A framework to diagnose factors influencing proenvironmental behaviors in water-sensitive urban design

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The ongoing challenge of maintaining and improving the quality of water that leaves urban stormwater systems is often addressed using technical rather than social solutions. The need for investment in often expensive water infrastructure can be reduced through better investing in promoting human behaviors that protect water quality as part of water-sensitive urban design (WSUD) initiatives. Successfully achieving this requires understanding factors that influence adoption of proenvironmental behaviors. We review past studies examining this topic and identify that factors influencing adoption of proenvironmental behaviors relevant to WSUD commonly fall into four domains: proenvironmental values and norms, awareness and knowledge of environmental problems and the actions that can address them, proximity and place-based identity, and life-stage and lifestyle factors. We propose the VAIL (values, awareness, identify, lifestyle) framework, based on these four domains and able to be contextualized to specific water-quality problems and individual communities, to assist in diagnosing factors influencing adoption of proenvironmental behaviors. We demonstrate the applicability of the framework in a case study examining adoption of gardening practices that support water quality in Canberra, Australia. We developed 22 locally relevant VAIL indicators and surveyed 3,334 residents to understand engagement in four water-friendly gardening behaviors that help improve water quality in local lakes. In regression modeling, the indicators explained a significant amount of variance in these behaviors and suggested avenues for supporting greater adoption of these behaviors. Predictor variables across all four VAIL domains were significant, highlighting the importance of a multidomain framework.

proenvironmental behavior | water quality | water-sensitive urban design | urban garden management

Urban stormwater runoff affects water quality in freshwater systems worldwide (1, 2). Traditional concrete channel-based stormwater infrastructure, together with large areas of impervious surfaces in cities, increases water runoff, transporting pollutants into waterways and reducing water quality (1). To address this, many cities are implementing water-sensitive urban design (WSUD). WSUD seeks to improve the quality of water exiting urban areas, improve amenity for urban residents, and improve environmental health in cities (3). It does this by slowing the speed of runoff and managing pollutant inputs through actions including naturalizing stormwater channels and establishing environmentally sensitive infrastructure such as bioretention systems, swales and buffer strips, porous paving, constructed urban wetlands, and rainwater tanks (4–6). Termed WSUD in the United States and Australia (7, 8), in other countries this approach is variously labeled sustainable drainage systems, sustainable urban stormwater management, integrated urban water management, low-impact development, and low-impact urban design and development (5, 7, 9). WSUD sits as a water-management-focused discipline within broader nature- and environment-led engineering and design disciplines, such as ecosystem-based adaptation, ecological design, and socioecological systems analysis (10, 11). WSUD initiatives can achieve significant improvements in water quality (2), although they do not always achieve their objectives (4).

WSUD initiatives typically implement technologically rather than socially based solutions (12), reflecting the "hydrosocial contract" (13) in which water management is considered a technical engineering challenge, rather than one to be addressed by changing human behavior. While many WSUD advocates identify a need for public support for, and acceptance of, WSUD, fewer envision changing human behavior as a key way of achieving improved water quality (2, 5, 7, 13–15). This is surprising, given the success of behavior-change campaigns in achieving reduced household water consumption in many cities; these campaigns can reduce water consumption more cost-effectively than alternatives such as large-scale water recycling, desalination, or dam projects (16). Similar potential exists to improve water quality by changing the behaviors of urban residents: Urban residences can contribute substantially to water-quality problems (17) with fertilizer application, sediment, and organic materials (leaves and grass clippings) as major sources of nutrients in urban runoff (18). Thus, inhabitants can improve

Significance

Urban stormwater runoff contributes significantly to water-quality problems in freshwater systems worldwide. Water-sensitive urban design (WSUD) typically addresses this through construction of ecologically sensitive infrastructure but rarely considers how encouraging change in human behaviors could contribute to improving water quality. The effectiveness of WSUD can be increased by encouraging adoption of proenvironmental behaviors that prevent water-quality deterioration at the source and improve the quality of water leaving stormwater systems, in turn reducing the investment needed in water-related infrastructure. The VAIL (values, awareness, identity, lifestyle) framework presented in this paper enables context-specific identification of factors that influence adoption of proenvironmental behaviors and can inform design of actions that seek to increase adoption of these behaviors.

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water quality through actions such as better retaining, treating, or using stormwater at the residence, changing garden management to reduce runoff speed and volume, and reducing nutrients (nitrogen, phosphorus, and carbon) entering stormwater systems (5, 6). This can in turn reduce the investment needed in infrastructure to filter pollutants from stormwater runoff. Despite this potential, there is often little attempt to increase adoption of these behaviors by urban residents in WSUD efforts (14), the exception being a small number of programs in Australia and the United States encouraging use of rainwater tanks and raingardens (15, 19, 20).

Designing programs that encourage human behavior change as part of WSUD initiatives requires understanding the factors that influence adoption of proenvironmental behaviors that can support improved water quality. The types of behavior change needed will differ, depending on the local context; for example, urban water quality may be improved by actions as diverse as reducing littering, changing fertilizer or pesticide use patterns, establishing gardens that retain water, and installing water tanks. Multiple studies have examined how to promote proenvironmental behaviors in a range of situations, including some examining urban water management, and a larger number focused on behavior changes that can reduce or mitigate human-induced global warming, loss of biodiversity, and pollution of land and water. This body of often diverse evidence, which has been developed over decades, can provide insight into how to diagnose factors likely to influence adoption of proenvironmental behaviors as part of WSUD initiatives. However, it is spread across a large number of studies, many of which examined only one or a limited number of factors that may influence proenvironmental behavior. This means it cannot be readily drawn on by those seeking to diagnose which factors might be most relevant in a specific WSUD context. There is a need for this disparate evidence to be synthesized into tools that enable better consideration of human behavior in the field of WSUD.

