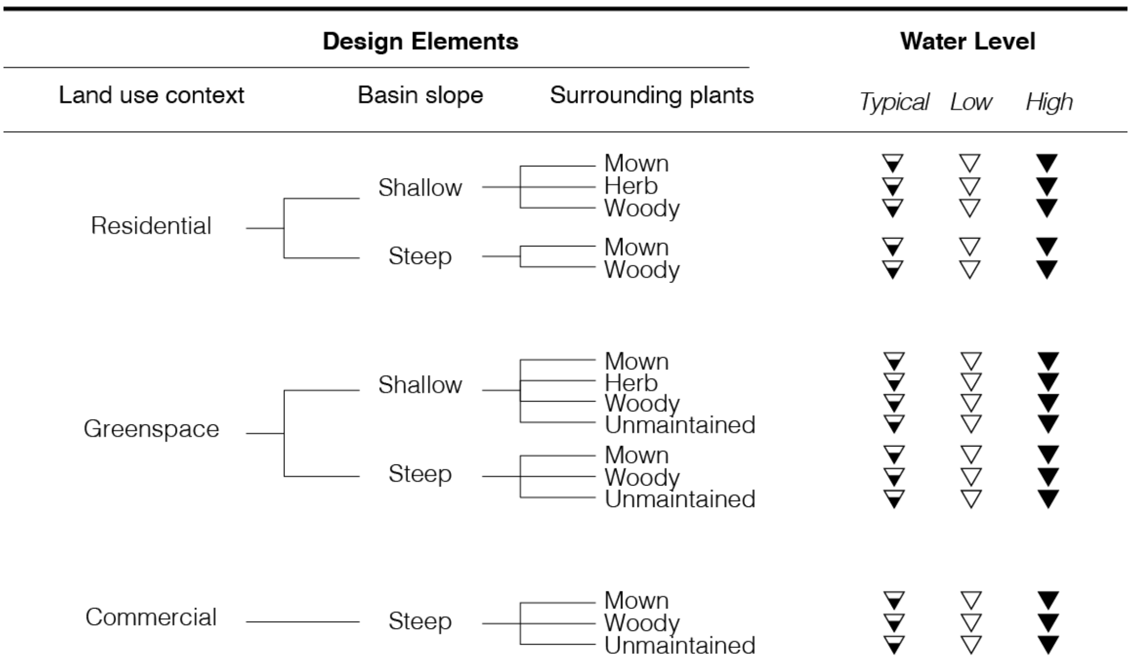
In this study, we focused on three US cities, each of which were in a different stage of adopting smart systems that entail manipulation of stormwater pond water levels. Smart stormwater systems have been adopted pervasively in South Bend, Indiana; have been partially adopted in Ann Arbor, Michigan; and have not yet been adopted in Knoxville, Tennessee (Figure 3.1).

Figure 3.1 *Three US cities were sample areas for this study.*

3.2.1.2 Development of pond landscape design alternatives

To answer our research questions, we employed a factorial design to test each water level with all relevant combinations of design elements of land use context, basin slope, and surrounding plants (Figure 3.2). We eliminated some combinations that were implausible in landscape applications. For example, in a commercial context, a steep-sloped basin is typically used to limit the spatial extent of ponds given high land costs, and in a residential context, maintenance typically controls tall weedy plants, like volunteer woody shrubs, at the edge of a pond.

Figure 3.2 *Landscape design alternatives of smart ponds.*
Smart pond landscape design alternatives were created by a factorial combination of design elements to make 15 landscape design alternatives. Each was applied to two different pond sites, resulting in 30 different pond landscape design alternatives. Each pond landscape design alternative was depicted at three different water levels, in a total of 90 visualizations.



3.2.1.3 Visualization generation

Based on these pond landscape design alternatives, we then created high verisimilitude visualizations as stimuli to elicit respondents' perceptions of smart ponds. Digitally generated realistic visualizations have been widely used in landscape perception research as validate surrogates to real landscapes (Daniel & Meitner, 2001; Deng et al., 2020; Jorgensen, Hitchmough, & Calvert, 2002; Sevenant & Antrop, 2011). Although such an approach does not account for multi-sensory and embodied landscape experiences, it offers the advantages of both high visual verisimilitude and controlled testing of design elements. Using Adobe Photoshop CC, landscape architects on our team created visualizations by manipulating photos of actual stormwater pond sites selected from the three study cities. In addition, other visible aspects of the pond landscape, such as light or weather conditions, were controlled across all visualizations. Figure 3.3 shows 9 of the 90 visualizations employed in our survey.

Figure 3.3 *Examples of survey visualizations of three pond landscape design alternatives at the typical, low, and high water level.*
These alternatives varied basin slopes and surrounding plants and were located in different land use contexts. Respondents viewed each alternative at three different water levels, as manipulated by smart systems.

3.2.2 Survey

3.2.2.1 Sampling frame

We employed a stratified random sampling method to obtain a more representative sample, increase generalizability, and to reduce sampling and non-sampling related error (Etikan & Bala, 2017). Using a factorial sampling design, we organized block groups as designated by the U.S. Census Bureau (U.S. Census Bureau, 1994) into four strata in each city according to income and flood risk. Low versus high income was determined by comparing the median household income of a census block group with that for each city. Low vs. high flood risk was determined by whether any part of a census block group fell within the Special Flood Hazard Areas or moderate flood hazard areas in US Federal Emergency Management Agency (FEMA) flood maps (FEMA https://msc.fema.gov/portal/home). Given our goal to survey full-time residents, we excluded census block groups with a median age less than 25, which were more likely to comprise temporary resident student clusters near large universities in the three cities.

Next, a random sample of household addresses from each of the 12 strata was obtained from the Marketing Systems Group, a vendor that supplies addressed-based random samples to research institutions. Structural equation modeling for the larger study suggested that a sample size of at least n = 200 per city (total n = 600) was needed (Kline, 2015). Informed by previous studies on green infrastructure that employed addressed-based mail surveys (Ambrey et al., 2017; Williams et al., 2019), we anticipated a 15% response rate to our survey. As a result, we obtained 336 household addresses within each of our 12 strata for a total of 1,344 per city and an overall total of 4,032 households in our mail sample.

3.2.2.2 Questionnaire design

Our questionnaire included two sections. The first section displayed visualizations of pond landscapes at three water levels. Respondents were asked to rate each pond landscape at typical, low, and high water level for its perceived attractiveness, safety, and neatness. Each was rated on a 5-point Likert scale (e.g., Attractive = 5, Somewhat attractive = 4, Neither = 3, Somewhat unattractive = 2, Unattractive = 1). The second section of the survey included questions about respondents' characteristics and their experiences related to flooding and stormwater management.

We randomly assigned each of the 336 household addresses within each of our 12 strata to be sent one of eight questionnaire versions. To avoid potential attention fatigue, each version of the questionnaire contained only five of the 30 pond landscape design alternatives, with each shown at all three water levels. We purposively selected these five alternatives to include varied design elements in each questionnaire version: all three land use contexts, both steep and shallow basin slopes, and at least three of the four types of surrounding plants. Further, to facilitate comparison across all respondents, we included one design alternative (a residential pond with shallow slope and herbaceous edge from Ann Arbor) in all versions, holding its order constant (the third). All other design alternatives were included in at least one but no more than two questionnaire versions, and randomly ordered in each version of the questionnaire.

Visualizations for typical, low, and high water level appeared in order on a single page for each pond landscape. Moreover, to facilitate respondents' understanding of water manipulations and land use context, we included text descriptions to accompany all visualizations (e.g., "The water level is drawn down before a storm and is temporarily higher after a storm." and "This is a pond in a commercial development."). The questionnaire was color-printed in high resolution as a letter-size booklet. There was a brief introduction explaining the concept of stormwater and stormwater management practices in non-technical language. Examples of questionnaire pages, including the explanatory text, are in Supplementary Materials.

3.2.2.3 Mail survey procedure

The survey was administered via the US postal mail in the fall of 2019. A postcard was first sent to each of the randomly selected households, notifying residents about the project and that a survey would be sent to their home soon. Next, the survey was sent, accompanied by a letter, an informed consent document, a pre-paid return envelope, and a $1 pre-incentive. The letter provided information about the project and survey, notified residents their household had been randomly selected, and invited a 'head of household (someone who is age 18 or older)' to participate. Respondents who completed and returned the survey with a mailing address were mailed a US $10 token of appreciation. The survey was reviewed and approved by the University of Michigan Institutional Review Board.

3.2.3 Data analysis

All analyses of survey data were conducted with R 4.0.2 (R Core Team, 2020). The original survey data were encoded at the respondent level, i.e., one row of data per respondent. The data were re-structured for analysis so that respondents' perceptions of each pond landscape design alternative at each water level were the unit of analysis, i.e., three rows of data for each of the five ponds that respondents were asked to rate (a total of 15 data lines per respondent). Data lines for a pond landscape design alternative were removed if a respondent did not provide any perception rating for one or more water level condition, resulting in a final analytic sample of n = 14,430.

To account for the non-independent data structure (i.e., that respondents reported on multiple pond landscapes at varying water levels and respondents did not see the same design alternatives but 5 out of all 30), we employed linear mixed effect models, considering both respondent and visualization as "crossed" random effects (Baayen, Davidson, & Bates, 2008; Spielhofer, Hunziker, Kienast, Wissen Hayek, & Grêt-Regamey, 2021; West, Welch, & Galecki, 2014). Mixed models also have the advantage of accounting for variation in data that is not explicitly modelled to specific variables, thus improving the generalizability of results to both residents and pond landscapes.

To address our research questions, we conducted mixed effects modeling predicting perceived attractiveness, perceived neatness, and perceived safety respectively with the R package 'lme4' (Bates, Maechler, Bolker, & Walker, 2015).

Models with random intercepts for both respondents and pond deign alternatives were confirmed by likelihood-ratio tests to have significantly better fit compared to models without the random effects. Modeling was executed in two steps to examine main and interaction effects. In the main effects models, independent variables included: water level (typical level as the reference group), land use context (residential as the reference group), basin slope (steep as the reference group), and surrounding plants (mown turf as the reference group). Then we tested interactions between water level and the three design elements: water level x land use, water level x basin slope, and water level x surrounding plants. Based on the interaction effects models, interactions were further examined for estimated marginal means for perceptions of typical, low, and high water levels among different design elements, as well as contrasts between estimated marginal means. R package 'emmeans' (Lenth et al., 2021) was employed to calculate and graph estimated marginal means and contrast.

3.3 Results

3.3.1 Demographic profile of respondents

The response rate for this survey was 24.2% (*n* = 974/4032), which was much higher than our pre-survey estimate. Table 3.1 shows the demographic and socioeconomic profile of the sample.

Table 3.1 *Demographic characteristics of respondents to our mail survey.*

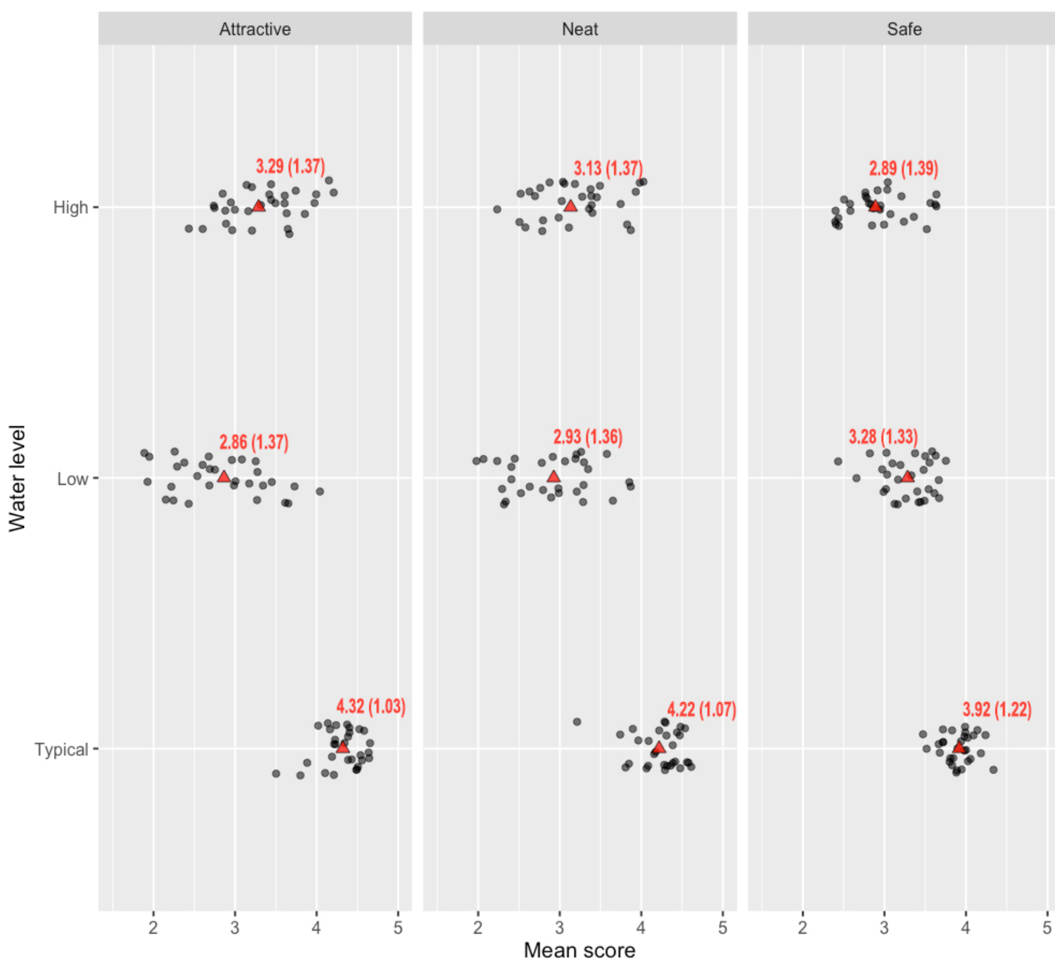
Respondents' characteristics	**Survey Respondents (*n* = 974)**	
	%[a]	***Mean (SD)***
Age (18-103 yrs)		52.1 (18.7)
Gender (% female)	57.3%	
Race (% non-white)	19.4%	
More than high school education	82.3%	
House tenure (% homeowner)	60.5%	
Household income (% above $35,000, before tax)	63.2%	

[a] Valid percentages are given, which exclude missing values.

3.3.2 Descriptive statistics: Perceptions of smart ponds

For all three perceptions, mean scores were lower for low and high water levels than the typical water level (Figure 3.4). Low and high water levels were associated with different perceptions: the low water level was perceived as less attractive and less neat than the high water level, but safer. Further, there were profound variations in mean scores by pond landscape design alternatives, especially for low and high water levels. This provides descriptive evidence that perceptions of pond landscapes at low and high water are moderated by microscale design elements.

