# ABSTRACT


Title of Thesis: KNOWLEDGE, ATTITUDES, AND IMPLEMENTATION OF BMPS AND MOSQUITO MANAGEMENT ACROSS A SOCIOECONOMIC GRADIENT

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To reduce nutrient pollution in our waterways and restore impaired watersheds, residents are needed to voluntarily practice a range of stormwater best management practices (BMPs). The overall goal of my thesis was to better understand barriers to BMP implementation by exploring the links among resident demographics, knowledge, and behaviors, as well as mosquito management, so that appropriate education can be more effectively developed and targeted. Importantly, this study found respondents who defined themselves as Caucasian or other races, and that were in owned houses, had higher mean BMP knowledge than respondents that identified themselves as African American and who are renters, respectively. This study also found that one barrier to BMP implementation, concern of mosquito breeding in BMPs, was not significant. Estimated abundances for all mosquito abundance metrics were significantly higher in combined other types of wet containers compared to wet disconnected downspouts, a commonly found BMP.

# KNOWLEDGE, ATTITUDES, AND IMPLEMENTATION OF BMPS AND MOSQUITO MANAGEMENT ACROSS A SOCIOECONOMIC GRADIENT

by

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# Dedication

This thesis is dedicated to my grandfather, Wilford W. Fraser.

# Acknowledgements

Many thanks to John McCoy from Columbia Association and Vaughn Perry from Anacostia Watershed Society for help designing the initial stormwater questionnaire, Samantha Keane, Sree Sinha, and Maya Spaur for help administering, and the residents of Washington, D.C. and Columbia, MD who participated in this study. Thank you to Dawn Biehler, Shannon LaDeau, Zara Dowling, and Danielle Bodner for your precedent studies and questionnaires on which the mosquito questionnaire was based. Thank you to my hard-working and dedicated field assistants Amy Milne and Michael Littleford. Megan Saunders, thank you for the extensive lab and mosquito ID training, and for answering my many questions. Thank you to my committee for helping shape and guide these studies. Thank you to the Office of Multi-Ethnic Student Education for supporting my studies and personal growth throughout my M.S. Finally, thank you to my supportive family: Makoto, Martha, Momoka, and Mikana Maeda. You all kept me inspired and reminded me to never give up. This thesis was funded by the U.S. EPA Science To Achieve Results (STAR) Program (R835284) and the Maryland Sea Grant 2017 Coastal Resilience and Sustainability Fellowship.

# A Note on Format

Chapter II is formatted for submission as an original contribution to the journal *PLOS One*.

Chapter III is formatted for submission as an original contribution to the *Journal of Medical Entomology*.

Preparation of chapters in this format has necessitated some overlap in content among sections.

# Table of Contents

# Chapter 1: General Introduction

### *Water Quality and Stormwater Management*

The quality of water in our streams, lakes, and estuaries results from interactions between the biophysical landscape and the attitudes and behaviors of citizens (Nowell, Capel et al. 1999). Unfortunately, the majority of watershed research and intervention programs have been on either the biophysical or the social components alone (Parkes, Panelli et al. 2003). Community-related watershed concerns tend to differ from regulatory requirements (NRC 2008). Regulations focus on managing quantities of stormwater nitrogen (N), phosphorous (P), sediment (S) and other pollutants. In contrast, community stormwater concerns often focus on flooding, trash, or mosquito-breeding. New stormwater management regulations place emphasis on on-site stormwater controls for new developments, but they have had limited acceptance within communities (NRC 2008). Recent research has emphasized that proper stormwater management is limited by prioritizing technical solutions while not adequately incorporating the social dimensions into planning and decision-making (Cettner, Ashley et al. 2014). There is an increasingly louder chorus from watershed professionals for the need to encourage community education and participation in watershed management (Söderberg and Aberg 2002). In particular, sustained resident-based participation is needed to help achieve watershed restoration goals by implementing household-scale Best Management Practices (BMPs), including rain barrels, disconnected gutters, and reducing the use of fertilizers.

### *Resident-based Stormwater Management*

Resident-based stormwater management is most desperately needed in America's urban watersheds. Urban development has decreased pervious surfaces, creating dramatic changes in the hydrologic regimes of whole watersheds (Thom, Borde et al. 2001). Infiltration rates and surface water retention storage capacities have decreased, while surface water runoff has become more likely to contribute to non-point source pollution (Miller, Kim et al. 2014). Excess N, P and S associated with urbanization are critical threats to watershed sustainability across the nation, while fertilizers, herbicides, insecticides, bacteria, and metals pose additional significant risks (Stein and Tiefenthaler 2005). In the Chesapeake Bay, N originating from urban landscapes is a major contributor to eutrophication (Boyer, Goodale et al. 2002, Gilbert, Virani et al. 2002, Howarth, Sharpley et al. 2002) and poses risks to ecosystem and human health through algal blooms and hypoxic conditions that can lead to fish kills and biodiversity loss (US EPA). Mitigating urban pollutants presents numerous social challenges. Urban watersheds consist of vast numbers of residents that manage small privately-owned parcels of land. Some residents contend with numerous socio-ecological disamenities, including higher poverty and crime rates, low home ownership, and decreased public greenspaces, which can deeply affect their perceptions of watersheds and the wider environment. These and other social factors can create significant barriers to the implementation of BMPs.

*Mosquito-borne diseases*

Perhaps one of the most interesting barriers to BMP implementation are resident concerns of mosquitoes. Mosquitoes cause astounding mortality and morbidity around the world (CDC), and are a substantial health concern in urban areas (Leisnham and Slaney 2009). Americans have endured a long history of struggle with mosquitoes. For example, West Nile virus (WNv) caused widespread fear when it was first detected in New York City in 1999. Today, WNv continues to haunt Americans as the most important contemporary mosquito-transmitted disease, having infected 46,086 individuals across the U.S. and caused 2,017 deaths (CDC) since it was first detected. In addition to WNv and other resident mosquito-vectored diseases (e.g. EEE, LAC), emerging new diseases threaten to establish and spread in the continental United States, even in temperate regions. In 2016, Zika virus surfaced as a novel mosquito-borne threat in the Americas and Caribbean. The United States has recently documented local Zika transmission, and the disease has been declared a risk to the eastern seaboard (Monaghan, Morin et al. 2016).

The invasive Asian tiger mosquito, *Aedes albopictus*, and the northern house mosquito, *Culex pipiens,* are the two most common urban mosquitoes in the northeastern United States (Darsie Jr and Ward 2004). *Aedes albopictus* is a capable vector for diseases currently in the United Sates, including WNv, La Crosse (LAC) encephalitis, and Eastern equine encephalitis (EEE), as well as those that threaten from overseas, including Chikagunya virus and Zika virus (Gerhardt, Gottfried et al. 2001, Gratz 2004, Turell, Dohm et al. 2005, Leisnham and Juliano 2012), but its greatest public threat may be its aggressive human-biting that has been associated with reduced outdoor activity and childhood obesity (Barker, Paulson et al. 2003, Braks, Honorio et al. 2003, Worobey, Fonseca et al. 2013). *Culex pipiens* is a less aggressive human biter (Fonseca, Keyghobadi et al. 2004, Turell, Dohm et al. 2005), but is the principle vector of WNv in the northern United States, maintaining and amplifying the virus among bird populations (Turell, Dohm et al. 2005). In the state of Maryland and Washington, D.C., WNv infections in humans have been reported, with 334 total disease cases in Maryland and 97 total disease cases in Washington, D.C. between 1999 and 2016 (CDC).

*Mosquito Ecology*

Both *Ae. albopictus* and *Cx. pipiens* grow and develop in a wide range of water-filled artificial containers common in urban landscapes, including trash receptacles, bird baths, gardening buckets, as well as some household stormwater BMPs (Unlu, Faraji et al. 2014), such as disconnected corrugated downspouts and rain barrels (Braks, Honorio et al. 2003, Darsie Jr and Ward 2004). Because of their breeding habits, the control of these species is largely dependent on resident behaviors, since mosquito control agencies or other entities may not have access or enough capacity to manage individual yards (Paupy, Delatte et al. 2009).

*Conventional Mosquito Control*

One strategy to help manage mosquito populations in urban areas is community-based source reduction, whereby residents are encouraged to minimize the numbers of containers that can collect rainwater and serve has mosquito developmental habitat. Source reduction can include removing container habitats, emptying water-filled containers that cannot be removed, or applying insecticides to habitats that cannot be removed or emptied, such as salts, oils or commercially available insecticides (e.g., Bti, *Bacillus thuringiensis serotype israelensis*) (WHO). Source reduction can be a cost-effective method of controlling mosquito populations and reducing transmission risk (Kay and Nam 2005), and is recommended by numerous mosquito control agencies, including the American Mosquito Control Association, the Centers for Disease Control and the World Health Organization as a vital tool for integrated mosquito management, worldwide (WHO 1997, CDC 2016, AMCA 2017). Because source reduction relies on community action, resident knowledge and behaviors demographics, are likely relevant to the effective management of container mosquitoes (Dowling, Armbruster et al. 2013).

The overall goal of my thesis is to better understand barriers to stormwater BMP implementation by exploring the links between resident demographics, knowledge and behaviors so that appropriate education can be more effectively developed and targeted. In 2014-15, a detailed questionnaire was administered door-to-door to randomly selected households in two urban resident watersheds in Maryland and Washington, D.C. (IRB Protocol: 11-0513) as part of an EPA-funded project (#R835284). This questionnaire gathered a rich dataset on household and individual demographics, knowledge, attitudes and BMP implementation. In Chapter 2, I use multi-factor generalized linear models to quantify empirical relationships within these data to shed new light on the socio-ecological factors influencing appropriate household-scale stormwater management. A main finding from Chapter 2, was that mosquito breeding within stormwater BMPs was a concern among a vast majority (233/297, 78.5%) of residents. This finding provided the motivation to undertake a follow-up study, which I report in Chapter 3. In this follow-up study I administered a second KAP questionnaire in 2016 to 92 randomly selected households that were previously sampled in 2014-15 to collect data on resident knowledge and behaviors related to mosquitoes in BMPs. I paired this 2016 questionnaire with comprehensive household yard surveys of water-containing habitats and the mosquitoes they harbored. A main objective of this study was to determine if the perceived risk from residents of mosquito production from stormwater structures is actually realized for the most common household BMP: disconnected downspouts. A second main objective was to test social predictors of resident mosquito knowledge, concern, and mosquito management so that targeted education can be developed and implemented. This education material could inform communities of bio-rational mosquito management (e.g., applying mosquito Bti dunks in rain barrels, tipping water out etc) in disconnected downspouts and other BMPs (e.g., rain-barrels), dispel misconceptions about mosquito ecology, and increase BMP adoption. Chapters 2 and 3 are written as a stand-alone papers ready for submission to peer-reviewed journals with their own Abstracts, Introduction, Methods, Results, and Discussion sections, and refer to group authorship.

# A Note on Format

Chapter II is formatted for submission as an original contribution to the journal *PLOS One*.

# Chapter 2: Linking Stormwater Best Management Practices to Social Factors in Two Suburban Watersheds

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# Abstract

To reduce nutrient pollution in our waterways and restore impaired watersheds, residents need to voluntarily practice a range of stormwater Best Management Practices (BMPs). However, little is still known about the underlying social factors that may act as barriers to BMP implementation. The overall goal of this study was to better understand barriers to BMP implementation by exploring the links among resident demographics, knowledge, and behaviors so that appropriate education can be more effectively developed and targeted. In 2014-2015, a detailed questionnaire was administered door-to-door to 311 randomly selected households in two Chesapeake Bay sub-watersheds to test relationships among resident demographics, knowledge and attitudes towards water resources and BMPs and BMP implementation. In multifactor regression models, which controlled for the effects of other key predictors, respondents that had higher knowledge lived in households that implemented greater numbers of BMPs. In turn, knowledge, specifically familiarity with BMPs, strongly varied with race and ownership status, with respondents who identified as Caucasian or within a collection of 'Other' races and who were home owners having higher BMP knowledge than respondents identifying as African American and home renters, respectively. Overall, respondents preferred to receive educational materials on stormwater via pamphlets and YouTube videos. These results suggest that resident knowledge is important to determining the number of household BMPs, and that education outreach should probably target African American and renting households using well-planned educational materials that have lower BMP knowledge.

# Introduction

Over half of America's tributaries are designated as impaired by the U.S. EPA [1]. A major cause of this impairment is nonpoint source (NPS) pollution from stormwater runoff, which is rainfall that flows over the ground surface from diffuse locations [2].Agriculture is the leading source of NPS pollution in the U.S. [3], but the built environment is also a major and growing contributor [2]. Urban and suburban development usually reduce pervious surfaces, creating dramatic changes in the hydrologic regimes of whole watersheds [4]. For example, impervious surfaces reduce local infiltration rates and groundwater percolation, resulting in higher surface water runoff, overall and peak discharges, and the export of sedimentation and associated nutrients (e.g., nitrogen, phosphorous) into local tributaries. Moreover, urban greenspaces (e.g., gardens and lawns) often export excess nutrients and sedimentation and when combined with higher stormwater runoff promotes eutrophication, while fertilizers, herbicides, insecticides, bacteria, and metals common in urban areas also pose additional risks to aquatic ecosystems [5].

To better manage the quantity and quality of urban stormwater, multiple legislative approaches through the 1972 Clean Water Act and later legislative amendments (e.g., 1987 Water Quality Act) have allowed more effective monitoring, policy development, and regulation of discharges [6]. Nevertheless, critics have argued that improvements in urban stormwater management have been costly and incremental because this 'top-down' legislative approach has been ineffective at regulating stormwater runoff from privately-owned households [7]. Because urban watersheds usually consist of numerous privately-owned residential parcels, household-scale Best Management Practices (BMPs) (e.g., rain barrels, disconnected gutters, fertilizer reduction) are vital to help reduce urban stormwater and improve watershed quality [8-10].

Resource management theory and empirical research have shown that a myriad of economic, cultural, and other social factors (hereafter referred in combination as "socio-economic factors") can affect how humans perceive their environment, and whether or not they implement particular conservation or management practices [11, 12]. Recent research suggests that urban stormwater management is limited by prioritizing technical solutions to reduce nutrient pollution, while not adequately incorporating socioeconomic factors into planning and decision-making [13]. For example, surveys indicate that flooding, safety, trash, and aesthetics are important stormwater-related concerns of most Americans, yet these concerns are typically not mitigated by common BMPs that instead aim to meet local and state regulatory discharge requirements [7]. More effective urban stormwater management may need to engage residential communities in 'bottom-up' outreach interventions that promote the benefits of household BMPs and their implementation [14].

The Chesapeake Bay is arguably America's most iconic estuary with a greater watershed area of over 64,000 $mi^2$ (166,0000 $km^2$) that intersects six states and the District of Columbia. Chesapeake Bay's natural resources (e.g., seafood, recreational boating) provide over $678 billion in economic activity to its neighboring states and is considered a national treasure [15]. Chesapeake Bay is also emblematic of the rapid urbanization and degraded water quality that is observed across many of America's watersheds. Between 1950-1980, it is estimated that the Chesapeake Bay watershed lost 2.7 million acres of natural habitat to development, compared to 1.7 million acres from 1600-1950 [16]. As a result, urban stormwater runoff is the fastest growing source of pollution in the Chesapeake Bay watershed [17], contributing an estimated 16%, 18%, and 24% of total nitrogen, phosphorous and sediment pollution, respectively, in 2015 [17]. Nitrogen and phosphorous from built environments has been shown to be a major contributor to eutrophication in many parts of the Chesapeake Bay watershed [18-20], and poses severe risks to ecosystem and human health through algal blooms and hypoxic conditions that lead to fish kills and biodiversity loss [21]. In 2009, President Barack Obama enacted Executive Order 13508 to renew efforts to protect Chesapeake Bay [22]. One of the key strategies of this Order was to promote the research of socio-economic factors in watershed management [23]. Although effective management of urban stormwater likely depends on the knowledge and behaviors of residents, there is a paucity of information of these factors in North America. Most studies that have investigated relationships between social factors and stormwater management have focused on qualitative analyses for planning or management purposes [24, 25] or public health interventions in developing countries [24, 26, 27]. Of the few quantitative studies on urban stormwater and social factors, their focus has been limited in demographic scope [14, 28]. To better engage residential communities in ‘bottom-up’ outreach interventions and promote the implementation of household BMPs we need a better understanding of the complex relationships between the socio-economic demographics, knowledge and behaviors residents and their communities.

The main goal of this chapter is to examine resident knowledge, attitudes, and BMP practice along socio-economic and other demographic gradients. We administered a Knowledge, Attitude and Practice (KAP) questionnaire of households among socio-economically diverse households in two sub-watersheds in the wider Chesapeake Bay basin, Wilde Lake watershed in the city of Columbia, Maryland and the Watts Branch watershed in both the southeast portion of the District of Columbia and Prince Georges County, Maryland. KAP surveys are often descriptive but some have been effective at finding statistically significant determinants of knowledge, attitudes and practices [29-31], and have been applied to a range of environmental contexts, including measuring baseline information on urban mosquito ecology and health impacts [29, 32], testing effects of education materials [33], and building awareness around drinking water quality [26, 27].

# Methods

## Study sites

Two sub-watersheds in the Chesapeake Bay watershed (Wilde Lake [WL], Watts Branch [WB]) were selected to study. WL and WB are located within 25 miles (40 km) of the Chesapeake Bay as the crow flies but more than 100 miles (160 km) upstream of the Chesapeake Bay along the flow paths of the Patuxent River and Anacostia Rivers, respectively (Fig 1). They lie in the Humid Subtropical climate zone. Precipitation occurs on average at a rate of 3 to 4 inches (76 to 102 mm) per month with the lower value in April and the high in September. The average yearly precipitation is 43 inches (1,100 mm). Both watersheds are suburban, cover areas of similar size, are dominated by private residential land use, have a similar percentage of impervious surface, and have severely impaired waters [34].

The main difference between the two watersheds is their socio-economic and cultural context. WL watershed occupies part of the Village of Wilde Lake in the City of Columbia, Maryland. Columbia is a planned community consisting of ten self-contained villages. Village governance is overseen by the housing association, Columbia Housing Association [35]. WL watershed has a highly educated, high-income citizenry and low minority population compared to national averages [36]. In contrast, WB watershed has a lower educated, low-income citizenry with a high minority population compared to national averages [36]. WB watershed has a higher population density compared to WL watershed, consistent with smaller parcels of private land, and no overarching housing association at a village or city level.