In this paper we develop a model for understanding adoption of proenvironmental behaviors relevant to WSUD, by reviewing past studies that have examined the adoption of proenvironmental behaviors both in general and in relation to urban water management and freshwater socioecological systems. The model is designed to be contextualized to specific urban water-management challenges in different locations, through the development of locally relevant indicators. Conceptually, this approach draws on the hybrid models of sustainability indicators increasingly argued to be optimal both to ensuring rigor in analysis and to including local knowledge and contextual information when assessing sustainability at the local scale (e.g., refs. 21 and 22). Developing a localizable model enables the large body of international evidence on the factors influencing proenvironmental behaviors to be used and translated into a form relevant to specific situations. This better enables water managers to identify practical approaches to encouraging changed water-management behaviors as part of specific WSUD initiatives.

We first propose an overall framework that can be applied to help diagnose the factors likely to be influential in achieving proenvironmental behavior changes relevant to WSUD. We then demonstrate how this framework can be contextualized to a specific issue and region, in this case the adoption of garden management practices that support urban water quality (water-sensitive gardening practices) by residents in the city of Canberra, Australia. Finally, we identify implications of our findings for water managers in the case-study region and the framework's broader applicability.

Adoption of Proenvironmental Behaviors

Many factors influence whether or not a person adopts specific proenvironmental behaviors (23), defined as behaviors that seek to minimize negative and promote positive environmental outcomes. We identified factors relevant to WSUD by reviewing literature on adoption of proenvironmental behaviors in the areas of water conservation, recycling and reducing energy use, and garden management. These are areas in which urban residents are asked to change behaviors in ways similar to those that may occur as part of WSUD initiatives. While there is a long history of research on some of these topics, we focused predominantly on studies published in the last two decades, because of the large body of research published in this period that built on and extended earlier work. We identified four areas commonly found to influence adoption of proenvironmental behaviors: (*i*) proenvironmental values and norms, (*ii*) awareness and knowledge, (*iii*) proximity and place-related identity, and (*iv*) life stage and lifestyle.

Proenvironmental Values and Norms. Multiple studies argue that people holding strong proenvironmental values more commonly engage in proenvironmental behaviors (24, 25). This association has been identified for both household water consumption (24) and for proenvironmental gardening behaviors such as establishment of low-water-use garden vegetation (26). Proenvironmental values are in turn influenced by social norms: the desire to engage in behaviors that generate approval by others in a person's social groups (23, 27, 28). Reviews of two programs that involved urban residents in WSUD identified that uptake of WSUD-friendly behavior required first building social norms supportive of these behaviors, such as use of raingardens and rainwater tanks/barrels (15, 20). More broadly, social norms about appropriate management of gardens, such as perceived pressure to maintain green lawns to meet neighborhood norms, have commonly been identified as influencing the quantity of water used in residential gardens (15, 29, 30). However, the association between values and behavior is at best inconsistent and at worst absent: Multiple studies have found little connection between proenvironmental values and behaviors, both in general (31) and in relation to water and urban garden management (23, 26, 28, 32–35). Holding a value may therefore be necessary, but not sufficient, to trigger behavior change: Factors such as the cost and difficulty of taking action, and the relative priority of environmental versus other values, may moderate the link between values and behaviors (23).

Awareness and Knowledge. Awareness of environmental problems is often considered a prerequisite to taking action to address them. For example, awareness of potential threats to water availability was found to increase adoption of decentralized water storage (28). Brown et al. (ref. 6, p. 89), meanwhile, found that "a general lack of knowledge . . . of the link between excess stormwater and the ecological degradation of waterways" led to lower participation in a project encouraging the use of raingardens and rainwater tanks. However, awareness of environmental problems is not always associated with a greater likelihood of taking action about those problems (23). This may be because people do not know how their own actions can help address a problem about which they are aware, an issue identified in studies examining proenvironmental behaviors related to climate change (36), water conservation (27, 35), and household energy efficiency (37). To trigger behavior change, awareness of a problem therefore needs to cooccur with awareness of actions that can address that problem. Making this connection can be particularly challenging for environmental problems in which achieving change requires many people to take action: The extent to which a person feels their actions "make a difference" (38, 39), and trusts others to also take action (38), are known barriers to increasing proenvironmental behavior in general and to achieving behavior change that helps achieve household water conservation (39).

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Proximity and Place-Related Identity. A person's proximity to an environmental problem in both space and time affects their likelihood of acting to address that problem, with action more likely for proximal issues than those perceived as occurring a distance away (38). For example, living closer to waterways has been shown to be associated with greater awareness of water-quality issues (40), while living in an area experiencing water scarcity has been associated with greater adoption of water-conservation behaviors (41). This is particularly relevant to WSUD, as water-quality problems often occur some distance from the urban residences contributing to the problems. However, proximity can also be understood in ways other than physical or temporal distance. In particular, it can be defined as the extent to which a person feels personally close to, or identifies with, a place (in this case, waterbodies or waterways). In this conceptualization, a person does not need to live close to a place to take action to protect it, but rather needs to feel emotionally close to the place—typically understood as place attachment or place-related identity. Place attachment and identity have been found to strongly predict proenvironmental behaviors (25). For example, Stedman (42) found that the extent to which a person held particular types of place attachment to a lake, particularly viewing it as providing an "escape from civilization," predicted willingness to take action to address environmental threats to that lake. Place attachment/identity can be measured in various ways, including examining how attached a person feels to a place, how often they spend time at that place, and the types of activities undertaken (23, 25).

Lifestyle and Life Stage. A person's lifestyle, life stage, and sociodemographic characteristics are sometimes argued to predict their likelihood of engaging in proenvironmental behaviors (23). Lifestyle- and life-stage-related factors found in past studies to influence water use and water conservation behavior include household income, educational attainment, gender, age, political orientation, home ownership and residence type (including whether a person is a homeowner or tenant, block size, and type of garden) (6, 27, 40, 41, 43, 44). However, these findings are inconsistent across studies (43). Broader lifestyle factors, such as a person's free time, have also been found to predict adoption of proenvironmental behaviors (37), including installing rain-gardens or rainwater tanks (6). Perhaps most importantly, the ways in which a proenvironmental behavior affects a person's lifestyle influence likelihood of adoption (23). For example, people may conserve energy use not because this reduces carbon dioxide emissions but because it saves money and thus supports their lifestyle (26). This means proenvironmental behaviors that support WSUD initiatives may be adopted not because they improve water quality but because they are consistent with a person's goals regarding things such as garden aesthetics, or their garden recreation activities—or they might not be adopted because they are incompatible with these things (26, 33).