Figure 3.4 *Grand means and group means for perceptions by water level.*
Grand means (represented by red triangles, labelled with Mean (SD)) were calculated over all observations; and group means (represented by black dots) were calculated for each pond landscape design alternative. Note that the grand means are not an average of the groups means because slightly different numbers of respondents rated each pond landscape design alternative.



3.3.3 Analysis for microscale landscape elements' effects on perceptions

3.3.3.1 Main effects of water level

Our main effects model showed that both high and low water levels of smart ponds were perceived as significantly less attractive, safe, and neat than the typical water level (Table 3.2). This confirms the differences in mean perception scores shown in Figure 3.4 between the typical water level and water level manipulations.

3.3.3.2 Main effects of design elements

The main effects models (Table 3.2) showed that ponds in a commercial context were perceived as significantly less attractive, safe, and neat than those in a residential context, and ponds in greenspace were perceived as significantly safer than those in a residential context. Considering basin slope and surrounding plants, ponds with a shallow slope were associated with significantly lower ratings across all three perceptions than those with a steep slope, and ponds with a woody edge were associated with significantly higher ratings for perceived attractiveness than those with a mown turf edge. However, given the presence of significant interactions between water level and microscale elements, these main effects are most usefully examined and interpreted with attention to different water levels.

Table 3.2 *Main and interactive effects of water level and design elements (i.e., land use context, basin slope, and surrounding plants) on perceived attractiveness, safety, and neatness.*

*The unstandardized regression coefficients (b) for each independent variable are presented, accompanied by the standard error (SE). Significance levels are set as: * $p < .05$ ** $p < .01$ *** $p < .001$. For random effects, σ2 denotes the residual variance and τ00 denotes the random effects of respondent and visualizations allowing for random intercepts, with standard deviations (SD). The marginal R-squared considers only the variance of the fixed effects, and the conditional R-squared accounts for both the fixed and random effects (Lüdecke, 2021; Nakagawa, Johnson, & Schielzeth, 2017).*

Independent Variables	Perceived Attractiveness		Perceived Neatness		Perceived Safety	
	Main effects model b (SE)	Interaction effects model b (SE)	Main effects model b (SE)	Interaction effects model b (SE)	Main effects model b (SE)	Interaction effects model b (SE)
Water level						
Typical water (reference group)	-	-	-	-	-	-
Low water	**-1.46 (.02)*****	**-1.30 (.05)*****	**-1.30 (.02)*****	**-1.26 (.05)*****	**-0.63 (.02)*****	**-0.60 (.05)*****
High water	**-1.03 (.02)*****	**-0.83 (.05)*****	**-1.08 (.02)*****	**-0.94 (.05)*****	**-1.03 (.02)*****	**-0.94 (.05)*****
Land use context						
Residential (reference group)	-	-	-	-	-	-
Commercial	**-0.63 (.14)*****	-0.22 (.14)	**-0.56 (.14)*****	-0.20 (.14)	**-0.37 (.09)*****	-0.13 (.10)
Greenspace	0.01 (.10)	0.14 (.10)	0.04 (.10)	0.11 (.10)	**0.18 (.07)***	**0.21 (.07)****
Basin slope						
Steep slope (reference group)	-	-	-	-	-	-
Shallow slope	**-0.31 (.10)****	-0.07 (.11)	**-0.34 (.10)****	-0.14 (.11)	**-0.23 (.07)****	-0.14 (.07)
Surrounding plants						
Mown turf (reference group)	-	-	-	-	-	-
Woody	**0.22 (.10)***	0.13 (.11)	0.11 (.10)	-0.01 (.11)	0.14 (.07)	0.10 (.07)
Herbaceous	0.18 (.15)	0.07 (.15)	0.11 (.15)	0.01 (.15)	0.15 (.10)	0.10 (.10)
Unmaintained	0.13 (.12)	-0.25 (.13)	0.01 (.12)	**-0.44 (.13)****	0.02 (.08)	**-0.19 (.09)***
Interactions						
Low water X Commercial		**-1.06 (.07)*****		**-0.90 (.07)*****		**-0.47 (.07)*****
High water X Commercial		**-0.17 (.07)***		**-0.20 (.07)****		**-0.23 (.07)*****
Low water X Greenspace		**-0.44 (.05)*****		**-0.33 (0.5)*****		**-0.21(.05)** ***
High water X Greenspace		0.05 (.05)		**0.13 (.05)****		**0.11 (.05)***
Low water X Shallow slope		**-0.22 (.06)*****		**-0.14 (.05)***		0.01 (.05)
High water X Shallow slope		**-0.47 (.06)*****		**-0.45 (.05)*****		**-0.31 (.05)*****
Low water X Woody		**0.37 (.06)*****		**0.42 (.05)*****		**0.17 (.05)****
High water X Woody		**-0.12 (.06)***		-0.07 (.05)		-0.04 (.05)
Low water X Herbaceous		**0.28 (.06)*****		**0.25 (.06)*****		0.06 (.06)
High water X Herbaceous		0.05 (.06)		0.04 (.06)		0.11 (.06)
Low water X Unmaintained		**0.77 (.06)*****		**0.80 (.06)*****		**0.34 (.06)*****
High water X Unmaintained		**0.37 (.06)*****		**0.47 (.06)*****		**0.29 (.06)*****
Random effects						
σ^2	1.00 (1.0)	0.95 (.98)	0.98 (.99)	0.94 (.97)	0.87 (.93)	0.86 (.93)
τ_{00}	0.52 (.72) $_{respondent}$ 0.05 (.22) $_{visualization}$	0.52 (.72) $_{respondent}$ 0.05 (.22) $_{visualization}$	0.57 (.75) $_{respondent}$ 0.05 (.22)$_{visualization}$	0.58 (.76) $_{respondent}$ 0.05 (.22) $_{visualization}$	0.80 (.90) $_{respondent}$ 0.02 (.14) $_{visualization}$	0.80 (.90) $_{respondent}$ 0.02 (.14) $_{visualization}$
Observations	14375	14375	14300	14300	14383	14383
Marginal R^2 / Conditional R^2	0.214 / 0.500	0.235 / 0.523	0.185 / 0.501	0.205 / 0.523	0.112 / 0.543	0.118 / 0.550
Deviance	42936.254	42306.716	42609.132	42011.777	41514.684	41303.760
log-Likelihood	-21484.271	-21194.834	-21320.690	-21047.385	-20776.288	-20696.760

3.3.3.3 Interactions between water level and design elements

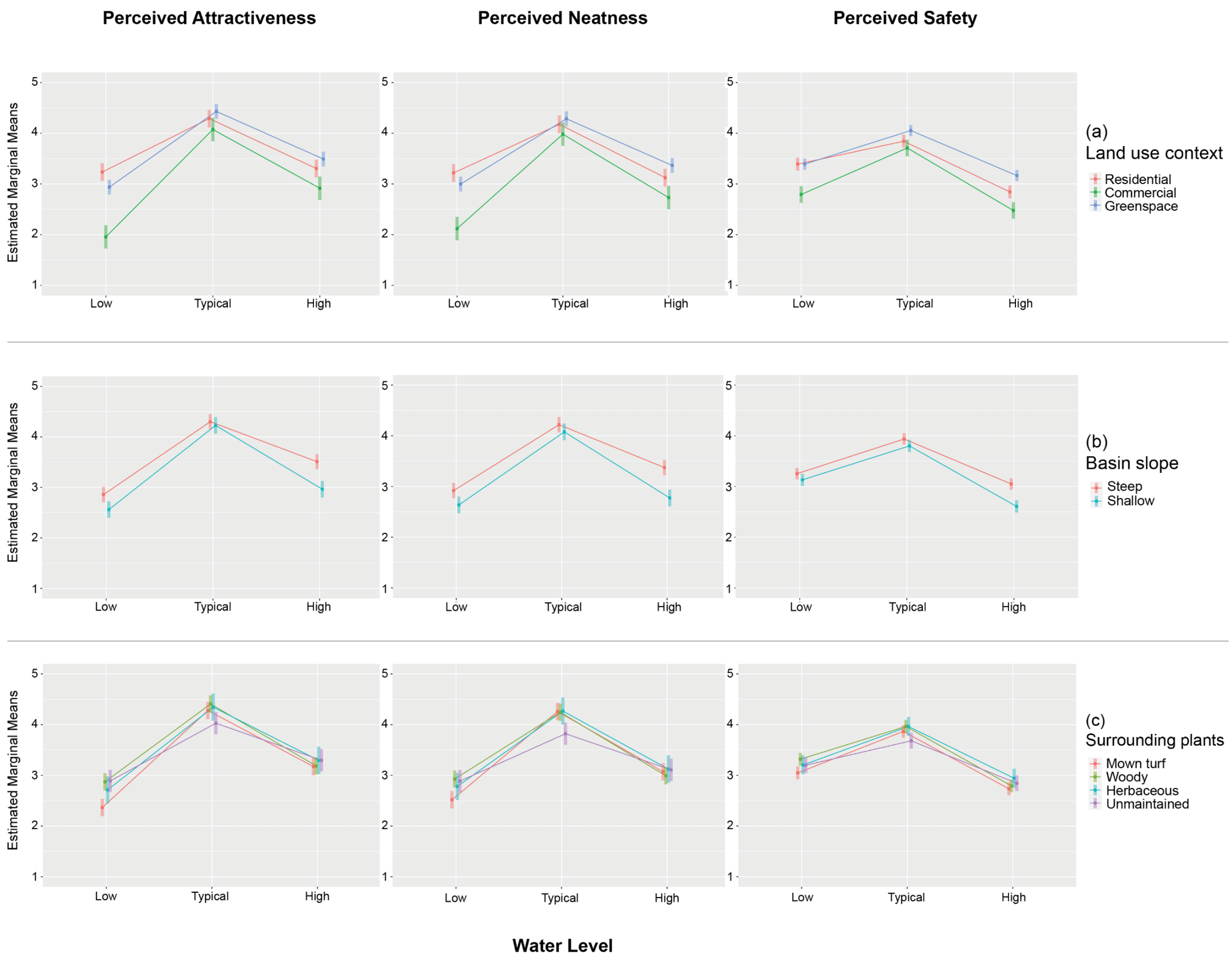
Our interaction effects models showed many statistically significant interactions between water level (low or high versus typical) and design elements (Table 3.2). This suggests that the negative effects of low and high water levels on perceptions are moderated by design elements. In other words, respondents may perceive low and high water levels differently for smart ponds of varying designs.

Water level × land use

Land use context of smart ponds differentially affects the association between water level and perceptions (Figure 3.5a). For all three perceptions, the negative effects of both low and high water levels (compared to typical) were significantly stronger for ponds in a commercial context than those in a residential context. Comparing greenspace and residential context, the negative effects of low water level on all three perceptions were statistically stronger for ponds in a greenspace context than those in a residential context. In contrast, the negative effects of high water on perceived neatness and safety were statistically stronger for residential ponds than greenspace ponds. For perceived attractiveness, the interaction was not significant.

Further examination of differences in the estimated marginal means reveals that low water level is perceived as significantly more attractive in a residential context compared to a greenspace context ($contrast = 0.298, se = .104, p < .05$), while high water level is perceived as significantly less safe ($contrast = -0.322, se = .072, p < .001$). There were no significant differences in perceptions of the typical water level when comparing ponds in commercial and residential contexts. However, both high and low water levels were perceived as significantly less attractive, neat, and safe for ponds in a commercial context, especially for low water level. Ponds in a commercial context were perceived as significantly less attractive and safe than those in a greenspace context for the typical water level ($contrast_{attractive} = -0.358, se = .129, p = p < .05;$ $contrast_{safe} = -0.344, se = .089, p < .05$).

Figure 3.5 *Interaction effects of (a) land use context, (b) basin slope, (c) surrounding plants on the association between water level and perceptions.*
Estimated marginal means were graphed with 95% CI (confidence interval).



Water level × basin slope

Basin slope of smart ponds differentially affects the association between water level and perceptions (Figure 3.5b). For all three perceptions, the negative effects of both low and high (compared to typical) water levels were significantly stronger for ponds with shallow slopes than those with steep slopes, except for perceived safety under low water level.

Perceptions of typical water level were not significantly different when comparing ponds with steep versus shallow basin slopes. In contrast, for both high and low water levels, ponds with steep slopes were perceived as significantly more attractive, neat, and safe than those with shallow slopes. The only exception is that low water level was perceived as similarly safe among steep and shallow-sloped ponds.

Water level × surrounding plants

Surrounding plants of smart ponds differentially affect the association between water level and perceptions (Figure 3.5c). Negative effects of low (versus typical) water level on all three perceptions were significantly stronger for ponds surrounded by mown turf than those surrounded by woody or unmaintained plants. Negative effects of low water level on perceived attractiveness and perceived safety were also significantly stronger for ponds surrounded by mown turf than those surrounded by herbaceous plants. Herbaceous plants and mown turf similarly affect the association between low water level and perceived safety. Negative effects of high (versus typical) water level were significantly different only when comparing mown turf with woody or unmaintained plants. Ponds surrounded by mown turf had significantly stronger negative associations between high water level and all three perceptions than ponds surrounded by unmaintained plants, and significantly stronger negative associations between high water level and perceived attractiveness than ponds surrounded by woody plants.

Further examination of differences in estimated marginal means reveals that, at low water level, ponds surrounded by mown turf were perceived as significantly less attractive, neat, and safe than those surrounded by woody plants ($contrast_{attractive} = -0.51$, $se = .11$, $p < .001$; $contrast_{neat} = -0.41$, $se = .11$, $p < .01$; $contrast_{safe} = -0.27$, $se = .07$, $p < .01$). They were also perceived as significantly less attractive and neat than ponds surrounded by unmaintained plants ($contrast_{attractive} = -0.52$, $se = .13$, $p < .01$; $contrast_{neat} = -0.37$, $se = .13$, $p < .05$). In contrast, at high water level, perceptions of smart ponds with different surrounding plants were not statistically different.

Perceptions of the typical water level were not significantly different when comparing ponds surrounded by different plants – except for when the plants are not regularly maintained. Ponds surrounded by unmaintained plants were perceived as significantly less neat than those surrounded by mown turf ($contrast = -0.44$, $se = .13$, p

$< .05$), and as significantly less attractive, neat, and safe than ponds surrounded by woody plants ($contrast_{attractive} = -0.38$, $se = .13$, $p < .05$; $contrast_{neat} = -0.42$, $se = .13$, $p < .05$; $contrast_{safe} = -0.28$, $se = .09$, $p < .05$).

3.4 Discussion

This study investigated public perceptions of stormwater retention ponds managed by smart systems. We found evidence that microscale landscape elements may dramatically affect residents' perceptions. Smart ponds in which water level is intentionally manipulated to enhance stormwater regulating capacity risk degrading landscape experiences. However, how residents perceive water level changes also depends on the overall pond landscape. This suggests that design elements may help temper the negative effects of manipulated water levels on perceptions. Below, we discuss our specific findings as related to previous studies on public perception of stormwater ponds and illuminate the implications for planning, design, and management of smart ponds and broader smart NBS practices.