## KAP questionnaires

One consenting adult (>18 years-old) completed a KAP questionnaire at each household. Demographic information was collected on respondent age (18-49 years, >50 years), gender (male, female), race (Caucasian, African American, other), education (high school, college, graduate/professional), financial decision making (0-100%), household income (<$75,000, >$75,000), household ownership status (rent, own), household association membership (Yes, No). Although every household in the WL watershed is a member of the Columbia Housing Association, 27.5% (28/102) of respondents from that watershed reported that they were not a part of a housing association. We decided to re-code these households as being a part of a housing association to increase the accuracy of this variable. As best as we could determine, all respondents (n=190) in the Watts Branch watershed correctly reported membership in a housing association (n = 51, 26.8%). Membership in a housing association was difficult for us to confirm and is open to some variability in respondent understanding. Therefore, some caution is needed in interpreting the results of this question. Questionnaire responses personally relevant to the individual respondent were assumed to be representative of the household.

## Knowledge

Respondents were assigned an overall knowledge score based on their answers to eight questions on water resources and BMPs (Appendix A). Knowledge questions tested whether respondents could identify the watershed in which they lived, knew that stormwater is untreated before being released into Chesapeake Bay, were aware of BMP rebate schemes and incentive programs, were aware of stormwater fees and how these fees were assessed, knew that nitrogen and phosphorous were responsible for polluting Chesapeake Bay, and that the amount and cleanliness of stormwater is important to stream health. All questions required residents to select answers from a list, and responses were coded correct or incorrect based on the selection. For some questions, there was more than one correct answer. Correct answers were summed to yield an overall knowledge score of 0-8. Respondents were also assigned a score for their knowledge of BMPs. Respondents were requested to indicate their opinions toward nine common BMPs by selecting responses from a table, including if they were familiar with each specific BMP.

Responses indicating that familiarity were summed across all BMPs to yield an overall BMP knowledge score from 0-9.

## Attitudes

Respondents were assessed on their overall attitudes to water resources based on their agreement to six statements on a four-point scale (Appendix A). The statements represented positive associations with and utilization of local and regional water resources, and a perceived ability to help restore Chesapeake Bay. Respondents received a mean score of 0-4 as an overall index of their motivation to protect water resources. Respondents were assessed on how positively they perceived specific BMPs based on their selection of four negative and three positive statements for each of nine specific BMPs. The perception of each BMPs was assessed from -4 to 3 and the mean score of all our nine BMPs was calculated. Respondents were also assessed on the degree to which they thought government vs. individuals are responsible for stormwater runoff based on a 5-point Likert scale.

## Practices

Respondents were asked a yes/no question about whether their household implemented any of nine BMPs. For some analyses, these responses were run as binary variables and for others the number of implemented BMPs was totaled.

## Specific incentives, barriers and education

In addition to gathering information on demographics, knowledge, attitudes, and BMP implementation, we asked if statements of specific lifestyle preferences or concerns related to water resources applied to respondents (Appendix A). Lifestyle preferences included whether or not respondents like to garden, were member of a local watershed organization, volunteer at environmental events, enjoy fishing and crabbing, or consider themselves an environmentalist. Concerns included the health of the Chesapeake Bay, mosquito breeding in BMPs, or safety issues related to BMPs. Additionally, respondents were asked to indicate their preferred education/outreach approach from a list of options, including pamphlets, a local watershed training, or YouTube videos.

## Data analysis

A total of 311 KAP questionnaires were administered but not all questions were answered by each respondent. Relationships between demographic factors, knowledge, attitudes, and practices were analyzed using generalized linear models following a step-wise approach [37] (Fig 2). For each analysis the appropriate error structure and link function were chosen. Overall knowledge followed a Poisson error distribution. Knowledge of BMPs, and attitudes toward responsibility, water resources and BMPs were all normally distributed. Numbers of implemented BMPs at each household followed a negative binomial distribution. Household BMP implementation, or the implementation of at least one BMP, was treated as a binomial variable (presence/absence). In addition to household BMP implementation, separate analyses were undertaken to test predictors of the three most common individual BMPS, reducing fertilizer use, downspout disconnections and natural landscaping (see results). For each of these BMPs, knowledge and attitudes of the individual BMP was tested in addition to the overall knowledge and attitudes of BMPs. Household

BMP implementation and the implementation of the individual BMPs were binary variables and analyzed using the logit link. For all analyses, factors with a screening significance of $p<0.250$ in single-factor tests were included in multi-factor models with all estimable two-way interactions. Final multi-factor models were selected using backward selection. In the first step, all two-way interactions were excluded from the model. If there was no significant loss of fit as evaluated by comparing AICc and -2 log-likelihood values, the least significant factor was removed until the model lost significant information compared with the previous model. Because a respondent's attitude on a specific BMP was not recorded if that respondent reported not having knowledge of the BMP, we ran separate sets of models that included either knowledge or attitudes to specific BMPs. Multicollinearity was tested for all multi-factor tests by means of Variance Inflation Characteristics (VIF), with a VIF above 5 for variable indicating a problem [38]; but no VIF above 3.5 was detected. Incidence rate ratios (IRR) were obtained for significant factors in final models by using a modified Poisson approach with robust error variances [39]. We conducted chi-squared tests of association between respondent agreement of statements of specific lifestyle preferences and concerns with implementation of reducing fertilizer use, downspout disconnections and natural landscaping, with sequential Bonferroni correction for 24 tests. All tests used experimentwise $\alpha=0.05$; marginal significance was defined at $\alpha=0.05$–$0.10$.

# Results

## Knowledge

Combined across both watersheds, mean overall and BMP knowledge scores were low on our 8 and 9-point scales, being 2.39 ± 1.51 and 4.20 ± 2.63, respectively. Moreover, for some knowledge questions, very few respondents gave correct answers. For example, only 27 out of 297 respondents correctly indicated that their county, city, town, or homeowner's association provides rebates for implementing BMPs. Overall knowledge varied with almost all individual and household level demographic factors, except individual gender, in single-factor tests (Table 1). In the final multi-factor model, however, overall knowledge only varied marginally with education ($\chi^2_1$=5.11, p=0.0777; Fig 3), with respondents with high school level education or lower having significantly less knowledge than college or graduate level educated respondents. Knowledge of BMPs varied by individual education and race, as well as watershed, household income, association membership and ownership status, in single-factor tests (Table 2). In multi-factor tests, BMP knowledge varied with individual race ($\chi^2_1$=7.32, p=0.0257) and marginally with household ownership status ($\chi^2_1$=3.40, p=0.0653), with respondents that are Caucasian or other races, and that were in owned houses, having higher BMP knowledge than respondents that were African American and who are renters, respectively (Fig 4).

## Attitudes

Combined across both watersheds, the mean attitude score toward water resources was 3.00 ± 0.03, which corresponded to “agree” on our four-point scale to our six positive statements. Overall, the most positively perceived BMP was reducing fertilizer use, which has a mean attitude score eight times higher than the least liked BMP, lawn depression. Attitudes towards water resources only varied with household membership in a housing association, and marginally with watershed and household ownership status (Table 3). In multifactor tests, membership in a housing association remained in the final model but it was not significant ($\chi^2_1$=1.01, p=0.3138). Overall attitudes to BMPs only marginally varied with the presence of children in a household (Table 3), with more favorable attitudes among respondents without children (Fig 5). No other variables had a P-value < 0.250. Respondents' opinions of the roles of individuals vs. government in protecting Chesapeake Bay varied with individual education, age, and race, watershed, and household ownership status (Table 3). In multi-factor tests, responsibility varied with respondent age ($\chi^2_1$=19.02, p<0.0001), household ownership status ($\chi^2_1$=9.93, p<0.0016), and marginally with watershed ($\chi^2_1$=3.35, p<0.0674). Respondents that were younger, that lived in owned dwellings, and that were from WL watershed thought individuals should have a larger role than government (Fig 6).

## Practices

Combined across both study watersheds, 63.3% (n=188/297) of respondents reported practicing at least one BMP. The most common BMP was reducing fertilizer use (42.1%, 125/297), followed by downspout disconnection (36.0%, 107/297) and natural landscaping (25.4%, 76/297). Less than 10.0% of respondents reported implementing each of the other five BMPs that that were listed in the survey (Table

4). In single factor tests, the implementation of at least one BMP was strongly related to household ownership, and the respondent's financial responsibility, overall knowledge, BMP knowledge, and attitudes to water resources (Table 5). In multi-factor models, household ownership ($\chi^2_1$=5.85, p=0.0155) and individual BMP knowledge ($\chi^2_1$=7.83, p=0.0051) remained related to BMP implementation, while association membership also emerged as a strong predictor ($\chi^2_1$=9.51, p=0.0020). Individual financial responsibility ($\chi^2_1$=3.55, p=0.0594) and overall knowledge ($\chi^2_1$=3.26, p=0.0710) were marginally significantly related to BMP implementation. Respondents who owned their own home, who had higher knowledge, especially specific knowledge of BMPs, and who were not part of a housing association were more likely to live in a household that implemented a BMP (Fig 7).

The most common BMP, reducing fertilizer, was related to a respondent's financial responsibility, overall knowledge, BMP knowledge, specific knowledge of and attitude to reducing fertilizer, and to household ownership (Table 5). In multi-factor models, household ownership, household financial responsibility, overall knowledge, and attitudes to reducing fertilizer were related to reduced fertilizer use. Respondents who owned their home, who had a larger role in household financial decisions, who had higher overall knowledge of water resources, and who had more favorable attitudes to reducing fertilizer were more likely to reduce fertilizer (Fig 8).

The implementation of downspout disconnections was related to a respondent's education, gender, watershed, household income, overall knowledge of BMPs, and specific knowledge and attitudes to downspout disconnections (Table 5).

In multi-factor models, only education remained an important predictor ($\chi^2_2$=6.93, p=0.0313), but no pairwise contrasts were significantly different (P > 0.05; data not shown). Overall knowledge emerged as only marginally related ($\chi^2_2$=3.69, p=0.0549). When models included attitudes to this specific BMP and run on the subset of respondents that reported being familiar with it, education and overall knowledge ceased to be related to the implementation of downspout disconnections and only attitudes to the BMP emerged as being marginally significant ($\chi^2_2$=3.32, p=0.0682), with a trend indicating that more favorable attitudes promoted greater implementation (Fig 9).

Natural landscaping was related to a respondent's household financial responsibility, watershed, ownership status, and knowledge and attitudes to water resources, BMPs, and natural landscaping in particular (Table 5). In multi-factor models, household ownership ($\chi^2_2$=8.45, p=0.0036), overall attitudes to BMPs ($\chi^2_2$=10.60, p=0.0011), and specific knowledge ($\chi^2_2$=14.34, p=0.0002) and specific attitudes ($\chi^2_2$=23.15, p<0.0001) of natural landscaping were related to natural landscaping practice. Respondents that were owners, had more favorable attitudes to BMPs and who reported being familiar and who had favorable attitudes with natural landscaping were all more likely to practice the BMP (Fig 10).

In single factor tests, total household BMP numbers varied with household ownership, the degree of a respondent's responsibility to household finances, overall knowledge, BMP knowledge, attitudes to water resources, attitudes to BMPs, and marginally with attitudes on the roles of individuals vs. governments (Table 5). In multi-factor models, BMP numbers varied with financial responsibility ($\chi^2_1$=7.27, p=0.0070), BMP knowledge ($\chi^2_1$=10.47, p=0.0012), attitudes to BMPs ($\chi^2_1$=4.24, p=0.0394), and household ownership ($\chi^2_5$=4.02, p=0.0449). Respondents who owned their own home, had a larger household financial responsibility, and who had higher knowledge of, and more favorable attitudes towards, BMPs were more likely to have higher numbers of BMPs (Fig 11).

Overall, when looking at respondent lifestyle preferences, the majority of respondents stated that they liked to garden (Table 6). When looking at respondent concerns, the majority of respondents were concerned about the overall health of the Chesapeake Bay, mosquito breeding in BMPs, and a large proportion were also concerned about safety issues related to stormwater BMPs (Table 6). Chi-square tests of association between the implementation of each of the three most common BMPs with lifestyle preferences and concerns found that those who considered themselves environmentalists were more likely to have implemented natural landscaping, while those who were concerned about the overall health of Chesapeake Bay were more likely to implement reduced fertilizer use (Table 6). Those who were concerned about safety issues related to BMPs were more likely to implement downspout disconnection (Table 6).

## Specific incentives, barriers and education

When looking at preferred educational/outreach methods, pamphlets were the preferred educational method of respondents, followed by YouTube videos (Fig 13A). When looking specifically at those demographic groups with lower knowledge of water resources or BMPs or groups with directly lower BMP implementation, there were similar findings. Those who identified as Black/African American, who had lower water resource and BMP knowledge, preferred pamphlets, followed by YouTube videos and local educational events (Fig 13B). Renters, who had lower BMP implementation, also preferred pamphlets, YouTube videos, and local educational events (Fig 13C). Finally, those who were members of a housing association, who also had lower BMP implementation, preferred pamphlets, YouTube videos, and lastly being visited by a watershed volunteer (Fig 13D).

# Discussion

There is a growing realization among water quality experts that more substantial reductions in NPS pollution and resultant improvements in watershed quality need community-based citizen engagement, especially in watersheds where numerous residential parcels constitute a large proportion of the total land cover on which household BMPs could be implemented [7, 40]. However few studies have rigorously examined important social predictors of household BMP implementation [14, 41]. This study used data from a detailed questionnaire to empirically test relationships between knowledge, attitudes, and BMP implementation across socioeconomic and other gradients in the U.S., and represents one of the few studies to rigorously examine potential social barriers to water quality management at the household level.

Among the most important findings of this study were the frequent and strong predictive relationships of resident knowledge on BMP implementation. Respondents with higher familiarity with BMPs were more likely to reside in households that practice at least one BMP, practice more BMPs, and practice the most common BMP, fertilizer reduction. Implementation of natural landscaping was also positively predicted by specific familiarity with that BMP. The questionnaire in this study cited common BMPs on which there is considerable research that has demonstrated their effectiveness in reducing NPS pollution [40, 42]. Therefore, my findings suggest that a lack of familiarity with these BMPs in general and of some BMPs in particular is likely a strong barrier to better water quality in many residential watersheds. Few prior studies have examined the effect of knowledge on residential BMP adoption in urban areas, however one precedent study by Brehm et al. 2013 [41] reached a similar conclusion to my study here, that knowledge of BMPs was an important factor predicting BMP implementation. These findings are also consistent with conclusions made by Cottrell and Graefe 1997 [43] that knowledge was a significant factor in predicting certain the implementation of environmentally responsible practices.

Importantly, this study found that variation in BMP knowledge was explained by specific demographic factors. Respondents who defined themselves as Caucasian or other races, and that were in owned houses, had higher mean BMP knowledge than respondents that identified themselves as African American and who are renters, respectively. These findings indicate that, through important variation in resident knowledge, there is a clear connection between the socio-economic and cultural environment and BMP implementation, and by extension water quality. These findings are broadly consistent with the growing body of literature demonstrating that environmental and natural resource management is heavily influenced by a society’s socioeconomic and cultural context [44-46]. For example, a study in New Jersey found that Asian Americans and Spanish-language Hispanic Americans had less concern of environmental pollution than other racial/ethnic groups [47]. When looking specifically at certain demographic groups by race, I also caution that race is a socially constructed variable and is therefore complex and dynamic, varying by factors such as location, culture, and language. It can also intersect with socioeconomic status, and when looking at implementing educational campaigns targeting race/ethnicity, it may be important to consider theories such as Maslow's hierarchy-of-needs, which states that individuals are concerned about meeting physiological and safety needs before other types of needs can be met [48].

Respondent attitudes also predicted BMP implementation in this study, although not as frequently as that of knowledge. Households with more positive attitudes to BMPs tended to implement more BMPs, and respondents with more positive attitudes to reducing fertilizer and natural landscaping in particular, were more likely to implement those specific BMPs. Interestingly however, respondent attitudes to BMPs were not explained by most demographic factors, with the exception being that of the presence of children. Respondents in households with children were more likely to have less favorable attitudes to BMPs. One explanation for this result may be a higher safety concerns of water-holding stormwater structures among respondents with children, but a follow-up test reveals that although nearly half of total respondents expressed safety concerns of stormwater structures (Table 6) there was no association between safety concern and the presence of children in the household ($X^2$=0.0056, p=0.9395). Although we found that respondents had favorable overall attitudes to water resources, variation in their level of favorability was not explained by any demographic factors nor did it predict BMP implementation.

Interestingly, respondent perceptions on whether government or individuals were mainly responsible for protecting Chesapeake Bay was related to demographic factors. Residents who were younger, that lived in owned dwellings, and that were from WL watershed thought that residents should take greater responsibility. This finding is consistent with a previous study that found that perceptions of government role in environmental protections differed by race/ethnicity [47]. Nevertheless, again, this component of resident attitudes, did not predict BMP implementation. I therefore suggest more qualitative research methods, such as focus groups or interviews, be explored to further determine what role attitudes may or may not be playing in BMP implementation. This method of follow-up focus group interviews has been implemented by other studies (e.g. Randolph et al. 2008) to look at behavioral trends [49].

The predictive relationships on BMP implementation of resident knowledge and attitudes in this study broadly supports the information-deficit hypothesis of environmental education [50]. This hypothesis suggests that public skepticism or hostility to science, technology, or more specifically, to environmental conservation, is a result of a lack of information [51-53]. Study respondents generally agreed with questionnaire statements that represented positive associations with, and utilization of, local and regional water resources, and a perceived ability to help restore Chesapeake Bay. However, combined across both watersheds, resident knowledge of water resources and of BMPs were low on the 0-8 and 0-9 scales in the questionnaire. Although correctly answering our knowledge questions does not necessarily suggest that a resident has reached a required knowledge level to appropriately manage water resources, the low scores may indicate that there is considerable scope for improvement of resident knowledge of their water resources and important means to management them.

Pamphlets and YouTube videos were the two most preferred types of education delivery across all respondents, as well as respondents who identified as black or African American, who were renters, or who were members of a housing association, three demographic groups that either had lower rates of BMP implementation or knowledge compared to comparison groups (see above). Identifying preferred outreach approaches of target populations is important to tailor education programs. Interestingly, both these approaches might be classified as "passive" education wherein there is not an experimental learning activity or face-to-face interaction with an education communicator. A large body of research has indicated that "passive" education tends to be less effective at effecting behavior change generally and in environmental management [54, 55]. Respondent's preference with passive education in this study may reflect prior adverse interactions with people with regards to stormwater management or a perception that they may be pressured into purchasing a BMP. Further research, possibly using social science methods to gather more detailed information, such as focus groups or interviews, needs to better understand the underlying factors dictating resident perceptions of education approaches. I also cannot discount that pamphlets and YouTube videos were the first choices in the survey and that this ordering may have led to their preferential selection. While pilot drafts of surveys indicated that the order of choice didn't affect response, the pilot drafts were administered to a small sample size and the same effect may only have become present on a larger scale.

