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Research Paper

# From the household to watershed: A cross-scale analysis of residential intention to adopt green stormwater infrastructure

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ABSTRACT

Improved stormwater management for the protection of water resources requires bottom-up stewardship from landowners, including adoption of Green Stormwater Infrastructure (GSI). We use a statewide survey of Vermont paired with a cross-scale and spatial analysis to evaluate the influence of interacting spatial, social, and physical factors on residential intention to adopt GSI across a complex social-ecological landscape. Specifically, we focus on how three GSI practices, ("rain garden (bio retention)," "infiltration trenches," and "actively divert roof runoff to a rain barrel/lawn/garden instead of the street/sewer") vary with barriers to adoption, and household attributes across stormwater contexts from the household to watershed scale. Private landowners, who may be motivated more by on-site and neighborhood stormwater problems, may gravitate toward practices like infiltration trenches compared with practices (e.g., rain gardens) perceived to serve stormwater function over larger areas. Diversion of roof runoff was found to be more likely to be a part of a larger assembly of green behaviors. Improved stormwater management outcomes at the watershed, town, neighborhood, and household levels depend on adaptive approaches and adjusting strategies along the rural-urban gradient, across the biophysical landscape, and according to varying norms and institutional arrangements.

## 1. Introduction

### 1.1. The challenge of stormwater management

Worldwide, altered hydrology and eutrophication threaten freshwater resources (Carpenter, Stanley, & Vander Zanden, 2011). In the United States, more than half of the assessed rivers, streams, lakes, reservoirs, ponds, bays, and estuaries were impaired for meeting "designated uses" including supporting drinking water supply, supporting aquatic life, and recreation (US EPA, n.d.). Many of these impairments are attributed to development in urban and rural landscapes including modified hydrology, habitat alteration, and point and nonpoint source pollution (US EPA, n.d.; Wear, Turner, & Naiman, 1998; Wemple, Clark, Ross, & Rizzo, 2017). Ineffective stormwater management can increase runoff rates and volumes, downstream flooding, stream bank erosion, turbidity, habitat loss, sewage spills, infrastructure damage, and transport of pollutants to receiving waters (Arnold & Gibbons, 1996; UNEP, 2014; US EPA, n.d.).

### 1.2. Green stormwater infrastructure

Green stormwater infrastructure (GSI) aims to mimic natural ecosystem functions to provide water storage and water quality regulation by promoting infiltration, treatment, and evapotranspiration using vegetation, soils, and other elements (UNEP, 2014; US EPA, 2015). On-site treatment such as GSI or Low Impact Development (LID) offers cost-effective alternatives that may be integrated with existing stormwater conveyance systems across lot sizes and landscapes ranging from highly urbanized to sparsely developed to provide provisioning and regulating ecosystem services from local to watershed scales (Pagella & Sinclair, 2014; Qiu & Turner, 2013; UNEP, 2014; U.S. EPA, 2000). GSI includes practices such as bioretention, pervious pavement, green roofs, tree box filters, infiltration trenches, rain barrels, and constructed wetlands, to slow runoff and treat pollutants including sediment, nutrients, bacteria,

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and heavy metals (Dietz, 2007; Hathaway & Hunt, 2007; UNEP, 2014; UNH, 2012; US EPA, 2015). Green infrastructure, as described by UNEP (2014), including grassed bio-swales and riparian buffers, extends beyond stormwater contexts and provides multiple ecosystem services, including water regulation. Additional GSI ecosystem services can include erosion control, temperature control, carbon sequestration, pollinator habitat, food production, as well as aesthetic, recreational, cultural, and social benefits (Dietz, 2007; UNEP, 2014; U.S. EPA, 2000, 2015). The effectiveness of GSI and potential for secondary benefits depend on the practices implemented and the surrounding context.

### 1.3. Engaging households and neighborhoods in stormwater management

The challenge of stormwater management and need for on-site GSI approaches invites engagement from residents and property owners (Brown, Bos, Walsh, Fletcher, & RossRakesh, 2016; Green, Shuster, Rhea, Garmestani, & Thurston, 2012). In a survey of two Syracuse, New York, neighborhoods, Baptiste, Foley, and Smardon (2015) found that efficacy, aesthetics, and cost were key factors influencing household willingness to implement GSI; and that some demographic differences, such as neighborhood, gender, and education level, influenced the importance of these factors. The same study found that relatively high levels of GSI knowledge did not differ by socio-demographic variables (Baptiste et al., 2015). "Lived experience" of combined sewer overflows and their negative impacts were noted to be drivers of willingness to adopt solutions and increased knowledge of stormwater problems in general (Baptiste et al., 2015; Baptiste, 2014).

Several studies illustrate tradeoffs and challenges of strategies designed to garner support for improved stormwater management and promote GSI adoption at the household and neighborhood scales (Ando & Freitas, 2011; Brown et al., 2016; Carter & Fowler, 2008). For example, Brown et al. (2016) found financial incentives and personal benefits to enhance adoption of at-source stormwater management practices in a retrofit program. Crisostomo, Ellis, and Rendon (2014) also found that "intangible benefits" including broad environmental, "green" benefits may be more motivating to homeowners than GSI as strictly a stormwater management strategy. Carter and Fowler's (2008) study of subsidy and incentive programs for green roofs across the United States illustrates tradeoffs between political will, cost of construction, and the ability to effectively target optimal sites for environmental benefit.

### 1.4. Stormwater management across scales

Water governance problems are fundamentally transboundary (Cash et al., 2006; Cohen & Davidson, 2011; Moss & Newig, 2010; Susskind & Islam, 2012) despite use of hydrological, political, and spatial boundaries to inform management. While watershed delineations are useful for hydrologic and water quality analysis, governance and coordinated implementation at the watershed scale faces technical, institutional, and perceptual barriers (Baptiste et al., 2015; Cohen & Davidson, 2011; Roy et al., 2008). Within administrative boundaries, implementation of stormwater utilities and fees may be vulnerable to political pressure (Keeley et al., 2013). Residential relationships with municipal governments may differ between urban and rural areas influencing willingness to adopt GSI (Barbosa, Fernandes, & David, 2012). A major US policy tool is the permitting of Municipal Separate Storm Sewer Systems (MS4) via the National Pollutant Discharge Elimination System (NPDES) program (OW US EPA, n.d.). Since 1990, 750 Phase I MS4 permits were issued in urbanized areas with populations over 100,000; since 1999, 6700 Phase II MS4 permits were issued to small municipal systems inside and outside urbanized areas (OW US EPA, n.d.; US EPA, 2015). Requiring municipal stormwater discharge permits can be an important motivator for local governments to encourage, or even require, GSI on private land (Copeland, 2016; Fowler, Royer, & Colburn, 2013). Within this transboundary landscape, stormwater management is determined by the interactions of hydrological, biophysical, infrastructural, social, and demographic factors (Ahiablame, Engel, & Chaubey, 2013; Pfeifer & Bennett, 2011; Wright, Liu, Carroll, Ahiablame, & Engel, 2016; Zhang, Guo, & Hu, 2015).

Research is needed on the influence of spatial, social, and physical factors on the adoption of GSI and sustainable water resource management across a complex social-ecological landscape (Chowdhury et al., 2011; Ostrom & Cox, 2010). Extensive research exists on environmental behaviors (Kollmuss & Agyeman, 2002; Noppers, Keizer, Bolderdijk, & Steg, 2014; Steg & Vlek, 2009), and specific socio-demographic factors (Baptiste et al., 2015), motivations, and barriers influencing GSI adoption (Ando & Freitas, 2011; Brown et al., 2016; Crisostomo et al., 2014; Baptiste, 2014; Baptiste et al., 2015). Without an understanding of how GSI adoption occurs within different stormwater contexts, our ability to develop effective solutions to address water resource problems is limited. Our major research questions are: (1) How do spatial factors from the site-scale to watershed-scale influence residents' intention to adopt GSI practices? (2) What key factors influence resident intentions to adopt specific GSI practices when spatial factors are considered with demographic factors and barriers?