3.4.1 Effects of water level and design elements on perceptions of smart ponds

People may be familiar with the typical water condition of stormwater retention ponds and their experiences can be degraded when pond water levels are manipulated in visible ways. In our study, respondents perceived both low and high water levels as significantly less attractive, neat, and safe than the typical water level of stormwater retention ponds. Moreover, low versus high water level may affect landscape experiences of smart ponds differently. In general, ponds are likely to be perceived as less attractive with low water level than with high water level, and less safe with high water level than with low water level. Differences in perceived neatness of low and high water levels were smaller.

These results are consistent with previous studies that suggest low aesthetic preferences for water bodies with visible sediments (Cottet et al., 2013; Flotemersch & Aho, 2021) and little surface water (Dobbie, 2013; Völker et al., 2016). They also support observations about safety concerns associated with stormwater ponds (Bastien et al., 2012; Jarvie et al., 2017) and residents' worries about flooding related to temporary detention (Williams et al., 2019). Our results enrich this literature by explicitly providing evidence on the relationship between perception and water level in ponds. Our study indicates that, visible, unfamiliar landscape changes introduced by smart stormwater systems may undermine pleasant everyday experiences valued by residents. While these changes support and benefit stormwater management, the pleasant experiences offered by more familiar, stable conditions of visible water might be a higher priority for nearby residents.

However, the potential degradation of residents' experiences by water level changes needs to be understood as part of the overall pond landscape. Notably, we found that the effects of water level changes on perceptions are affected by microscale design elements including land use contexts, surrounding plants, and pond basin slopes. Our results showed that water level manipulations can be perceived dramatically different across different pond designs. Although microscale design elements may not fully ameliorate the negative effect of water level changes, certain design choices promise to elicit more positive experiences than others.

That residents may perceive water level changes differently under different pond designs might be attributed to shared expectations for how stable a landscape should appear in a specific locale. For example, people may perceive water level changes in a commercial context as far more negative than that in a residential or greenspace context because they expect businesses to maintain an attractive, neat, welcoming landscape appearance. The interactions between water level and design elements could also be attributed to the visibility of water. For example, water level changes in a steep-sloped pond can be less visible and noticeable than those in a shallow, gradual sloped pond due to the blocking of the bank, and consequently, have more positive effects on perception.

Furthermore, our study suggests that a design element might affect residents' perceptions under water level manipulations in very different ways than under the typical water condition. For example, a large literature concludes that mown turf contributes to perceived attractiveness and neatness around stormwater ponds or wetlands (Hu, Yue, & Zhou, 2019; Li & Nassauer, 2020; Nassauer, 2004), while "messy-looking", unmaintained plants are often disliked (Bastien et al., 2012; Flotemersch & Aho, 2021; Suppakittpaisarn et al., 2019). Our study shows that, when at low water level, ponds surrounded by mown turf are likely to be perceived as significantly less attractive and neat than ponds surrounded by regularly maintained woody plants or by unmaintained volunteer plants. We note that, compared with taller plants, mown turf allows unimpeded sight lines to unattractive sediments at low water. Moreover, we speculate that manicured mown turf around ponds signals expectations for neatness, while pond appearance at the low water level may signal neglect or malfunction. These contradictory perceptions may not be compatible.

In contrast with low and high water levels, at typical water levels, perceptions of varied pond landscape designs were significantly different only when comparing a few design elements (e.g., unmaintained surrounding plants versus mown turf or woody plants, commercial versus greenspace context). Consistent with abundant literature that associates native plants around wetlands and ponds with messiness (Bastien et al., 2012; Flotemersch & Aho, 2021; Jarvie et al., 2017; Nassauer, 2004), our results showed that unmaintained surrounding plants were perceived as significantly less positive than other surrounding plants (Figure 3.5c). However, respondents in our study did not show strong preferences for mown turf over woody plants as some studies have reported (Hu, Hansen, & Monaghan, 2017). We also found that ponds in greenspace contexts were perceived as significantly more attractive, neat, and safe than those in commercial contexts and safer than those in residential contexts at typical water levels (Figure 3.5a). These findings provide nuance to those reported in previous studies that indicate positive (Nassauer, 2004) or negative (Rooney et al., 2015) effects of "natural" contexts (e.g., nature reserve, protected area) on perceptions and landscape experiences. Considering basin slope, similar to what Bastien et al. (2012) have observed, we found no obvious differences in perceived safety when pond slopes are less steep.

Compared with perceived neatness and attractiveness, perceived safety of smart ponds might be more strongly shaped by past experiences of flooding or demographic and socioeconomic characteristics (Lechowska, 2018) than by microscale landscape elements. In our study, main effects and interaction effects models for perceived safety showed smaller marginal R-squared yet greater conditional R-squared than perceived attractiveness and neatness (Table 3.2). This suggests that variations in our respondents' ratings of safety were explained by microscale elements to a lesser degree than variations in their ratings for the other two perceptions. Further, respondent characteristics may have greater impacts on perceived safety, a topic that is in need of further research.

3.4.2 Implications for the design, planning, and management of smart stormwater systems

Overall, our study suggests that attention to public perception is necessary to the success of smart ponds and NBS broadly. Specifically, manipulation of pond water levels may undermine urban residents' experience of stormwater ponds, with implications for human well-being as well as public support for smart system adoption (Li & Nassauer, 2021). Moreover, though beyond the scope of this paper, ecological implications of water level manipulation must also be considered – for example, whether flashy manipulated water levels, coupled with steep slopes, threaten habitats and biodiversity and impact sedimentation and carbon accumulation (Moore & Hunt, 2012; Rooney et al., 2015). Such implications are also related to residents' perceptions given that wildlife is widely valued in everyday experiences that pond landscapes can offer (Bastien et al., 2012; Nassauer, 2004; Williams et al., 2019). If smart stormwater systems are to provide a more complete set of ecosystem services, their development should integrate measures informed by both public perception and ecological functions (Kabisch et al., 2016; Keeler et al., 2019; Raymond et al., 2017).

Our results suggest that design, planning, and management choices can affect residents' perceptions of water level manipulations with implications for these potential impacts. Design approaches should be pursued to mitigate possible negative perceptions of smart ponds' attractiveness and safety in commercial settings. In residential settings, our results suggest that smart pond design may benefit from reshaping basin slopes to be steeper, and by planting trees or perennial flowers in the surroundings. In low-lying areas, adoption of smart systems may be prioritized in greenspace contexts, given that extra retention and resulting high water level are less likely to arouse safety concerns and fear in greenspace. Moreover, opportunities to provide other ecosystem services such as biodiversity support and carbon sequestration should be pursued – for example, introducing low-maintenance woody and herbaceous plants in some less accessible sections (Hassall, 2014; Moore & Hunt, 2012).

Knowing which microscale elements in pond landscapes are important for public perception of smart ponds, managers can also design public outreach more effectively to address residents' concerns (Derkzen, van Teeffelen, & Verburg, 2017). For example, communication strategies can be tailored to specific land use contexts. In residential contexts, they may target safety concerns related to high water levels and emphasize the intentional, controlled water level manipulations; in greenspace contexts, they can focus on articulating when to expect low water level conditions and how it prepares the community for extreme storms.

3.4.3 Limitations

Limitations of our study suggest grounds for carefully and critically drawing on the study results and related implications when considering smart systems adoption for specific ponds and other NBS for stormwater management. First, using visualizations to collect perception data addressed only visual qualities of smart ponds. Other sensory experiences such as smell and sound can influence residents' perceptions (Flotemersch & Aho, 2021). This could be a further concern for smart stormwater systems that may produce a foul odor from dampened or saturated soils and sediments. Moreover, the still visualizations employed in our study depicted discrete water level conditions, and the timeframe for water level change was described verbally. This can feel different from real-world experiences that take place over time. Therefore, future research may investigate in-situ experiences through, for example, on-site interviews, or explore how the dynamic process of water level manipulation may affect perception.

Second, although our data analyses have accounted for random effects associated with respondents, the study results may not be generalizable to communities that are distinct from the three in our sample. This is particularly relevant for perceived safety, for which variation might be more attributable to past experiences of flooding and demographic characteristics. Future research may examine whether respondents' past experiences with flooding or their home location relative to flood zones affect safety perceptions of smart ponds. Further, while we recognize that perceptions can have important implications for support, we did not explicitly examine residents' support for smart systems adoption and how their support is related to perception.

Finally, visualizations for our study employed a uniform prototype of a rounded shape pond, with design elements shown only in a small area around the edge of ponds. Responses to smart ponds with varied shapes, more varied planting compositions, and more complex edge conditions could be different. Further, these more complex designs could prioritize different landscape experiences and other ecosystem services in different zones, especially when a large area of land is allocated for smart ponds.

3.5 Conclusion

Smart technologies are changing how cities function, including the management of everyday urban landscapes and their embedded ecosystems. Smart stormwater systems may better prepare cities to respond to climate change and aging infrastructure. However, enhancement of stormwater regulating services cannot automatically ensure pleasant everyday experiences, a critical cultural ecosystem service, or other ecosystem services such as habitat provision. Rather, noticeable yet unfamiliar changes that smart systems introduce into the urban landscape can degrade landscape experiences valued by nearby residents.

Focusing on the example of smart ponds, our study offers insights into residents' perceptions related to water level manipulations and other design elements of land use context, basin slopes, and surrounding plants, with implications for planning, design, and management. We found that high and low water levels are likely to degrade landscape experiences, but their negative effects may be moderated by planning and design choices. In general, adoption of smart ponds may be prioritized in residential neighborhoods and greenspace over commercial contexts. Moreover, avoiding shallow basin slopes and mown turf around ponds may help to alleviate negative effects of water level manipulation on perceptions. In contrast, steeper basin slopes and surrounding woody and herbaceous plants may contribute to more positive perceptions, as long as regular maintenance can keep pond landscapes looking attractive and neat at the typical water condition.

With promise for promoting collective stormwater regulating services at a catchment or watershed scale, smart NBS like smart ponds could serve as a ubiquitous measure of climate change resilience and adaptation in cities. We assert that considerations about how such practice could change residents' everyday landscape experiences must be integral to its implementation. Everyday landscape experiences can have far-reaching implications for urban residents' well-being as well as public support for smart NBS. To avoid degrading landscape experiences that residents value, adopting smart systems to manage urban landscapes requires considerations about microscale landscape elements – both those directly controlled by smart systems and those shaped by broader landscape planning, design, and management choices.

References

Ambrey, C., Byrne, J., Matthews, T., Davison, A., Portanger, C., & Lo, A. (2017). Cultivating climate justice: Green infrastructure and suburban disadvantage in Australia. *Applied Geography, 89*, 52-60.

Andersson, E., Tengö, M., McPhearson, T., & Kremer, P. (2015). Cultural ecosystem services as a gateway for improving urban sustainability. *Ecosystem Services, 12*, 165-168.

Arts, K., van der Wal, R., & Adams, W. M. (2015). Digital technology and the conservation of nature. *Ambio, 44*(4), 661-673.

Baayen, R. H., Davidson, D. J., & Bates, D. M. (2008). Mixed-effects modeling with crossed random effects for subjects and items. *Journal of Memory and Language, 59*(4), 390-412.

Bartos, M., Wong, B., & Kerkez, B. (2018). Open storm: a complete framework for sensing and control of urban watersheds. *Environmental Science: Water Research & Technology, 4*(3), 346-358.

Bastien, N. R. P., Arthur, S., & McLoughlin, M. J. (2012). Valuing amenity: public perceptions of sustainable drainage systems ponds. *Water and Environment Journal, 26*(1), 19-29.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software, 67*(1), 1-48.

Brown, T. C., & Daniel, T. C. (1991). Landscape Aesthetics of Riparian Environments: Relationship of Flow Quantity to Scenic Quality Along a Wild and Scenic River. *Water Resources Research, 27*(8), 1787-1795.

Cottet, M., Piégay, H., & Bornette, G. (2013). Does human perception of wetland aesthetics and healthiness relate to ecological functioning? *Journal of Environmental Management, 128*, 1012-1022.

Daniel, T. C., & Meitner, M. M. (2001). Representational Validity of Landscape Visualizations: The Effects of Graphical Realism on Perceived Scenic Beauty of Forest Vistas. *Journal of Environmental Psychology, 21*(1), 61-72.

Daniel, T. C., Muhar, A., Arnberger, A., Aznar, O., Boyd, J. W., Chan, K. M. A., . . . von der Dunk, A. (2012). Contributions of cultural services to the ecosystem services agenda. *Proceedings of the National Academy of Sciences of the United States of America, 109*(23), 8812-8819.

Deng, L., Luo, H., Ma, J., Huang, Z., Sun, L.-X., Jiang, M.-Y., . . . Li, X. (2020). Effects of integration between visual stimuli and auditory stimuli on restorative potential and aesthetic preference in urban green spaces. *Urban Forestry & Urban Greening, 53*, 126702.

Derkzen, M. L., van Teeffelen, A. J., & Verburg, P. H. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences? *Landscape and Urban Planning, 157*, 106-130.

Dobbie, M., & Green, R. (2013). Public perceptions of freshwater wetlands in Victoria, Australia. *Landscape and Urban Planning, 110*, 143-154.

Dobbie, M. F. (2013). Public aesthetic preferences to inform sustainable wetland management in Victoria, Australia. *Landscape and Urban Planning, 120*, 178-189.
Dronova, I. (2019). Landscape beauty: A wicked problem in sustainable ecosystem management? *Science of the Total Environment, 688*, 584-591.
Eckart, K., McPhee, Z., & Bolisetti, T. (2017). Performance and implementation of low impact development - A review. *Science of the Total Environment, 607-608*, 413-432.
Etikan, I., & Bala, K. (2017). Sampling and sampling methods. *Biometrics & Biostatistics International Journal*, 5(6), 00149.
Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., . . . Viklander, M. (2014). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal, 12*(7), 525-542.
Flotemersch, J., & Aho, K. (2021). Factors influencing perceptions of aquatic ecosystems. *Ambio, 50*(2), 425-435.
Flotemersch, J. E., Shattuck, S. M., Aho, K. B., Cox, C. E., & Cairns, M. R. (2019). Factors influencing social demands of aquatic ecosystems. *Ecology and Society, 24*(4), 1-9.
Gobster, P. H., Nassauer, J. I., Daniel, T. C., & Fry, G. (2007). The shared landscape: what does aesthetics have to do with ecology? *Landscape Ecology, 22*(7), 959-972.
Goddard, M. A., Davies, Z. G., Guenat, S., Ferguson, M. J., Fisher, J. C., Akanni, A., . . . Dallimer, M. (2021). A global horizon scan of the future impacts of robotics and autonomous systems on urban ecosystems. *Nature Ecology & Evolution, 5*(2), 219-230.
Gulsrud, N. M., Raymond, C. M., Rutt, R. L., Olafsson, A. S., Plieninger, T., Sandberg, M., . . . Jönsson, K. I. (2018). 'Rage against the machine'? The opportunities and risks concerning the automation of urban green infrastructure. *Landscape and Urban Planning, 180*, 85-92.
Hassall, C. (2014). The ecology and biodiversity of urban ponds. *WIREs Water, 1*(2), 187-206.
Herzog, T. R. (1985). A cognitive analysis of preference for waterscapes. *Journal of Environmental Psychology, 5*(3), 225-241.
Hu, S., Hansen, G., & Monaghan, P. (2017). Optimizing shoreline planting design for urban residential stormwater systems: Aligning visual quality and environmental functions. *HortTechnology, 27*(3), 310-318.
Hu, S., Yue, H., & Zhou, Z. (2019). Preferences for urban stream landscapes: Opportunities to promote unmanaged riparian vegetation. *Urban Forestry & Urban Greening, 38*, 114-123.
Jarvie, J., Arthur, S., & Beevers, L. (2017). Valuing multiple benefits, and the public perception of SUDS ponds. *Water, 9*(2), 128.
Jones, J. E., Guo, J., Urbonas, B., & Pittinger, R. (2016). Essential safety considerations for urban stormwater retention and detention ponds. *Stormwater Magazine.*

Jorgensen, A., Hitchmough, J., & Calvert, T. (2002). Woodland spaces and edges: Their impact on perception of safety and preference. *Landscape and Urban Planning, 60*(3), 135-150.