We combined these elements in a single, simple framework (Fig. 1). The VAIL framework is based on the premise that adoption of proenvironmental behaviors will depend on the nature of, and interactions between and relative strength of, proenvironmental values and norms, awareness of problems and knowledge of actions, identity developed based on proximity and place attachment, and lifestyle and life stage. Importantly, any one of these may be enough to achieve or prevent adoption of a proenvironmental behavior on its own or may interact with others to achieve sometimes unanticipated outcomes. For example, a person with few proenvironmental values, no knowledge of a water-quality problem, and no sense of connection to local waterways may still adopt a behavior that supports water quality, simply because it supports their lifestyle goals. Conversely, a person with strong proenvironmental values and exposed to social norms of expected proenvironmental behavior, who has strong attachment to a local lake with water-quality problems, and who can save money by adopting a proenvironmental behavior, may elect not to because they are unaware that adopting that action could help improve health of the lake at which they spend time.

Localizing the VAIL Framework: Canberra Case Study

We applied the VAIL framework in a case study examining the management of urban garden organic matter in Canberra, Australia. In urban environments, organic matter (leaves, grass, etc.) can fall directly or be blown, swept, or washed onto impervious surfaces and subsequently enter the urban stormwater system. The roadside zone in Canberra is managed by urban residents as part of their gardening practices. Consequently, the

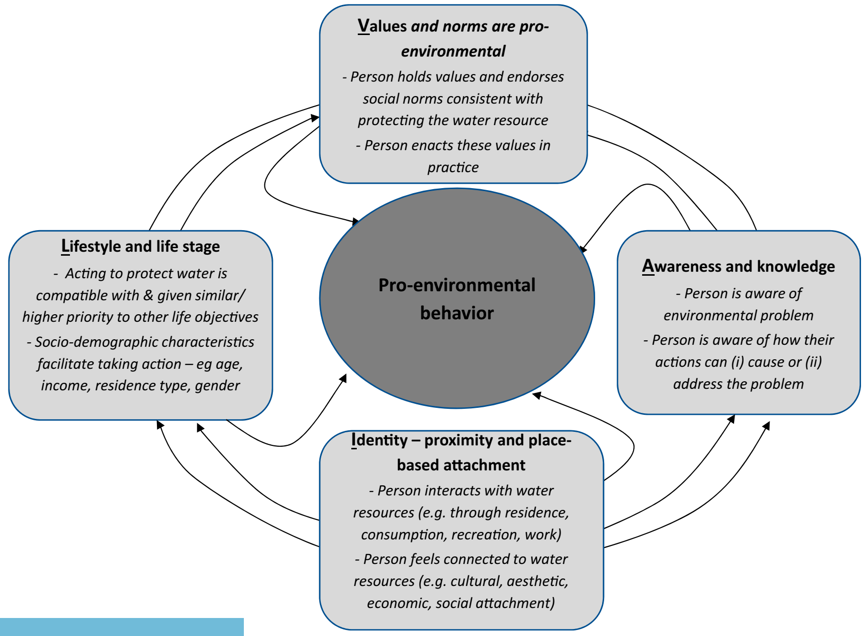

Fig. 1. The VAIL framework for adoption of proenvironmental behaviors: values, awareness, identity, and lifestyle.

management of organic matter (leaves, grass, etc.) is one area where adoption of proenvironmental behaviors has strong potential to improve water quality as part of WSUD initiatives in Canberra. Organic matter contributes nutrients to freshwater systems (45) as well as directly influencing water quality by modifying oxygen dynamics (44). Aerobic bacteria use oxygen to break down leaf litter, grass clippings, and animal wastes; if an excessive amount of organic matter is present in urban waterways, particularly when the water is warm, this oxygen use can severely deplete oxygen levels. The resulting conditions are associated with multiple adverse consequences: anaerobic bacteria take over the organic matter decomposition, causing release of noxious gases and foul smelling compounds; conditions become unsuitable for fish and other organisms; and nutrients previously bound to sediments can be released in forms that support algal growth. This can result in blooms of algal species toxic to the health of humans and animals and death of fish and other water-dependent fauna (46, 47).

Incidences of toxic algal blooms driven by this process are increasing worldwide (48–50). Australia's capital city of Canberra is a typical example of this issue. Most of the city's 390,800 residents (51) live in suburban housing with gardens. Much of the urban stormwater system drains into lakes and ponds that filter water before it enters rivers. The city's lakes, commonly used for recreation, regularly experience algal blooms. Key indicators of algae in water were higher-than-acceptable levels in 31% of water samples during 2011–2015; water leaving the city's catchment in this period often had higher-than-acceptable nutrient levels (52). These issues were largely driven by "urban runoff with high nutrient concentrations" (ref. 52, p. 185). In Canberra, as in many cities worldwide, these problems can be partly addressed by reducing the amount of organic matter entering stormwater systems. One way of achieving this is to encourage residents to change their management of garden organic matter.

To help identify the factors likely to influence adoption of proenvironmental behaviors that reduce organic matter entering Canberra's stormwater drains, we first identified both locally relevant proenvironmental behaviors and locally relevant values, awareness, identity, and lifestyle factors. The framework was localized in two steps, the first being a workshop with local water scientists (53) which identified four practices urban residents could undertake to reduce the volume of organic matter entering waterways in Canberra:

- Composting at the residence. This can reduce organic material washed into drains.
- Mulching garden beds. This reduces both speed of water runoff and the volume of organic materials washed into drains in rain events.
- Raking leaves away from curbside stormwater drains. This reduces volumes of organic matter entering stormwater drains.
- Not blowing leaves/clippings into the street. Stormwater drains receive water from Canberra streets, and raking or blowing garden organic materials into the street increases the likelihood of their entering the stormwater system.