In addition to predicting BMP implementation indirectly via knowledge, some demographic factors directly predicted variation in BMP implementation. Households that owned their dwellings were more likely to practice at least one BMP, practice both reduced fertilizer and natural landscaping, and practice more BMPs. This result is consistent with considerable environmental management literature that indicates that citizens are more likely to invest in their environment if they have an economic and emotional involvement in it [56-58]. For example, Blake 1999 [58] found that those who did not own their homes did not implement environmental practices because they would not directly benefit from these actions. More practically, even if renters want to implement a BMP, they have restrictions to doing so by their landlord. In the study here, there were negative associations between household membership in a housing association and BMP implementation. Similar to renters, members of housing associations may have additional restrictions to BMP implementations, including additional permitting by the housing association and associated restrictions on building materials etc. that may act as an additional barrier to implementation.

This study has examined some key social predictors BMP implementation that can be further examined to increase their practice at the household level. Groups lacking knowledge, and specifically BMP knowledge, may need to be more qualitatively studied to determine the most effective ways to educate them on stormwater. Increasing BMP implementation by other groups with reduced practice, such as renters and members of housing associations, may require changes in regulations to increase home ownership and require housing associations to allow residents to implement stormwater management on their properties.

## Chapter 2 – Tables and Figures

**Tables**

1. **Table 1. Linear model results testing respondent demographics on overall knowledge.** Factors with $p<0.250$ were included in multi-factor models.
2. **Table 2. Linear model results testing respondent demographics on BMP knowledge.** Factors with $p<0.250$ were included in multi-factor models.
3. **Table 3. Linear model results of respondent demographics on overall attitudes to water resources, attitudes to BMPs, and perceived responsibility of individuals vs. government for protecting Chesapeake Bay.** Factors with $p<0.250$ were included in multi-factor models.
4. **Table 4. Percentage of respondents in Watts Branch and Wilde Lake watersheds practicing Best Management Practices (BMPs).**
5. **Table 5. Linear model results of respondent demographics, knowledge and attitudes on the implementation of BMPs.** Factors with $p<0.250$ were included in multi-factor models. Although numbers of installed BMPs is a household-level practice, individual level demographic variables were still tested against it because they may either be representative of the household (e.g., education, age, race) or affect respondent interpretation or self-reporting accuracy (e.g., gender, financial responsibility).
6. **Table 6. Number and percent of total respondents (n=297) that agree with statements of specific lifestyle preferences and concerns, and number and percent of respondents who implement the three most common BMPs out of those who agree with the statement.** Results of chi-

square tests of association between respondent agreement and BMP implementation are in parentheses. Bolded p-values indicate significance at experimentwise = 0.05; bolded and italicized p-values indicate marginal significance at experimentwise = 0.05-0.10 (sequential Bonferroni). Dfs=1.

**Figures**

1. **Figure 1. Map of Watts Branch and Wilde Lake sub-watersheds.** Wilde Lake and Watts Branch are located within 25 miles (40 km) of the Chesapeake Bay as the crow flies but more than 100 miles (160 km) upstream of the Chesapeake Bay along the flow paths of the Patuxent River and Anacostia Rivers, respectively.
2. **Figure 2. Conceptual diagram of the step-wise approach to analyzing relationships among demographics, knowledge, attitudes and BMP implementation from collected questionnaire data.**
3. **Figure 3. Mean (±1 SE) overall knowledge scores by respondent education level.** Different letters denote statistical significance among factor levels ($P < 0.05$).
4. **Figure 4. Mean (±1 SE) BMP knowledge scores by respondent homeownership status (a) and race/ethnicity (b).** Different letters denote statistical significance among factor levels ($P< 0.05$).
5. **Figure 5. Mean (±1 SE) attitudes towards BMPs by household presence/absence of children.** Respondents received a mean score of 0-4 as an overall index of their motivation to protect water resources.
6. **Figure 6. Mean (±1 SE) perceived responsibility for managing Chesapeake Bay by respondent age (a), homeownership status (b), and watershed (c).** Different letters denote statistical significance among factor levels ($P< 0.05$). Respondents were assessed on the degree to which they

thought government vs. individuals are responsible for stormwater runoff based on a 5-point Likert scale.

7. **Figure 7. Mean (±1 SE) BMP implementation by respondent housing association membership (a), homeownership status (b), and BMP knowledge score (c).** Different letters denote statistical significance among factor levels (P< 0.05).
8. **Figure 8.** Mean (±1 SE) reducing fertilizer use by respondent homeownership status (**a**), financial responsibility (**b**), overall knowledge score (**c**), and attitudes towards this specific BMP (**d**). Different letters denote statistical significance among factor levels (P< 0.05).
9. **Figure 9. Mean (±1 SE) downspout disconnection implementation by respondent attitudes towards this specific BMP.**
10. **Figure 10. Mean (±1 SE) implementation of natural landscaping by homeownership status (a) and familiarity with this BMP (b).** Different letters denote statistical significance among factor levels (P< 0.05).
11. **Figure 11. Mean (±1 SE) implementation of natural landscaping by respondent attitude towards BMPs in general (a) and this specific BMP (b).**
12. **Figure 12. Mean (±1 SE) number of BMPs implemented by respondent homeownership status (a), financial responsibility (b), BMP knowledge score (c) and attitudes towards BMPs (d).** Different letters denote statistical significance among factor levels (P< 0.05).

**13. Figure 13. Education/outreach preference overall (a) and by respondents who identify as black/African American (b), renters (c), and members of a homeowners association (d).**

**Table 1.**

| | | Overall knowledge | |
|---|---|---|---|
| Factor | df | $X^2$ | P-value |
| Individual level | | | |
| education | 2 | 23.41 | <0.0001 |
| gender | 1 | 1.91 | 0.1672 |
| age | 1 | 5.34 | 0.0209 |
| race | 2 | 20.61 | <0.0001 |
| financial responsibility | 1 | 3.41 | 0.0647 |
| Household level | | | |
| watershed | 1 | 12.29 | 0.0005 |
| income | 1 | 6.24 | 0.0125 |
| children | 1 | 6.36 | 0.0117 |
| association membership | 1 | 10.03 | 0.0015 |
| house ownership | 1 | 9.65 | 0.0019 |

**Table 2.**

| | | BMP knowledge | |
|---|---|---|---|
| Factor | df | $X^2$ | P-value |
| Individual level | | | |
| education | 2 | 25.39 | <0.0001 |
| gender | 1 | 3.34 | 0.0677 |
| age | 1 | 1.75 | 0.1861 |
| race | 2 | 26.82 | <0.0001 |
| financial responsibility | 1 | 1.32 | 0.2513 |
| Household level | | | |
| watershed | 1 | 17.18 | <0.0001 |
| income | 1 | 8.38 | 0.0038 |
| children | 1 | 2.45 | 0.1177 |
| association membership | 1 | 14.00 | 0.0002 |
| house ownership | 1 | 13.90 | 0.0002 |

**Table 3.**

| | | Attitudes to water resources | | | Attitudes to BMPs | | | Responsibility | |
|---|---|---|---|---|---|---|---|---|---|
| Factor | df | $X^2$ | P-value | | $X^2$ | P-value | | $X^2$ | P-value |
| Individual level | | | | | | | | | |
| education | 2 | 3.61 | 0.1641 | | 0.31 | 0.8548 | | 6.22 | 0.0447 |
| gender | 1 | 0.20 | 0.6520 | | 0.08 | 0.7797 | | 2.05 | 0.1521 |
| age | 1 | 0.01 | 0.9205 | | 0.02 | 0.9021 | | 8.84 | 0.0029 |
| race | 2 | 2.76 | 0.2521 | | 0.61 | 0.7368 | | 8.13 | 0.0171 |
| financial responsibility | 1 | 2.24 | 0.1346 | | 0.23 | 0.6334 | | 0.15 | 0.6944 |
| Household level | | | | | | | | | |
| watershed | 1 | 3.76 | 0.0526 | | 0.29 | 0.5916 | | 7.36 | 0.0067 |
| income | 1 | 1.33 | 0.2479 | | 0.02 | 0.8854 | | 1.60 | 0.2054 |
| children | 1 | 0.14 | 0.7058 | | 3.53 | 0.0601 | | 1.77 | 0.1832 |
| association membership | 1 | 4.55 | 0.0329 | | 0.73 | 0.3914 | | 0.61 | 0.4330 |
| house ownership | 1 | 3.78 | 0.0519 | | 0.00 | 0.9777 | | 7.79 | 0.0053 |

**Table 4.**

| | Watts Branch (n=194) | Wilde Lake (n=105) | Total (n=299) |
|---|---|---|---|
| Reducing fertilizer | 24.7 (48) | 73.3 (77) | 41.8 (125) |
| Downspout disconnection | 40.7 (79) | 26.7 (28) | 35.8 (107) |
| Natural landscaping | 21.6 (42) | 32.4 (34) | 25.4 (76) |
| Lawn infiltration | 7.2 (14) | 14.3 (15) | 9.7 (29) |
| Pervious paving | 9.8 (19) | 8.6 (9) | 9.4 (28) |
| Rain barrels | 7.2 (14) | 9.5 (10) | 8.0 (24) |
| Lawn depression | 3.6 (7) | 6.7 (7) | 4.7 (14) |
| Rain gardens | 2.6 (5) | 5.7 (6) | 3.7 (11) |

**Table 5.**

| | | Any BMP | | Specific BMP | | | | | | Numbers of BMPs | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Reducing fertilizer | | Downspout disconnection | | Natural landscaping | | | |
| Factor | df | $X^2$ | P-value | $X^2$ | P-value | $X^2$ | P-value | $X^2$ | P-value | $X^2$ | P-value |
| Individual level demographics | | | | | | | | | | | |
| education | 2 | 0.56 | 0.7568 | 1.92 | 0.3828 | 5.94 | 0.0512 | 1.32 | 0.5171 | 1.89 | 0.3882 |
| gender | 1 | 0.48 | 0.4878 | 0.20 | 0.6523 | 4.17 | 0.0412 | 1.91 | 0.1668 | 0.00 | 0.9686 |
| age | 1 | 3.76 | 0.0525 | 2.23 | 0.1355 | 0.13 | 0.7182 | 3.72 | 0.0537 | 1.87 | 0.1710 |
| race | 2 | 1.28 | 0.5263 | 1.55 | 0.4618 | 4.45 | 0.1079 | 7.61 | 0.0233 | 2.84 | 0.2417 |
| financial responsibility | 1 | 8.92 | 0.0028 | 13.52 | 0.0002 | 0.87 | 0.3512 | 5.90 | 0.0151 | 11.38 | 0.0007 |
| Household level demographics | | | | | | | | | | | |
| watershed | 1 | 0.09 | 0.7620 | 1.31 | 0.2517 | 5.47 | 0.0193 | 4.46 | 0.0347 | 1.26 | 0.2619 |
| income | 1 | 0.24 | 0.6271 | 0.00 | 0.9527 | 4.80 | 0.0284 | 0.13 | 0.7175 | 0.12 | 0.7267 |
| children | 1 | 0.00 | 0.9946 | 0.14 | 0.7091 | 0.13 | 0.7222 | 1.47 | 0.2250 | 1.18 | 0.2772 |
| association membership | 1 | 1.97 | 0.1609 | 0.56 | 0.4523 | 2.28 | 0.1311 | 2.25 | 0.1334 | 0.26 | 0.6085 |
| house ownership | 1 | 13.11 | 0.0003 | 15.33 | <0.0001 | 0.02 | 0.8907 | 16.19 | <0.0001 | 16.13 | <0.0001 |
| Overall knowledge | 1 | 13.35 | 0.0003 | 15.99 | <0.0001 | 2.86 | 0.0909 | 16.33 | <0.0001 | 20.72 | <0.0001 |
| BMP knowledge | 1 | 17.67 | <0.0001 | 4.37 | 0.0365 | 5.79 | 0.0161 | 22.27 | <0.0001 | 37.04 | <0.0001 |
| Specific BMP knowledge | 1 | - | - | 4.46 | 0.0347 | 6.99 | 0.0082 | 33.87 | <0.0001 | - | - |
| Attitudes to water resources | 1 | 4.53 | 0.0333 | 3.76 | 0.0524 | 0.04 | 0.8336 | 8.98 | 0.0027 | 9.77 | 0.0018 |
| Attitudes to BMPs | 1 | 0.15 | 0.6977 | 0.71 | 0.4009 | 0.12 | 0.7333 | 9.45 | 0.0021 | 5.71 | 0.0169 |
| Attitude to specific BMP | 1 | - | - | 8.66 | 0.0032 | 6.99 | 0.0082 | 21.21 | <0.0001 | - | - |
| Roles of individuals vs. government | 1 | 0.00 | 0.9521 | 1.30 | 0.2538 | 0.40 | 0.5260 | 3.76 | 0.0524 | 2.77 | 0.0962 |

**Table 6.**

| Statement | Overall agreement | Reducing fertilizer use | Downspout disconnects | Natural landscaping |
|---|---|---|---|---|
| I like to garden. | 171, 57.6% | 79, 46.2% (0.0945) | 67, 39.2% (0.1871) | 51, 29.8% (0.0513) |
| I am a member of my local watershed organization. | 4, 1.3% | 2, 50.0% (0.7469) | 2, 50.0% (0.5578) | 1, 25.0% (0.9783) |
| I volunteer at environmental events. | 56, 18.9% | 33, 58.9% (***0.0046***) | 30, 53.6% (**0.0024**) | 20, 35.7% (0.0539) |
| I enjoy fishing and crabbing. | 120, 40.4% | 59, 49.2% (0.0419) | 51, 42.5% (0.0557) | 31, 25.8% (0.9367) |
| I consider myself an environmentalist. | 136, 45.8% | 67, 49.3% (0.0213) | 59, 43.4% (0.0152) | 47, 34.6% (**0.0011**) |
| I am concerned about the overall health of the Chesapeake Bay. | 240, 80.8% | 113, 47.1% (**0.0003**) | 93, 38.8% (0.0449) | 70, 29.2% (***0.0037***) |
| I am concerned about mosquito breeding in stormwater BMPs. | 233, 78.5% | 107, 45.9% (0.0106) | 91, 39.1% (0.0380) | 57, 24.5% (0.3963) |
| I am concerned about safety issues related to stormwater BMPs. | 121, 40.7% | 56, 46.3% (0.2248) | 58, 47.9% (**0.0004**) | 33, 27.3% (0.5814) |

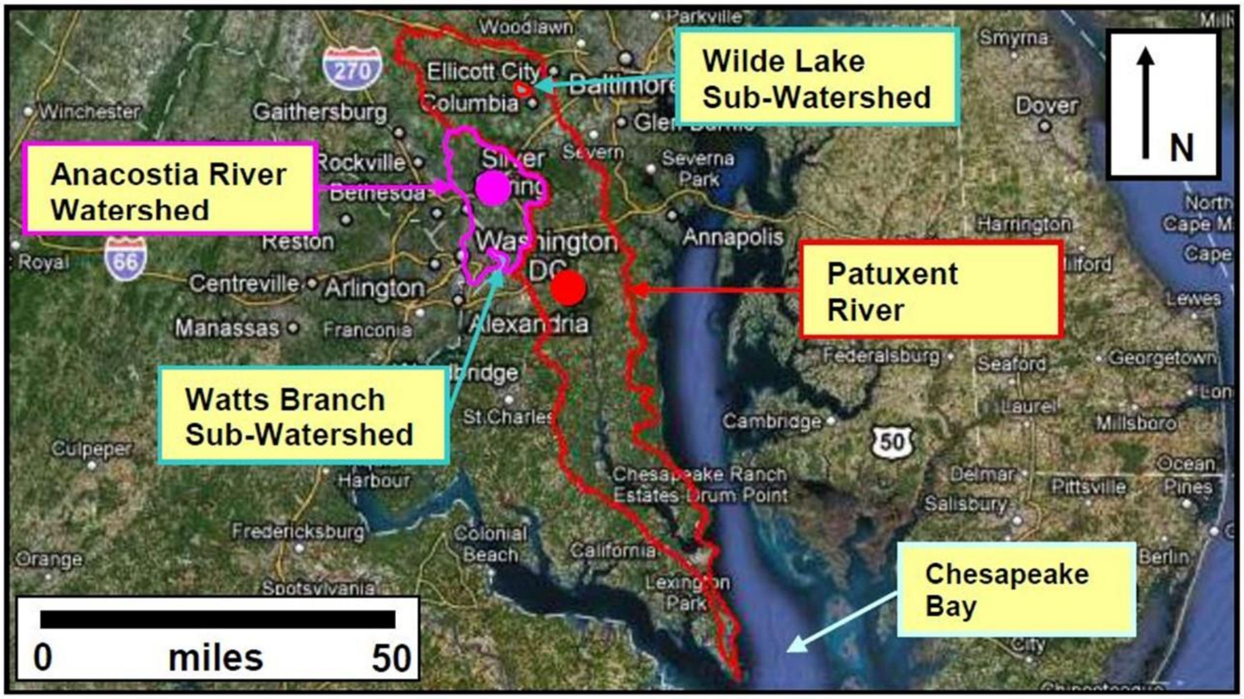

Wilde Lake
Sub-Watershed
Anacostia River
Watershed
Patuxent
River
Watts Branch
Sub-Watershed
Chesapeake
Bay
N
0
miles
50

**Fig 1.**

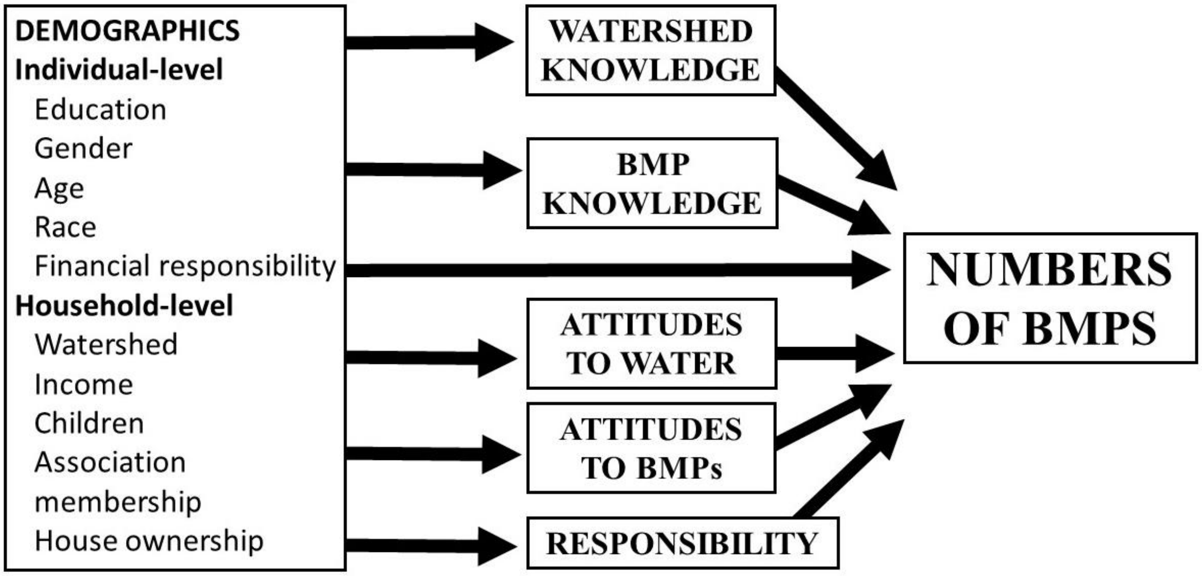

DEMOGRAPHICS
Individual-level
Education
Gender
Age
Race
Financial responsibility
Household-level
Watershed
Income
Children
Association membership
House ownership
WATERSHED KNOWLEDGE
BMP KNOWLEDGE
ATTITUDES TO WATER
ATTITUDES TO BMPs
RESPONSIBILITY
NUMBERS OF BMPS