Kabisch, N., Frantzeskaki, N., Pauleit, S., Naumann, S., Davis, M., Artmann, M., . . . Bonn, A. (2016). Nature-based solutions to climate change mitigation and adaptation in urban areas: perspectives on indicators, knowledge gaps, barriers, and opportunities for action. *Ecology and Society, 21*(2).

Kaplan, R., & Kaplan, S. (1989). *The experience of nature: A psychological perspective*. Cambridge: Cambridge University Press.

Keeler, B. L., Hamel, P., McPhearson, T., Hamann, M. H., Donahue, M. L., Prado, K. A. M., . . . Finlay, J. C. (2019). Social-ecological and technological factors moderate the value of urban nature. *Nature Sustainability, 2*(1), 29-38.

Kerkez, B., Gruden, C., Lewis, M., Montestruque, L., Quigley, M., Wong, B., . . . Pak, C. (2016). Smarter Stormwater Systems. *Environmental Science & Technology, 50*(14), 7267-7273.

Kline, R. B. (2015). *Principles and practice of structural equation modeling*. Guilford publications.

Lamond, J., & Everett, G. (2019). Sustainable Blue-Green Infrastructure: A social practice approach to understanding community preferences and stewardship. *Landscape and Urban Planning, 191*.

Lechowska, E. (2018). What determines flood risk perception? A review of factors of flood risk perception and relations between its basic elements. *Natural Hazards, 94*(3), 1341-1366.

Lenth, V. R., Buerkner, P., Herve, M., Love, J., Riebl, H., & Singmann, H. (2021). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.6.0.

Li, J., & Nassauer, J. I. (2020). Cues to care: A systematic analytical review. *Landscape and Urban Planning, 201*, 103821.

Li, J., & Nassauer, J. I. (2021). Technology in support of nature-based solutions requires understanding everyday experiences. *Ecology and Society*, 26(4).

Lüdecke, D. (2021). sjPlot: Data Visualization for Statistics in Social Science. R package version 2.8.7.

Lund, N. S. V., Borup, M., Madsen, H., Mark, O., Arnbjerg-Nielsen, K., & Mikkelsen, P. S. (2019). Integrated stormwater inflow control for sewers and green structures in urban landscapes. *Nature Sustainability*, 1-8.

Meng, T., & Hsu, D. (2019). Stated preferences for smart green infrastructure in stormwater management. *Landscape and Urban Planning, 187*, 1-10.

Monaghan, P., Hu, S., Hansen, G., Ott, E., Nealis, C., & Morera, M. (2016). Balancing the Ecological Function of Residential Stormwater Ponds with Homeowner Landscaping Practices. *Environmental Management, 58*(5), 843-856.

Moore, T. L., & Hunt, W. F. (2012). Ecosystem service provision by stormwater wetlands and ponds - a means for evaluation? *Water Res, 46*(20), 6811-6823.

Mullapudi, A., Bartos, M., Wong, B., & Kerkez, B. (2018). Shaping Streamflow Using a Real-Time Stormwater Control Network. *Sensors, 18*(7), 2259.

Nakagawa, S., Johnson, P. C., & Schielzeth, H. (2017). The coefficient of determination R 2 and intra-class correlation coefficient from generalized linear mixed-effects models revisited and expanded. *Journal of the Royal Society Interface*, 14(134), 20170213.

Nassauer, J. I. (2004). Monitoring the success of metropolitan wetland restorations: Cultural sustainability and ecological function. *Wetlands, 24*(4), 756-765.

Nassauer, J. I., Webster, N. J., Sampson, N., & Li, J. (2021). Care and safety in neighborhood preferences for vacant lot greenspace in legacy cities. *Landscape and Urban Planning, 214*, 104156.

Nitoslawski, S. A., Galle, N. J., Van Den Bosch, C. K., & Steenberg, J. W. N. (2019). Smarter ecosystems for smarter cities? A review of trends, technologies, and turning points for smart urban forestry. *Sustainable Cities and Society, 51*, 101770.

O'Donnell, E., Maskrey, S., Everett, G., & Lamond, J. (2020). Developing the implicit association test to uncover hidden preferences for sustainable drainage systems. *Philosophical Transactions of the Royal Society A, 378*(2168), 20190207.

Pflüger, Y., Rackham, A., & Larned, S. (2010). The aesthetic value of river flows: An assessment of flow preferences for large and small rivers. *Landscape and Urban Planning, 95*(1-2), 68-78.

R Core Team. (2020). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Raymond, C. M., Breil, M., Nita, M. R., Kabisch, N., de Bel, M., Enzi, V., . . . Cardinaletti, M. (2017). *An impact evaluation framework to support planning and evaluation of nature-based solutions projects. Report prepared by the EKLIPSE Expert Working Group on Nature-Based Solutions to Promote Climate Resilience in Urban Areas*: Centre for Ecology and Hydrology.

Raymond, C. M., Frantzeskaki, N., Kabisch, N., Berry, P., Breil, M., Nita, M. R., . . . Calfapietra, C. (2017). A framework for assessing and implementing the co-benefits of nature-based solutions in urban areas. *Environmental Science & Policy, 77*, 15-24.

Rooney, R. C., Foote, L., Krogman, N., Pattison, J. K., Wilson, M. J., & Bayley, S. E. (2015). Replacing natural wetlands with stormwater management facilities: Biophysical and perceived social values. *Water Research, 73*, 17-28.

Sevenant, M., & Antrop, M. (2011). Landscape representation validity: a comparison between on-site observations and photographs with different angles of view. *Landscape Research, 36*(3), 363-385.

Shishegar, S., Duchesne, S., Pelletier, G., & Ghorbani, R. (2021). A smart predictive framework for system-level stormwater management optimization. *Journal of Environment Management, 278*(Pt 1), 111505.

Spielhofer, R., Hunziker, M., Kienast, F., Wissen Hayek, U., & Grêt-Regamey, A. (2021). Does rated visual landscape quality match visual features? An analysis for renewable energy landscapes. *Landscape and Urban Planning, 209*, 104000.

Suppakittpaisarn, P., Larsen, L., & Sullivan, W. C. (2019). Preferences for green infrastructure and green stormwater infrastructure in urban landscapes:

Differences between designers and laypeople. *Urban Forestry & Urban Greening, 43*.
Taguchi, V., Weiss, P., Gulliver, J., Klein, M., Hozalski, R., Baker, L., . . . Nieber, J. (2020). It Is Not Easy Being Green: Recognizing Unintended Consequences of Green Stormwater Infrastructure. *Water, 12*(2).
U.S. Census Bureau (1994). *Geographic Areas Reference Manual*. Retrieved from [https://www2.census.gov/geo/pdfs/reference/GARM/Ch11GARM.pdf]
Völker, S., Matros, J., & Claßen, T. (2016). Determining urban open spaces for health-related appropriations: a qualitative analysis on the significance of blue space. *Environmental Earth Sciences, 75*(13), 1067.
West, B. T., Welch, K. B., & Galecki, A. T. (2014). *Linear mixed models: a practical guide using statistical software*: Crc Press.
White, M., Smith, A., Humphryes, K., Pahl, S., Snelling, D., & Depledge, M. (2010). Blue space: The importance of water for preference, affect, and restorativeness ratings of natural and built scenes. *Journal of Environmental Psychology, 30*(4), 482-493.
Williams, J. B., Jose, R., Moobela, C., Hutchinson, D. J., Wise, R., & Gaterell, M. (2019). Residents' perceptions of sustainable drainage systems as highly functional blue green infrastructure. *Landscape and Urban Planning, 190*.
Yamashita, S. (2002). Perception and evaluation of water in landscape: Use of Photo-Projective Method to compare child and adult residents' perceptions of a Japanese river environment. *Landscape and Urban Planning, 62*(1), 3-17.

Chapter 4 Experience of Localized Flooding Predicts Perceptions of Urban Flood Risk and Perceived Safety of Nature-based solutions

Abstract

Understanding community members' flood risk perception is critical to developing new approaches to manage flood risks and enhance resilience under climate change. "Risk as feelings" has informed thinking around how people perceive flood risks in an intuitive, experiences-based way that differs from experts' technical assessment. This paper expands the current use of "risk as feelings" and investigates community members' perceptions of stormwater dynamics visible in everyday urban landscapes including both localized flooding and intentional stormwater detention in nature-based solutions (NBS). We examine risk perceptions of localized flooding and perceived safety of innovative vs. traditional NBS practices under the storm condition, including floodable sites, a novel NBS practice that temporarily inundates urban open spaces in wet weather and retention ponds, a familiar NBS practice that can hold extra water. Data were collected through visualization-assisted surveys with residents from high and low flood hazard areas in three US cities (n = 884). We found that respondents who noticed standing water near their homes more frequently were more worried about potential property damage caused by localized flooding. Further, they also perceived floodable sites as less safe. However, such experiences of localized flooding did not affect perceived safety of high-water-level retention ponds. Other contextual and socio-demographic factors, including prior stormwater-related property damage, knowledge and involvement of stormwater management issues, gender, age, race, and having young children, also influenced flood risk perception and perceived safety of NBS in different ways. We conclude by discussing the implications of these findings for urban stormwater management and NBS development.

Keywords: urban flooding; risk perception; stormwater management; community resilience; green infrastructure

4.1 Introduction

Climate change, coupled with urban development and aging infrastructure, is increasing flood risks in cities worldwide (Berndtsson et al., 2019; National Academies of Sciences & Medicine, 2019; O'Donnell & Thorne, 2020). As a result, the management of urban stormwater and flooding risks is moving from resistance to resilience, the capacity to absorb, recover from, and adapt to extreme storm events and their uncertain impacts (Disse, Johnson, Leandro, & Hartmann, 2020; Liao, 2012; McClymont, Morrison, Beevers, & Carmen, 2020). Such a shift calls for changes in urban landscapes to make space for water. Nature-based solutions (NBS) are widely explored as a promising approach. NBS include various practices (e.g., retention ponds, detention swales and basins, constructed wetlands) that seek to use natural processes to manage stormwater and mitigate flooding while offering other societal benefits (Axelsson, Soriani, Culligan, & Marcotullio, 2021; Hobbie & Grimm, 2020; O'Donnell et al., 2020). One increasingly discussed NBS innovation is floodable sites, urban spaces designed to accommodate different dry and wet weather functions (Ashley, Gersonius, & Horton, 2020; Kuang & Liao, 2020; La Loggia, Puleo, & Freni, 2020; Palazzo, 2019). In dry weather, they accommodate everyday activities (e.g., recreation, parking, light traffic); in wet weather, they are temporarily inundated to mitigate flooding and enhance flood resilience.

A challenge to more resilient management of stormwater and flooding risks is that the general public may have different risk perceptions from experts (Birkholz, Muro, Jeffrey, & Smith, 2014; Kellens, Terpstra, & De Maeyer, 2013; Lechowska, 2021). Lack of experience of flooding can lead to low perceived flood risks among community members, hindering adaptive behaviors such as insurance purchase and adoption of household mitigation measures (Wachinger et al., 2013). Furthermore, public acceptance of NBS can be affected by benefits people can directly experience (e.g., aesthetic and recreational), and community members may not support NBS that lack such benefits despite their functions for climate change adaptation (Anderson &

Renaud, 2021; Derkzen, van Teeffelen, & Verburg, 2017; Frantzeskaki, 2019; Han & Kuhlicke, 2019; Li & Nassauer, 2021).

Prior research has drawn on "risk as feelings" to conceptualize risk perception of major riverine and coastal flooding, highlighting its subjective nature and dependence on personal experiences (Botzen, Aerts, & van den Bergh, 2009; Kellens et al., 2013; Lechowska, 2018; O'Neill, Brereton, Shahumyan, & Clinch, 2016; Wachinger, Renn, Begg, & Kuhlicke, 2013). However, little attention has been paid to urban pluvial flooding, which occurs more frequently and poses great cumulative damage (National Academies of Sciences & Medicine, 2019; Netzel, Heldt, Engler, & Denecke, 2021). Furthermore, to our knowledge, no study has examined perceived risks related to interventions like floodable sites that temporarily inundate urban spaces to manage stormwater. In cities, drainage systems have long been adopted to quickly remove stormwater from built areas, treating standing water as a nuisance and disturbance to daily activities (Ashley, Gersonius, & Horton, 2020; Kuang & Liao, 2020; Tempels & Hartmann, 2014). As a result, urban residents may have negative affective reactions toward stormwater ponding, puddling, and localized flooding based on lived experiences. Also, they may intuitively perceive novel NBS practices such as floodable sites as unsafe.

This paper uses "risk as feelings" as an organizing framework to investigate perceived risks related to urban stormwater dynamics, aiming to offer new insights for managing urban flooding, especially through NBS. "Risk as feelings" suggests that people can quickly and intuitively perceive how risky or dangerous a situation is, based on their lived experience (Loewenstein, Weber, Hsee, & Welch, 2001; Slovic, Finucane, Peters, & MacGregor, 2004). Such perceptions involve affective processing, the rapidly occurring perception of something as good or bad, which differs from analytical estimates of the probability of a hazard and its potential damages (Disse et al., 2020; Slovic, MacGregor, & Peters, 1998).

Importantly, we take a theoretical perspective of landscapes as a visible medium in everyday lived experience (Nassauer, 2012) and, therefore, a stimulus for intuitive feelings of risk. We define visible stormwater dynamics here as the phenomenon of water temporarily covering typically dry land, which includes both uncontrolled localized flooding and intentional water detention in NBS. We investigate how people with different past experiences with localized flooding perceive the risk of urban flooding as well as NBS that embody visible stormwater dynamics, focusing on the perceived safety. We compare two NBS practices: floodable sites, a novel NBS practice that temporarily inundates urban landscapes under the storm condition; stormwater retention ponds, a familiar NBS practice that can hold excess water under the storm condition. We also examine how other contextual and socio-demographic factors may affect perceived flood risks and perceived safety of NBS.