We use a statewide survey of Vermont residents and spatial analysis to evaluate how differing stormwater contexts including exposure to site-level runoff, erosion or flooding, perception of neighborhood-level challenges, town-level stormwater regulation, and watershed impairment in rural and urban landscapes may impact residential intention to adopt GSI practices (Fig. 1). In addition, this study evaluates whether the influence of these multi-scalar contexts and other household factors differ between three GSI practices ("rain garden (bio retention)," "infiltration trenches," and "actively divert roof runoff to a rain barrel/lawn/garden instead of the street/sewer"). This cross-scale research on GSI adoption reveals key dimensions needed in sustainable management of water resources.

### 1.5. Challenges for Vermont

The state of Vermont is actively engaged in a series of initiatives

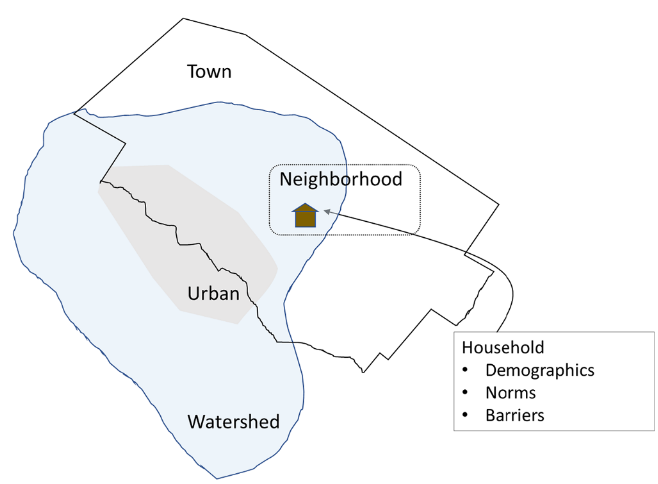



**Fig. 1.** Conceptual diagram of potential factors influencing residential intention to adopt GSI practices across scales. Here, each household resides in a neighborhood, town and watershed, and urban type. In addition to household demographics, norms, and barriers, residents may experience stormwater problems at the site-level. Various transboundary conditions related to stormwater at neighborhood, town, and watershed scales, as well as development density, may also influence intention to adopt different GSI practices. These household settings vary across and within boundaries. In the example depicted here, a household is located in a neighborhood spanning two watersheds, and a town where a river creates part of the boundary with an adjoining town. Urban development straddles both sides of the river between two towns and the remaining area is less developed.

related to nutrient pollution for its major basins, all of which are transboundary, including Lake Champlain, Lake Memphremagog, and the Connecticut River, to the west, north, and east, respectively, crossing state and/or national boundaries (VT DEC, 2017). Multiple sources contribute to pollution of these waters, including stormwater and wastewater, agriculture, forests, floodplains, and riparian land (State of Vermont, 2015). The clean-up responsibility is shared between federal, state, and local governments, the International Joint Commission, non-governmental organizations, landowners, concerned citizens, the private sector, and interest groups (Coleman, Hurley, Koliba, & Zia, 2017; Koliba, Reynolds, Zia, & Scheinert, 2014). The 2016 Total Maximum Daily Load for Vermont's portion of Lake Champlain illustrates the challenge of improving water quality related to nutrient pollution in that this plan "will require new and increased efforts from nearly every sector of society, including state government, municipalities, farmers, developers, businesses and homeowners" (State of Vermont, 2015, p. 2).

## 2. Methods

In the summer of 2015, a statewide survey entitled "Green Infrastructure Survey for Vermont Residential Properties" was administered to Vermont residents. Survey questions addressed demographics, watershed and stormwater experience, adoption of or intention to adopt specific GSI practices, and barriers to adoption (see Supplementary Materials I). This study extends beyond the more traditional urban and suburban stormwater management settings and allows for spatial analysis across different household, social, spatial, administrative, and watershed dimensions. Respondents were asked about current adoption and intention to adopt seven GSI practices: (1) actively divert roof runoff to a rain barrel or to lawn or garden instead of to street/sewer (henceforth this will be referred to "diversion of roof runoff"), (2) rain garden (bio retention), (3) permeable pavement, (4) infiltration trenches, (5) tree box filters, (6) constructed wetlands, and (7) green roofs. Individual practices were described in the survey (Supplementary Materials I).

### *2.1. Survey design*

The survey questions, list of GSI practices, and barriers were developed with expert input including contributions from survey design consultants as well as Vermont's Green Infrastructure Roundtable, which convenes stormwater professionals from state and municipal agencies, planning commissions, academia, and the private sector. The questions were modeled after similar previous surveys to allow for comparison. A probability-based, address-based sample of Vermont was used for survey dissemination using the U.S. Postal Service's Delivery Sequence File. The sample was purchased from ASDE Survey Sampler, Inc. Each addressee was mailed a pre-notification letter, a survey packet (including a cover letter, the survey booklet, and a postage-paid, addressed business-reply envelope), and a reminder postcard separately. The top of the survey booklet instructed the primary household decision-maker to complete the survey. There are an estimated 257,004 households in Vermont; and 4000 surveys were distributed. The response rate, adjusted to account for undeliverable surveys, was 16.5%. The 577 survey responses were weighted to the 2014 U.S. Census American Community Survey population projections. Data were adjusted for the base probability of selection, sample level nonresponse, and post-stratification weights based on region. The post-stratification weights were based on three geographic regions of Vermont (Supplementary Materials II). No adjustments were made for the design effects due to weighting or clustering. Fig. 2 shows recipient locations; and those who completed the survey depict a representative sample population. Areas running north to south through the center of the state that lack survey responses reflect the state's mountainous topography along the spine of the Green Mountains (Fig. 2).

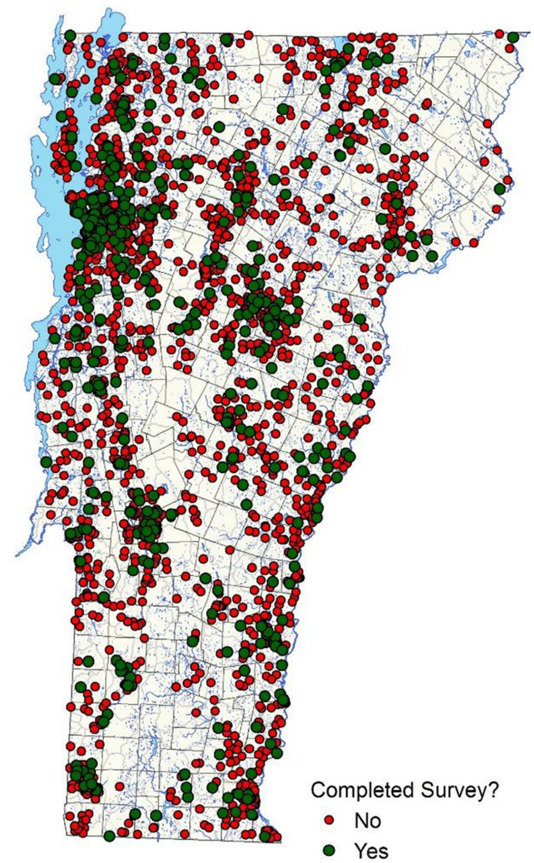



**Fig. 2.** Map showing distribution of completed surveys (green) and non-responses (red) with Lake Champlain to the west. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

### *2.2. Data analysis*

Data points nested within multiple spatial contexts (e.g. neighborhood, town, and watershed; Fig. 1) were derived from both the survey and spatial analysis. Information about site-level experience as well as perception of neighborhood stormwater and flooding problems, and town residence was derived from the survey. Addresses were geolocated to measure proximity to water bodies and place households in broader stormwater contexts including population, urban classification, and watershed scale.

#### *2.2.1. Geocoded survey responses*

To evaluate how residential intention to adopt the three GSI practices varies with household attributes and adoption barriers across stormwater contexts, the survey data included addresses that were geolocated (where possible) using Vermont's E911 road address range geocoder (VCGI, 2016). Geo-location of four hundred seventy (470) surveys allowed the cross-referencing of responses with spatial variables including proximity to water, urban zones, and residence in impaired watersheds. One hundred and seven (107) survey response addresses were PO Boxes and could not be geo-located to the exact residence, impeding analysis beyond the survey data.