**Fig 2.**

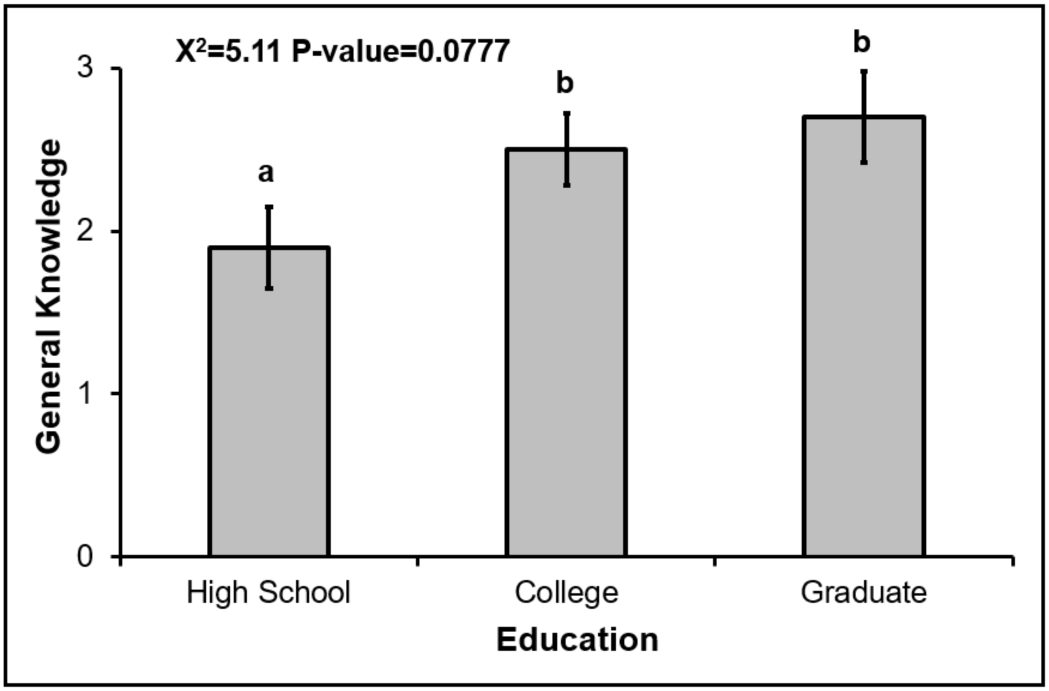

X²=5.11 P-value=0.0777
General Knowledge
3
2
1
0
a
b
b
High School
College
Graduate
Education

**Fig 3.**

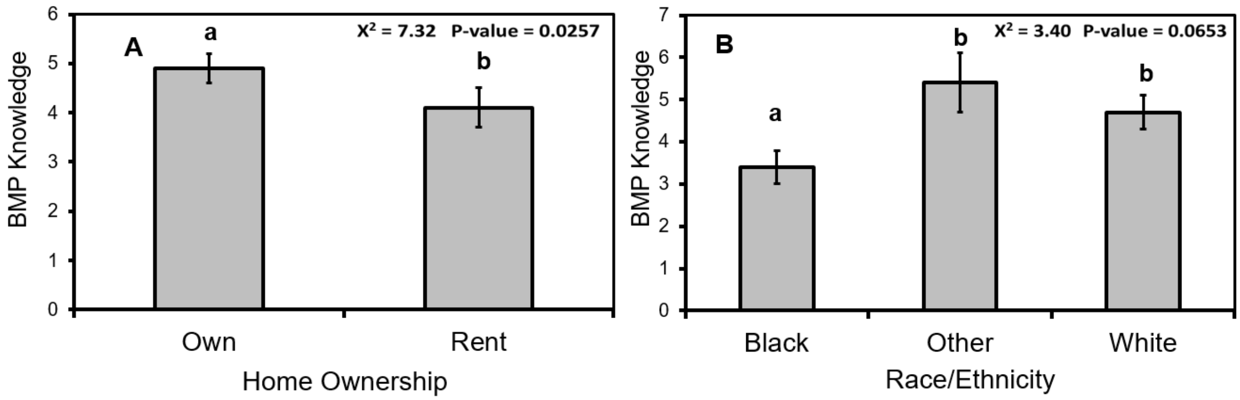

A
X² = 7.32 P-value = 0.0257
a
b
BMP Knowledge
0
1
2
3
4
5
6
Own
Rent
Home Ownership
B
X² = 3.40 P-value = 0.0653
a
b
b
BMP Knowledge
0
1
2
3
4
5
6
7
Black
Other
White
Race/Ethnicity

**Fig 4.**

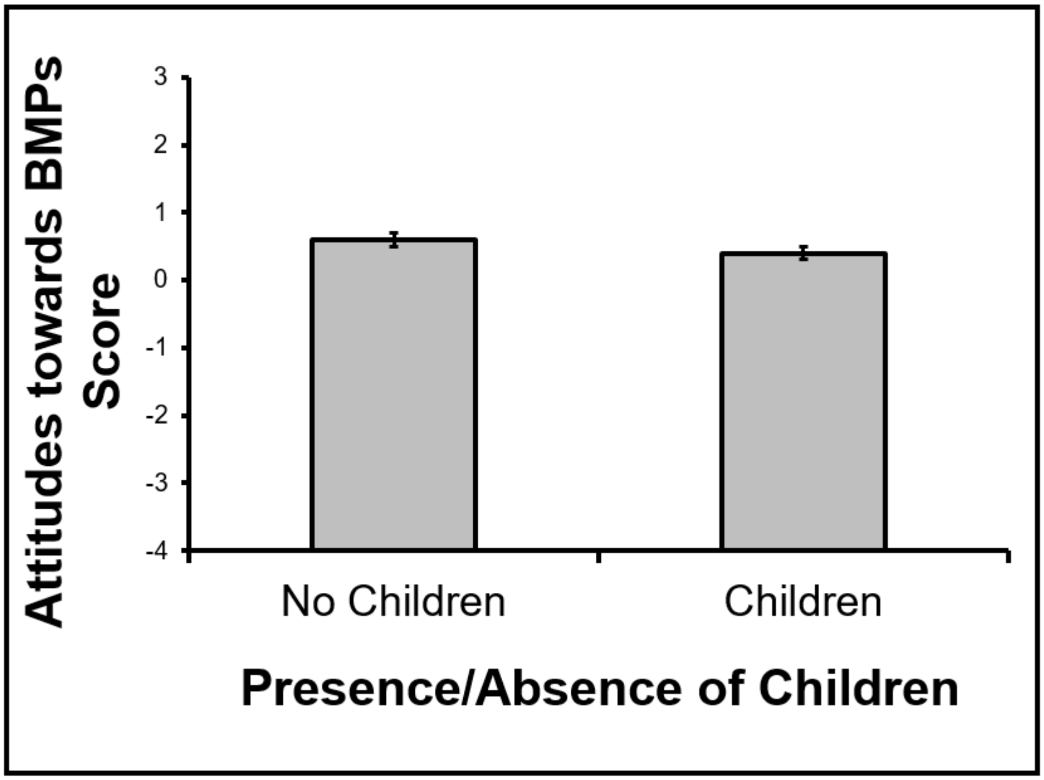
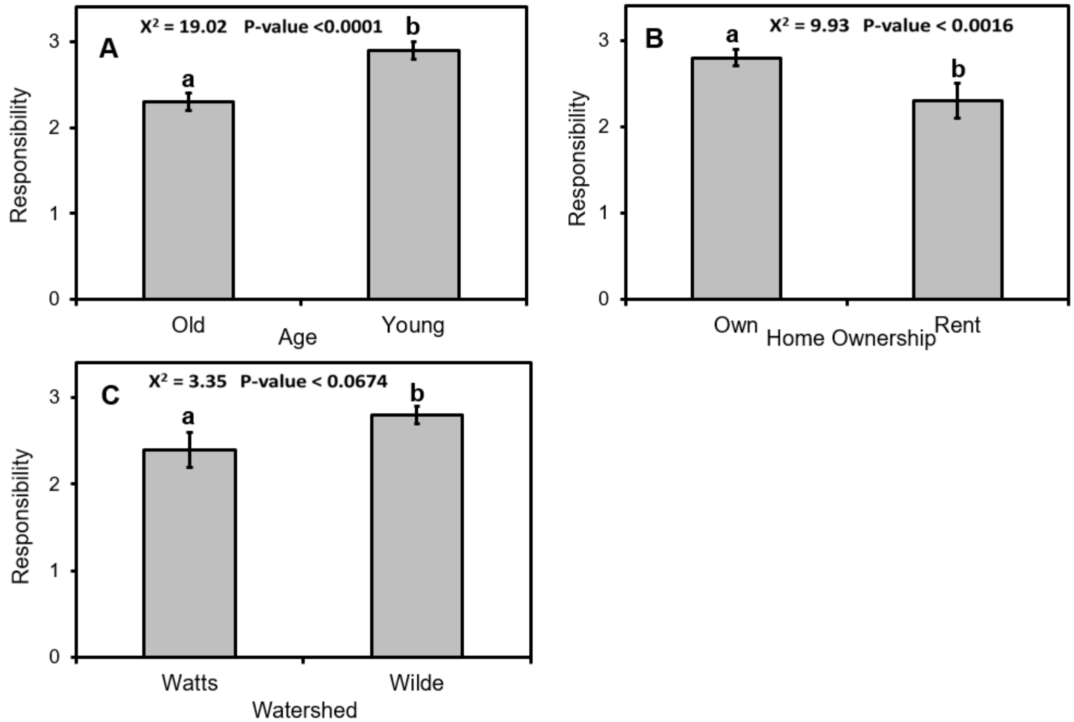

Attitudes towards BMPs Score
3
2
1
0
-1
-2
-3
-4
No Children
Children
Presence/Absence of Children

**Fig 5.**



A
X² = 19.02 P-value <0.0001
a
b
Responsibility
0
1
2
3
Old
Young
Age
B
X² = 9.93 P-value < 0.0016
a
b
Responsibility
0
1
2
3
Own
Rent
Home Ownership
C
X² = 3.35 P-value < 0.0674
a
b
Responsibility
0
1
2
3
Watts
Wilde
Watershed


**Fig 6.**

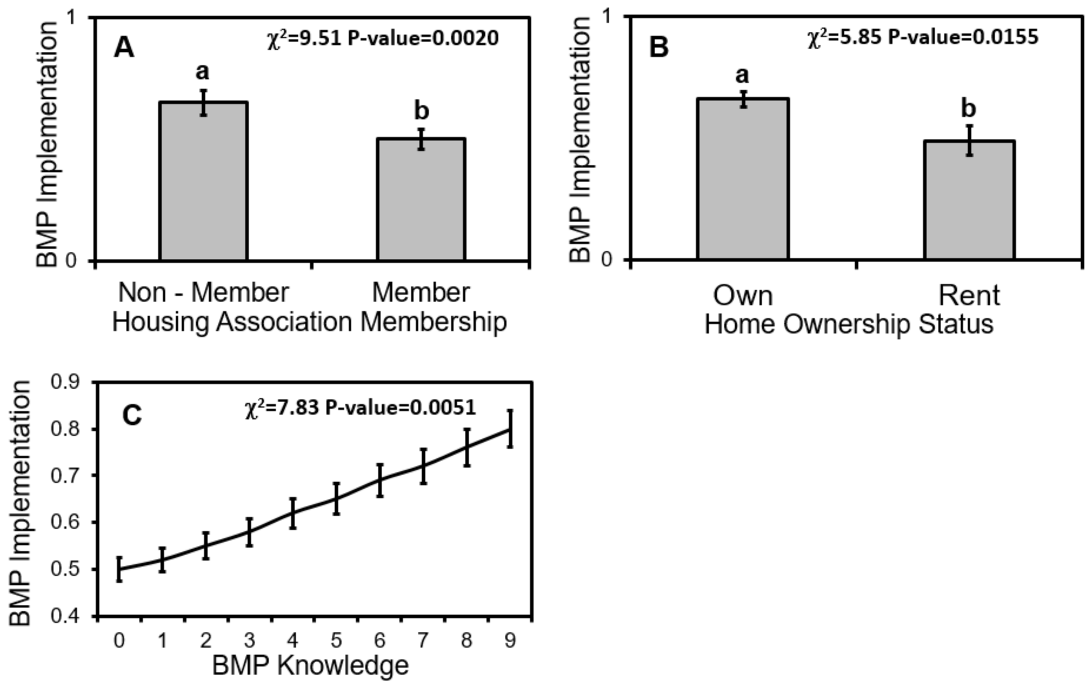

A
χ²=9.51 P-value=0.0020
BMP Implementation
a
b
1
0
Non - Member
Member
Housing Association Membership
B
χ²=5.85 P-value=0.0155
BMP Implementation
a
b
1
0
Own
Rent
Home Ownership Status
C
χ²=7.83 P-value=0.0051
BMP Implementation
0.9
0.8
0.7
0.6
0.5
0.4
0 1 2 3 4 5 6 7 8 9
BMP Knowledge

**Fig 7.**

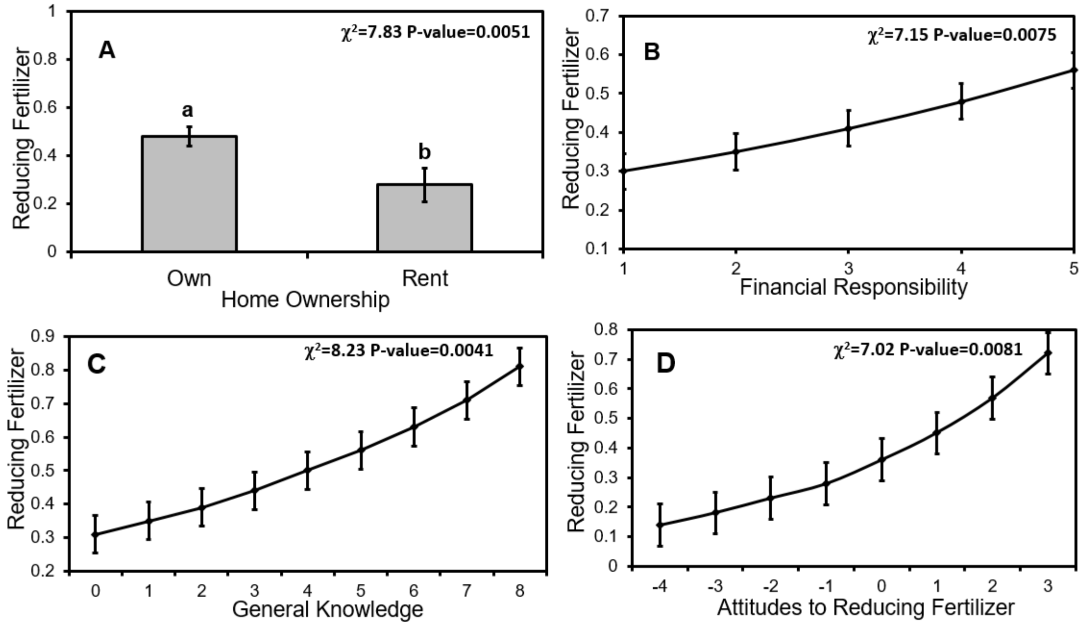

A
χ²=7.83 P-value=0.0051
a
b
Reducing Fertilizer
Own
Rent
Home Ownership
B
χ²=7.15 P-value=0.0075
Reducing Fertilizer
Financial Responsibility
C
χ²=8.23 P-value=0.0041
Reducing Fertilizer
General Knowledge
D
χ²=7.02 P-value=0.0081
Reducing Fertilizer
Attitudes to Reducing Fertilizer

**Fig 8.**

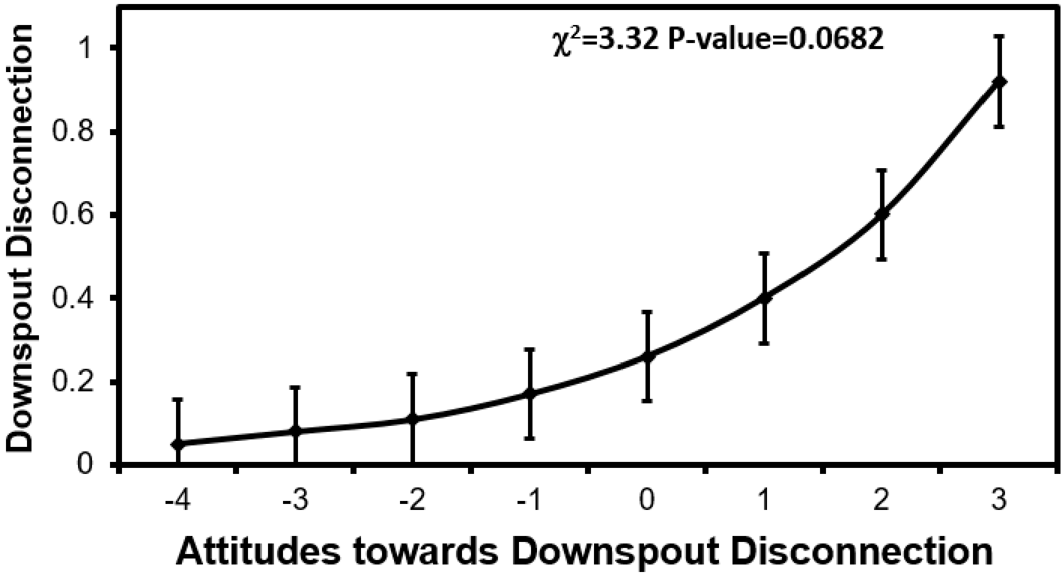

χ²=3.32 P-value=0.0682
Downspout Disconnection
1
0.8
0.6
0.4
0.2
0
-4
-3
-2
-1
0
1
2
3
Attitudes towards Downspout Disconnection