To measure engagement in these practices, an overall measure of water-sensitive gardening practices, described in Table 1, was developed, ranging from a score of 1 (never engaged in any of the four water-sensitive gardening practices) to 4 (regularly engaged in all four practices).

The second step used to localize the framework was consultation with 14 representatives of a community consultative committee established to inform management of stormwater in Canberra. These 14 representatives were asked to discuss the types of values and norms, awareness, identity, and lifestyle issues that may affect adoption of a range of WSUD-friendly behaviors by Canberra's residents. Based on this discussion, localized indicators (listed in Table 2) were designed to measure each of the framework elements:

- Values and norms: To identify values likely to influence adoption of water-sensitive gardening behaviors, residents were asked whether they actively implemented actions intended to (*i*) conserve water and (*ii*) protect water quality. Water conservation was considered an important value to local residents (in addition to valuing water quality) as Canberra had experienced extended drought in the 2000s which resulted in severe water-use restrictions in urban gardens. Asking questions that identified whether residents took actions based on these values enabled identification of whether these values were strong enough to motivate behavior change. While water conservation was considered an important social norm in the region, no dominant social norms related to water quality were identified during the survey design, and hence none were included.
- Awareness and knowledge: In the case study, the local issue being examined was quality of water leaving stormwater systems

Table 1. Measurement of water-sensitive gardening behavior (dependent variable)

Measure	Survey item/s used and response scale	Descriptive results, % respondents
Composting	Compost or mulch leaves and grass clippings on own property	No & don't plan to: 15.1% No & would like to: 11.0% Sometimes: 21.1% Regularly: 52.9%
Mulching	Mulch garden beds (e.g., with bark, straw)	No & don't plan to: 7.8% No & would like to: 6.4% Sometimes: 31.1% Regularly: 54.7%
Raking	Rake up leaves (not using a leaf blower)	No & don't plan to: 17.0% No & would like to: 2.1% Sometimes: 41.7% Regularly: 39.2%
Raking–blowing to street	Rake–blow leaves or grass clippings onto the street	No & don't plan to: 92.0% No & would like to: 1.0% Sometimes: 6.0% Regularly: 1.0%
Water-sensitive gardening behavior	Mean of four measures above, from 1 (No & don't plan to) to 4 (Regularly) (scoring reversed for "Rake–blow leaves or grass clippings onto the street")	Low adoption (score 1–2.4): 10.3% Moderate adoption (2.5–3.5): 39.2% High adoption (3.6–4.0): 37.9%

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Table 2. Measures and descriptive results for predictors of water-sensitive gardening practices

Label	Survey item/s	Response options†	Descriptive results (score): % respondents	Bivariate association with dependent variable‡
Proenvironmental values				
Water conservation values	I actively try to reduce the amount of water my household uses	A	Disagree (1–3): 7.0%; agree (5–7): 83.7%	$r_s = 0.221$***
Water-quality values	I am careful not to do things that might pollute waterways	A	Disagree (1–3): 3.8%; agree (5–7): 77.4%	$r_s = 0.182$***
Awareness and knowledge				
Awareness of lake-water–quality problems	Do you think any of the following are problems in your local region at the moment? Poor water quality in lakes	B	No/low problem (1–3): 20.3%; problem (5–7): 68.3%	$r_s = 0.132$***
Awareness of gardening–water-quality link	Does the following regularly cause problems for water quality in your region: leaf litter or grass clippings going into the stormwater system	B	No/low problem (1–3): 15.1%; problem (5–7): 47.0%	$r_s = 0.131$***
Belief own actions affect water quality	The things I do around my house can affect the quality of water in local waterways	A	Disagree (1–3): 17.4%; agree (5–7): 74.3%	$r_s = 0.149$***
Proximity and identity				
Residential proximity to lake–pond	How far away from your residence (walking or driving) is the nearest lake–pond–large body of water?	C	<1 km: 35.4%; 1 km+: 15.1%	$r_s = 0.048$**
Water recreation score	What types of recreation do you do near Canberra's waterways? *Participants could select up to eight recreational activities, at nine locations*	D	Low (0–9): 40.2%; high (20+): 22.3%	$r = 0.123$***
Swimming in waterways	Do you swim in waterways or waterbodies in Canberra?	E	Does swim: 30.6%; doesn't swim: 69.4%	H = 21.52***
Importance of (*i*) exercise, (*ii*) parkland, (*iii*) birds/animals, (*iv*) native vegetation, (*v*) fishing	How important is . . . the following when you're around waterways?: *Getting exercise/getting active; spending time in attractive parklands; seeing birds or animals; seeing native vegetation; being able to go fishing*	F	Important: exercise 80.9%; parklands 80.5%; birds/animals 84.4%; native veg 79.9%; fishing 20.3%	Ex'se $r_s = 0.098$***; P'lands $r_s = 0.052$**; An'ls $r_s = 0.187$***; Veg $r_s = 0.150$***; Fishing $r_s = -0.053$**
Life stage and lifestyle				
Age	Measured in categories: <25, 25–29, 30–34 . . . 84–89, ≥90 y	G	Mean age: 50–54 y	$r_s = 0.309$***
Gender	Male, female	G	Percent female: 52.7%	H = 1.81
Educational attainment	High school completion, university qualification	G	High school: 96.3%; university: 68.5%	HS: H = 7.96**; univ. H = 26.16***
Dependent children	Defined as person living at home with dependent children	G	Yes: 41.7%	H = 0.043
Health	(*i*) No limitation or (*ii*) some/severe limitations, to walking 1 km	G	Some/severe limitations: 11.6%	H = 1.16
Residence status	Renter or owner/mortgage holder	G	Renter: 16.5%	H = 200.97***
Time spent gardening	I spend a lot of time gardening	A	Disagree (1–3): 36.5% agree (5–7): 46.4%	$r_s = 0.412$***
Enjoyment of gardening	I enjoy gardening	A	Disagree (1–3): 18.0% agree (5–7): 69.5%	$r_s = 0.364$***

†Response options. A: 1 (strongly disagree) to 7 (strongly agree); B: 1 (not a problem) to 7 (very big problem); C: distance: <200 m, 200–500 m; 501 m to 1 km; 1–5 km; >5 km; D: water recreation score = recreational activities × waterways, range 0 (no water recreation) to 72 (eight activities at nine waterways); E: Yes/no; F: 1 (not at all important at any waterway), 2, 3, 4 (important at some of the waterways I spend time at), 5, 6, 7 (very important any time I'm around waterways); G: response options described in table.