Household proximity to water was defined as the closest distance to a body of water as measured using the Vermont Hydrography spatial layers of streams and rivers (order 4 and higher), lakes and ponds (U.S. Geological Survey et al., 2010). The American Community Survey (2015) was used to geolocate respondents in urban areas and clusters (classified as urban for analysis) as well as the population of census tracts (Supplementary Materials III). For the sub-basin level of analysis,

**Table 1**
Descriptive Statistics for the variables related to stormwater challenges at different spatial levels.

| | Spatial Variables | Percent% | Mean | Std. Dev | Median | Min | Max |
|---|---|---|---|---|---|---|---|
| *Household* | | | | | | | |
| Survey | Flooding on property | 9.91 | | 0.30 | 0.00 | | |
| | Basement flooding | 16.99 | | 0.38 | 0.00 | | |
| | Runoff, erosion, and washouts of driveway or road to your house | 32.18 | | 0.47 | 0.00 | | |
| | Runoff, erosion, or washouts of lawns or gardens | 11.77 | | 0.32 | 0.00 | | |
| | Household "Problem" | 54.19 | | 0.50 | 1.00 | | |
| Geolocated | Proximity to water (meters) | | 374.57 | 291.50 | 314.5 | 13 | 2031 |
| *Neighborhood* | | | | | | | |
| Survey | Stormwater problem in neighborhood | 20.50 | | 0.40 | 0.00 | | |
| | Flooding problem in neighborhood | 14.06 | | 0.35 | 0.00 | | |
| | Neighborhood Stormwater and/or Flooding problem | 25.88 | | 0.44 | 0.00 | | |
| *Population and Urban* | | | | | | | |
| Geolocated | Census Tract Population (1000) | | 4.06 | 1.67 | 3.84 | 0.91 | 9.05 |
| | Census Urban clusters and areas | 36.29 | | 0.48 | 0.00 | | |
| *Town* | | | | | | | |
| Survey | Town has MS4 permit | 24.88 | | 0.43 | 0.00 | | |
| *Watershed* | | | | | | | |
| Geolocated | Development impairment/Watershed (1000 m) | | 4.28 | 7.92 | 0.00 | 0.00 | 30.33 |

streams and rivers, listed on the 2014 303(d) list (VT DEC, 2016) as being impaired for stormwater and development sources more broadly, were mapped; and the length of water body impairment per HUC12 watershed was summed for each respondent. (See Supplementary Materials III for pollutant sources included in this classification.) One hundred and four segments were included in the final development-related stormwater impairment classification spanning twenty-seven HUC12 watersheds in Vermont.

#### 2.2.2. Household attributes, barriers to adoption and intention to adopt GSI

The survey asked questions about social and physical attributes of respondent residence, current adoption of GSI, and the intention to adopt GSI practices. Survey respondents reported whether they had experienced one or more of the following residential stormwater and flooding problems: basement flooding, flooding of property, washout of lawns, and washout and erosion of driveway or road to house. In addition, the survey asked if they believed stormwater or flooding to be a problem in the respondent's neighborhood. Respondents' identification with neighborhood was based on individual perception and was not externally defined or mapped. Survey respondents were also analyzed for residence in one of Vermont's 12 Phase II Small MS4 towns using the respondents' mailing address (as opposed to geo-located data) (VT DEC, n.d.).

Household-level demographic and management data were collected including lot size, estimated imperviousness, type of residence, tenure, income, education level, age, and gender. Respondents also answered whether compost or fertilizer was used on-site. These ten variables were used in preliminary logistic regression. The survey also included "yes or no' questions about ten barriers to adoption for five of the GSI practices; constructed wetlands and green roofs were excluded. Factors included: "not enough space," "costs too much," "no interest," "don't believe it works," "too much upkeep," "no need," "against property rules," "doesn't look good," "not suitable on my property," and "not enough information to decide". The percent of respondents reporting barriers to adoption for each practice was measured. Differences in barriers to adoption of rain gardens between households in MS4 communities and non MS4 communities were compared using paired T-tests. The barriers were also used in preliminary logistic regression models.

Overall intention to adopt GSI assesses whether respondents are "likely" to implement one or more practices. A survey question asked about intention to adopt on a scale of 0–5 (with 0 meaning unlikely and 5 meaning highly likely) For each practice, scores of 3–5 were assigned a "1" and all values less than 3 a "0". Respondents reporting adoption of the GSI practices were not included in the variable of intention to adopt. To assess intention to adopt across all the seven practices surveyed, the values were summed. Respondents likely to adopt one or more GSI practice were assigned a "1" and respondents with no intention were assigned "0".

Differences in overall intention to adopt between five spatial extents (Fig. 1) were compared using paired T-tests for initial analysis. For four dependent variables; intention to adopt one or more GSI practice as well as for diversion of roof runoff, rain gardens, and infiltration trenches, two separate binary logistic regression models were performed. These three practices are well-suited and commonly identified for residential implementation in Vermont. The first set of independent variables included seven spatial predictors. For the second model, two preliminary logistic regression models were run. The first tested ten demographic and management variables, and the second preliminary model tested barriers to GSI adoption. In the second model, only the independent variables that were significant from the two preliminary logistic regression models (household attributes and barriers to adoption) were included. Since the barrier to adoption questions were specific to each GSI practice, the logistic regression models for overall intention to adopt GSI included only the spatial and demographic predictors. Binary logistic regression analysis was conducted using SPSS Statistics 24 for Windows using the "ENTER" method for standard regression analyses (IBM Corp., 2016).

## 3. Results

### 3.1. Spatial and demographic attributes of households

Of the households surveyed, 54% experienced at least one erosion, flooding, washout, or stormwater runoff problem. About a third reported experiencing "runoff, erosion, or washouts of driveway or road to your house"; and about a sixth reported experiencing "basement flooding." Even fewer, around a tenth, reported either "runoff, erosion, or washouts of lawns or gardens," or "flooding on property." Most households (85.2%) that did not experience on-site problems also did not perceive runoff or flooding to be a problem at the neighborhood scale. In contrast, over a third (35.3%) of households with on-site challenges also perceived stormwater and or flooding problems at the neighborhood-scale (Table 1 and Fig. 3). A greater proportion (69.4%) of households that experienced on-site challenges fell in non-urban areas, which likely reflects the higher frequency of reported runoff-related driveway and road problems. A one-way ANOVA showed that