**Fig 9.**

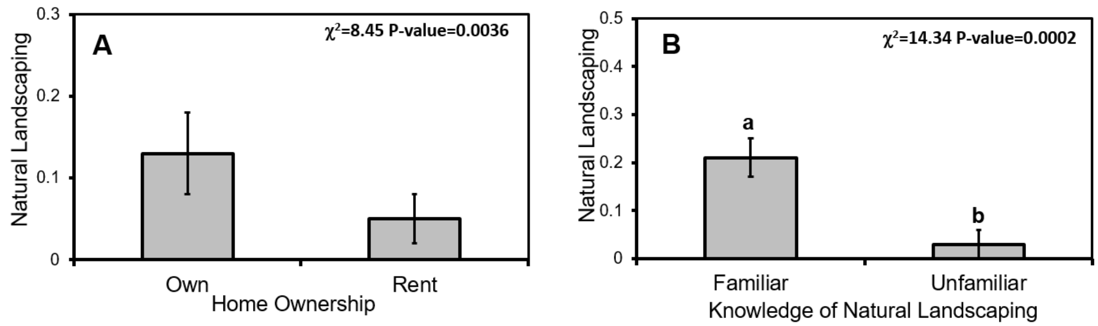

A
χ²=8.45 P-value=0.0036
Natural Landscaping
0.3
0.2
0.1
0
Own
Rent
Home Ownership
B
χ²=14.34 P-value=0.0002
Natural Landscaping
0.5
0.4
0.3
0.2
0.1
0
a
b
Familiar
Unfamiliar
Knowledge of Natural Landscaping

**Fig 10.**

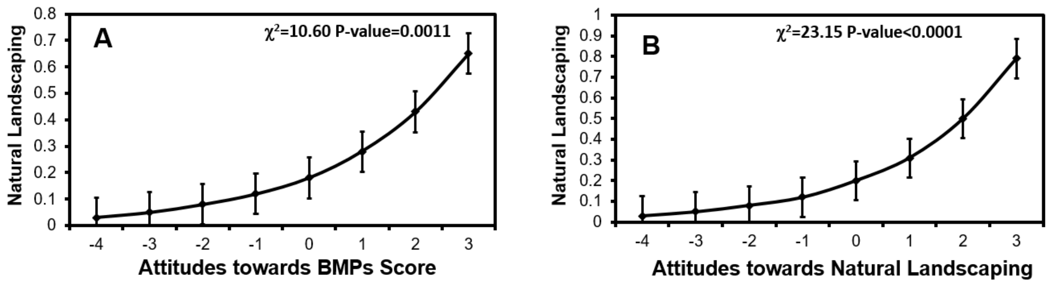

A
χ²=10.60 P-value=0.0011
Natural Landscaping
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-4
-3
-2
-1
0
1
2
3
Attitudes towards BMPs Score
B
χ²=23.15 P-value<0.0001
Natural Landscaping
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-4
-3
-2
-1
0
1
2
3
Attitudes towards Natural Landscaping

**Fig 11.**

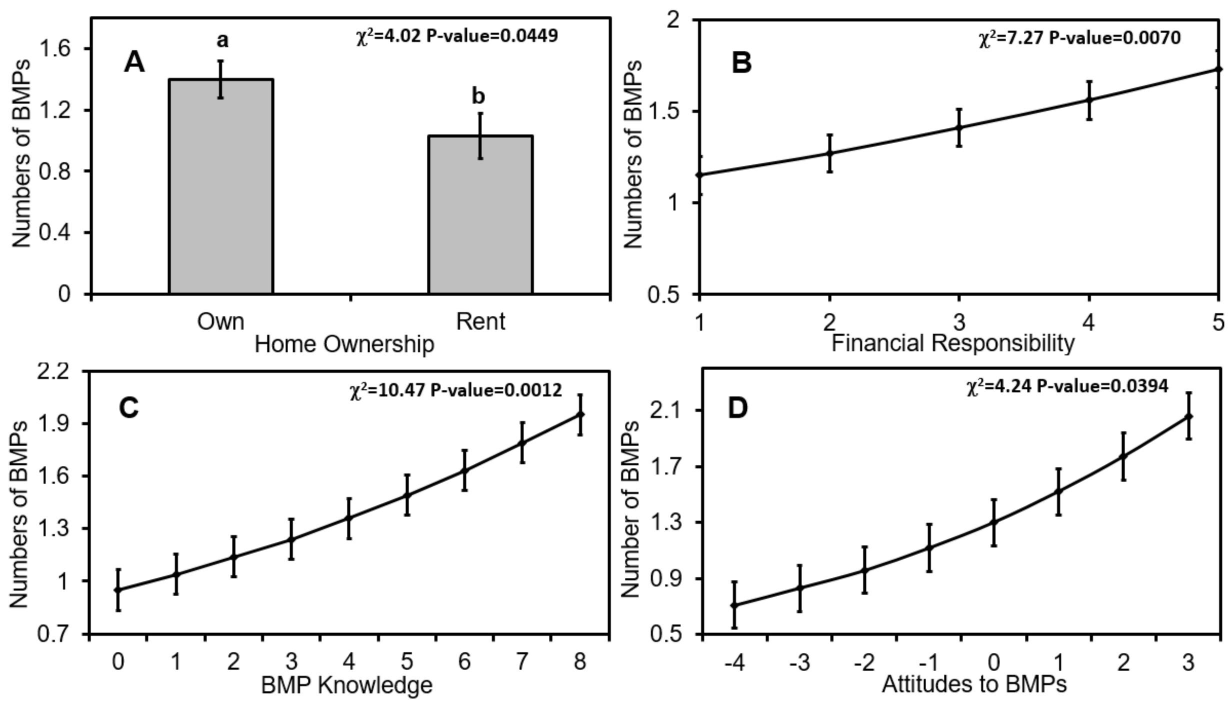

A
B
C
D
χ²=4.02 P-value=0.0449
χ²=7.27 P-value=0.0070
χ²=10.47 P-value=0.0012
χ²=4.24 P-value=0.0394
a
b
Numbers of BMPs
Number of BMPs
Own
Rent
Home Ownership
Financial Responsibility
BMP Knowledge
Attitudes to BMPs

**Fig 12.**

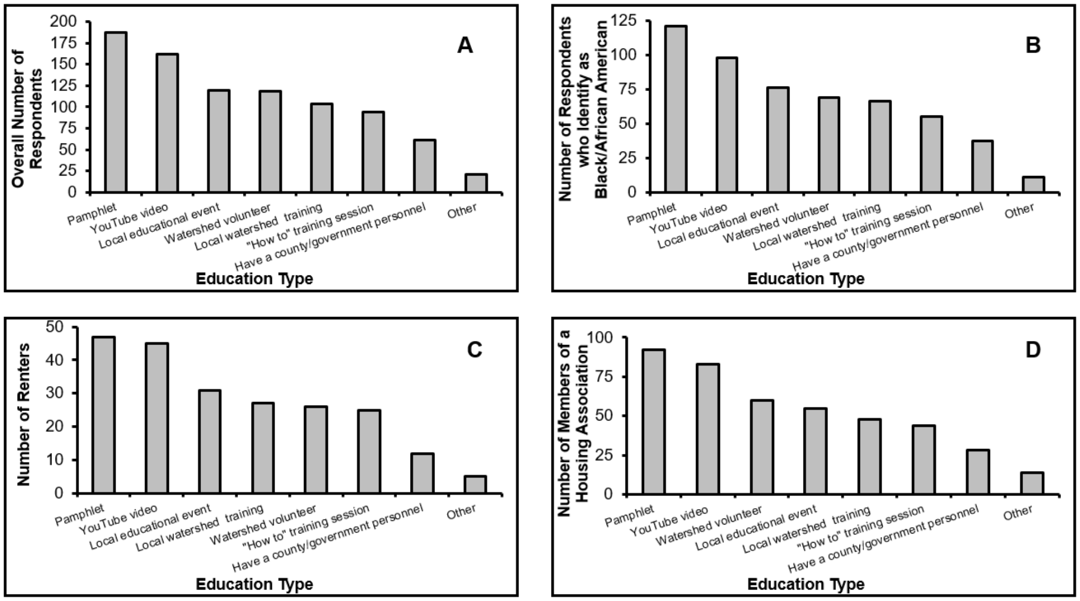

A
Overall Number of Respondents
200
175
150
125
100
75
50
25
0
Pamphlet
YouTube video
Local educational event
Watershed volunteer
Local watershed training
"How to" training session
Have a county/government personnel
Other
Education Type
B
Number of Respondents who Identify as Black/African American
125
100
75
50
25
0
Pamphlet
YouTube video
Local educational event
Watershed volunteer
Local watershed training
"How to" training session
Have a county/government personnel
Other
Education Type
C
Number of Renters
50
40
30
20
10
0
Pamphlet
YouTube video
Local educational event
Local watershed training
Watershed volunteer
"How to" training session
Have a county/government personnel
Other
Education Type
D
Number of Members of a Housing Association
100
75
50
25
0
Pamphlet
YouTube video
Watershed volunteer
Local educational event
Local watershed training
"How to" training session
Have a county/government personnel
Other
Education Type

**Fig 13.**

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# A Note on Format

Chapter III is formatted for submission as an original contribution to the *Journal of Medical Entomology*.

# Chapter 3: Knowledge, Attitudes, and Mosquito Management in BMPs and Common Containers Across a Socioeconomic Gradient

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**Key Words:** BMPs, Chesapeake Bay, human-environment system, KAP, stormwater, mosquitoes, source reduction

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## Abstract

To reduce nutrient pollution in our waterways and restore impaired watersheds, residents are needed to voluntarily practice a range of stormwater best management practices (BMPs). However, still little is known of the underlying social factors that may act as barriers to BMP implementation. A questionnaire in 2014-15 (Chapter 2) confirmed prior research that an overwhelming majority of respondents (77.7%, 233/299 of households) were concerned of mosquito breeding in stormwater structures. The overall goal of this study was to test whether respondent concern of mosquito production in stormwater structures is real by comparing mosquito presence and abundances in a common household BMP, disconnected downspouts, with those of other receptacles. In addition, this study also aimed to define specific demographic, knowledge, and attitude predictors of mosquito production metrics. In 2016, a follow-up questionnaire was administered to 91 households that were previously survey in 2014-15 to examine their knowledge, attitudes, and practices towards mosquito management and in disconnected downspouts specifically. Questionnaires were coupled with surveys of wet containers and mosquito population in household yards. This study consistently found that disconnected downspouts had significantly lower mosquito abundances when compared to other types of water-holding containers, including trash cans, tarps, or trash. Gender, age, membership in a homeowner's association, and watershed were all related to mosquito practice and attitudes. These results suggest that younger, male residents, who are not members of a housing association, should be targeted to mosquito education interventions, specifically those with lower knowledge, attitudes, and mosquito management practice levels.

## Introduction

Mosquitoes cause astounding mortality and morbidity around the world (CDC 2017a), and are increasingly becoming a health concern in urban areas (Leisnham and Slaney 2009). Americans have endured a long history of struggle with mosquitoes. For example, West Nile virus (WNv) caused widespread fear when it was first detected in New York City in 1999. Today, WNv continues to haunt Americans as the most important mosquito-transmitted disease, having infected 46,086 individuals across the U.S. and caused 2,017 deaths (CDC 2017b). In 2016, Zika virus emerged as a novel mosquito-borne threat in the Americas and Caribbean. The United States has recently documented local Zika transmission, and the disease has been declared a risk to the eastern seaboard (Monaghan et al. 2016).

The invasive Asian tiger mosquito, *Aedes albopictus*, and the northern house mosquito, *Culex pipiens*, are the two most common urban mosquitoes in the Northeastern United States (Barker et al. 2003, Braks et al. 2003, Darsie Jr and Ward 2004). *Aedes albopictus* is a capable vector for diseases currently in the United Sates, including WNv, La Crosse (LAC) encephalitis, and Eastern equine encephalitis (EEE), as well as those that threaten from overseas, including Chikagunya and Zika virus (Gerhardt et al. 2001, Gratz 2004, Turell et al. 2005, Leisnham and Juliano 2012), but its greatest public threat may be its aggressive human-biting that has been associated with reduced outdoor activity and childhood obesity (Barker et al. 2003, Braks et al. 2003, Worobey et al. 2013). *Culex pipiens* is a less aggressive human biter (Fonseca et al. 2004, Turell et al. 2005), but is the principle vector of WNv in the northern United States, maintaining and amplifying the virus among bird populations (Fonseca et al. 2004, Turell et al. 2005).

Both *Ae. albopictus* and *Cx. pipiens* grow and develop in a wide range of water-filled artificial containers common in urban landscapes, including trash receptacles, bird baths, gardening buckets etc, as well as some household stormwater BMPs (E.P.A. 2006, Unlu et al.

2014), such as disconnected corrugated downspouts and rain barrels (Vinogradova 2000, Barker et al. 2003, Braks et al. 2003, Darsie Jr and Ward 2004). Because of their breeding habits, the control of these species is largely dependent on resident behaviors, since mosquito control agencies or other entities may not have access or enough capacity to manage individual yards. One strategy to help manage mosquito populations in urban areas is community-based source reduction whereby residents are encouraged to minimize the numbers of containers that can collect rainwater and serve has mosquito developmental habitat, by removing container habitats, emptying water-filled containers, or applying insecticides to habitats that cannot be removed or emptied, such as salts, oils or commercially available insecticides (e.g., Bti, *Bacillus thuringiensis serotype israelensis*) (WHO 1997). Source reduction can be a cost-effective method of controlling mosquito populations and reduce transmission risk (Kay and Nam 2005), and is recommended by numerous mosquito control agencies, including the American Mosquito Control Association, the Centers for Disease Control and the World Health Organization as a vital tool for integrated mosquito management, worldwide (WHO 1997, CDC 2016, AMCA 2017). Because source reduction relies on community action, resident knowledge and behaviors demographics, are likely relevant to the effective management of container mosquitoes (Dowling et al. 2013b).

Unfortunately most studies investigating relationships between resident knowledge, attitudes, source reduction practices (KAP) and mosquito infestation have been conducted in developing countries where there are greater disease risks and fewer options for robust control by agencies (WHO 1997). Fewer studies have tested these relationships in developed nations (Tuiten et al. 2009, Dowling et al. 2013b, Bodner et al. 2016, Potter et al. 2016). Dowling et al. 2013a found that knowledge of mosquitoes differed by demographics, and in particular, higher

SES respondents had increased knowledge of mosquitoes but lower motivation to control mosquito breeding in their yards (Dowling et al. 2013a). Bodner et al. 2016 followed-up on this survey to examine the impact of educational materials on KAP and mosquito breeding. This study found that passive education on mosquito management was ineffective at reducing mosquito breeding (Bodner et al. 2016). This study builds on this earlier work by focusing specifically on KAP and mosquito infestation in a commonly found household Best Management Practice (BMP), disconnected downspouts.

Disconnected downspouts work by redirecting runoff to pervious surfaces where it can be infiltrated. One type of extension that can be attached to disconnected downspouts are corrugated extension spouts (CES), which are plastic, often removable, spouts. To my knowledge, only one study has previously done rigorous surveys in this type of disconnected downspout (Unlu et al. 2014) in the Northeastern United States, and found that CES attached to disconnected downspouts were a significant source of *Ae. albopictus* species (Unlu et al. 2014). Despite the need to implement household scale BMPs to mitigate stormwater runoff and the ability of some of these BMPs, including disconnected downspouts, to hold standing water, no studies have rigorously examined resident KAP and mosquito infestation in the context of resident-based watershed management.

The overall goal of this study is to examine potential of disconnected downspouts in providing important developmental habitat to urban mosquitoes in the Northeastern United States, and social factors that may influence mosquito production in disconnected downspouts and other contaiers. This study has three main objectives. First, it will compare mosquito infestation in disconnected downspouts with that of other containers in household yards to determine if they pose a greater source of adult mosquito production. Second, it will test relationships among resident demographics, knowledge, attitudes and mosquito source reduction practices of both disconnected downspouts and other containers. Third it will test the effectiveness of education materials at improving resident KAP of mosquitoes and familiarity of stormwater fees and BMP incentive or rebate schemes. In this study, we administered a questionnaire to households in two watersheds: Wilde Lake sub-watershed of the Patuxent River watershed in Columbia, Maryland and the Watts Branch sub-watershed of the Anacostia River Watershed, which straddles Washington, D.C. and Prince George's County, Maryland. Study households were a subset of those previously surveyed in Chapter 2 (Maeda et al. 2017), which tested relationships between resident knowledge and attitudes of water resources and BMPs, including their familiarity of local rebate/incentive schemes, and the implementation of common household BMPs. A main finding from Chapter 2 was that mosquito breeding within stormwater BMPs was a concern among a vast majority (233/297, 78.5%) of residents. The study here, will determine if this perceived risk from stormwater structures is realized for disconnected downspouts. After administering the survey in Chapter 2, half of the households were randomly selected to receive education materials on water resources, local rebate schemes for BMPs and mosquito management, and the follow-up questionnaire in my study here can test for variation in knowledge between households that received education with those that did not and increases in familiarity of BMP rebates/schemes for individual residents that were resurveyed.

**Methods**

*Study Sites*

The study took place in the Watts Branch [WB] and Wilde Lake [WL] sub-watersheds of Washington, D.C. and Maryland. Both sub-watersheds are located in the Humid Suptropical climate zone, where the average precipitation is 3 to 4 inches (76 to 102 mm) per month and 43 inches (1,100 mm) per year. WB sub-watershed is a 22 square mile tributary located in suburban Maryland and Washington, D.C. that leads to the Potomac River and also serves as a tributary to the Chesapeake Bay. The main uses of land in WB sub-watershed are residential, commercial, and institutional (City of Rockville 2001). WL sub-watershed is located in Columbia, Maryland and was created as a regional stormwater facility. The land in the WL is used for residential, commercial, and institutional uses (Center for Watershed Protection and Tetra Tech 2005). Overall, both WL and WB are of similar size, made up of similar landuse, have similar levels of impervious surface, and contained highly polluted water resources.