4.2 Background

4.2.1 "Risk as feelings"

The concept of "risk as feelings" (Loewenstein et al., 2001; Slovic et al., 2004) is embedded in a broader theory in cognitive psychology and neuroscience that humans use a "dual process" model to comprehend the world. In this model, affective (i.e., feeling good or bad) processing is often labeled experiential, intuitive, and automatic; cognitive processing is often labeled analytical, deliberative, and based on explicit reasoning (Epstein, 1994; Kahneman, 2011). Both processes are now recognized as integral to human decision-making processes. When faced with risk or uncertainty, though, people are prone to make judgements driven by how they feel about an outcome rather than by deliberation about its probability and consequences (Slovic et al., 2004). For example, if people have unfavorable feelings toward using pesticides, they tend to perceive high risk and low benefit; if they have favorable feelings, they tend to perceive the opposite (Alhakami & Slovic, 1994).

Affective reactions largely depend on associative processing (i.e., using principles of similarity), and past experiences can trigger strong affective and emotional reactions to current ones (Loewenstein et al., 2001). Through lived experience and learning, certain sights, sounds, smells, ideas, and words can become associated with positive and negative feelings, forming “affective images” that guide responses in future situations (Slovic et al., 1998). Consequently, factors unrelated to the issue being considered, such as how vividly an outcome is described or mentally represented, can also impact affective reactions (Loewenstein et al., 2001). For example, after looking at photos of houses during a flood, respondents considered living in a neighborhood with a 1% chance of a severe flood in a year as riskier than participants who did not see such photos (Keller, Siegrist, & Gutscher, 2006).

“Risk as feelings” suggests that people’s perceived risk of a phenomenon can be affected by their experiences of the same phenomenon or a different one with similar perceptible characteristics. Related to urban stormwater, because drainage systems in cities have long been designed to quickly remove runoff to discourage ponding and puddling, people may feel unpleasant and unsafe when seeing standing water in everyday urban landscapes. As a result, such visible stormwater dynamics may be perceived as unsafe even when they result from intentional stormwater detention, especially among people with experiences of localized flooding.

4.2.2 Flood risk perception

Flood risk perception denotes how people intuitively and subjectively comprehend flood risks, often framed in contrast to experts’ assessment of risks in a technical manner (Birkholz et al., 2014; Kellens et al., 2013; Lechowska, 2021; Wachinger et al., 2013). As the communication and management of flood risks increasingly involve the general public and community members, understanding flood risk perception is critical. Studies on flood risk perception have operationalized it in various ways using both single or multiple items (Kellens et al., 2013). Specific measures include perceived probability of flooding, perceived damage of flooding, perception of the overall level of flooding risk, worry about flooding, and awareness of living in a flood zone (Altarawneh, Mackee, & Gajendran, 2018; Botzen et al., 2009; Kellens et al., 2013; Lechowska, 2021; O'Neill et al., 2016; Wachinger et al., 2013).

In the context of major riverine and coastal flooding, many studies have observed strong effects of flood experience on risk perception, and reviews have used "risk as feelings" to explain this finding (Kellens et al., 2013; Lechowska, 2018; Wachinger et al., 2013). Prior studies also drew on this framework to hypothesize factors that may affect risk perception (Botzen et al., 2009; Kellens et al., 2013; O'Neill et al., 2016). For example, Botzen et al. (2009) hypothesized that experiences with flooding or evacuation may cause or reinforce negative feelings toward flooding and found that individuals who had experienced or been evacuated for a major flood event in Netherlands' history reported a higher perceived probability of flooding. Besides flood experience, living closer to waterways may predict greater perceived risks of flooding (Bubeck, Botzen, & Aerts, 2012). Moreover, factors related to socio-demographic chracteristics (e.g., age, gender, income, education, having young children) may also influence flood risk perception, though their reported effects are mixed (Kellens et al., 2013; Lechowska, 2021; Wachinger et al., 2013).

Risk perceptions of pluvial flooding in cities has received little attention to date. A recent study in two German cities found that respondents were aware of heavy rains in Germany but rarely perceived it as a risk to themselves (Netzel et al., 2021). In addition, experiences of pluvial flooding, older age, and lower education level predicted greater perceived personal risk. However, this study measured perceived risks as a latent variable based on questions about the expected occurrence and damage of heavy rains rather than addressing affective aspects of risk.

4.2.3 Novel NBS for urban flood resilience

Many government agencies and organizations are developing NBS for urban stormwater and flood risk management (Ashley et al., 2020; Axelsson et al., 2021; Fletcher et al., 2014; Lennon, Scott, & O'Neill, 2014; O'Donnell et al., 2020). NBS may help mitigate localized flooding against increasingly extreme storm events by infiltrating and storing stormwater in the landscape with engineered landforms, soils, and plants (Fletcher et al., 2014; Han & Kuhlicke, 2019).

Recently, floodable sites have been discussed as a novel NBS that can leverage larger areas and more diverse types of urban paces to manage stormwater (La Loggia, Puleo, & Freni, 2020; Liao, 2012; Palazzo, 2019). For example, recreational fields and minor streets have been proposed to hold or convey stormwater temporarily in planning frameworks (Bertilsson et al., 2019; Rogers et al., 2020), simulation models (Lund et al., 2019), and design projects (Mariano & Marino, 2018; Silva & Costa, 2018). Such floodable sites are designed to transition between dry and inundated conditions to increase the stormwater management capacity of a city and realize more flexible uses of urban landscapes. Moreover, some scholars have argued that introducing such practices may help urban residents observe and learn about stormwater dynamics, thus encouraging a shift in social-cultural norms to "live with water" and "make space for water" (Kuang & Liao, 2020; Lennon et al., 2014; McClymont et al., 2020; Silva & Costa, 2018). Scant research exists on how people perceive such novel NBS practices, but there are anecdotes of residents calling a water plaza designed as a floodable landscape a "drowning plaza" (Silva & Costa, 2018).

In addition, community members' perceptions of NBS practices may also depend on contextual factors – both situational (e.g., environmental knowledge, socio-demographic characteristics) and landscape related (e.g., landscape types, land use, spatial extent) (Gobster, Nassauer, Daniel, & Fry, 2007). Broader literature on public perception of NBS for stormwater management suggests that environmental knowledge may encourage a more positive perception of practices that may not widely viewed as desirable such as constructed wetlands (Feng & Nassauer, 2022; Flotemersch & Aho, 2021; Venkataramanan et al., 2020). Perception of NBS has also been reported to relate to socio-demographic factors such as age, gender, race, education, and income, but with inconsistent results (Anderson & Renaud, 2021; Feng & Nassauer, 2022; Flotemersch & Aho, 2021; Han & Kuhlicke, 2019; Venkataramanan et al., 2020).

4.2.4 Research questions

In this study, we address three groups of questions related to perceptions of flood risks and the safety of different NBS practices under the storm condition:

1) Does community members' experience of localized flooding affect their perceived flood risks? What other contextual and socio-demographic factors may have an impact?

2) Are floodable sites, a novel NBS practice that temporarily inundates urban landscapes, perceived as unsafe under the storm condition? Is their perceived safety affected by community members' experience of localized flooding? What other contextual and socio-demographic factors affect community members' perceptions?

3) Are high-water-level stormwater retention ponds, a familiar NBS practice that temporarily holds more water under the storm condition, perceived as safer than inundated floodable sites? What contextual and socio-demographic factors may affect the perceived safety of retention ponds under high water levels?

4.3 Methods

4.3.1 Study area

We conducted a mail survey in three US cities: Ann Arbor, Michigan, South Bend, Indiana, and Knoxville, Tennessee. In recent years, all three cities have experienced severe urban flooding in recent years (e.g., South Bend in February 2018, Knoxville in February 2019, and Ann Arbor in June 2021). Further, these cities may also face growing flood risks. For example, the First Street Foundation (2022) projects that, for the next 30 years, Ann Arbor has a moderate risk of flooding, with 4% of properties (1,345) having over a 26% chance of being severely affected by flooding. South Bend and Knoxville have a major risk of flooding, with 11% of properties (5,431 and 8,379, respectively) having over a 26% chance of being severely affected by flooding.

4.3.2 Sampling methods

To include respondents with potentially varied experiences of flooding, we employed a stratified random sampling method to recruit survey respondents for our survey. We first applied a factorial design to categorize census block groups in each city into four strata, considering low/high income and low/high flood hazards. High versus low income was based on comparisons of a census block group's median household income to the city's median household. High versus low flood hazards was based on whether a census block intersects with the Special Flood Hazard Area (100-year flood) and moderate flood hazard areas (500-year flood) designated by FEMA (https://msc.fema.gov/portal/home). We excluded block groups with a median age of less than 25 to avoid recruiting participants from areas populated by students near major universities who are temporary residents.

Then we randomly selected 336 household addresses within each of the strata to receive the survey invitation, resulting in a mail sample of a total of 4,032 household addresses from the 12 strata across the three cities. This sample size was based on structural equation modeling that suggested a minimum of n = 200 per city (Kline, 2015) and an estimated response rate of 15% based on previous studies on green infrastructure that used a mail survey (Ambrey et al., 2017; Williams et al., 2019).

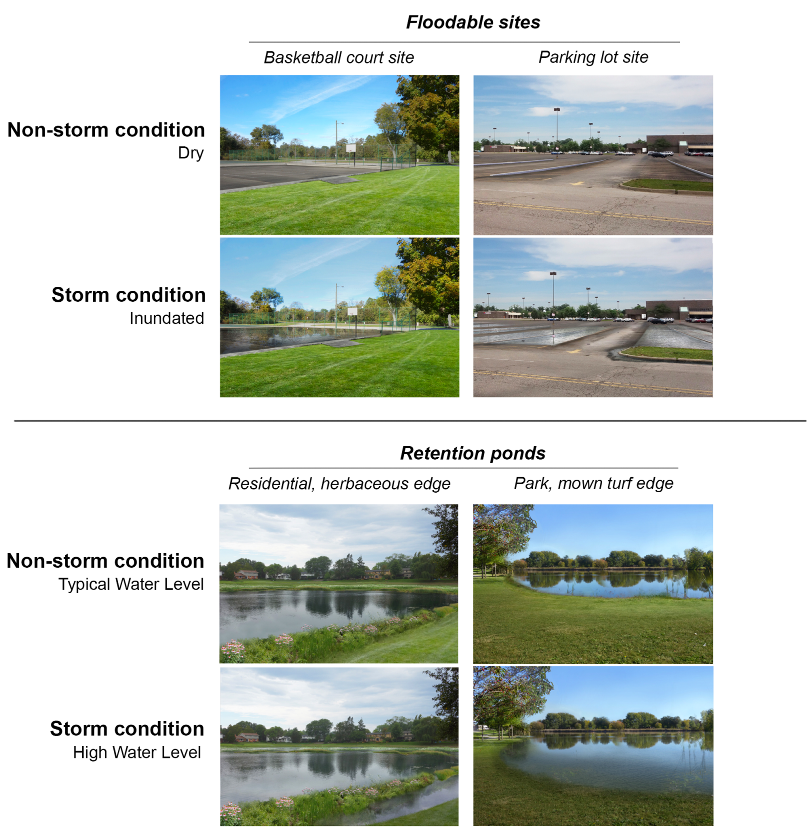
4.3.3 Survey design

4.3.3.1 Landscape visualizations to represent NBS practices

We developed landscape visualizations for floodable sites and stormwater retention ponds to represent NBS practices. This is a widely used method to study visual perception of landscapes (Jorgensen, Hitchmough, & Calvert, 2002; Sevenant & Antrop, 2011). Moreover, realistic visual imagery may help ground new information and facilitate understanding of possible landscape futures (Sheppard, 2005), which is particularly useful for representing novel NBS like floodable sites because these practices are unfamiliar to the general public.

Our team manipulated photos of potential sites for NBS development in the three study cities in Adobe Photoshop CC to create visualizations. These visualizations realistically depicted floodable sites and stormwater retention ponds under both storm and non-storm conditions (Figure 4.1). Floodable sites were shown as both dry and inundated in two different locations (i.e., basketball courts in greenspace and parking lots around building complexes), with two replicate sites for each location. Stormwater ponds were shown at both typical and high water levels and with different combinations of design choices (i.e., basin slopes, surrounding plants, and land use), with two replicate sites for each landscape design alternative. Details about stormwater ponds visualization development and assignment to respondents are in another paper (Li et al., 2022).

Figure 4.1 *Examples of visualizations for floodable sites and retention ponds under storm and non-storm conditions.*
Image credit: [The Landscape Ecology, Perception, and Design Lab], University of Michigan.



4.3.3.2 Questionnaire design

The questionnaire used in the survey had two sections. The first part displayed visualizations for floodable sites and stormwater ponds under storm and non-storm conditions. Respondents were asked to rate their perceptions of each site under each condition. The visualizations were color-printed in high resolution and laid out on a single page for comparison, with a short statement describing that respondents were seeing a stormwater management practice under different storm conditions (e.g., "This is a basketball court. It holds water only temporarily, after a storm."). The second part of the questionnaire contained questions asking respondents about their experiences with flooding, worry about potential damages caused by stormwater, knowledge and behaviors related to general environmental and stormwater issues, and socio-demographic characteristics. The measures used in this study are explained in detail in Section 4.3.4.1.

To reduce the potential for attention fatigue or effects of visualization ordering, we created eight sets of questionnaires with different visualizations and respondents were randomly assigned to receive one of the eight sets. Each set had one floodable site and five randomly ordered stormwater pond landscapes. A balanced assignment of visualizations among the questionnaire sets ensured that each set contained varied design options (Li et al., 2022).

4.3.3.3 Survey procedure

We administered the survey via the US postal mail in 2019. To increase the response rate, we first introduced the project and upcoming survey by postcard. Next, we mailed the questionnaire with an explanatory letter, an informed consent document, a pre-paid return envelope, and a $1 pre-incentive. The letter provided information about the project and survey and invited a household member at least 18 to participate. A US $10 token of appreciation was offered to respondents who completed and returned the survey.

4.3.4 Data analysis

The overall survey response rate was 24.2% (974/4032). We excluded respondents who did not provide information on their addresses to confirm that they were inside our sampling area. We used this sample (n = 884) in subsequent data analysis. We used R 4.0.2 (R Core Team, 2020) for data analysis.

4.3.4.1 Measures

To address the research questions, we focused on three independent variables: 1) flood risk perception, 2) perceived safety of floodable sites under the storm condition, and 3) perceived safety of retention ponds under the storm condition.