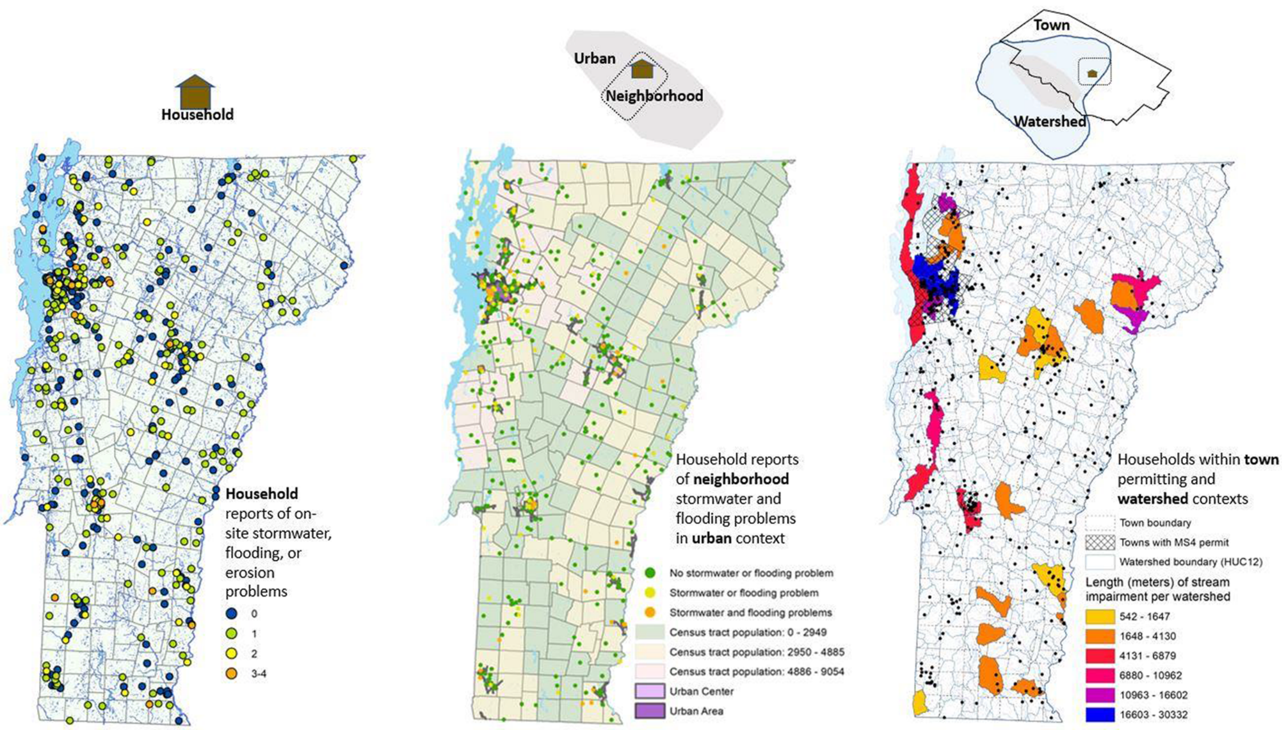



**Fig. 3.** Concept diagrams and maps showing spatial distribution of stormwater-related challenges at the household (site-scale) to watershed level for geolocated survey respondents. The left-most map shows households colored by number of on-site stormwater, flooding, or erosion problems reported in the last three years, with the hydrography spatial layers used to measure proximity to streams and rivers (order 4 and higher), and lakes and ponds (U.S. Geological Survey et al., 2010). The center map shows households that did not perceive stormwater or flooding to be a problem (green dots), perceived stormwater or flooding to be a problem (yellow dots), and perceived both stormwater and flooding to be a problem (orange dots) in the neighborhood over the last three years. Household perception of neighborhood stormwater and flooding problems are also shown in the context of Census tract population and Urban Center and Urban Area designation using the 2015 US Census. In the right column map, survey respondents are geolocated in town and HUC12 watershed contexts. Towns with MS4 permits and watersheds with varying length of steam impairment are shown. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

households that experienced erosion, flooding, washouts, or stormwater runoff had smaller census tract populations and had less impaired stream length within the local watershed. This is counter to what might be expected; more households experienced water-related problems in watersheds with less designated stormwater-impaired waterways (Fig. 3).

Some of the results confirm expected rural-urban differences. For example, lot size and estimated proportion of built area (imperviousness) are negatively correlated. Imperviousness and smaller lot size were associated with urban areas, towns with stormwater permits, and watersheds with development-related impairment. Types of on-site residential water challenges also differed across lot size and proportional imperviousness. Imperviousness was positively correlated with reported "runoff, erosion, or washouts of lawns or gardens," whereas larger (less impervious) lots were positively correlated with reported "runoff, erosion, or washouts of driveway or road to your house." "Basement flooding," was more likely to occur in urban areas. Ownership, single-family residences, and decision-making about landscaping, were negatively associated with imperviousness, urban residence, towns with MS4 permits, and level of watershed impairment. Single family residences were more likely than other residence types to report making property decisions and reported comparatively higher incomes. Use of compost was positively correlated with education level and was negatively correlated to imperviousness (See Supplementary Materials IV).

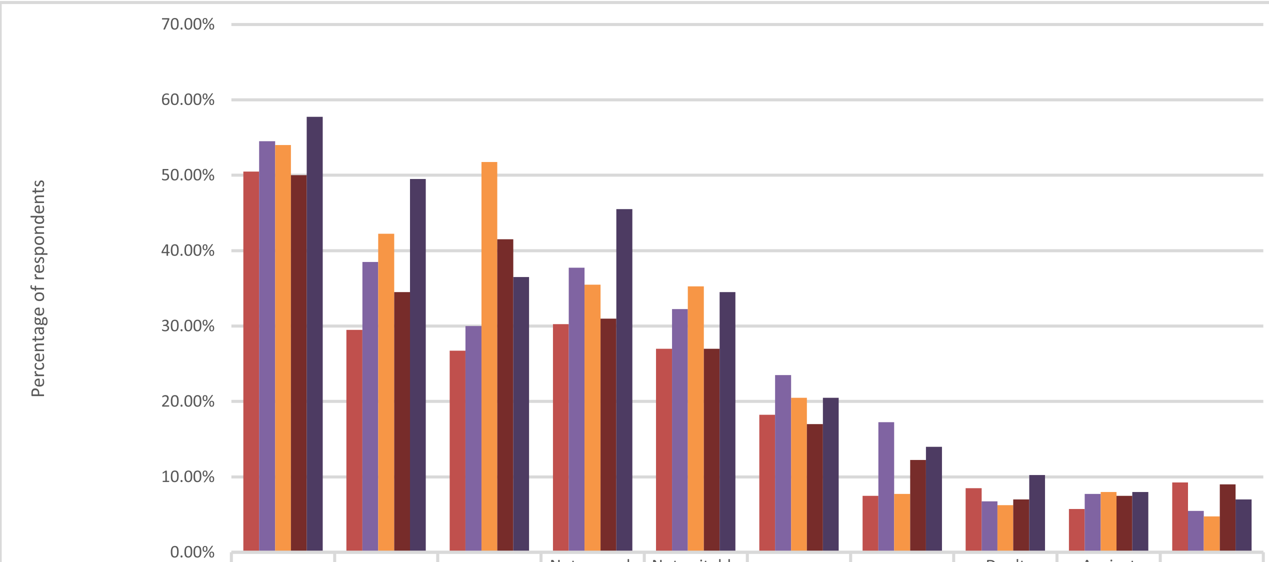
### 3.2. Barriers to adoption of GSI across spatial boundaries

For five GSI practices, survey respondents indicated their perceptions for ten barriers to implementation. Over half of respondents reported "no need" across the five practices. "No interest," "costs too much," and "not enough information to decide" followed (Fig. 4). Fewer than 10%, reported that "doesn't look good" was a barrier. In general, perceptions about the barriers were similar, but some notable differences exist among the specific practices. For example, significantly more respondents reported that permeable pavers "cost too much" compared to the other practices surveyed. For rain gardens, permeable pavers, and tree box filters, more respondents reported "not enough information to decide," while lack of information was less likely to be indicated for diversion of roof runoff and infiltration trenches. Both "too much upkeep" and "not enough space" were reported as barriers for rain gardens significantly more than diversion of roof runoff and infiltration trenches. Significantly fewer respondents reported "doesn't look good" as a barrier for rain gardens and permeable pavers compared to other practices.

Perceived barriers to adoption likely depend on the specific practice as well as other contextual factors. As one example, the percent of respondents reporting barriers to adoption of rain gardens from towns with and without MS4 permits (Fig. 5) show differences between "no need," "not enough space," "against property rules," and "doesn't look good." While fewer respondents from MS4 communities reported "no need," a relatively greater number of respondents from MS4 communities answered, "not enough space," against property rules," and "doesn't look good."

### 3.3. Implementation and intention to adopt GSI practices

Adoption of GSI and intention to adopt varied across the seven




| | No need | No interest | Costs too much | Not enough information to decide | Not suitable on my property | Too much upkeep | Not enough space | Don't believe it works | Against property rules | Doesn't look good |
|---|---|---|---|---|---|---|---|---|---|---|
| Diversion of roof runoff | 50.50% | 29.50% | 26.75% | 30.25% | 27.00% | 18.25% | 7.50% | 8.50% | 5.75% | 9.25% |
| Rain garden | 54.50% | 38.50% | 30.00% | 37.75% | 32.25% | 23.50% | 17.25% | 6.75% | 7.75% | 5.50% |
| Permeable pavers | 54.00% | 42.25% | 51.75% | 35.50% | 35.25% | 20.50% | 7.75% | 6.25% | 8.00% | 4.75% |
| Infiltration trenches | 50.00% | 34.50% | 41.50% | 31.00% | 27.00% | 17.00% | 12.25% | 7.00% | 7.50% | 9.00% |
| Tree box filters | 57.75% | 49.50% | 36.50% | 45.50% | 34.50% | 20.50% | 14.00% | 10.25% | 8.00% | 7.00% |

**Fig. 4.** Percentage of survey respondents reporting on the ten barriers to adoption for each of the five GSI practices: Diversion of roof runoff, rain gardens, permeable pavers, infiltration trenches, and tree box filters.