While WB and WL sub-watersheds share comparable environmental traits, the two sub-watersheds differ in socio-economic status, demographics, and culture. WL sub-watershed is part of a planned community, the Village of Wilde Lake, which is overseen by a housing association, the Columbia Association. WB sub-watershed does not have an overarching governing association, has a higher population density, and is composed of small parcels of land. In addition, WL's population is composed of highly educated (~60% college degree), high-income residents (mean ~$70,000), with a low minority population (60% Caucasian), while WB population is composed of lower educated (14% college degree<), low-income residents (avg. income ~$45,000), with a high minority population (95.2% black/African American) (U.S. Census Bureau 2016).

*KAP Questionnaires*

A follow-up survey was administered to a total of 92 randomly selected households that were surveyed in Chapter 2 (Appendix B). Households that had returned completed questionnaires and whose address was able to be located on Google Maps (288/311, 92.6%) were selected for potential re-visiting in 2016. Approximately half of these households (139/288, 48.3%) had also received education materials on local BMP incentive or rebate schemes and mosquito management as part of the 2014-2015 survey (see Chapter 2). Therefore, households that had vs. had not received prior education materials were alternatively chosen to be re-visited. Households were revisited from 8 July to 16 September, 2016, during the period of peak mosquito activity (Dowling et al. 2013b).

For each KAP questionnaire, a consenting adult (>18 years-old) completed the questionnaire with the assistance of a field assistant. Similar demographic information was collected as in Chapter 2, such as respondent age (18-49 years, >50 years), gender (male, female), race (Caucasian, black/African American, other), education (high school, college, graduate/professional), financial decision making (0-100%), household income (<$75,000, >$75,000), household ownership status (rent, own), household association membership (Yes, No). Questionnaire responses personally relevant to the individual respondent were assumed to be representative of the household. For households that remembered completing the questionnaire from Chapter 2, demographic information from the original survey was used in analyses. In the Wilde Lake watershed, every resident is a member of the Columbia Housing Association, however 20.0% (6/30) of respondents from that watershed reported that they were not members of a homeowners association. Similar to Chapter 2 analyses, we recoded these households as members of a homeowners association for accuracy. All of the respondents from Watts Branch watershed (n=61) correctly indicated that they were not members of a homeowners association.

*Knowledge*

A total of 3 open-ended questions on mosquito knowledge were tested and scored 1 or 0 based on responses, using similar methods from Dowling et al. 2013a. Question one asked if respondents knew which diseases can be contracted from mosquitoes in Washington D.C. and Maryland. Responses that included WNv or EEE were given 1 point. Question two asked respondents to list which animals can contract these same diseases. If respondents answered WNv or EEE and also answered birds or horses, they were given 1 point. Finally, question three asked respondents to describe where mosquitoes lay eggs and grow. Answers relating to water, standing water, or moist areas were given 1 point. Points for questions 1-3 were summed to give an overall mosquito knowledge score of 0-3 based on Dowling et al. 2013a. To test for changes in water resources knowledge following a print education intervention, respondents were also assigned an overall knowledge of water resources score based on their answers to 3 questions that were repeated from the original 2014-15 questionnaire. Water resources knowledge tested whether respondents could identify the watershed in which they lived, were aware of BMP rebate schemes and incentive programs, and were aware of stormwater fees and how these fees were assessed. All questions required residents to select answers from a list (Appendix A), and responses were coded correct or incorrect based on the selection. For some questions there was more than one correct answer. Correct answers were summed to yield an overall water resources knowledge score of 0-3.

*Attitudes*

Four questions were scored to address respondent attitudes towards mosquitoes that likely reflected resident motivation to control mosquitoes, using a similar approach as Dowling et al. 2013a. Question one measured mosquito nuisance by asking how often respondents were bothered by mosquitoes, with a range from ‘Never’ to ‘Every day.’ Respondents who reported being bothered every day or a few days a week scored 1 point. Other answers scored a 0 on question one. Question two measured concern of mosquito disease by asking respondents to rate their concern on a five-point Likert scale. Respondents were scored a 0 for a rating between 1-3 and a 1 for a rating between 4-5. The third question asked respondents who indicated that there are mosquitoes present on their property if their presence caused them to alter their behavior. This question was scored as 1 for 'Yes' and 0 for 'No'. The final question on attitudes towards mosquitoes asked respondents who they felt was responsible for mosquito control, with answers ranging from 'Residents' to the 'Public Health Department.' Respondents who reported residents, or residents and a control agency, scored 1 point and all others scored 0. The scores for all four questions were totaled and respondents were given an overall motivation score of 0-4, with higher scores indicating more concern/motivation to control mosquitoes.

*Practices*

Respondent mosquito management practices were assessed both through self-reported source reduction and through surveys of water-holding ("wet") containers in yards. Self-reported source reduction was recorded through a yes/no question on whether or not respondents did anything to reduce mosquitoes in theirs yard, followed by an open-ended answer if they answered yes. Answers were then scored 1 if they resembled practices that managed container habitats, including removing, emptying water from, or applying larvicides (Bti, salt, oils) to containers. Because this study was particularly interested in mosquito production in BMPs, an second practice question asked respondents whether or not they practiced source reduction in any stormwater structures. This question was scored 1 for answer yes, and 0 for no. Other mosquito management behaviors that do not involve the management of water-holding containers, including the use of repellents, such as Off!™ spray or citronella candles, were given a separate score of 0 or 1.

*Mosquito Surveys*

After administering the questionnaire, we requested from each respondent consent to search for and enumerate all water-holding (“wet”) disconnected downspouts, other wet containers, and mosquitoes that were within reach (and that therefore could be easily managed) in their yard. We defined a disconnected downspout as a downspout that no longer led directly to a stormwater drain but that had been re-directed onto a pervious surface. This included disconnected downspouts that directed towards a plastic or concrete slab, extended directly to pervious surface, or were connected to plastic corrugated extension spout (CES) or, in one case, a PVC pipe fitted to the disconnected downspout. Other container types that were recorded during surveys were further categorized by purpose, following the definitions by LaDeau et al. 2013: trash, structural, recreation, yard care, and storage. Trash containers included any litter/garbage not properly stored in a garbage can. Structural containers included AC puddles, and permanent pipes/fixtures. Recreation containers included toys, tables, chairs, grills, or other outdoor objects used for entertainment. Yard care containers included equipment used to clean/care for the yard, garbage cans or tarps. Storage containers included containers being stored outside that were not intended for outdoor use (LaDeau et al. 2013).

Each wet disconnected downspout or other container was sampled for mosquito larvae. For each container, we homogenized the water and sampled a proportion of the total volume, which was then measured. Depending on the size of the container, water sample volumes ranged from 2 mL to 1.8 L, with volumes less than 1 L often represented the entire contents of the habitat. For each sample, all late ($3^{rd}$ and $4^{th}$) instar larvae were enumerated and identified to the species level using an established key (Darsie Jr and Ward 2004). All pupae and early instar larvae were also enumerated but could only be reliably identified to genus level for lack of a reliable key. This approach follows standard procedures from other mosquitoes surveys (e.g., Dowling et al. 2013a) and yields particularly efficient and reliable data systems where only one species dominates each genera (see Results). Estimated total abundances of three mosquito abundance metrics (total mosquitoes, *Aedes* pupae, *Culex* pupae) were then calculated by multiplying total volume with sample density for each container and summing across all containers by type (disconnected downspouts, other containers) for each yard to yield total abundances at the household scale.

*Data Analysis*

A total of 92 KAP questionnaires were administered, with some questionnaires not having all questions answered. A total of 86 of the 92 households that completed the questionnaire also consented to a full yard mosquito survey. For an additional 26 households, respondents declined responding to the questionnaire but allowed a mosquito survey of their yard to give a total of 118 household mosquito surveys. Entire yard surveys could not be completed for 7 households, and these households were only included in analyses that compared mosquito production of specific container types. Mean total infested containers, mean total estimated mosquito abundances, and total estimated pupae abundance by genus per household were compared between wet disconnected downspouts vs. wet other containers using Wilcoxon Signed-Rank tests. Relationships between source reduction metrics (self-reported source reduction, numbers of wet disconnected downspouts, wet other containers) and mosquito infestation metrics (total infested containers, total estimated mosquito abundances, and total estimated pupae abundance by genus) were tested using generalized linear models with negative binomial error structure and sequential Bonferroni correction for 12 tests. Relationships between demographic factors, knowledge, attitudes, and source reduction were analyzed using generalized linear models following a step-wise approach, similar to that in Chapter 2 (SAS

Institute 2003) (Figure 1). For these analyses, source reduction included self-reported source reduction, source reduction in disconnected downspouts, and source reduction in 'other' containers. In addition, because a number of respondents indicated they used repellents instead of source reduction, this practice was also analyzed between demographic factors, knowledge, and attitudes. For each analysis the appropriate error structure and link function were chosen. Overall mosquito knowledge and attitudes towards mosquitoes followed a Poisson error distribution. Concern of mosquito diseases, responsibility for mosquito control, and self-report source reduction followed Binomial error distribution. Container metrics of total estimated mosquitoes, total infested containers, total estimated *Aedes* pupae, and total estimated *Culex* pupae all followed negative binomial distribution. For all analyses, factors with a screening significance of $p<0.250$ in single-factor tests were included in multi-factor models with all estimable two-way interactions. Final multi-factor models were selected using backward selection. In the first step, all two-way interactions were excluded from the model. If there was no significant loss of fit as evaluated by comparing AICc and -2 log-likelihood values, the next step was to exclude the least significant factor until the model lost significant information compared with the previous model. Multicollinearity was tested for all multi-factor tests by means of Variance Inflation Characteristics (VIF), with a VIF above 5 for a variable indicating a problem (Scheiner 2001, Kutner et al. 2004). All tests used experimentwise $\alpha=0.05$; marginal significance was defined at $\alpha=0.05$–$0.10$.

## Results

### *Mosquito Production*

A total of 39 wet disconnected downspouts and 269 'other' wet containers were located across the 118 surveyed yards. Almost all wet disconnected downspouts (32/39, 82.1%) included corrugated extension piping, or CES. In contrast, a common other downspout was entirely metal or included a plastic or concrete slab placed under the downspout, but these never contained mosquitoes. In total, 44.2% (n=136) of total wet containers (disconnected downspouts and other containers) harbored mosquitoes. *Aedes albopictus* accounted for 49.7% (n=982) and *Cx. pipiens* for 30.7% (n=606) of total late-instar larvae. Other late instar species collected included *Aedes japonicus japonicus* (Andreadis et al.) (14.7%), *Culex restuans* (Andreadis et al.) (1.6%) and *Aedes triseriatus* (Say) (1.8%). *Aedes* pupae accounted for 90.6% (n=163) and *Culex* pupae for 9.4% (n=17) of total collected pupae. No other genus of pupae were identified.

Other container types (i.e., not disconnected downspouts) made up the majority of mosquito infested containers (120/136, 88.2%). Of these other containers, yard care receptacles were the most common type that were infested by mosquitoes (56/120, 46.7%). Estimated abundances for all mosquito abundance metrics were significantly higher in combined 'other' wet containers compared to wet disconnected downspouts (Figure 2). When parsing out mosquito abundances among different container purposes, it is clear that yard care and trash containers had higher total estimated mosquito abundances than containers with 'other' purposes (Figure 3), and drove the trend of higher abundances in all 'other' containers vs. disconnected downspouts. Household mosquito infestation also appeared related to source reduction of these other containers. Total infested containers (Fig. 4A), total estimated mosquitoes (Fig. 4B) and total estimated abundances of *Aedes* pupae (Fig. 4C) were positively predicted by total numbers of wet 'other' containers (Table 1). No other mosquito metrics were predicted the other measures of source reduction, including self-reported source reduction or numbers of wet disconnected downspouts.

*Knowledge*

Across both watersheds, the mean mosquito knowledge score was 0.88 ± 0.06 out of 3. Overall knowledge of mosquitoes did not vary by any household or individual level demographics in single factor tests or in the final multifactor model (Table 2). Specific knowledge of mosquito breeding varied by education level, race/ethnicity, watershed, homeowner association membership, and home ownership, and marginally by gender, household income, and presence/absence of children in single factor tests (Table 2) but none of these demographics were significant in the final multifactor model. Respondents in WB watershed had significantly lower mosquito breeding knowledge than respondents in WL (Fig. 5A). Respondents who owned homes had significantly higher mosquito breeding knowledge than renters (Fig. 5B). College and graduate-level educated respondents had significantly higher knowledge than high school educated respondents (Fig. 5C). Racial/ethnic groups did not differ significantly in mosquito breeding knowledge (Fig. 5D), however those who were not members of a homeowners association membership had significantly lower mosquito breeding knowledge than those who were members (Fig. 5E).

A total of 13 individual respondents were resurveyed and belonged to a household that received educational materials. Out of these 13 individuals only 15.4% increased their overall knowledge whereas 23.1% decreased their knowledge of water resources. A total of 17 respondents from the initial questionnaire did not receive educational materials, and from these 29.4% increased their knowledge and 29.4% decreased their knowledge.

*Attitudes*

Combined across both watersheds, the mean attitudes score toward mosquitoes was 1.67 ± 0.11 out of 4, indicating moderately low motivation to manage mosquitoes in resident yards. Overall attitudes to mosquitoes varied by gender (Table 3), with respondents identifying as female having significantly higher attitudes/motivation to control mosquitoes than males (Fig. 6). Concern of mosquito-borne diseases varied by race/ethnicity, watershed, and homeowner association membership (Table 3). Respondents located in WL had significantly higher concern for mosquito diseases than respondents in WL (Fig. 7A). Respondents who identified as black/African American or Other races had significantly higher concern than respondents that identified as white (Fig. 7B). Respondents who were not members of a homeowners association had significantly higher concern for mosquito diseases (Fig. 7C). Perceived responsibility of individuals vs. the government for mosquito control varied by education level, race/ethnicity, watershed, income, homeowner association membership, and, marginally, with homeownership (Table 3). In the final multifactor model, however, only watershed remained significant ($\chi^2_1$= 7.96, p= 0.0048). When comparing demographic groups, respondents in WL watershed held significantly higher belief in individuals having more responsibility for mosquito control (Fig. 8A). At the education level, college and graduate-level educated respondents held significantly higher belief in individuals having more responsibility for mosquito control than high school educated respondents (Fig. 8B). Respondents who identified as ‘Other’ or White held significantly higher belief in individuals vs. control agency responsibility than respondents who identified as black/African American (Fig. 8C). Respondents whose household made <$75,000 annually had significantly lower belief in individuals being more responsible than control agencies than households making >$75,000 annually (Fig. 8D). In terms of homeowner association membership, nonmembers had significantly lower belief in individuals being more responsible than control agencies than members (Fig. 8E).

*Practice*

In single factor tests, self-reported practice of source reduction in any containers was related to age, and, marginally, with homeownership (Table 4). In the final multifactor model, self-reported source reduction in any containers was related to age ($\chi^2_1$= 5.78, p= 0.0162)**,** with respondents over 50 years of age practiced source reduction significantly more than respondents under 50 years (Fig. 9B). Self-reported practice of source reduction in disconnected downspouts, was related to responsibility for mosquito control, and, marginally, with education level, presence/absence of children, and concern of mosquito-borne diseases (Table 4). Respondents who felt that control agencies were more responsible for mosquito control practiced source reduction in disconnected downspouts significantly more than those who felt individuals were more responsible for mosquito control (Fig. 10). In single factor tests, self-reported practice of source reduction in 'other' containers was related to age and marginally related to race/ethnicity, homeownership, concern of mosquito-borne diseases, and responsibility for mosquito control (Table 4). In multifactor tests, age was the only factor related to self-reported source reduction in 'other' containers ($\chi^2_1$=4.63, p=0.0314), with respondents over 50 years of age practicing source reduction significantly more than respondents under 50 years of age (Fig. 11). Because several respondents mentioned the use of repellants, we also analyzed repellant usage (such as mosquito sprays) as a practice. The use of repellants instead of source reduction was related to gender, presence/absence of children, and responsibility for mosquito control (Table 4). Repellant usage was also marginally related to age and watershed (Table 4). Female respondents practiced use of repellents significantly more than male respondents (Fig. 12A), and respondents who felt control agencies were more responsible for mosquito control practiced use of repellents more than those who felt individuals were more responsible (Fig. 12B). In the final multifactor model, only responsibility for mosquito control remained as a predictor for repellant usage ($\chi^2_1$=4.71, p=0.0299), with gender remaining marginally significant ($\chi^2_1$=2.81, p=0.0935).

**Discussion**

This study found that disconnected downspouts had lower infestation and significantly lower *Aedes* and *Culex* mosquito abundances compared to other types of water-holding containers, especially yard care containers. This finding is inconsistent with the only other study to rigorously study mosquito abundances in household disconnected downspouts in the United States (Unlu et al. 2014), which found significantly higher abundances of immature *Ae. albopictus* in downspouts with CES compared to other containers in New Jersey. A likely explanation for this difference, may be that Unlu et al (2014) compared individual adjacent containers and not total abundance at the household level, thereby not accounting for other types of water-holding containers typically found in most yards that may be more productive than CES (Unlu et al. 2014). This study estimated total household mosquito abundances by multiplying sampled densities by container volume. Using this estimation method, this study included types of other containers found in yards that had much higher mosquito production. For example, the mean total estimated mosquitoes per yard care container, which were generally higher in volume than other types of containers, was 338.27 ± 152.50, compared to disconnected downspouts which had a mean of 10.70 ± 3.78. This difference in comparison between mosquito production in other containers and disconnected downspouts is also present when accounting for volume differences. The average density of mosquitoes per mL in other containers was 0.42 mosquitoes/mL, compared with disconnected downspouts which had an average density of 0.07 mosquitoes/mL. When looking at specific species, only *Aedes* pupae were found in disconnected downspout, with both *Aedes* pupae and late instar *Ae. albopictus* composing the majority of mosquitoes found in disconnected downspouts. Of the disconnected downspouts that were infested, only *Aedes* pupae were found, which is consistent with Unlu et al. 2014 who found that *Aedes* species were often the most species found in CES (Unlu et al. 2014).

When looking at the demographic factors related to mosquito reduction strategies, gender created an underlying theme for KAP and certain mosquito practices. Female respondents held higher concern/motivation to control mosquitoes than males, however this concern led to more mosquito repellent usage rather than source reduction. This finding is similar to that of a similar KAP study administered in Australia, in which female respondents were more likely to be concerned of mosquito issues and mosquito diseases than males, both of which were encompassed in our mosquito attitudes score (Potter et al. 2016). Further research into gender as a predictor for mosquito KAP could shed light onto whether or not this trend was related to the summer 2016 Zika public health epidemic, which may have played a role in education interventions specific to women. However, it is notable that Potter et al. 2016's questionnaire was administered in 2014, prior to the Zika scare.