‡Bivariate associations: r_s = Spearman's Rho; r = Pearson's correlation coefficient; H = Kruskal–Wallis test statistic. ***$P < 0.001$, **$P = 0.001$–0.01.

and entering urban lakes and ponds. Residents were therefore asked about their (*i*) awareness of water-quality problems in Canberra's lakes and (*ii*) awareness of the links between their own actions and water quality in nearby urban lakes and ponds.

- Identity and proximity: The principal ways in which Canberra residents were believed to develop a sense of connection to local waterways was via recreational use of lakes and of the many parks, playgrounds, and walking/cycle paths located adjacent to lakes and stormwater drains in Canberra. Some residents also live physically close to lakes; however, spatial variation in location of residences was not identified as a major driver or issue in the city, with residents often visiting and recreating at lakes that were not those they lived closest to. Residents were therefore asked about (*i*) physical proximity of their residence to any of the city's lakes, (*ii*) the extent to which they spent time recreating around these lakes, and (*iii*) the ways in which they self-identified that recreation as being important to their lives. In particular, initial consultations identified ongoing debate about community preferences for the parklands near lakes: Some residents preferred a "parkland" environment dominated by deciduous (exotic to Australia) tree species and grassy lawns, while others preferred to spend time in an environment that was more "Australian," with more native tree species, and a focus on seeing native bird and mammals.

- Lifestyle and life stage: Key lifestyle and life-stage factors identified as potentially relevant to management of organic matter in Canberra gardens were age, gender, education, number of dependent children, whether the person owned or rented their residence, and whether the person had a strong sense of identity related to their garden and gardening activities. Spatial location of their residence (e.g., the suburb they lived in) was not identified as a factor, because of the homogeneity of Canberra in terms of physical structure (most suburbs have similar mixes of housing types) and sociodemographic characteristics (Canberra does not have large differences in cultural and ethnic makeup in different locations).

Survey Findings

The localized VAIL framework was applied in a survey of 3,334 Canberra adults living in residences with gardens, with the aim of identifying which framework elements best predicted use of water-sensitive gardening practices. Bivariate analyses were used to explore whether hypothesized predictor variables (the localized indicators of the four VAIL framework domains) were associated with water-sensitive gardening behavior, and their overall suitability for subsequent regression modeling (Table 2). Almost all predictors were statistically associated with gardening behavior to the $P < 0.001$ level, indicating strong associations between water-sensitive gardening behavior and hypothesized predictor variables. No multicollinear relationships of concern existed among predictor variables (*Methods*). However, gender, health, and presence of dependent children were not significantly associated with water-sensitive gardening activities, while high school completion, proximity of a person's residence to lakes/ponds, importance of parklands, and importance of fishing were not strongly associated with these activities, being significant to the $P < 0.01$ level but not the $P < 0.001$ level. Given the importance of some of these variables as part of the VAIL framework, all were retained in subsequent regression modeling. This is consistent with the common call to ensure regression model specification is driven by theory, rather than data-driven (54, 55).

Multiple linear regression was performed to assess overall model fit, that is, whether engagement in water-sensitive gardening behaviors was predicted by the measures of proenvironmental values, awareness and knowledge, proximity and place-related identity, and lifestyle/life stage. The regression was performed with SPSS 21.0's multiple imputation module after using fully conditional specification to impute missing data (Table 3). Across the five imputed datasets, the overall model fit was significant and strong: Mean adjusted R^2 was 0.317, identical to the adjusted R^2 for the unimputed dataset, and all models were significant at the $P < 0.001$ level. The contribution of predictor variables to the model was then examined (Table 4).

All but two hypothesized predictor variables were significant at the $P < 0.05$ level. Residents were more likely to engage in gardening practices that were protective of water quality if they had the following characteristics:

- Values: Having proenvironmental values related to either water conservation or to taking action to protect water quality significantly predicted engagement in gardening practices that reduce organic matter entering storm drains. Water conservation values were a much stronger predictor than valuing high water quality, suggesting reasons for engagement in water-sensitive gardening practices may be more related to reducing water use than protecting water quality.
- Awareness: Awareness of water-quality problems in lakes was significantly associated with greater use of water-quality-protective gardening methods. Similarly, people who believed the things they did around their residence could affect local water quality were more likely to engage in water-quality-protective gardening practices. However, awareness that leaves and grass clippings entering the stormwater system was a problem for local water quality was not a significant predictor in the model, suggesting there may not be a simple or direct causal link between being aware of water-quality problems and gardening in ways that support water quality.
- Identity: While residential proximity was a moderately significant variable, recreational proximity in the form of more frequently spending time recreating around the region's lakes and waterways, particularly swimming, was a stronger predictor in the model. Those who found it important when around water to have attractive parklands or go fishing were less likely to engage in water-sensitive gardening behaviors, while those who found seeing birds, animals, or native vegetation important were more likely to engage in these behaviors. Finding it important to exercise around waterways was not significantly associated with water-sensitive gardening behaviors.
- Lifestyle and life stage: Those who owned their home, and older people, were more likely than renters and younger people to engage in water-sensitive gardening behavior. To a lesser extent, so were those with dependent children, those who had not completed high school (many of whom are older), those with a university qualification, and those in good health. The strongest predictor in this area was gardening lifestyle: Time spent gardening and a person's enjoyment of gardening were very strong predictors of using gardening methods that reduce organic matter entering stormwater drains.