To operationalize these variables, we used the following items. Regarding flood risk, respondents rated how much they would worry about potential damages to their home or property when noticing standing water caused by water from rain or melting snow near home on a 4-point Likert scale (Do not worry at all = 1, Worry a little = 2, Worry some = 3, Worry a lot = 4). Perceived safety of floodable sites and stormwater ponds was measured by each respondent's rating of the site as shown in the questionnaire on a 5-point Likert scale (Dangerous = 1, Somewhat dangerous = 2, Neither = 3, Somewhat safe = 4, Safe = 5). Table 4.1 summarizes the explanatory variables in our analysis.

Table 4.1 *Coding of explanatory variables for data analysis.*
Including experiences with localized flooding and other contextual and socio-demographic fact

Variable	**Mean (SD)**	**Percent of response**	**Description**
Frequency of noticing standing water near home [a]	1.93(0.66)		Integral variable: range 1-4, where 1 indicates "never" and 4 indicates "always".
Contextual factors			
Stormwater-related property damage		21.9	Dummy variable: 1 indicates that a respondent had spent money due to damages caused by stormwater in any locations including basement, home, driveway, and yard in the past 2 years.
Living in high flood hazard areas		52.1	Dummy variable: 1 indicates that a respondent was sampled from strata with high flood hazard based on FEMA hazard maps.
Perceived home location relative to flood zone		4.5	Dummy variable: 1 indicates that a respondent thought their home located in officially designated flood zone.
Knowledge of local water quality	2.28(0.94)		Categorical variable: range 1-4, where 1 is knowing nothing about water quality in nearby lakes, rivers, and streams and 4 indicates knowing a lot.
Participation in activities to address stormwater management issues		16.7	Dummy variable: 1 indicates that a respondent had acted to influence issues or policy related to stormwater management in their community in the past two years.
Participation in activities to promote stormwater management		21.3	Dummy variable: 1 indicates that a respondent had supported flooding or stormwater management specifically through donation, volunteering, organization leadership, or voting in the past two years.
Participation in activities to promote environmental sustainability in general		73.0	Dummy variable: 1 indicates that a respondent had supported environmental sustainability generally through donation, volunteering, organization leadership, or voting in the past two years.
Socio-demographic factors			
Age	51.73(18.80)		Measured as an interval (18-103 years old)
Gender		57.2	Dummy variable: 1 indicates that a respondent was female
Race		19.6	Dummy variable: 1 indicates that a respondent was non-white
Education attainment	3.80(1.16)		Measured as an interval: 1 = Less than high school, 2 = High school or equivalent, 3 = Some college or Associate's degree, 4 = Bachelor's degree, 5 = Post-graduate degree
Household Income	4.01(2.19)		1 = Less than $20k, 2 = 20k-35k, 3 = 35k-50k, 4 = 50k-65k, 5 = 65k-80k, 6 = 80k-100k, 7 = More than 100k
Have children of 12 or younger in the household			Dummy variable: 1 indicates that a respondent's household had children of 12 or younger

Notes: [a] Measured as a composite item based on the average ratings across the frequency of noticing flooding or standing water in five locations: home driveway, home yard, neighbor's property, street, and nearby block, in the past two years when there was rain or snow melting. The original separate ratings were based on a 4-point Likert scale (Never =1, Sometimes = 2, Often =3, Always = 4). Cronbach's alpha for the scale was 0.81.

4.3.4.2 Statistical analysis

We examined descriptive statistics for: experience of localized flooding, stormwater-induced property damage in the past, knowledge and involvement of general environmental and stormwater-specific issues, and socio-demographic characteristics. We excluded "perceived home location relative to flood zone" as an explanatory variable in further data analysis due to its low variability: while 52.1% of sampled respondents lived in high flood hazard areas, only 4.5% identified themselves as living in an officially designated flood zone. We also calculated descriptive statistics to compare the perceived safety of floodable sites and stormwater ponds under storm and non-storm conditions. Specifically, perceived safety of stormwater ponds was averaged across ratings for the five pond landscapes each respondent saw.

We conducted multiple linear regression modeling to test the effects of experience of localized flooding, as well as other contextual and socio-demographic factors on 1) flood risk perception, 2) perceived safety of floodable sites under the storm condition, and 3) perceived safety of stormwater ponds under the storm condition, using *p-value < 0.05* as the threshold of significance. To model perceived safety of floodable sites and stormwater ponds under the storm condition, we controlled for perceived safety under the non-storm condition for both NBS practices (i.e., dry floodable sites and typical-water-level ponds). We then calculated and presented the unstandardized (b) and standardized (β) coefficients for each of the three models.

4.4 Results

4.4.1 Survey respondents' profile

The socio-demographic characteristics of the 884 survey respondents were similar to the characteristics of the study area population (Table 4.2). Given that we recruited only household members who were at least 18 years of age and excluded census block groups with a median age of less than 25, we expected our respondents to be older than the study area population.

Table 4.2 *Respondents to our mail survey in three cities compared with the study area population.*

	Survey Respondents (n = 884)	***Study area population*** [a]
	%	**%**
Age (18-103)		
18-44	41.3	50.2
45-64	28.9	30.6
65 and above	29.9	19.2
Gender (% Female)	57.2	52.3
Race (% Non-white)	19.6	23.9 [b]
Less than high school education	3.5	9.0 [c]
Have children under 12 in the household	16.4	19.9 [d]
Household income below $35k	33.0	33.8 [e]

Notes: [a] Study area population data are pooled five-year estimates (2015–2019) from the American Community Survey (Census Bureau, 2019). Data were aggregated across 378 census block groups that comprise the four strata in the sampling frame; [b] % of non-white of all residents in study area census block groups; [c] Include only residents of 25 years of age and older; [d] % of residents of 14 years of age and younger in all residents in sampling area census block groups; [e] percentage of households with income less than $34,999 in the past 12 months (in 2019 inflation-adjusted dollars), average median household income of study area census block groups is $60968.36, and median household income of survey respondents is 50k-65k.

4.4.2 Descriptive results

4.4.2.1 Flood risk perception

Fewer than a third of respondents indicated that they did not worry at all about potential property damage when noticing standing water or flooding near their home (Table 4.3).

Table 4.3 *Respondents' flood risk perception.*
Measured by their indicated level of worry about potential property damage when noticing standing water or flooding near home.

Worry about potential stormwater-related damage ***N* = 884**	
Do not worry at all = 1	32.2%
Worry a little = 2	30.0%
Worry some = 3	24.8%
Worry a lot = 4	11.2%
Did not respond	1.8%

4.4.2.2 Perceived safety of floodable sites and stormwater ponds

Comparing storm vs. non-storm conditions, for both practices, perceived safety was generally lower under the storm condition. Inundated floodable sites were perceived as significantly less safe than in the typical dry state (*paired t-test, 95% CI [-1.79, -1.60], $p < 0.000$*) (Table 4.4). High-water-level stormwater ponds were also perceived as significantly less safe than under the typical water level (*paired t-test, 95% CI [-1.10, -0.97], $p < 0.000$*).

Table 4.4 *Mean scores (SD) for perceived safety of different NBS practices under storm and non-storm conditions.*

	Perceived safety of NBS	
	Under the non-storm condition	***Under the storm condition***
	Dry	*Inundated*
Floodable sites	4.23 (1.09)	2.54 (1.27)
	Typical water level	*High water level*
Stormwater ponds	3.92 (1.01)	2.88(1.10)

Comparing stormwater ponds and floodable sites, on average, stormwater ponds under the typical water level were perceived as significantly less safe than floodable sites under the dry condition (*paired t-test, 95% CI [-0.39, -0.22], $p < 0.000$*). In contrast, with temporary stormwater detention, stormwater ponds under the high water level were perceived as significantly safer than inundated floodable sites (*paired t-test, 95% CI [0.26, 0.45], $p < 0.000$*).

4.4.3 Model results

4.4.3.1 Does community members' experience of localized flooding affect their perceived flood risks? What other contextual and socio-demographic factors may have an impact?

Respondents who more frequently noticed standing water or flooding near their homes indicated significantly greater worry about potential damages caused by stormwater (Table 4.5a). Respondents who had stormwater-related property damage in the past two years, participated in activities addressing stormwater management issues in the past two years, or knew more about local water quality, also indicated significantly greater worry. Moreover, respondents who were female or participated in activities to promote general environmental sustainability in the past two years indicated significantly less worry.

4.4.3.2 Is perceived safety of floodable sites under the storm condition affected by experiences of localized flooding? What other contextual and socio-demographic factors may also have effects?

Respondents who more frequently noticed standing water or flooding near their homes perceived inundated floodable sites as significantly less safe (Table 4.5b). Respondents who were female or sampled from high flood hazard areas also perceived inundated floodable sites as significantly less safe. In addition, perceived safety of floodable sites under the dry condition had significant positive effects – floodable sites that were perceived as safer when dry were also perceived as safer with stormwater detention.

4.4.3.3 What contextual and socio-demographic factors may affect perceived safety of stormwater ponds under the storm condition?

Respondents who were female, non-white, and those with children under the age of 12 in their household perceived stormwater ponds under high water levels to be significantly less safe (Table 4.5c). In contrast, older respondents perceived stormwater ponds under high water levels to be significantly safer. Furthermore, stormwater ponds that were perceived as safer under the typical water level were also perceived as safer under high water levels.

Table 4.5 *Results from multiple linear regression models for (a) flood risk perception, (b) perceived safety of inundated floodable sites, controlling for perceived safety in the dry condition, and (c) perceived safety of stormwater ponds under the high water level.*
*Controlling for perceived safety under typical water level. B(SE) denotes the unstandardized coefficients and standard errors, β denotes the standardized coefficients (*** p-value < 0.001, ** p-value < 0.01, * p-value < 0.05).*

	(a) Flood risk perception		**(b) Perceived safety of floodable sites**		**(c) Perceived safety of stormwater ponds**	
	B(SE)	β	B(SE)	β	B(SE)	β
Frequency of seeing flooding or standing water	0.40(0.05)***	0.26	-0.14(0.07)*	-0.07	-0.06(0.05)	-0.04
Had stormwater-related property damage	0.69(0.08)***	0.29	0.04(0.11)	0.04	0.05(0.08)	0.02
Sampled from high flood hazard area	-0.04(0.06)	-0.02	-0.22(0.09)*	-0.17	-0.09(0.06)	-0.04
Knowledge of local water quality	0.08(0.04)*	0.07	0.08(0.05)	0.06	0.04(0.04)	0.04
Participation in activities to address stormwater management issues	0.22(0.09)*	0.08	-0.01(0.13)	-0.01	0.11(0.09)	0.04
Participation in activities to promote stormwater management	-0.04(0.09)	-0.02	0.06(0.12)	0.05	0.01(0.08)	0.00
Participation in activities to promote general environmental sustainability	-0.17(0.08)*	-0.07	-0.02(0.11)	-0.02	0.02(0.08)	0.01
Socio-demographic factors						
Age	-0.00(0.00)	-0.01	0.00(0.00)	0.04	0.01(0.00)**	0.09
Gender (Female)	0.19(0.07)**	0.09	-0.22(0.09)*	-0.18	-0.24(0.06)***	-0.11
Race (Non-white)	0.14(0.08)	0.06	-0.05(0.11)	-0.04	-0.29(0.08)***	-0.10
Education	-0.00(0.03)	-0.01	0.04(0.05)	0.03	-0.02(0.03)	-0.02
Household Income	0.01(0.02)	0.02	0.04(0.02)	0.07	0.02(0.02)	0.03
Have children under age 12 in the household	0.10(0.09)	0.04	-0.05(0.12)	-0.04	-0.23(0.09)**	-0.08
Perceived safety of floodable sites in the dry condition			0.35(0.04)***	0.30		
Perceived safety of ponds under the typical water level					0.65(0.03)***	0.58
Observations	780		774		783	
R-squared	0.238		0.136		0.401	
Adjusted R-squared	0.225		0.120		0.390	

4.5 Discussion

We investigated the perceived risk of localized flooding and perceived safety of NBS for urban stormwater management interventions, using "risk as feelings" to frame our research questions. We studied how flood risk perceptions and perceived safety of NBS practices are affected by experiences of localized flooding, as well as other contextual and socio-demographic factors. Further, to shed light on how different design solutions for storing stormwater may affect perceived safety of NBS, we compared two types of practices: floodable sites, a novel NBS practice that temporarily inundates urban landscapes, and stormwater retention ponds, a familiar NBS practice that always has water.

We learned that respondents with more experiences of flooding near home worried more about flooding and perceived inundated floodable sites as less safe. Respondents also perceived both innovative floodable sites and conventional stormwater ponds as less safe under storm conditions than under typical, non-storm conditions. However, they generally perceived high-water-level ponds as safer than inundated floodable sites. These results call attention to public acceptance of floodable sites as a stormwater management approach, especially in communities that have experienced flooding in the past.

This study is not the first to draw on "risk as feelings" to examine flood experience and flood risk perception. However, it distinguishes itself from other studies in four ways: by 1) relating experiences of minor localized flooding to risk perceptions of urban flooding and its management, 2) identifying factors that may affect risk perception of localized flooding, 3) revealing how NBS that introduce visible stormwater dynamics into everyday urban landscapes can elicit safety concerns, and 4) offering insights into how NBS design and adoption may better address community members' perception to gain acceptance and support. We next elaborate on these four aspects.

First, we demonstrated the relevance of everyday experiences of stormwater in understanding flood risk perception. Prior studies have shown that personal experience of flooding is linked with greater perceived risks of major riverine and coastal flooding (Botzen et al., 2009; Kellens, Zaalberg, Neutens, Vanneuville, & De Maeyer, 2011; O'Neill et al., 2016). These studies used "risk as feelings" to argue that witnessing disastrous events may encourage concrete imaginations of low-probability extreme events. Importantly, we found that more frequent experience of standing water and flooding in one's everyday landscape surroundings also was associated with greater worry about flooding. This finding suggests that everyday experiences of stormwater can also shape risk perception. As "risk as feelings" implies, intuitive perceptions of risks involve affective processing and do not always reflect the actual magnitude of damage. While we did not measure respondents' feelings, this study provides a basis for further research to examine affective reactions to localized flooding through, for example, the psychometric paradigm (Birkholz et al., 2014).

Second, our findings contribute empirical evidence to understanding what contextual and socio-demographic factors may affect the risk perception of localized urban flooding, which is not adequately studied. Besides experiences of localized flooding, we also found notable effects of prior flood-related damage, gender, and environmental knowledge and behavior. Consistent with research focused on riverine and coastal flooding, respondents in our study perceived greater risks of localized flooding if they were female or recently had stormwater-related property damage (Kellens et al., 2013; Lechowska, 2021). Different from previous studies (Botzen et al., 2009; Kellens et al., 2013), we did not find that education attainment was associated with perceived lower risk. However, our measures related specifically to environmental knowledge offer nuanced insights. In this study, more knowledge about local water quality or participation in activities addressing stormwater management issues (e.g., attending public meetings or making phone calls to influence policy) was associated with greater perceived flood risks. In contrast, participation in activities promoting general environmental sustainability was associated with lower perceived flood risks. Perhaps people who participate in activities to promote general sustainability are concerned about other environmental issues (e.g., carbon reduction, wildlife protection) rather than stormwater management.