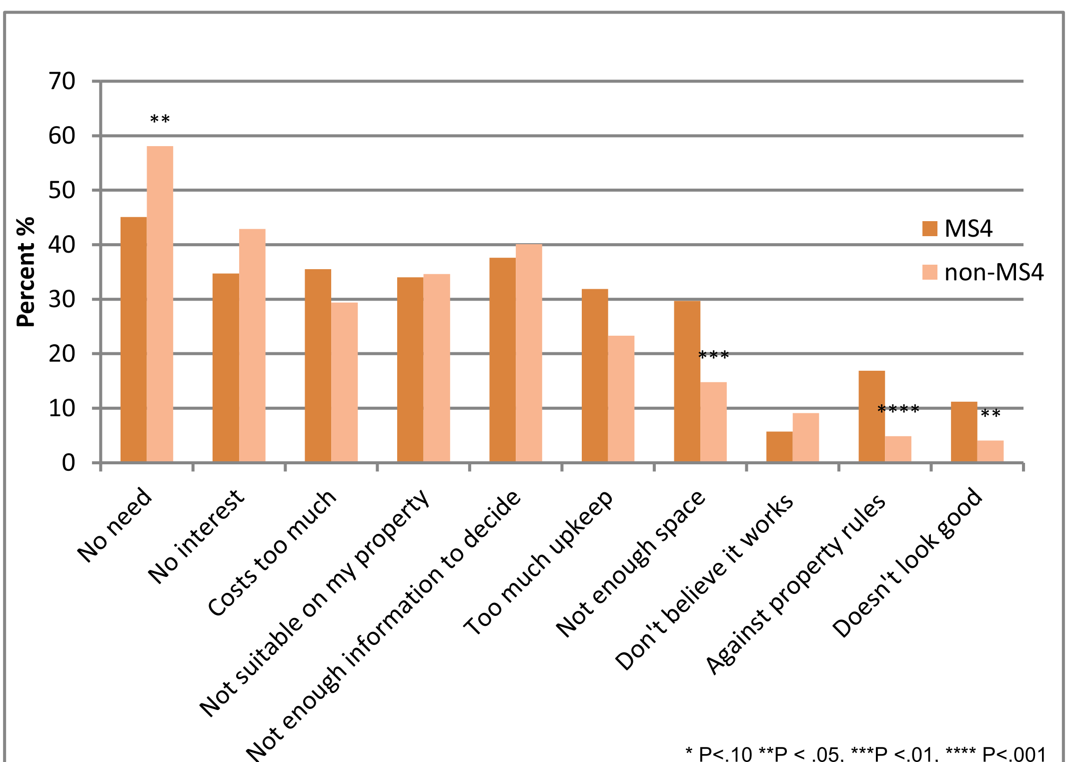



**Fig. 5.** Percent of respondents reporting on 10 barriers to adoption of rain gardens from MS4 and non-MS4 communities. Significant differences between groups are shown with an *.

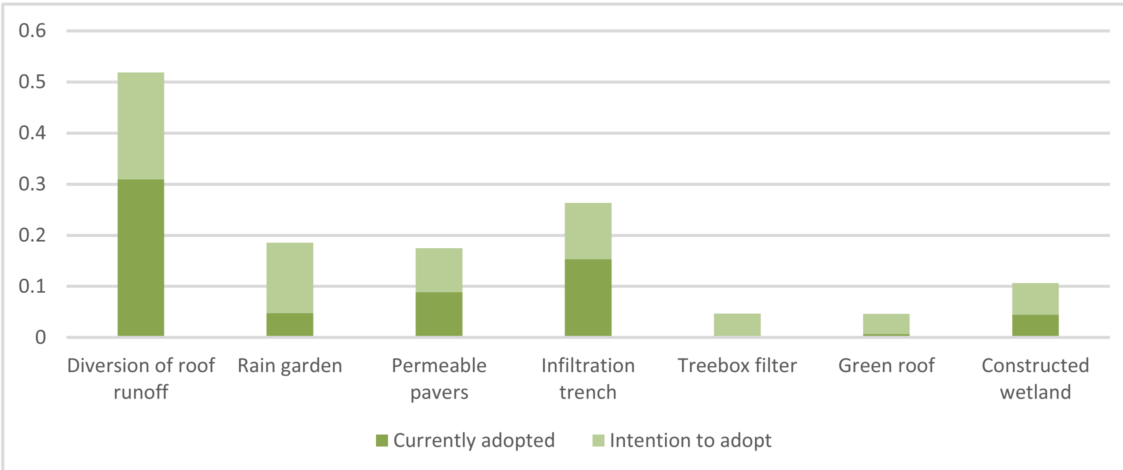



**Fig. 6.** Proportion of survey respondents reporting adoption and intention to adopt the seven GSI practices.

practices surveyed. In general, 65% of the survey respondents had either adopted or intended to adopt at least one of the GSI practices; 57% of the survey respondents reported no adoption of GSI practices; 28% had adopted one GSI practice; and 11% reported having two GSI practices at their residence. About two-thirds (68%) of the respondents reported little likelihood to adopt any of the GSI practices. About 16% and 8% of the survey respondents reported intention to adopt one or two GSI practices, respectively, in the next three years. "Diversion of roof runoff" was the most frequently reported GSI practice for both adoption and intention to adopt. Infiltration trenches followed in current adoption, but did not differ significantly from rain gardens or permeable pavers for intention to adopt. The remaining practices (tree box filters, green roofs, and constructed wetlands) had significantly lower reports of both adoption and intention to adopt. However, frequency of reported current adoption of rain gardens and constructed wetlands did not significantly differ (Fig. 6).

The intention to adopt one or more GSI practice was compared among groups with varied types of development and reported stormwater and flooding problems across spatial levels (Fig. 7). A significantly greater proportion of the groups that experienced at least one problem related to water management at the household-site or the neighborhood-scale indicated intention to adopt one or more GSI practice regardless of whether the respondent lived in a rural or urban area. There was no significant difference between level of intention to adopt GSI practices between groups in watersheds with development-related impairment or in towns with MS4 permits.

In predicting the intention to adopt three of the GSI practices, we see that the importance of the spatial, demographic, and barrier variables differs. Having experienced stormwater runoff and erosion at the site-scale, perception of neighborhood stormwater and flooding problems, and living in a more populated area each increased the odds of the intention to adopt diversion of roof runoff. The spatial predictors for rain gardens and infiltration trenches also differed. For example, residence in an MS4-permitted town and the perception of stormwater and flooding problems in the neighborhood were significant predictors of intention to adopt rain gardens. Residents of watersheds with less development-related impairment were slightly more likely to have intention to adopt both rain gardens and infiltration trenches. For infiltration trenches, two of the spatial predictors (residence in urban areas, and the experience of stormwater and flooding problems at the household-site) increased the likelihood of intention to adopt by 2.9 and 2.3 times, respectively. Logistic regression showed that experience and perception of stormwater and flooding problems at both the site and neighborhood-scale were significant predictors of the intention to adopt one or more GSI practice. Each of these spatial factors increased the odds of having intention to adopt by about 1.6 times. Intention to adopt also increased by 1.12 times with increases in population, and by 1.66 times with being in an urban area.

When the significant demographic variables and barriers to adoption from the preliminary models (Supplementary Materials IV) were included with the spatial variables in the logistic regression models the patterns evolved. For diversion of roof runoff, only increasing population predicted intention to adopt; whereas having increased development-related impairment within the watershed reduced the likelihood of intention to adopt. Younger respondents and users of compost were also significant social attributes that increased the likelihood of intention to adopt this practice. The model showed four significant barriers: "no interest," "no need," and "not suitable" reduced the likelihood of adopting a roof runoff diversion practice, whereas "don't believe it works" increased the likelihood of having intention.