Table 3. Water-sensitive gardening linear regression model: Overall model fit

Imputation no.*	R^2	Adjusted R^2	SE	F	Significance
Original data	0.324	0.317	0.489	46.07	0.000
1	0.322	0.318	0.511	71.60	0.000
2	0.319	0.315	0.512	70.56	0.000
3	0.326	0.321	0.509	72.64	0.000
4	0.323	0.319	0.510	71.82	0.000
5	0.319	0.314	0.512	70.42	0.000

Dependent variable: water-sensitive gardening behavior. Independent variables: water-conservation values; water-quality values; awareness of lake-water–quality problems; awareness of gardening–water-quality link; belief own actions affect water quality; residential proximity to lake–pond; water recreation score; engagement in swimming in waterways; exercise importance; parkland importance; bird/animal importance; native vegetation importance; fishing importance; age; gender; high school completion; university qualification; dependent children; health; residence status; time spent gardening; and enjoyment of gardening.

*Model fit is shown for original data (missing data unimputed) and for five models generated with missing data imputed using the SPSS 21.0 multiple imputation module.

Table 4. Water-sensitive gardening behavior model: Regression model coefficients

Domain	Independent variable	Unstandardized coefficients		Standardized coefficients		
		B	SE	*B*	*t*	Significance
	(Constant)	1.782	0.080		22.152	0.000
Proenvironmental values	Water-conservation values***	0.035	0.007	0.076	4.667	0.000
	Water-quality values*	0.018	0.008	0.034	2.120	0.034
	Awareness of lake-water–quality problems***	0.025	0.006	0.070	4.320	0.000
Awareness and knowledge	Awareness of gardening–water-quality link	−0.004	0.006	−0.012	−0.663	0.509
	Belief own actions affect water quality**	0.016	0.005	0.049	2.971	0.004
	Residential proximity to lake–pond**	0.028	0.009	0.048	3.071	0.002
Proximity	Water recreation score***	0.005	0.001	0.094	5.472	0.000
	Engagement in swimming in waterways***	0.101	0.021	0.076	4.723	0.000
	Exercise importance	−0.004	0.008	−0.009	−0.517	0.605
	Parkland importance***	−0.034	0.008	−0.074	−4.130	0.000
Identity	Bird–animal importance**	0.028	0.009	0.062	3.197	0.001
	Native vegetation importance*	0.016	0.007	0.041	2.388	0.017
	Fishing importance***	−0.022	0.005	−0.077	−4.906	0.000
	Age***	0.043	0.004	0.210	11.696	0.000
	Gender*	−0.039	0.019	−0.032	−2.033	0.042
	High school completion**	−0.162	0.048	−0.051	−3.350	0.001
Life stage	University qualification**	0.056	0.021	0.042	2.646	0.008
	Dependent children**	0.066	0.019	0.053	3.448	0.001
	Health*	−0.070	0.032	−0.037	−2.218	0.029
	Residence status***	−0.247	0.026	−0.149	−9.566	0.000
Lifestyle	Time spent gardening***	0.072	0.007	0.225	9.870	0.000
	Enjoyment of gardening***	0.038	0.008	0.111	4.860	0.000

This table presents pooled estimates of the linear regressions run on five imputed datasets generated with missing data imputed using the SPSS 21.0 multiple imputation module. Data were not standardized in the SPSS pooled estimates, but standardized estimates of *B* were generated for each model, and the standardized variable shown is the average of standardized estimates for the five individual models. *$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.

Discussion

In this paper we begin to address the common exclusion in WSUD of behavior change strategies that can contribute to improving urban water quality (7, 13, 14). The VAIL framework synthesizes existing studies into a framework that can guide identification of factors likely to influence adoption of WSUD-relevant proenvironmental behaviors. It enables collection of context-specific data while being guided by the large body of existing evidence on factors influencing adoption of these behaviors (56). To develop the framework, we drew on evidence from studies using methods ranging from cross-sectional studies to longitudinal and experimental design; together this evidence meets the Bradford Hill criteria often used to argue the presence of likely causal associations (57).

The framework supports collecting locally relevant data in a flexible manner. We localized the framework in two steps, first identifying behaviors relevant to improving water quality in Canberra using expert elicitation and second engaging with a community stakeholder forum to identify locally relevant indicators for each of the four domains. We then used cross-sectional survey data to identify which localized indicators most strongly predicted adoption of water-sensitive gardening practices. While the study data, being cross-sectional, do not demonstrate causal directionality, they are consistent with causal pathways identified in the larger body of evidence the VAIL framework is based on.

The framework had good explanatory power in the case study, with the locally relevant measures predicting a significant proportion of variance in adoption of the proenvironmental behaviors being examined. This suggests the framework has validity for identifying the most relevant factors in a given situation. This in turn can guide design of strategies that encourage increased adoption of these behaviors, by explicitly engaging with the values/norms, awareness, identity, or lifestyle factors identified as most relevant in a given context. In Canberra, factors from all four domains contributed significantly to predicting proenvironmental gardening behaviors. This suggested that water managers should encourage behavior change using actions designed to target all four elements of the VAIL framework, particularly increasing awareness of the links between garden management and lake-water quality, emphasizing the benefits of water-quality-friendly gardening for achieving desired benefits (whether related to water quality or other objectives), and improving the sense of connection Canberra residents have to local waterways.