We did not find notable effects of flood zone home location on flood risk perception, a factor prior studies found important (Botzen et al., 2009; O'Neill et al., 2016). In our study, flood risk perception did not differ significantly among respondents sampled from high versus low flood hazard areas. First, many respondents were not aware they were living in high flood hazard areas: while 66% of our respondents indicated some degree of worry about potential stormwater-related damage and 22% had actual property damage recently, fewer than 5% identified themselves as living in an officially designated flood zone. Second, the FEMA flood map we used to determine areas of high versus low flood hazards in our sampling frame may be too coarse to accurately reflect localized flooding experiences.

Third, this study demonstrates that community members may perceive NBS practices that introduce visible stormwater dynamics into everyday urban landscapes as unsafe. Temporary stormwater storage undermined the perceived safety of both floodable sites, a novel NBS practice designed to inundate urban landscape temporarily, and stormwater retention ponds, a familiar NBS practice always has water. Further, holding more water in stormwater ponds was perceived as safer than inundating floodable sites. People may perceive high-water-level ponds as safer because stormwater ponds are a more familiar and natural-looking practice where water is typically present and water level fluctuations are more expected.

Importantly, our results indicate different potential causes for reduced perceived safety of different NBS practices under the storm condition. For floodable sites, the low perceived safety under the storm condition might be explained by negative affective responses to their flooding-like inundation rather than by concerns about actual threats to property or personal safety. For example, while more frequent experience of localized flooding was associated with lower perceived safety, prior stormwater-related damage or having children under 12 in the household showed little effects. Reflecting on these results through the “risk as feelings” framework, we speculate that people who often see standing water or flooding near home may have stronger affective reactions toward it, and they may intuitively perceive inundated floodable sites, which look like localized flooding, as more unsafe.

In contrast, the low perceived safety of high-water-level retention ponds may relate more to personal safety and landscape preferences. For example, respondents with young children in their household perceived stormwater ponds under high water levels as significantly less safe, which can be explained by concerns about drowning hazards (Bastien, Arthur, & McLoughlin, 2012; Jarvie, Arthur, & Beevers, 2017; Williams et al., 2019). In addition, unlike floodable sites, the perceived safety of stormwater ponds was related to age and race, with older or white respondents perceiving them as safer. Given that retention ponds have been used for managing stormwater for decades, people of different ethnic groups or generations may have different experiences of neighborhood landscapes as well as cultural traditions and social norms that affect their perceptions.

Notably, female respondents indicated greater worry about flooding and lower perceived safety of floodable sites and stormwater ponds. Existing literature on flood risk perception often points to the greater vulnerability of females given their generally lower socioeconomic status and physical capacity (Kellens et al., 2013; Lechowska, 2021). Our study suggests a new interpretation: females might have stronger affective reactions toward visible disturbances in their everyday landscape surrounding, possibly because they often take more responsibilities in upkeeping and caring for the environment of their homes and communities (Riedman, 2021).

Finally, this study has several implications for urban flood risk management and NBS development for flood resilience. First, we call attention to the need to better assess chronic localized flooding in urban stormwater management. As our findings suggest, experiences of localized flooding can increase community members' worry about flood risks and affect their perceptions of proposed NBS practices. However, compared to riverine and coastal flooding, localized urban flooding is more difficult to predict in part because it is caused not only by precipitation and topographic position but also by less obvious factors such as infrastructure inadequacies and connected impervious surfaces. Publicly available data are needed to more precisely map areas prone to pluvial flooding at the local scale and effectively communicate the characteristics and risks of localized flooding to the public. Second, different from experts who know about stormwater management function, community members may intuitively perceive visible stormwater dynamics in NBS practices as unsafe, especially when they have experienced localized flooding. Interestingly, knowledge or involvement in stormwater and general sustainability issues was not associated with the perceived safety of either floodable sites or stormwater ponds in this study. Perceived risks of stormwater detention in everyday urban landscapes may outweigh considerations about its management function. Therefore, practitioners should avoid assuming that visible stormwater dynamics introduced by NBS will have positive, educational impacts, especially for novel practices like floodable sites. Such benefits may only be realized through additional outreach programs and intentional design choices that respond to community perceptions. For example, the design of floodable sites can incorporate interactive signage systems or storage zones with varied elevations or landforms to convey the stormwater management intention and stimulate positive affective experiences. Third, renovating familiar NBS practices (e.g., retention ponds) to increase their storage capacity may be more preferable to developing novel NBS practices that temporarily inundate urban spaces (e.g., floodable sites) given public concerns about safety. Although engagement with local communities should anticipate possibly greater concerns of different socio-demographic groups (e.g., females, people of color, and families with young children). Lastly, regular maintenance of the appearance of NBS can enhance their perceived safety. Floodable sites and stormwater ponds that were perceived as safer under the typical condition were also perceived as safer when stormwater storage occurs. Perhaps stormwater dynamics that feel less safe are associated with neglect and malfunction, since perceived safety has been found to be explained by perceived care (Nassauer, Webster, Sampson, & Li, 2021).

4.5.1 Limitations

This study has several limitations. First, we treated floodable sites and stormwater ponds homogeneously in our analysis, without further accounting for various design choices. The effects of design choices for pond landscape elements on perceived safety were examined in a different study (Li, Nassauer, & Webster, 2022). This study included only two types of land uses for floodable sites and assigned each respondent to see visualizations for only one type. Future research may test a variety of land uses and design alternatives within land uses for floodable sites. Besides parking lots and basketball courts – the land uses in our study, potential land uses for floodable sites include minor streets, blue roofs, parks, and urban plazas. Further, studies can also examine how the frequency of inundation and community members' use of floodable sites in the dry weather may affect their perceptions.

Second, we used FEMA flood maps to identify census blocks with low and high flood hazards in our sampling frame. However, our survey results showed low correlations between the high flood hazards group and experiences of localized flooding, flood risk perception, and prior stormwater-related damage. The FEMA flood map used coarse resolution spatial data to assess riverine and coastal flooding and did not account for fine-scale environmental characteristics contributing to localized flooding in cities (e.g., buildings, stormwater infrastructure, topography) (National Academies of Sciences & Medicine, 2019). To more accurately describe the relationship between localized flooding, community members' experiences, and flood risk perception, future studies may use finer-scale data and ideally, localized flood report data, to assess actual localized flooding risks.

Third, this study only examines the effects of experiences of localized flooding at the individual level. Given that some neighborhoods and communities are more prone to localized flooding than others, future research may investigate whether flood experiences at the neighborhood or community level also affect individuals' risk perceptions. Furthermore, investigations may also examine whether experiences of localized flooding at the neighborhood or community level are associated with socio-demographic characteristics. This question is not only important for addressing environmental injustice (Eakin, Parajuli, Hernández Aguilar, & Yogya, 2022; National Academies of Sciences & Medicine, 2019), but can also have implications for NBS development in different communities and their adaptive capacity.

4.6 Conclusions

Drawing on "risk as feelings," this paper provides new insights into how community members perceive localized flooding and stormwater detention in nature-based solutions (NBS). Many respondents had the experience of seeing standing water or flooding near their homes and indicated some degree of worry about potential property damage caused by stormwater. Furthermore, such experience was associated with lower perceived safety of floodable sites, a novel NBS practice that temporarily inundates urban spaces to manage stormwater. We assert that urban flood risk management needs to engage with social science theories such as "risk as feelings" to account for peoples' affective responses to and intuitive perceptions of noticeable landscape change. For NBS that intervene with the generation, diversion, and collection of stormwater in urban landscapes, the attendant stormwater dynamics can prompt safety concerns among community remembers, with implications for public support for their adoption. Resident informed design and management strategies can improve perceived safety of floodable sites and stormwater ponds renovated with excess storage capacity. We call for inter and trans-disciplinary collaborations in exploring new landscape interventions of NBS to address more extreme rainfalls and aging urban infrastructure. Pervasive adoptions of NBS must consider potential impacts on people's everyday experiences in their neighborhoods and communities, in addition to stormwater management objectives, to gain broad societal support.

References

Alhakami, A. S., & Slovic, P. (1994). A psychological study of the inverse relationship between perceived risk and perceived benefit. *Risk analysis, 14*(6), 1085-1096.

Altarawneh, L., Mackee, J., & Gajendran, T. (2018). The influence of cognitive and affective risk perceptions on flood preparedness intentions: A dual-process approach. *Procedia Engineering, 212*, 1203-1210.

Ambrey, C., Byrne, J., Matthews, T., Davison, A., Portanger, C., & Lo, A. (2017). Cultivating climate justice: Green infrastructure and suburban disadvantage in Australia. *Applied Geography, 89*, 52-60.

Anderson, C. C., & Renaud, F. G. (2021). A review of public acceptance of nature-based solutions: The 'why', 'when', and 'how' of success for disaster risk reduction measures. *Ambio, 50*(8), 1552-1573.

Ashley, R., Gersonius, B., & Horton, B. (2020). Managing flooding: from a problem to an opportunity. *Philosophical Transactions of the Royal Society A, 378*(2168), 20190214.

Axelsson, C., Soriani, S., Culligan, P., & Marcotullio, P. (2021). Urban policy adaptation toward managing increasing pluvial flooding events under climate change. *Journal of Environmental Planning and Management, 64*(8), 1408-1427.

Bastien, N. R. P., Arthur, S., & McLoughlin, M. J. (2012). Valuing amenity: public perceptions of sustainable drainage systems ponds. *Water and Environment Journal, 26*(1), 19-29.

Berndtsson, R., Becker, P., Persson, A., Aspegren, H., Haghighatafshar, S., Jönsson, K., . . . Nilsson, J. (2019). Drivers of changing urban flood risk: A framework for action. *Journal of Environmental Management, 240*, 47-56.

Bertilsson, L., Wiklund, K., de Moura Tebaldi, I., Rezende, O. M., Veról, A. P., & Miguez, M. G. (2019). Urban flood resilience–A multi-criteria index to integrate flood resilience into urban planning. *Journal of Hydrology, 573*, 970-982.

Birkholz, S., Muro, M., Jeffrey, P., & Smith, H. M. (2014). Rethinking the relationship between flood risk perception and flood management. *Science of the Total Environment, 478*, 12-20.

Blecken, G.-T., Hunt III, W. F., Al-Rubaei, A. M., Viklander, M., & Lord, W. G. (2017). Stormwater control measure (SCM) maintenance considerations to ensure designed functionality. *Urban Water Journal, 14*(3), 278-290.

Botzen, W. J., Aerts, J., & van den Bergh, J. C. (2009). Dependence of flood risk perceptions on socioeconomic and objective risk factors. *Water Resources Research, 45*(10).

Bubeck, P., Botzen, W. J. W., & Aerts, J. C. (2012). A review of risk perceptions and other factors that influence flood mitigation behavior. *Risk Analysis: An International Journal, 32*(9), 1481-1495.

Derkzen, M. L., van Teeffelen, A. J., & Verburg, P. H. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green

infrastructure shape adaptation preferences? *Landscape and Urban Planning, 157*, 106-130.
Disse, M., Johnson, T. G., Leandro, J., & Hartmann, T. (2020). Exploring the relation between flood risk management and flood resilience. *Water Security, 9*.
Eakin, H. C., Parajuli, J., Hernández Aguilar, B., & Yogya, Y. (2022). Attending to the social–political dimensions of urban flooding in decision-support research: A synthesis of contemporary empirical cases. *Wiley Interdisciplinary Reviews: Climate Change, 13*(1), e743.
Epstein, S. (1994). Integration of the cognitive and the psychodynamic unconscious. *American psychologist, 49*(8), 709.
Feng, Y., & Nassauer, J. (2022). Community experiences of landscape-based stormwater management practices: A review. *Ambio*.
First Street Foundation. (2022). First Street Aggregated Flood Risk Summary Statistics Version 2.0 (2.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.6498206
Fletcher, T. D., Shuster, W., Hunt, W. F., Ashley, R., Butler, D., Arthur, S., . . . Viklander, M. (2014). SUDS, LID, BMPs, WSUD and more – The evolution and application of terminology surrounding urban drainage. *Urban Water Journal, 12*(7), 525-542.
Flotemersch, J., & Aho, K. (2021). Factors influencing perceptions of aquatic ecosystems. *Ambio, 50*(2), 425-435.
Frantzeskaki, N. (2019). Seven lessons for planning nature-based solutions in cities. *Environmental Science & Policy, 93*, 101-111.
Gobster, P. H., Nassauer, J. I., Daniel, T. C., & Fry, G. (2007). The shared landscape: what does aesthetics have to do with ecology? *Landscape Ecology, 22*(7), 959-972.
Han, S., & Kuhlicke, C. (2019). Reducing hydro-meteorological risk by nature-based solutions: What do we know about people's perceptions? *Water, 11*(12), 2599.
Hobbie, S. E., & Grimm, N. B. (2020). Nature-based approaches to managing climate change impacts in cities. *Philosophical Transactions of the Royal Society B, 375*(1794), 20190124.
Jarvie, J., Arthur, S., & Beevers, L. (2017). Valuing multiple benefits, and the public perception of SUDS ponds. *Water, 9*(2), 128.
Jorgensen, A., Hitchmough, J., & Calvert, T. (2002). Woodland spaces and edges: Their impact on perception of safety and preference. *Landscape and Urban Planning, 60*(3), 135-150.
Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.
Kellens, W., Terpstra, T., & De Maeyer, P. (2013). Perception and communication of flood risks: a systematic review of empirical research. *Risk Analysis: An International Journal, 33*(1), 24-49.
Kellens, W., Zaalberg, R., Neutens, T., Vanneuville, W., & De Maeyer, P. (2011). An analysis of the public perception of flood risk on the Belgian coast. *Risk Analysis: An International Journal, 31*(7), 1055-1068.
Keller, C., Siegrist, M., & Gutscher, H. (2006). The role of the affect and availability heuristics in risk communication. *Risk analysis, 26*(3), 631-639.

Kline, R. B. (2015). *Principles and practice of structural equation modeling*. Guilford publications.

Kuang, D., & Liao, K.-H. (2020). Learning from Floods: Linking flood experience and flood resilience. *Journal of Environmental Management, 271*, 111025.

La Loggia, G., Puleo, V., & Freni, G. (2020). Floodability: A New Paradigm for Designing Urban Drainage and Achieving Sustainable Urban Growth. *Water Resources Management, 34*(10), 3411-3424.

Lechowska, E. (2018). What determines flood risk perception? A review of factors of flood risk perception and relations between its basic elements. *Natural Hazards, 94*(3), 1341-1366.

Lechowska, E. (2021). Approaches in research on flood risk perception and their importance in flood risk management: a review. *Natural Hazards*, 1-36.

Lennon, M., Scott, M., & O'Neill, E. (2014). Urban design and adapting to flood risk: the role of green infrastructure. *Journal of Urban Design, 19*(5), 745-758.

Li, J., & Nassauer, J. I. (2021). Technology in support of nature-based solutions requires understanding everyday experiences. *Ecology and Society, 26*(4).