For rain gardens, residence in a MS4 community and having flooding or stormwater problems at the neighborhood-scale were significant positive predictors, and like diversion of roof runoff, less impairment within the watershed increased the likelihood of intention to adopt. As expected, "no need" and "no interest" were significant barriers for intention to adopt rain garden; however, "against property rules" increased the likelihood (Table 2). In other words, people who said GSI was against property rules still wanted to adopt rain gardens.

The spatial variables (household-site and neighborhood problems) remained significant predictors of intention to adopt infiltration trenches; and of the demographic and barrier variables tested, "no need" was the only additional significant determinant. Because the barrier to adoption questions were specific to each GSI practice, the model for predicting intention to adopt one or more GSI practice could only test for spatial and demographic variables. When the significant demographic variables were added to the model for one or more GSI practice, experience of household-scale runoff management problems, population, and urban-ness remained significant spatial predictors. In addition, being situated in a watershed with development-impaired streams had a slightly negative impact on intention to adopt, with residents in less impaired watersheds being 1.05 times more likely to have intention to adopt. Younger respondents were more likely to have intention to adopt. Interestingly, respondents' reported use of compost increased the likelihood of having intention to adopt one or more GSI practice by 1.923 times (Table 2). For each of the four logistic regression models, the full model increased the R-squared value, but is still low for the general GSI practice model, implying the specific practices have specific explanatory factors.

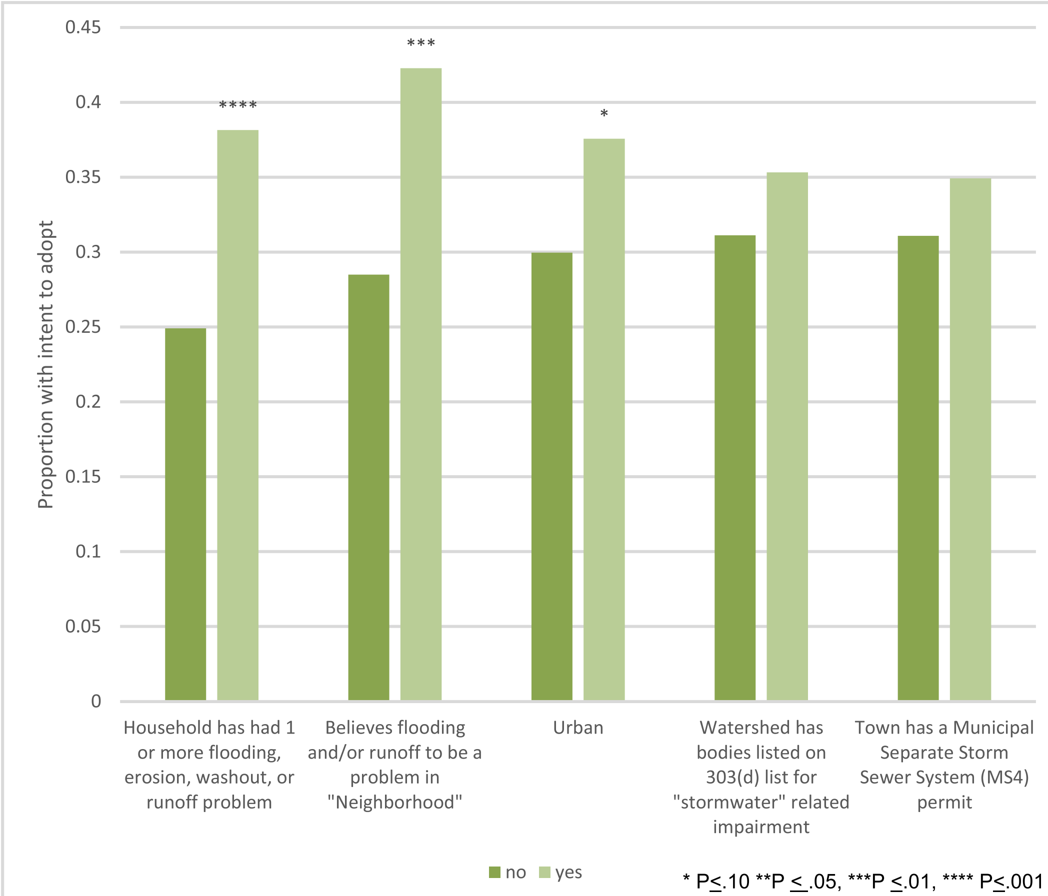



**Fig. 7.** Differences in intention to adopt between spatial groups. The watershed variable was transformed to a binary variable for this figure.

## 4. Discussion

### 4.1. Spatial and demographic attributes of households and barriers to adoption of GSI

The problems reported at the site-scale reflect the landscapes and topography of Vermont. In more urban areas, capacity of stormwater infrastructure to manage flooding is more likely to be of concern (Barbosa et al., 2012). While the impacts of runoff from urban areas are well known, the impacts on water quality of erosion from unpaved roads in forested landscapes still needs more attention (Pechenick et al., 2014; Wemple et al., 2017; Wemple & Jones, 2003).

The analysis of the barriers for the reported GSI practices raises additional questions about perception across different settings. The high frequency of “no need” responses may reflect that respondents living in a largely rural state were surveyed about more urban-suited GSI practices (US EPA, 2015) (Fig. 4). Given a more rural population experiencing problems at the site-scale, the survey could have included GSI and restoration practices such as bio-swales, riparian buffers, wetland and forest restoration, stone lined or vegetated ditches, bank stabilization, vegetated grass banks, or directing flow to retention areas (UNEP, 2014; U.S. EPA, 2000, 2015; Wemple et al., 2017) to better understand the perception of the “no need” response between rural and urban areas.

The barrier “against property rules” was selected fairly consistently across all the GSI practices. A further investigation of the drivers of these rules, such as aesthetic norms or perceptions of upkeep, might help decision-makers to select practices more appropriate for residential rental properties, homeowner associations, and other types of property management settings so that various types of residential sites could realize GSI benefits (Ando & Freitas, 2011; Fraser, Bazuin, Band, & Grove, 2013). The increased incidence of “doesn’t look good” with respect to diversion of roof runoff, infiltration trenches, and tree box filters (Fig. 4) highlights where other practices may be more desirable, or a need to change aesthetic preferences (Goddard, Dougill, & Benton, 2013; Nassauer, Wang, & Dayrell, 2009). Goddard et al. (2013) point to examples where influencing neighbors to follow early adopters changed the neighborhood norms with respect to lawn aesthetics to provide more ecological functions. It is possible that changing norms might also impact property rules and perceptions of upkeep. These barriers can be interdependent; the influence of removing one barrier can offset others and influence implementation (Roy et al., 2008; Wilson & Dowlatabadi, 2007). While aesthetic standards and norms may hamper adoption of some GSI practices (Fraser et al., 2013; Goddard et al., 2013; Nassauer et al., 2009), for other households, adoption is also likely limited by cost, tenure, and decision-making ability. In future research, ranking the barriers to adoption could improve understanding of the relative importance of each barrier (Roy et al., 2008; Steg & Vlek, 2009; Wilson & Dowlatabadi, 2007).