Two of the strongest predictors of engaging in water-sensitive gardening practices were being older and not renting a residence. These factors in themselves are not readily changeable but suggest that the greatest gains in water quality could result from behavior change among younger residents who rent their residence. Change is difficult in these groups because of low existing use of these gardening practices. A simpler approach may be focusing on existing active gardeners and seeking change in their practices, as gardening identity also strongly predicted adoption of water-sensitive gardening practices. However, many enthusiastic gardeners who used water-sensitive gardening practices were unaware of the connection between their gardening practices and lake-water quality. This suggests that their existing use of these practices is likely motivated by fulfilling values associated with their enjoyment of gardening, rather than by resulting improvements in water quality. Proenvironmental behavior change can be achieved by promoting the benefits an action will have other than the environmental outcome being achieved (58), suggesting adoption of water-sensitive gardening practices could be achieved by promoting benefits for achieving gardening objectives such as improved plant growth. However, this may predominantly reach those who already use these practices.

The results also identified the presence of strong concern about local lake-water quality combined with low awareness of the consequences of organic matter entering storm drains. This provided more feasible avenues for designing behavior change strategies, as it suggests lack of adoption of water-sensitive gardening practices results in part from lack of awareness that this type of action can fulfill values related to concern about water quality. Lack of awareness of actions that can fulfill values is a process commonly identified as reducing adoption of proenvironmental behaviors, particularly if associated with low self-efficacy (59). Campaigns that increase a person's confidence that they can act to improve water quality have potential to achieve behavior change among the many residents with strong proenvironmental values and awareness of water-quality problems but low awareness of the link between their actions and water quality in Canberra lakes.

These findings informed development of a behavior change component of a WSUD initiative in Canberra. The H_2OK: Keeping our Waterways Healthy program launched in 2017 was in early stages of implementation at the time of this writing and aimed to encourage behavior changes that, together with investment in WSUD infrastructure, would improve water quality. The H_2OK program aims to increase awareness that reducing organic matter entering storm drains can improve local water quality, giving residents a way to fulfill the values they hold about protecting water quality. The program included campaigns promoting the importance of water quality (values), developing local demonstration projects showing how these values can be translated to practice (values and awareness), increasing understanding of how stormwater flows from residential areas to lakes and rivers through direct education and drain art projects (awareness), increasing connection to waterways through art projects and placement of information at recreational sites (identity), and targeting messages and actions to different demographic groups (lifestyle and life stage) (60).

The findings also suggested that encouraging greater recreational use of waterways could encourage greater adoption of water-sensitive gardening practices. Those who spent more time recreating around local lakes and waterways had greater awareness of water-quality problems, and likely stronger motivation to act on these problems. Place attachment and identity theory suggests this occurs through processes in which a person develops strong psychological identification with a resource (in this case lakes and waterways) and this identification leads to greater awareness of problems and increased likelihood of acting to address them (e.g., ref. 42). However, the results suggested caution if seeking to build "identity" to achieve proenvironmental behaviors: Not all water-related identities were positive for water-sensitive gardening. Those who more strongly preferred "parklands" (in Canberra, referring to treed and grassed areas established with nonendemic, often deciduous species that contribute high organic matter loads to water systems) were less likely to engage in WSUD-friendly practices. Those who valued birds, animals, and endemic vegetation were more likely to engage in WSUD-friendly practices. Why this is the case is not known, but previous studies have suggested that the nature of a place attachment (what a person values about a place, rather than simply whether they value it) influences whether that identity is compatible with or increases likelihood of adoption of proenvironmental behaviors (61). In addition to this caution, building stronger recreation-based identity is challenging, as it requires promoting activities that, on the surface, are unrelated to water quality. Given this the H_2OK program did not include actions seeking to increase recreational use and associated identity. Instead, it included actions seeking to build place identity by strengthening awareness of the spatial links between the stormwater system and lakes and waterways, using methods such as drain art and radio advertisements that seek to translate existing place-based identity into action by ensuring those with strong recreation-based identities have increased awareness of actions they can take to protect water quality.

As identified earlier, the VAIL framework is designed to be enacted through development locally relevant indicators. In this case study, this was achieved through active engagement of local representatives in collectively identifying indicators for each of the four VAIL domains. This in turn helped encourage critical reflection among local stakeholders with different interests and responsibilities in water management regarding the human behaviors relevant to achieving improved water quality, and informed design of the subsequent program. More broadly, development of locally relevant indicators can help increase confidence of local stakeholders and residents that local context, knowledge, concerns, and conditions have driven design of strategies aiming to achieve behavior change (62), although whether this outcome was achieved in our case study was not possible to identify at the time of writing. Our case study demonstrated how the framework can be localized for a specific region and population of people. The use of multiple localized measures within each domain of the framework enabled a stronger understanding of the complexity of the drivers of adoption of water-sensitive gardening practices. While in our study the framework was operationalized via a survey, the framework can be operationalized using other methods such as field walks, focus groups, interviews, and other formats (e.g., refs. 56 and 63), with the VAIL framework designed to be compatible with diverse methods of data collection. For example, in many countries undergoing rapid urbanization, there is a need to engage in WSUD among populations with low literacy who are undergoing rapid rural-to-urban transitions. In these cases, rapid appraisal methods commonly used in developing countries could be used to assess the values, awareness, identity, and lifestyles relevant in that culture. The framework can also be used to assess multiple types of WSUD practices; for example, instead of water-sensitive gardening practices, the framework could be applied to assess the value/norm, awareness, identity, and lifestyle factors related to practices such as increasing use of raingardens, establishment of community wetlands, or greater use of permeable paving or water tanks.

The framework has limitations; in particular, while designed to be applicable in a wide range of cultural contexts and to a wide range of WSUD-related practices, its applicability in a range of situations has not yet been demonstrated, and this type of further application is needed to refine the framework and better specify how to localize it to support WSUD initiatives. The process we used to localize the framework is just one example of the way local indicators could be developed, and additional work specifying how to localize indicators in differing situations may be needed to assist managers in applying the framework. There is a risk of bias when developing local indicators for the four domains, which are broadly specified in the framework. In our case study, for example, social norms were not identified as an indicator when initially operationalizing the framework and thus were not studied in detail. This highlights a tension between including all "common" factors identified in past studies, versus enabling flexibility in the indicators examined in different local situations. Finally, not all factors that predict proenvironmental behavior are readily amenable to change, with some of the strongest predictors identified in this study not simple to address through campaigns seeking to promote increased adoption of proenvironmental behavior. The effectiveness of the H_2OK program could not be evaluated for this paper, with follow-up work needed to assess the success or otherwise of the work to promote behavior change.