Li, J., Nassauer, J. I., & Webster, N. J. (2022). Landscape elements affect public perception of nature-based solutions managed by smart systems. *Landscape and Urban Planning, 221*, 104355.

Liao, K.-H. (2012). A theory on urban resilience to floods—a basis for alternative planning practices. *Ecology and Society, 17*(4).

Loewenstein, G. F., Weber, E. U., Hsee, C. K., & Welch, N. (2001). Risk as feelings. *Psychological bulletin, 127*(2), 267.

Lund, N. S. V., Borup, M., Madsen, H., Mark, O., Arnbjerg-Nielsen, K., & Mikkelsen, P. S. (2019). Integrated stormwater inflow control for sewers and green structures in urban landscapes. *Nature Sustainability*, 2(11), 1003-1010.

Mariano, C., & Marino, M. (2018). Water landscapes: from risk management to a urban regeneration strategy. *UPLanD-Journal of Urban Planning, Landscape & environmental Design, 3*(1), 55-74.

McClymont, K., Morrison, D., Beevers, L., & Carmen, E. (2020). Flood resilience: a systematic review. *Journal of Environmental Planning and Management, 63*(7), 1151-1176.

Nassauer, J. I. (2012). Landscape as medium and method for synthesis in urban ecological design. *Landscape and Urban Planning, 106*(3), 221-229.

Nassauer, J. I., Webster, N. J., Sampson, N., & Li, J. (2021). Care and safety in neighborhood preferences for vacant lot greenspace in legacy cities. *Landscape and Urban Planning, 214*, 104156.

National Academies of Sciences, E., & Medicine. (2019). *Framing the challenge of urban flooding in the United States*: National Academies Press.

Netzel, L. M., Heldt, S., Engler, S., & Denecke, M. (2021). The importance of public risk perception for the effective management of pluvial floods in urban areas: A case study from Germany. *Journal of Flood Risk Management, 14*(2), e12688.

O'Donnell, E., Thorne, C., Ahilan, S., Arthur, S., Birkinshaw, S., Butler, D., . . . Glenis, V. (2020). The blue-green path to urban flood resilience. *Blue-Green Systems, 2*(1), 28-45.

O'Donnell, E. C., & Thorne, C. R. (2020). Drivers of future urban flood risk. *Philosophical Transactions of the Royal Society A, 378*(2168), 20190216.

O'Neill, E., Brereton, F., Shahumyan, H., & Clinch, J. P. (2016). The impact of perceived flood exposure on flood-risk perception: The role of distance. *Risk analysis, 36*(11), 2158-2186.

Palazzo, E. (2019). From water sensitive to floodable: Defining adaptive urban design for water resilient cities. *Journal of Urban Design, 24*(1), 137-157.

R Core Team. (2020). R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing.

Riedman, E. (2021). Othermothering in Detroit, MI: understanding race and gender inequalities in green stormwater infrastructure labor. *Journal of Environmental Policy & Planning, 23*(5), 616-627.

Rogers, B., Bertram, N., Gersonius, B., Gunn, A., Löwe, R., Murphy, C., . . . Wong, T. (2020). An interdisciplinary and catchment approach to enhancing urban flood resilience: a Melbourne case. *Philosophical Transactions of the Royal Society A, 378*(2168), 20190201.

Sevenant, M., & Antrop, M. (2011). Landscape representation validity: a comparison between on-site observations and photographs with different angles of view. *Landscape Research, 36*(3), 363-385.

Sheppard, S. R. (2005). Landscape visualisation and climate change: the potential for influencing perceptions and behaviour. *Environmental Science & Policy, 8*(6), 637-654.

Silva, M. M., & Costa, J. P. (2018). Urban floods and climate change adaptation: The potential of public space design when accommodating natural processes. *Water, 10*(2), 180.

Slovic, P., Finucane, M. L., Peters, E., & MacGregor, D. G. (2004). Risk as analysis and risk as feelings: Some thoughts about affect, reason, risk, and rationality. *Risk Analysis: An International Journal, 24*(2), 311-322.

Slovic, P., MacGregor, D. G., & Peters, E. (1998). Imagery, affect, and decision making.

Tempels, B., & Hartmann, T. (2014). A co-evolving frontier between land and water: dilemmas of flexibility versus robustness in flood risk management. *Water international, 39*(6), 872-883.

Venkataramanan, V., Lopez, D., McCuskey, D. J., Kiefus, D., McDonald, R. I., Miller, W. M., . . . Young, S. L. (2020). Knowledge, attitudes, intentions, and behavior related to green infrastructure for flood management: A systematic literature review. *Science of the Total Environment, 720*, 137606.

Wachinger, G., Renn, O., Begg, C., & Kuhlicke, C. (2013). The risk perception paradox—implications for governance and communication of natural hazards. *Risk analysis, 33*(6), 1049-1065.

Williams, J. B., Jose, R., Moobela, C., Hutchinson, D. J., Wise, R., & Gaterell, M. (2019). Residents' perceptions of sustainable drainage systems as highly functional blue green infrastructure. *Landscape and Urban Planning, 190.*

Chapter 5 Conclusions

This dissertation responds to the growing interest in exploring novel nature-based solutions (NBS) that combine green and grey components for climate change adaptation (Castellar et al., 2021; Grimm et al., 2015; Seddon et al., 2020). Positioning novel NBS within everyday urban landscapes, this work contributes to the understanding of novel NBS' social impacts and services. It investigates how community members perceive novel NBS and offers insights into addressing community experiences through design and management.

Chapter 2 builds a conceptual basis for considering how novel NBS managed by smart systems can affect everyday landscape experiences, which it argues to be an essential cultural ecosystem service. Novel NBS can actively intervene with environmental processes (e.g., manipulate water storage in retention ponds) or automatically conduct maintenance (e.g., control the irrigation of green roofs), noticeably and pervasively changing how everyday urban landscapes look. As this chapter elucidates, while adopting smart systems to manage NBS can increase specific ecosystem services, community members may not perceive the attendant changes as positive and desirable. Such perceptions can further affect support for adoption of NBS. Since landscape experiences cannot be directly inferred from environmental functions, the development of novel NBS must pay attention to their noticeable characteristics to better address local community members' perceptions. Ensuring pleasant everyday experiences may increase the social-cultural values of NBS and encourage people to accept and support novel practices.

Chapter 3 investigates how immediately perceivable landscape characteristics affect community members' perceptions of novel NBS, using smart ponds as an example. This chapter has two main findings. First, smart management systems' manipulations of the water level decreased the perceived attractiveness, neatness, and safety of retention ponds, a widely employed stormwater control measure. Furthermore, high and low water levels affected these perceptions differently. Respondents generally perceived ponds under low water levels as less attractive but safer than under high water levels. Second, other microscale landscape elements affected by design and management choices (i.e., surrounding plants, landuse context, basin slopes) moderated the effects of water level manipulations on perception. For example, respondents perceived smart ponds in greenspace and residential contexts as more attractive, neater, and safer than those in a commercial context. Adopting smart systems to manage retention ponds may undermine everyday landscape experiences and related social-cultural benefits despite increased stormwater regulating services. The development of smart ponds can use design and management choices for microscale elements to offer more pleasant landscape experiences to reduce such a trade-off and gain support from local communities for their adoption.

Chapter 4 investigates how experiences with localized flooding and other contextual and socio-demographic factors affect community members' perceived flood risks and perceived safety of innovative vs. traditional NBS practices. This chapter draws on "risk as feelings" to consider how people may intuitively perceive standing water in everyday urban landscapes, whether it results from overwhelmed drainage systems or intentional stormwater detention. It found that more frequently noticing standing water near one's home was associated with greater worry about potential stormwater-related damage. It was also associated with lower perceived safety of floodable sites, a novel NBS practice that temporarily inundates urban spaces. However, experiences with localized flooding did not affect perceived safety of stormwater retention ponds, a familiar NBS practice, under high water levels. Furthermore, respondents generally perceived high-water-level ponds as safer than inundated floodable sites. Other contextual and personal factors (e.g., past stormwater-related property damage, gender, race) also influenced flood risk perception and the perceived safety of NBS. These findings have implications for public acceptance of floodable sites as a stormwater management approach in communities that have experienced flooding in the past. They also suggest the need to consider local communities' experiences with flooding and socio-demographic characteristics when developing NBS.

This dissertation can be extended in several ways.

First, this research used visualizations to collect perception data, which only accounted for the visual perception of NBS. Other sensory pathways such as smell and touch can also influence perceptions of aquatic systems (Flotemersch & Aho, 2021) and nature experiences in general (Franco, Shanahan, & Fuller, 2017). This could be a further concern for novel NBS practices for stormwater management since they may lead to dampened or saturated soils and sediments, which can produce odor and increase humidity. Moreover, the visualizations used in this research depicted discrete water conditions and did not reflect the speed of change between different states. This can feel different from real-world experiences. For example, stormwater ponds' water level can also rise or fall greatly due to extended rains and droughts, but the manipulation of water level by smart systems is likely to be more rapid and unexpected (e.g., having low water level during rainy periods). Future research may investigate in-situ experiences through, for example, on-site interviews in community where smart systems have been adopted for some time, or immersive virtual reality techniques. Moreover, qualitative research may further our understandings of why community members perceive certain noticeable change in the landscape unpleasant or unsafe.

Second, this study only examines perceptions and experiences of individual community members. Given that experiences of both localized flooding and everyday landscapes are shared to some degree within a neighborhood, future research should pay more attention to how experiences and support may vary at the neighborhood level. Furthermore, investigations may also examine how neighborhood experiences of climate change impacts (e.g., urban flooding) and perceptions of NBS may be associated with socio-demographic characteristics. These questions are not only important for addressing environmental injustice (Eakin, Parajuli, Hernández Aguilar, & Yogya, 2022; National Academies of Sciences & Medicine, 2019), but can also have implications for NBS development in different communities and their adaptive capacity.

Third, this research focused on community members' experiences and did not quantify other benefits of NBS. Future research could use the ecosystem services framework to holistically evaluate NBS proposed in everyday urban landscapes through inter and trans-disciplinary collaborations (Nesshover et al., 2017). Growing research is exploring how to account for both monetary and socio-cultural values of NBS for climate change adaptation (e.g., Derkzen, van Teeffelen, & Verburg, 2017, Raymond et al., 2017). But there remain challenges to assess and address services across different spatial scales from cultural services that reflect everyday experiences at the human scale to regulating or provisioning services at local and regional scales that are inherent to their functions.

Besides NBS for stormwater management examined in this dissertation, novel practices aimed at other functions are also increasingly discussed and implemented, as in the examples of green roofs and green walls, solar and wind farms in open spaces, and high-precision urban agriculture (Castellar et al., 2021; Goddard et al., 2021). While the primary goal of NBS rarely concerns the experiences they offer to people, disregarding this issue risks causing unintended consequences. Interventions that will visibly change everyday landscapes, including those aimed to provide more ecosystem services and support climate change adaptation, may also prompt affective responses for better or worse.

Some researchers have warned against framing NBS as always offering various environmental and social benefits (Keeler et al., 2019; Osaka et al., 2021). This dissertation supports such an insight: NBS are not always perceived as positive. Rather, they can introduce noticeable yet unfamiliar changes in the landscape, prompting safety concerns and diminishing the amenity value of urban nature. At the same time, this dissertation points to the potential for using planning, design, and management choices that affect microscale landscape elements to moderate community members' perceptions of novel NBS and offer more pleasant everyday experiences. It also suggests the need to tailor community engagement and outreach strategies to account for local experiences with environmental issues and socio-demographic characteristics.

Given the rapid development of innovative technologies and the urgent need to conserve natural capital, we can expect growing exploration and adoption of novel NBS. This dissertation stresses the need to understand community members' perceptions and better align targeted functions of novel NBS with what people value in everyday landscape surroundings. This requires collaborations across social and natural sciences, engineering, humanities, and landscape planning and design. Expanding the role of everyday landscape experiences will not only imbue novel NBS with cultural-social benefits but also encourage societal support for proactive landscape changes that are urgently needed for climate change adaptation and long-term human well-being.

References

Castellar, J. A. C., Popartan, L. A., Pueyo-Ros, J., Atanasova, N., Langergraber, G., Säumel, I., Corominas, L., Comas, J., & Acuña, V. (2021). Nature-based solutions in the urban context: Terminology, classification and scoring for urban challenges and ecosystem services. *Science of The Total Environment*, *779*, 146237.

Derkzen, M. L., van Teeffelen, A. J., & Verburg, P. H. (2017). Green infrastructure for urban climate adaptation: How do residents' views on climate impacts and green infrastructure shape adaptation preferences? *Landscape and Urban Planning, 157*, 106-130.

Flotemersch, J., & Aho, K. (2021). Factors influencing perceptions of aquatic ecosystems. *Ambio, 50*(2), 425-435.

Franco, L. S., Shanahan, D. F., & Fuller, R. A. (2017). A review of the benefits of nature experiences: more than meets the eye. *International journal of environmental research and public health, 14*(8), 864.

Goddard, M. A., Davies, Z. G., Guenat, S., Ferguson, M. J., Fisher, J. C., Akanni, A., . . . Dallimer, M. (2021). A global horizon scan of the future impacts of robotics and autonomous systems on urban ecosystems. *Nat Ecol Evol, 5*(2), 219-230.

Grimm, N. B., Cook, E. M., Hale, R. L., & Iwaniec, D. M. (2015). Benefits and challenges of built, natural or hybrid system function. In *The Routledge handbook of urbanization and global environmental change* (pp. 227-236).

Keeler, B. L., Hamel, P., McPhearson, T., Hamann, M. H., Donahue, M. L., Prado, K. A. M., Arkema, K. K., Bratman, G. N., Brauman, K. A., & Finlay, J. C. (2019). Social-ecological and technological factors moderate the value of urban nature. *Nature Sustainability*, *2*(1), 29–38.

Nesshover, C., Assmuth, T., Irvine, K. N., Rusch, G. M., Waylen, K. A., Delbaere, B., . . . Wittmer, H. (2017). The science, policy and practice of nature-based solutions: An interdisciplinary perspective. *Sci Total Environ, 579*, 1215-1227.

Osaka, S., Bellamy, R., & Castree, N. (2021). Framing "nature-based" solutions to climate change. *WIREs Climate Change*, *12*(5).

Raymond, C. M., Breil, M., Nita, M. R., Kabisch, N., de Bel, M., Enzi, V., . . . Cardinaletti, M. (2017). *An impact evaluation framework to support planning and evaluation of nature-based solutions projects. Report prepared by the EKLIPSE Expert Working Group on Nature-Based Solutions to Promote Climate Resilience in Urban Areas*: Centre for Ecology and Hydrology.

Seddon, N., Chausson, A., Berry, P., Girardin, C. A. J., Smith, A., & Turner, B. (2020). Understanding the value and limits of nature-based solutions to climate change and other global challenges. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *375*(1794), 20190120.