Given that in the coterminous United States, 39% of all houses exist in the “wildland-urban interface” with continued development pressure (Radeloff et al., 2005; Wear et al., 1998), a unique set of challenges for conservation, infrastructure, and water quality exists. The higher frequency of reported household experiences with stormwater and erosion problems in rural areas also raises an important question about perceptual differences between rural and urban households as to what qualifies as “stormwater.” For example, mismanaged stormwater can cause water runoff problems as well as soil erosion, but the latter may not be as readily attributed to the concept of “stormwater management” in rural areas, dampening the perceived need for GSI or improved

**Table 2**
Logistic regression of 4 dependent variables: Intention to adopt diversion of roof runoff, rain gardens, infiltration trenches, 1 or more practice.

| | Diversion of roof runoff: spatial predictors | | | Diversion of roof runoff: combined variables | | | Raingarden: spatial predictors | | | Raingarden: combined variables | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | Sig. | Exp(B) | B | Sig. | Exp(B) | B | Sig. | Exp(B) | B | Sig. | Exp(B) |
| Proximity to water | 0.000 | 0.550 | 1.000 | 0.001 | 0.318 | 1.001 | 0.000 | 0.511 | 1.000 | −0.001 | 0.221 | 0.999 |
| Population | 0.151 | 0.066* | 1.163 | 0.366 | 0.015** | 1.442 | −0.020 | 0.828 | 0.980 | −0.111 | 0.434 | 0.895 |
| Impairment length/HUC12 watershed | −0.007 | 0.777 | 0.993 | −0.082 | 0.078* | 0.921 | −0.043 | 0.091* | 0.958 | −0.060 | 0.089* | 0.942 |
| Household-site runoff, erosion, washout problems | 0.514 | 0.063* | 1.672 | 0.501 | 0.246 | 1.650 | 0.164 | 0.594 | 1.178 | −0.285 | 0.486 | 0.752 |
| Consider stormwater/flooding a problem in neighborhood | 0.696 | 0.02** | 2.006 | 0.739 | 0.141 | 2.093 | 0.803 | 0.010** | 2.231 | 0.943 | 0.040** | 2.567 |
| Urban | 0.080 | 0.814 | 1.083 | 0.643 | 0.291 | 1.903 | 0.122 | 0.744 | 1.130 | −0.547 | 0.302 | 0.579 |
| Town has MS4 permit | 0.181 | 0.687 | 1.198 | −0.031 | 0.969 | 0.969 | 1.015 | 0.024** | 2.759 | 1.699 | 0.013** | 5.468 |
| Age | | | | −0.030 | 0.067* | 0.971 | | | | | | |
| Female | | | | −0.333 | 0.448 | 0.717 | | | | 0.327 | 0.415 | 1.387 |
| Rent | | | | | | | | | | 0.166 | 0.840 | 1.180 |
| Compost | | | | 0.820 | 0.063* | 2.271 | | | | 0.390 | 0.383 | 1.477 |
| No interest | | | | −1.368 | 0.024** | 0.255 | | | | −2.693 | 0.003*** | 0.068 |
| Don't believe it works | | | | 1.756 | 0.035** | 5.790 | | | | | | |
| No need | | | | −1.762 | 0.000*** | 0.172 | | | | −1.955 | 0.000*** | 0.142 |
| Against property rules | | | | | | | | | | 2.788 | 0.006*** | 16.252 |
| Not suitable on my property | | | | −1.436 | 0.01** | 0.238 | | | | | | |
| Constant | −1.903 | 0.000 | 0.149 | 0.074 | 0.951 | 1.077 | −1.998 | 0.000 | 0.136 | −0.332 | 0.664 | 0.717 |
| -2 Log likelihood | 350.397a | | | 153.213a | | | 319.391a | | | 167.971[a] | | |
| Cox & Snell R Square | 0.062 | | | 0.375 | | | 0.046 | | | 0.250 | | |
| Nagelkerke R Square | 0.085 | | | 0.503 | | | 0.078 | | | 0.393 | | |
| Model Chi-sq | 18.083 | | | 79.906 | | | 17.853 | | | 66.843 | | |
| df | 7.000 | | | 14.000 | | | 7.000 | | | 13.000 | | |
| Sig | 0.012 | | | 0.000 | | | 0.013 | | | 0.000 | | |
| | Infiltration Trench: spatial predictors | | | Infiltration Trench: combined variables | | | GSI Practices: spatial predictors | | | GSI Practices: combined variables (without barriers) | | |
| | B | Sig. | Exp(B) | B | Sig. | Exp(B) | B | Sig. | Exp(B) | B | Sig. | Exp(B) |
| Proximity to water | 0.001 | 0.316 | 1.001 | 0.000 | 0.550 | 1.000 | 0.000 | 0.614 | 1.000 | −0.001 | 0.177 | 0.999 |
| Population | 0.030 | 0.803 | 1.030 | −0.130 | 0.411 | 0.878 | 0.115 | 0.085* | 1.122 | 0.136 | 0.063* | 1.145 |
| Impairment length/HUC12 watershed | −0.095 | 0.019* | 0.909 | −0.079 | 0.104 | 0.924 | −0.031 | 0.105 | 0.969 | −0.049 | 0.015** | 0.952 |
| Household-site runoff, erosion, washout problems | 0.824 | 0.032** | 2.279 | 0.834 | 0.071* | 2.302 | 0.530 | 0.015** | 1.699 | 0.640 | 0.007*** | 1.897 |
| Consider stormwater/flooding a problem in neighborhood | 0.570 | 0.126 | 1.768 | 1.218 | 0.008*** | 3.380 | 0.515 | 0.029** | 1.674 | 0.415 | 0.105 | 1.515 |
| Urban | 1.057 | 0.012** | 2.877 | 0.575 | 0.287 | 1.777 | 0.505 | 0.063* | 1.657 | 0.531 | 0.07* | 1.701 |
| Town has MS4 permit | −0.161 | 0.765 | 0.852 | −0.485 | 0.459 | 0.616 | 0.081 | 0.823 | 1.084 | 0.401 | 0.300 | 1.493 |
| Age | | | | | | | | | | −0.045 | 0.000*** | 0.956 |
| Female | | | | | | | | | | | | |
| Rent | | | | | | | | | | | | |
| Compost | | | | | | | | | | 0.654 | 0.006*** | 1.923 |
| No interest | | | | | | | | | | | | |
| Don't believe it works | | | | | | | | | | | | |
| No need | | | | −1.696 | 0.000*** | 0.183 | | | | | | |
| Against property rules | | | | | | | | | | | | |
| Not suitable on my property | | | | | | | | | | | | |
| Constant | −3.013 | 0.000 | 0.049 | −1.518 | 0.048 | 0.219 | −1.588 | 0.000 | 0.204 | 0.623 | 0.312 | 1.865 |
| -2 Log likelihood | 237.019a | | | 161.078a | | | 555.553a | | | 476.508a | | |
| Cox & Snell R Square | 0.064 | | | 0.143 | | | 0.049 | | | 0.136 | | |
| Nagelkerke R Square | 0.119 | | | 0.257 | | | 0.067 | | | 0.187 | | |
| Model Chi-sq | 22.201 | | | 37.656 | | | 22.527 | | | 60.563 | | |
| df | 7.000 | | | 8.000 | | | 7.000 | | | 9.000 | | |
| Sig | 0.002 | | | 0.000 | | | 0.002 | | | 0.000 | | |

stormwater management. In rural residential areas, infrastructure is more likely to be ditches and culverts than storm sewers, but stormwater still flows off roofs, driveways, and roads. Understanding differences in stormwater perceptions would allow for a more nuanced strategy for rural areas that are often undergoing development with fewer restrictions related to zoning and master planning.

### 4.2. Different determinants of intention to adopt among GSI practices

Our logistic regression models for "intention to adopt" suggest that given a landscape of multiple-level stormwater problems, the intentions vary with specific practice being proposed. Compared with other GSI practices, interpretation of the results associated with the diversion of roof runoff becomes more complicated when the demographic variables and barriers to adoption are included with the spatial predictors. Population size was the predictive spatial variable, and younger age, compost use, and barriers such as "no need," "not suitable," "no interest," and "don't believe it works" were significant factors (Table 2). The counter-intuitive effect of the barrier, "don't believe it works" may reflect a perception of the practice of roof runoff diversion as more of a "green" behavior with drivers beyond perceived utility and stormwater management objectives. The study by Noppers et al. (2014) on the purchase of electric cars demonstrates that weaker instrumental benefits can be superseded by symbolic and environmental motivators in the adoption of "green" behaviors. Also, Ando and Freitas (2011) found that the adoption of rain barrels was not correlated with experience of local flooding, but instead adoption correlated with areas with higher incomes, located near rain barrel distribution sites, and where fewer residents renting their homes. Intention to adopt in this study may also have been motivated by additional co-benefits of diversion of roof runoff such as, rainwater harvesting for irrigation (US EPA, 2015). Interpreting the intention to adopt diversion of roof runoff is also complicated in that —as described in the survey— diversion could encompass somewhat different practices including disconnection of downspouts, routing water to lawns and gardens, and the use of rain barrels (US EPA, 2015).