Age was another demographic factor that was related to mosquito practice. Age was significantly related to self-reported source reduction practice in any containers, and also with "other" containers, with older respondents being more likely to practice source reduction. To the author's knowledge, this finding has not been found in prior studies, however Dowling et al. 2013 found that older respondents had higher knowledge specific to mosquito development (Dowling et al. 2013b).

A key demographic finding related to mosquito knowledge was that residents from our higher SES watershed had significantly higher knowledge of mosquito breeding knowledge than those from our lower SES watershed. This finding supports Dowling et al. 2013 who found that overall knowledge of mosquitoes was higher in higher income household. When looking specifically at mosquito breeding knowledge, our study also found that higher education level was correlated with higher knowledge, a finding also shared with Dowling et al. 2013 (Dowling et al. 2013b). Residents from our higher SES study site were more likely to think that residents are more responsible for mosquito control than agencies. This finding differs from Dowling et al. 2013a, who also included responsibility for mosquito control in their overall attitudes towards mosquitoes score and found that lower SES had stronger motivation to control mosquitoes than higher SES respondents (Dowling et al. 2013a). It is also important to note that our respondents from our higher SES watershed were all members of a homeowner's association, which as a governing agency may affect their attitudes towards managing their yards. Members of homeowner associations had higher mosquito breeding knowledge, yet lower concern for mosquito diseases in single factor tests. To the author's knowledge, no other KAP and mosquito management studies have included homeowner association membership in demographic predictors, making this a potential area for further research.

One of the objectives of this study was to test the effectiveness of print educational materials over time, for which we found that receiving educational materials was either ineffective or detrimental to increasing knowledge of water resources. This finding differs from a review by Redman and Paul (1997), who found that print educational materials were effective at changing both knowledge and attitudes in a public health context (Redman and Paul 1997). While our study looked at just changes in knowledge, print educational materials may have different effects at changing actual respondent practices, with several studies finding print educational materials to be ineffective at changing behaviors (Lloyd et al. 1992, Bodner et al. 2016). Our results from this question should be carefully interpreted for several reasons. First, our sample size for this question was only 30 respondents, of which we were relying on respondents to self-report whether or not they remembered being surveyed 2 years prior. This time period is also important to note when interpreting this result because even if respondent knowledge increased following the initial education intervention, it is difficult to say whether or not that knowledge is retained after 2 years. Finally, the education intervention itself does not guarantee that respondents actually read, and comprehended, the water resources information from the print materials. For example, Paul et al. (1998) found that changes in knowledge related to print educational materials was largely related to whether or not the materials were targeted at the correct audience and made readable based on demographics (Paul et al. 1998). Further research could study all aspects of KAP related to print educational interventions, with a shorter period between which changes are measured.

## Chapter 3 – Tables and Figures

### Tables

**Figures**

1. **Figure 1.** Conceptual diagram of the step-wise approach to analyzing relationships among demographics, knowledge, attitudes and mosquito practice from collected questionnaire data.
2. **Figure 2.** Mean (±1 SE) total estimated mosquitoes by container type (**a**), mean (±1 SE) total infested containers by container type (**b**), mean (±1 SE) total estimated *Aedes* pupae by container type (**c**), and mean (±1 SE) total estimated *Culex* pupae by container type (**d**). Different letters denote statistical significance among factor levels ($P < 0.05$).
3. **Figure 3.** Mean (±1 SE) total estimated mosquitoes per household by container type. Different letters denote statistical significance among factor levels ($P < 0.05$).
4. **Figure 4.** Mean (±1 SE) total infested containers (**a**), total estimated mosquitoes (**b**), and total estimated *Aedes* pupae (**c**) by total numbers of 'wet' containers.
5. **Figure 5.** Mean (±1 SE) mosquito breeding knowledge scores by respondent watershed (**a**), homeownership status (**b**), education level (**c**), race/ethnicity (**d**), and homeowner association membership (**e**). Different letters denote statistical significance among factor levels ($P < 0.05$).
6. **Figure 6.** Mean (±1 SE) attitudes towards mosquitoes by gender. Different letters denote statistical significance among factor levels ($P < 0.05$).

7. **Figure 7.** Mean (±1 SE) concern of mosquito diseases by respondent watershed (**a**), race/ethnicity (**b**), and homeowner association membership (**c**). Different letters denote statistical significance among factor levels ($P< 0.05$).
8. **Figure 8.** Mean (±1 SE) perceived responsibility for mosquito control by respondent watershed (**a**), education level (**b**), race/ethnicity (**c**), income (**d**), and homeowner association membership (**e**). Different letters denote statistical significance among factor levels ($P< 0.05$).
9. **Figure 9.** Mean (±1 SE) self-reduction source reduction practice by respondent homeownership status (**a**) and age (**b**). Different letters denote statistical significance among factor levels ($P< 0.05$).
10. **Figure 10.** Mean (±1 SE) implementation of source reduction in disconnected downspouts by respondent responsibility for mosquito control. Different letters denote statistical significance among factor levels ($P< 0.05$).
11. **Figure 11.** Mean (±1 SE) implementation of source reduction in ‘other’ containers by age. Different letters denote statistical significance among factor levels ($P< 0.05$).
12. **Figure 12.** Mean (±1 SE) implementation of repellent use by respondent gender (**a**) and responsibility for mosquito control (**b**). Different letters denote statistical significance among factor levels ($P< 0.05$).

**Table 1.**

| | | Total infested containers | | | Total estimated mosquitoes | | | Total estimated *Aedes* pupae | | | Total estimated *Culex* pupae | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Factor | df | $X^2$ | P-value | | $X^2$ | P-value | | $X^2$ | P-value | | $X^2$ | P-value |
| Self-reported source reduction | 1 | 0.03 | 0.8700 | | 2.74 | 0.0976 | | 1.29 | 0.2554 | | 0.07 | 0.7882 |
| Total wet disconnected downspouts | 1 | 0.20 | 0.6554 | | 1.83 | 0.1758 | | 1.17 | 0.2799 | | 1.52 | 0.2182 |
| Total wet 'other' containers | 1 | 62.94 | **<0.0001** | | 5.93 | ***0.0149*** | | 7.25 | ***0.0071*** | | 0.08 | 0.7745 |

**Table 2.**

| | | Overall mosquito knowledge | | | Mosquito breeding knowledge | |
|---|---|---|---|---|---|---|
| Factor | df | $X^2$ | P-value | | $X^2$ | P-value |
| Individual level | | | | | | |
| education | 2 | 2.96 | 0.2281 | | 14.45 | 0.0007 |
| gender | 1 | 0.14 | 0.7094 | | 3.16 | 0.0755 |
| age | 1 | 0.29 | 0.5887 | | 1.92 | 0.1659 |
| race | 2 | 2.07 | 0.3556 | | 7.84 | 0.0198 |
| financial responsibility | 1 | 0.03 | 0.8559 | | 1.33 | 0.2483 |
| Household level | | | | | | |
| watershed | 1 | 2.58 | 0.1081 | | 7.52 | 0.0061 |
| income | 1 | 1.42 | 0.2332 | | 3.43 | 0.0641 |
| children | 1 | 0.36 | 0.5460 | | 3.36 | 0.0669 |
| association membership | 1 | 1.11 | 0.2919 | | 5.25 | 0.0219 |
| house ownership | 1 | 1.17 | 0.2789 | | 9.05 | 0.0026 |
| educational materials | 1 | 0.05 | 0.8317 | | 0.00 | 0.9949 |

**Table 3.**

| | | Attitudes to mosquitoes | | | Concern of mosquito-borne diseases | | | Responsibility | |
|---|---|---|---|---|---|---|---|---|---|
| Factor | df | $X^2$ | P-value | | $X^2$ | P-value | | $X^2$ | P-value |
| Individual level | | | | | | | | | |
| education | 2 | 0.50 | 0.7800 | | 4.06 | 0.1311 | | 10.10 | 0.0064 |
| gender | 1 | 4.28 | 0.0385 | | 0.00 | 0.9697 | | 0.00 | 0.9738 |
| age | 1 | 0.78 | 0.3774 | | 0.19 | 0.6610 | | 1.33 | 0.2495 |
| race | 2 | 0.14 | 0.9326 | | 10.62 | 0.0049 | | 15.19 | 0.0005 |
| financial responsibility | 1 | 0.01 | 0.9207 | | 0.94 | 0.3314 | | 0.37 | 0.5453 |
| Household level | | | | | | | | | |
| watershed | 1 | 0.59 | 0.4416 | | 15.40 | <.0001 | | 18.01 | <.0001 |
| income | 1 | 0.22 | 0.6409 | | 1.52 | 0.2177 | | 6.07 | 0.0138 |
| children | 1 | 1.01 | 0.3154 | | 0.44 | 0.5077 | | 0.27 | 0.6006 |
| association membership | 1 | 0.33 | 0.5639 | | 6.38 | 0.0115 | | 8.36 | 0.0038 |
| house ownership | 1 | 0.05 | 0.8240 | | 0.30 | 0.5832 | | 2.66 | 0.1028 |
| educational materials | 1 | 0.00 | 0.9672 | | 0.81 | 0.3685 | | 0.08 | 0.7818 |

**Table 4.**

| | | Source reduction in any containers | | Source reduction in disconnected downspouts | | Source reduction in 'Other' containers | | Repellant | |
|---|---|---|---|---|---|---|---|---|---|
| Factor | df | $X^2$ | P-value | $X^2$ | P-value | $X^2$ | P-value | $X^2$ | P-value |
| Individual level | | | | | | | | | |
| education | 2 | 2.48 | 0.2892 | 5.67 | 0.0586 | 3.26 | 0.1959 | 0.29 | 0.8638 |
| gender | 1 | 1.60 | 0.2058 | 0.06 | 0.8017 | 1.41 | 0.2355 | 4.30 | 0.0381* |
| age | 1 | 7.37 | 0.0066 | 0.00 | 0.9516 | 10.14 | 0.0015 | 3.05 | 0.0806 |
| race | 2 | 3.07 | 0.2152 | 2.85 | 0.2404 | 4.81 | 0.0902 | 4.16 | 0.1249 |
| financial responsibility | 1 | 0.01 | 0.9129 | 0.55 | 0.4600 | 0.28 | 0.5959 | 0.24 | 0.6222 |
| Household level | | | | | | | | | |
| watershed | 1 | 0.48 | 0.4882 | 0.11 | 0.7396 | 0.29 | 0.5931 | 2.78 | 0.0954 |
| income | 1 | 0.09 | 0.7597 | 0.04 | 0.8495 | 0.04 | 0.8393 | 1.23 | 0.2673 |
| children | 1 | 1.92 | 0.1660 | 3.18 | 0.0744 | 1.11 | 0.2930 | 3.83 | 0.0504 |
| association membership | 1 | 0.20 | 0.6519 | 1.52 | 0.2178 | 0.22 | 0.6363 | 0.66 | 0.4170 |
| house ownership | 1 | 3.50 | 0.0615 | 1.36 | 0.2436 | 2.78 | 0.0952 | 0.01 | 0.9132 |
| educational materials | 1 | 0.09 | 0.7631 | 1.29 | 0.2555 | 0.06 | 0.8042 | 0.22 | 0.6390 |
| Other Predictors | | | | | | | | | |
| overall knowledge of mosquitoes | 1 | 0.21 | 0.6453 | 0.06 | 0.8010 | 0.15 | 0.7009 | 1.00 | 0.3163 |
| knowledge of mosquito breeding | 1 | 1.76 | 0.1844 | 1.58 | 0.2088 | 1.25 | 0.2636 | 0.13 | 0.7193 |
| attitudes towards mosquitoes | 1 | 0.68 | 0.4091 | 0.55 | 0.4573 | 0.22 | 0.6353 | 0.21 | 0.6459 |
| concern of mosquito-borne diseases | 1 | 1.74 | 0.1872 | 2.80 | 0.0943 | 2.74 | 0.0976 | 0.00 | 1.0000 |
| responsibility of mosquito control | 1 | 1.92 | 0.1661 | 4.66 | 0.0309 | 3.02 | 0.0825 | 5.84 | **0.0156** |

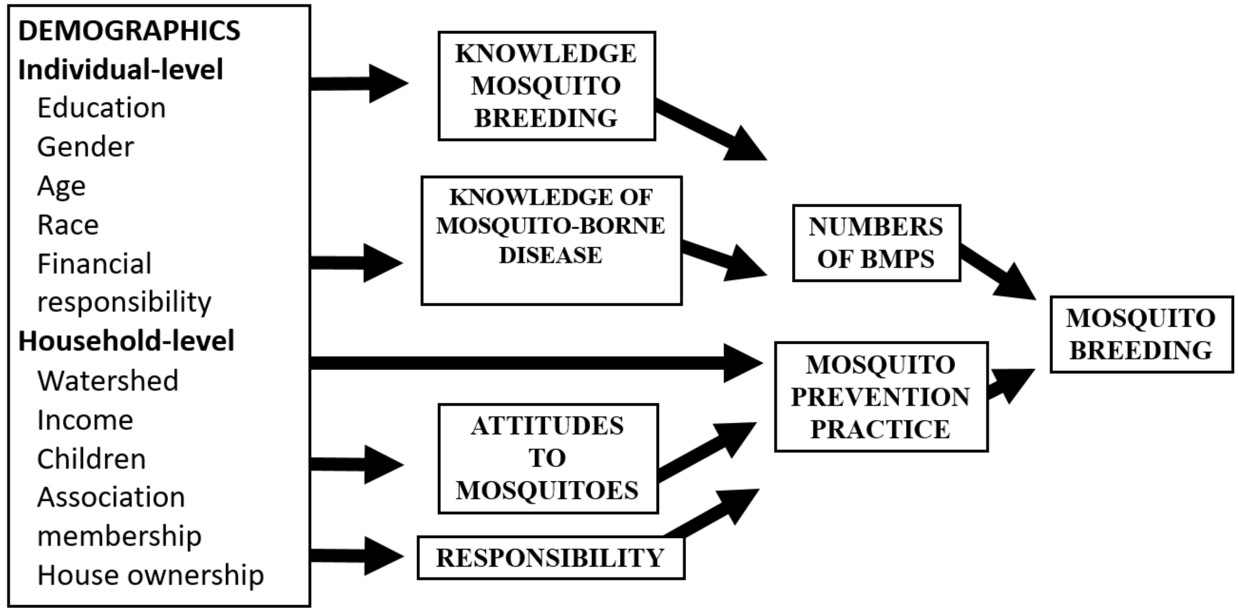
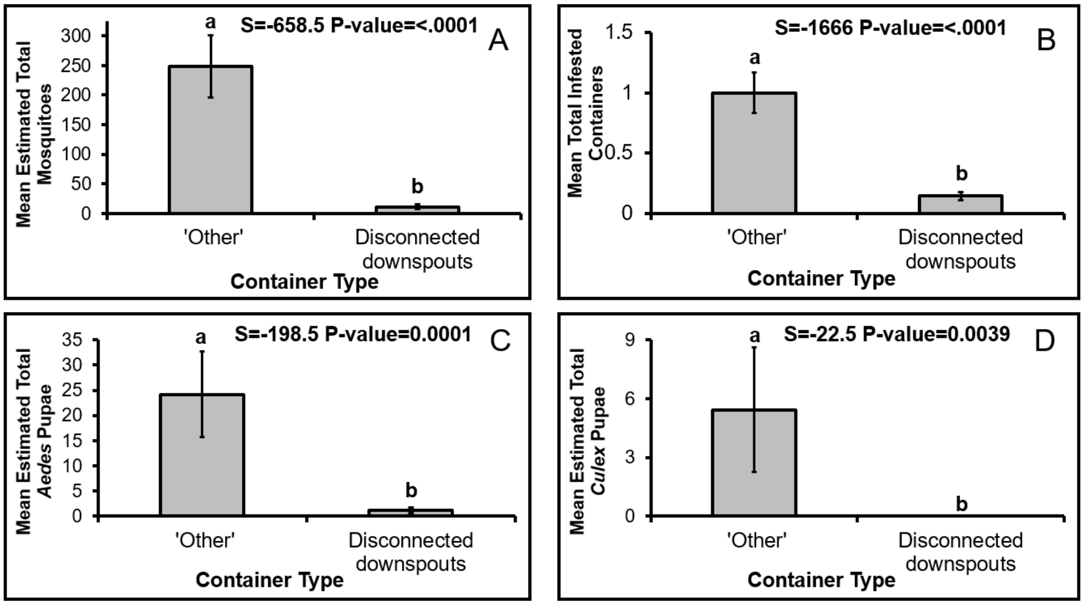

DEMOGRAPHICS
Individual-level
Education
Gender
Age
Race
Financial responsibility
Household-level
Watershed
Income
Children
Association membership
House ownership
KNOWLEDGE MOSQUITO BREEDING
KNOWLEDGE OF MOSQUITO-BORNE DISEASE
ATTITUDES TO MOSQUITOES
RESPONSIBILITY
NUMBERS OF BMPS
MOSQUITO PREVENTION PRACTICE
MOSQUITO BREEDING

**Fig. 1**



S=-658.5 P-value=<.0001
A
Mean Estimated Total Mosquitoes
300
250
200
150
100
50
0
a
b
'Other'
Disconnected downspouts
Container Type
S=-1666 P-value=<.0001
B
Mean Total Infested Containers
1.5
1
0.5
0
a
b
'Other'
Disconnected downspouts
Container Type
S=-198.5 P-value=0.0001
C
Mean Estimated Total *Aedes* Pupae
35
30
25
20
15
10
5
0
a
b
'Other'
Disconnected downspouts
Container Type
S=-22.5 P-value=0.0039
D
Mean Estimated Total *Culex* Pupae
9
6
3
0
a
b
'Other'
Disconnected downspouts
Container Type