Conclusions

Maintaining and improving water quality in urban areas is an ongoing challenge, typically addressed using technical, rather than social, solutions. Increasing adoption of proenvironmental behaviors by urban residents in WSUD initiatives can assist in achieving improved water quality while reducing expenditure on water infrastructure. Encouraging more widespread adoption of proenvironmental behaviors requires understanding factors influencing this adoption, a topic examined in multiple studies. We developed and tested the VAIL framework, which identifies four domains that commonly influence adoption of proenvironmental behaviors relevant to WSUD: proenvironmental values and norms, awareness and knowledge of environmental problems and the actions that can address them, proximity and place-based identity, and life-stage and lifestyle factors. The framework is simple and localizable to specific water-quality problems and specific communities. The framework was effective in predicting variance in adoption of one type of WSUD-relevant behavior—water-sensitive gardening practices—in a case study in Canberra, Australia, with factors across all four domains predicting adoption of these behaviors. These findings informed design of a new program aiming to achieve behavior change, which was targeted to the factors (*i*) found to most strongly predict adoption of these practices and (*ii*) which were amenable to a behavior-change program.

Methods

Participants. Participants were surveyed between July 16 and August 14, 2015. Of 4,701 respondents, 3,334 lived in Canberra and managed a garden area. Participants were recruited using flyers mailed to their residence, encouraging completion of an online survey, with nine prizes offered as survey incentives. Residents aged 18 y and older were eligible to participate. This approach was selected as 91% of Canberra households have internet access (64), more than have landline phones, and flyers reached a more representative sample of household residents compared with use of directly addressed mail due to lack of up-to-date addressed mailing databases.

Survey Content. The survey included many items, only a subset of which were relevant to this paper (Tables 1 and 2). All questions were closed-ended. Survey items were drafted in consultation with experts and a community consultative committee (described earlier), tested by 47 people who provided feedback on difficulties with interpretation, sensitivity, or completion of items; and pilot-tested with a random sample of 45 residents.

Representativeness. Of survey respondents 52.6% were female, compared with 51.1% of the adult population; median age was 50–54 y, compared with 42 y in the study region. Residents aged under 24 y were underrepresented and those aged 50–69 y overrepresented. This may not represent a bias, as we studied residents with gardens: Younger residents are more likely to live in residences with no garden area such as apartments. Median household income of the sample was \$78,000–\$103,999, the same as the median household income range for Canberra. There was bias to more highly educated respondents: 70.7% of respondents had completed high school and 68.5% a university degree compared with 70.6% and 38.8% of adult Canberrans.

Analysis. Data were analyzed using IBM SPSS Statistics 21. The variables proposed for the model were inspected for missing data. A key decision was how to treat "don't know" responses: These are often treated as missing data but can represent important information in their own right (65). "Don't know" responses represented more than 5% of responses for two variables (awareness of poor water quality in lakes/ponds – 7.5%; awareness that leaf litter–grass clippings entering the stormwater system caused water-quality problems – 13.4%). For all other variables, fewer than 5% of responses were missing. Little's MCAR test indicated patterns of missingness were not completely at random, $\chi^2(999) = 1{,}766$, $P < 0.000$. Use of multiple imputation requires data meet the assumption of missing at random (MAR), meaning patterns of missingness are not related to the dependent variable, after controlling for other variables in the study known to predict missingness (66). Several sociodemographic variables were significant predictors of missingness for variables in which a substantial amount of data were missing:

- Own actions affect water quality: Missingness significantly associated with gender.
- Awareness of water-quality problems in lakes: Missingness significantly associated with gender, housing residence status, health, high school completion, and dependent children.
- Awareness that leaves–clippings could affect water quality: Missingness significantly associated with age, dependent children, and gender.
- Proximity of residence to nearest lake–pond: Missingness significantly associated with high school completion and health.
- Importance of fishing to person's identity: Missingness significantly associated with age and dependent children.

Patterns of missingness were not related to the dependent variable after controlling for these significant predictors of missingness, thus meeting the MAR criterion that the likelihood of data being missing is not related to the dependent variable after controlling for other variables (66). Therefore, use of multiple imputation was appropriate, as long as variables predicting missing data were included in the imputation model (67, 68). To further ensure no impact of imputation on the dependent variable, we included variables that predicted missingness in our regression analysis (age, gender, residence status, dependent children, health, and high school completion). Missing data were imputed using SPSS 21.0 using the fully conditional specification method, an iterative Markov chain Monte Carlo method that is appropriate when patterns of missingness in data are arbitrary. Five imputed datasets were created, based on the common standard that the number of models should approximate the proportion of missing data (with less than 5% missing data overall in the dataset) (69). The SPSS multiple imputation module was used to combine parameter estimates and SEs obtained for each dataset into pooled estimates and inferential statistics.

Inspection of the unimputed and imputed datasets found no violations of the assumptions of normality, linearity, homoscedasticity, or multicollinearity. Variance inflation factor values in the unimputed dataset and in the five imputed datasets ranged from 1.02 to 2.53, and tolerances ranged from 0.396 to 0.981, well outside the thresholds of >4 and <0.10, respectively, considered indicative of likely multicollinearity (70).

Ethics. This study was approved by the University of Canberra Human Research Ethics Committee, protocol number HREC 15–94. Participants completed the survey only after being provided information enabling informed consent to take part; taking part in the survey constituted their informed consent.

Data Availability. The dataset used for this analysis has been deposited in the Australian Data Archive (https://ada.edu.au/). Ethical requirements to deidentify data and ensure privacy and confidentiality have been met, and the dataset will be made available by the archive on request for purposes of replicating this analysis.

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