The logistic regression model for rain gardens portrays a different picture. In addition to perception of stormwater or flooding problems in the neighborhood, residence in an MS4 municipality emerges as a significant predictor of greater intention to adopt rain gardens. This may be a signal of the outreach and education efforts required as "minimum measures" in MS4 communities (VT DEC, n.d.). For example, Chittenden County Regional Planning Commission's (n.d.) "Rethink Runoff" campaign in Vermont promotes disconnecting downspouts and use of rain barrels and rain gardens. Other GSI practices may be equally suitable for residences in MS4 communities, but educational information concerning those practices may be less prevalent. The barrier "against property rules" which can apply to homeowners and renters, had an unexpected effect on intention to adopt rain gardens. Rain gardens were shown to be desirable despite presence of a property rules barrier, suggesting rain gardens uniquely have appeal even for renters and owners that do not make their own landscaping decisions (Table 2).

Infiltration trenches may be perceived as a more appropriate GSI practice for addressing site-scale stormwater management. When demographic and barrier predictors were included in the models, "no need" was the only additional significant variable among those variables describing experience of household and neighborhood-scale stormwater problems (Table 2); this implies a focus on utility or "need" of infiltration trenches at the site-scale.

Performing logistic regression on intention to adopt one or more GSI practice allowed for analysis of spatial and demographic determinants that are less specific to individual practices. Our finding "experience of one or more stormwater-related problems at the household-site" to be a significant predictor of willingness to adopt aligns with previous research citing "lived experience" as a significant driver (Baptiste, 2014; Baptiste et al., 2015). The likelihood of intention to adopt a GSI practice also increased with population size and urban-ness of residence. Additional demographic and management factors that were found to influence likelihood to adopt GSI practices warrant further investigation. Finding that being younger and using compost correspond with increased intention to adopt GSI (Table 2) could be important when considering strategies for promoting GSI; these relationships may signal green behaviors in respondents (Ando & Freitas, 2011). Potential opportunities and risks need to be considered for coupling GSI practices with other green behaviors in order to achieve real water quality and stormwater management improvements. For example, recent research calls attention to the risk of nutrient leaching from compost incorporated into saturated soils, including bioretention soil media (Hurley, Shrestha, & Cording, 2017).

### *4.3. Limitations of a cross-scale analysis of residential green stormwater infrastructure*

This study surveyed the entire state of Vermont across a diverse set of rural, suburban and urban landscapes making it difficult to uniformly assess stormwater contexts and the appropriateness of the surveyed GSI practices. Although it is conceivable that residents who experience stormwater issues might be more likely to complete the survey, and given that this research does not allow us to verify the reported neighborhood stormwater issues, we believe that having 20.5% respondents report "perceived stormwater problems in their neighborhoods" is realistic, and not a reflection of selection bias. New England has increased potential for extreme precipitation events (Guilbert et al., 2014) as well as challenges with aging and under-designed stormwater infrastructure that are prevalent in Vermont and across the United States. At the watershed level, the impairment measure depends on 303(d) assessment and listing procedures that may not capture all pollution and degradation related to development and stormwater runoff across rural and urban landscapes (US EPA, n.d.). The use of this variable may limit our understanding of how watershed health relates to intention to adopt at the residential scale, particularly in rural areas reporting on-site stormwater problems. These challenges in verifying actual conditions from site to watershed scale, limits our ability to assess the appropriateness of specific GSI for any residence. We hope future research coupling surveys with spatial analysis might provide a deeper level of household analysis and interpretation of stormwater and infrastructure challenges across spatial scales and along a rural to urban gradient.

Future research could also aid understanding of demographic factors like age, home ownership, and income, as well as other barriers like "against property rules" and the cost of GSI practices. Due to the sample size, this study did not permit finer scale analysis of the differences between intention to adopt GSI practices in smaller geographic areas of Vermont with younger populations. The presence of property rules prohibiting GSI also could not be analyzed separately by home ownership (e.g. by rental versus owned) because of the sample size. Lastly, while cost is an important factor of GSI adoption (Baptiste et al., 2015; Brown et al., 2016), providing realistic cost estimates for GSI practices in varying residential site conditions was beyond the scope of this research. Deeper analysis of these variables and other factors like length of residence and existing stormwater infrastructure, would add to the research presented here.

These research directions also require a deeper understanding of respondents' conceptions of their surrounding context and knowledge of stormwater and the distinct GSI practices surveyed. The term "neighborhood" can invoke varying spatial areas and boundaries across different settings (Coulton, Korbin, Chan, & Su, 2001), and some rural Vermont respondents may not have perceived being a resident of a "neighborhood." Also, the survey did not ask respondents whether they lived in a town with an MS4 permit, or if their watershed was impaired for stormwater and development (these were ascertained through geolocation of addresses). Although brief definitions of each GSI practice were included in the survey, lack of familiarity with the practices may have influenced responses. In addition, the volume of questions may have presented a cognitive burden to respondents. Future research could further explore knowledge and perception across these spatial contexts. Lastly, while this study focused on understanding the predictors of intention to adopt, we recognize that more attention is needed to understand the gap between stated intention and actual future adoption (Kollmuss & Agyeman, 2002).

### 4.4. Residential GSI practices from the household to the watershed

There is a need to develop adaptive approaches across a complex social-ecological landscape to capture and treat stormwater runoff and encourage cross-scale benefits. The ability of policy-makers and planners to develop appropriate strategies to promote residential GSI adoption for property owners is especially important given that survey responses indicate different drivers and barriers to adoption across GSI practices and stormwater contexts. Identifying how contextual factors affect environmental behavior (Steg & Vlek, 2009), will be important as towns face more pressure to improve stormwater management and increasingly look to private landowners (Thurston, 2006) to incorporate GSI on their properties. For example, households in urban, MS4-permitted towns, with impaired watersheds, may have less decision-making ability to implement appropriate GSI practices despite our finding of increased interest in rain garden adoption within MS4-permitted towns. Specialized programs to encourage investments by landlords in rental housing may need to be developed (Ando & Freitas, 2011). Ando and Freitas (2011) point out that rain barrels may be appropriate in single family rentals, but permeable pavement, rain gardens, and green roofs may be more appropriate for larger multi-unit residences.

Outreach efforts may also benefit from directing more attention toward residential motivations for GSI adoption that go beyond stormwater function to improve stormwater management at neighborhood, town, and watershed scales. While, Keeley et al. (2013) highlight that private landowners in urban areas may not perceive stormwater management to be something they are directly responsible for, Crisostomo et al. (2014) found motivation to adopt GSI extended beyond stormwater management alone to intangible green benefits. In a study of low-carbon lifestyles, Howell (2013) showed the importance of altruistic values in predicting environmental behavior more than environmental values. Social marketing strategies that go beyond traditional educational interventions involved in public outreach could be helpful in leveraging the power of social norms including the influence of neighbors and community members (Goddard et al., 2013; Kollmuss & Agyeman, 2002; Rosenberg & Margerum, 2008; Steg & Vlek, 2009). Continued research is needed to promote a broader commitment to sustainability and integrative sustainability policies (Newell, Pattberg, & Schroeder, 2012) and desirable co-benefits of GSI practices across scales.

## 5. Conclusion

Improved stormwater management outcomes at the watershed and local levels depend on adaptive approaches that adjust strategies along the rural-urban gradient, across the bio-physical landscape, and according to varying norms and institutional arrangements. As stormwater management conditions vary at the site-scale across landscapes, stormwater best management practices must be inclusive of multiple motivations across a complex social-ecological landscape. In this context, future management and research approaches should account for varying dimensions of biophysical and social motivators of green stormwater infrastructure practices from the household-site to the watershed-scale. While much of the GSI and LID literature focuses on implementing best management practices in urban and suburban areas, some practices may provide needed mitigation of downstream erosion and sediment transport in rural areas, while also addressing site challenges.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.landurbplan.2018.09.005.

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