**Fig. 2**

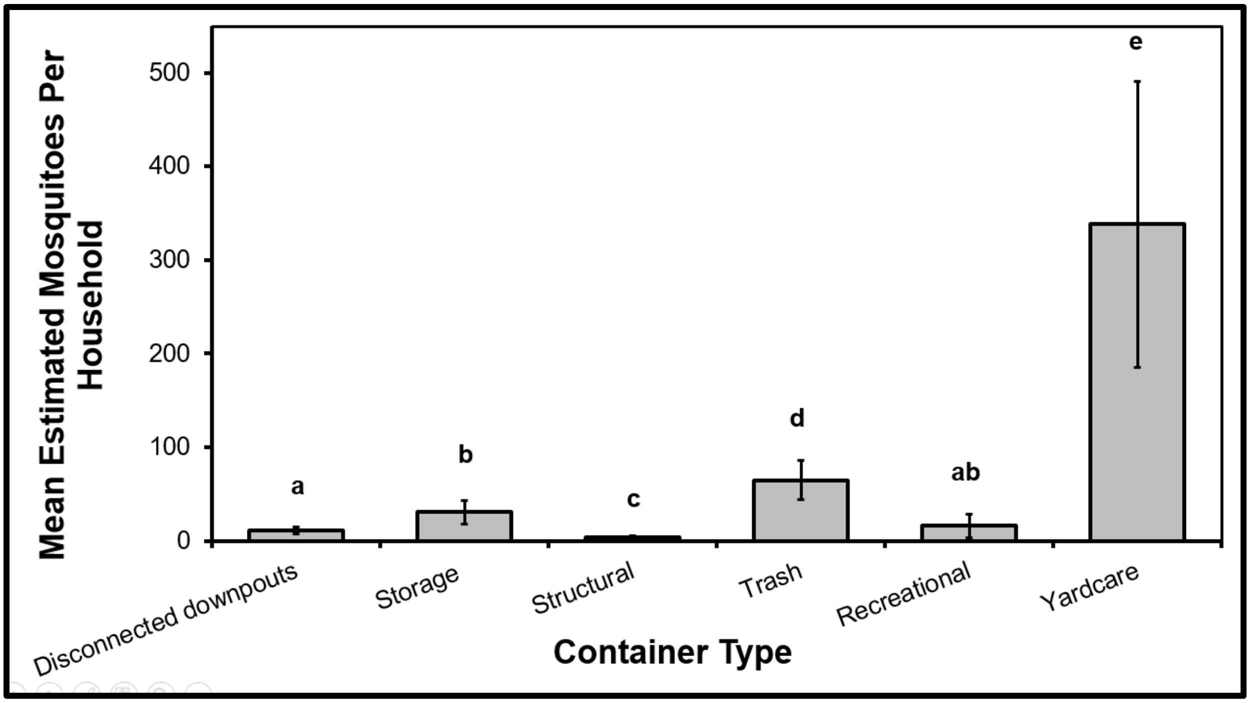

Mean Estimated Mosquitoes Per Household
0
100
200
300
400
500
a
b
c
d
ab
e
Disconnected downpouts
Storage
Structural
Trash
Recreational
Yardcare
Container Type

**Fig. 3**

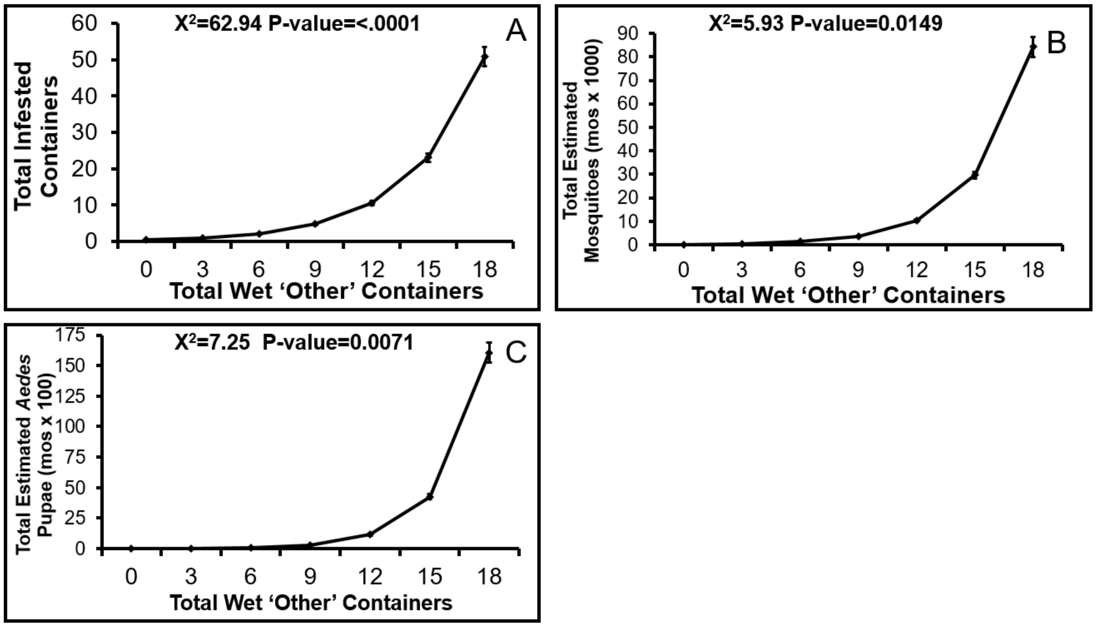
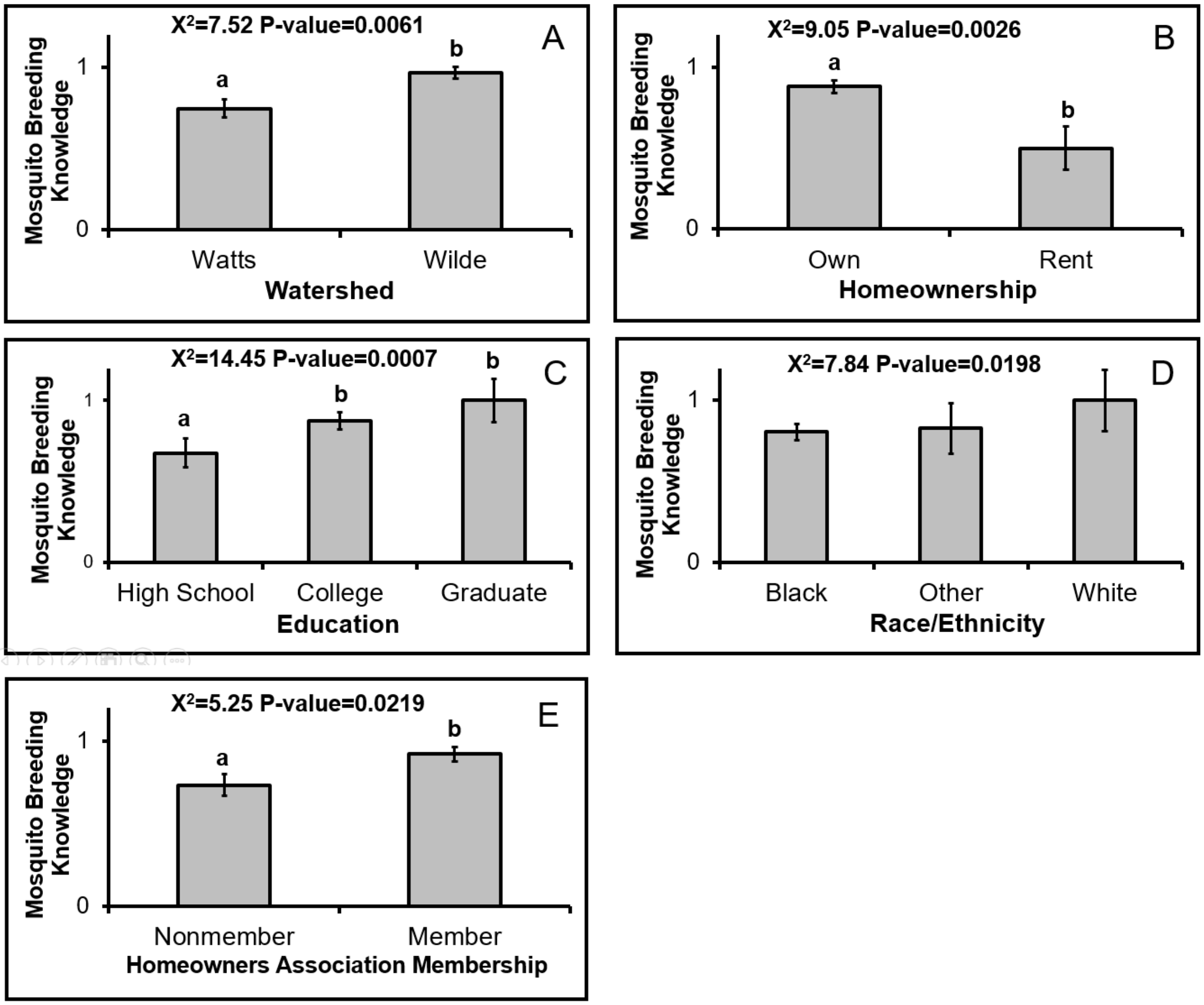

X²=62.94 P-value=<.0001
A
Total Infested Containers
60
50
40
30
20
10
0
0 3 6 9 12 15 18
Total Wet 'Other' Containers
X²=5.93 P-value=0.0149
B
Total Estimated Mosquitoes (mos x 1000)
90
80
70
60
50
40
30
20
10
0
0 3 6 9 12 15 18
Total Wet 'Other' Containers
X²=7.25 P-value=0.0071
C
Total Estimated *Aedes* Pupae (mos x 100)
175
150
125
100
75
50
25
0
0 3 6 9 12 15 18
Total Wet 'Other' Containers

**Fig. 4**



X²=7.52 P-value=0.0061
A
Mosquito Breeding Knowledge
1
0
a
b
Watts
Wilde
Watershed
X²=9.05 P-value=0.0026
B
Mosquito Breeding Knowledge
1
0
a
b
Own
Rent
Homeownership
X²=14.45 P-value=0.0007
C
Mosquito Breeding Knowledge
1
0
a
b
b
High School
College
Graduate
Education
X²=7.84 P-value=0.0198
D
Mosquito Breeding Knowledge
1
0
Black
Other
White
Race/Ethnicity
X²=5.25 P-value=0.0219
E
Mosquito Breeding Knowledge
1
0
a
b
Nonmember
Member
Homeowners Association Membership


**Fig. 5**

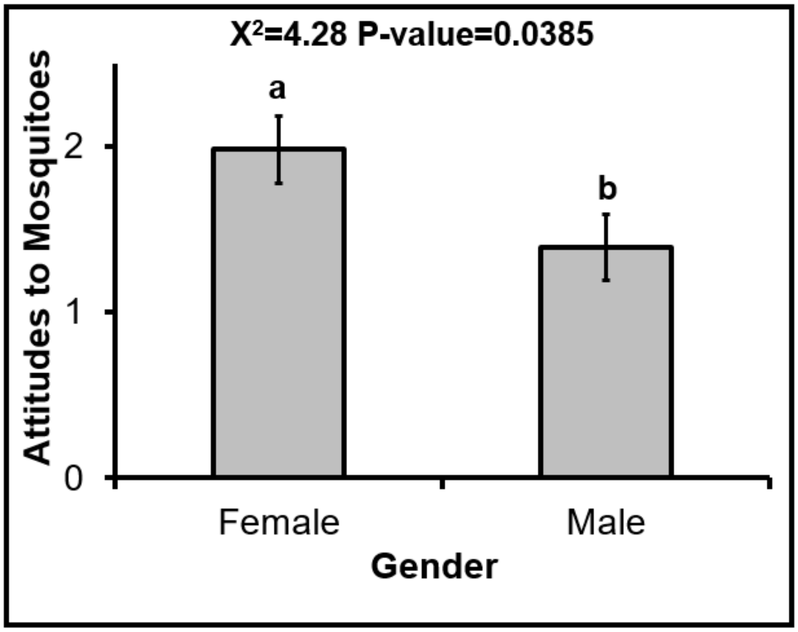
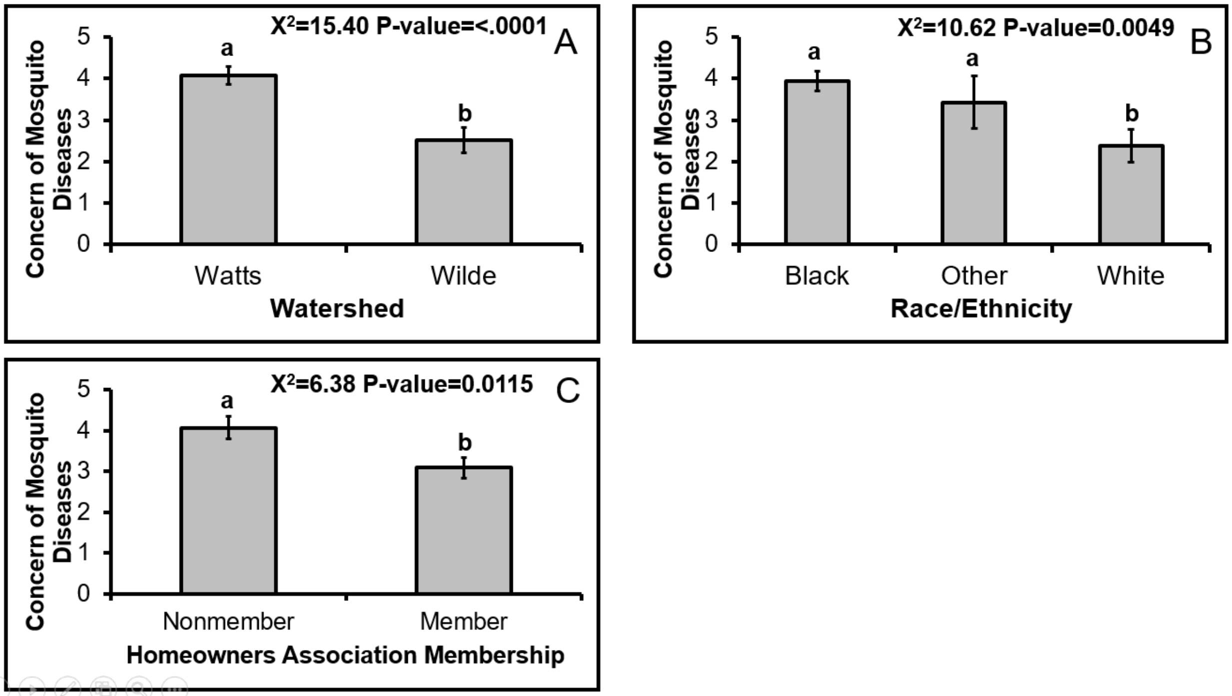
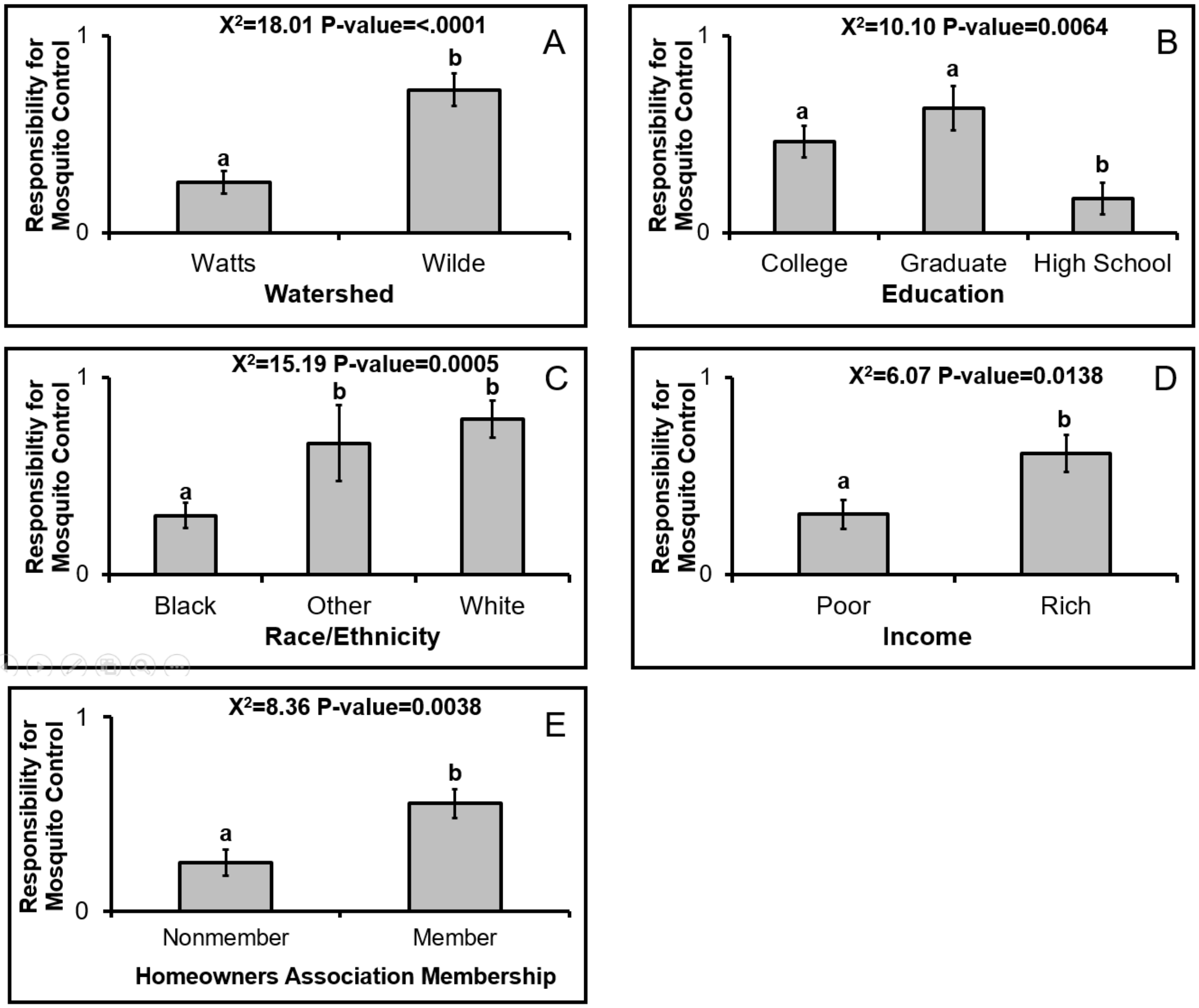

X2=4.28 P-value=0.0385
Attitudes to Mosquitoes
a
b
2
1
0
Female
Male
Gender

**Fig. 6**



X²=15.40 P-value=<.0001
A
Concern of Mosquito Diseases
5
4
3
2
1
0
a
b
Watts
Wilde
Watershed
X²=10.62 P-value=0.0049
B
Concern of Mosquito Diseases
a
a
b
Black
Other
White
Race/Ethnicity
X²=6.38 P-value=0.0115
C
Concern of Mosquito Diseases
a
b
Nonmember
Member
Homeowners Association Membership


**Fig. 7**



X2=18.01 P-value=<.0001
A
Responsibility for Mosquito Control
1
0
a
b
Watts
Wilde
Watershed
X2=10.10 P-value=0.0064
B
Responsibility for Mosquito Control
a
a
b
College
Graduate
High School
Education
X2=15.19 P-value=0.0005
C
Responsibility for Mosquito Control
a
b
b
Black
Other
White
Race/Ethnicity
X2=6.07 P-value=0.0138
D
Responsibility for Mosquito Control
a
b
Poor
Rich
Income
X2=8.36 P-value=0.0038
E
Responsibility for Mosquito Control
a
b
Nonmember
Member
Homeowners Association Membership


**Fig. 8**

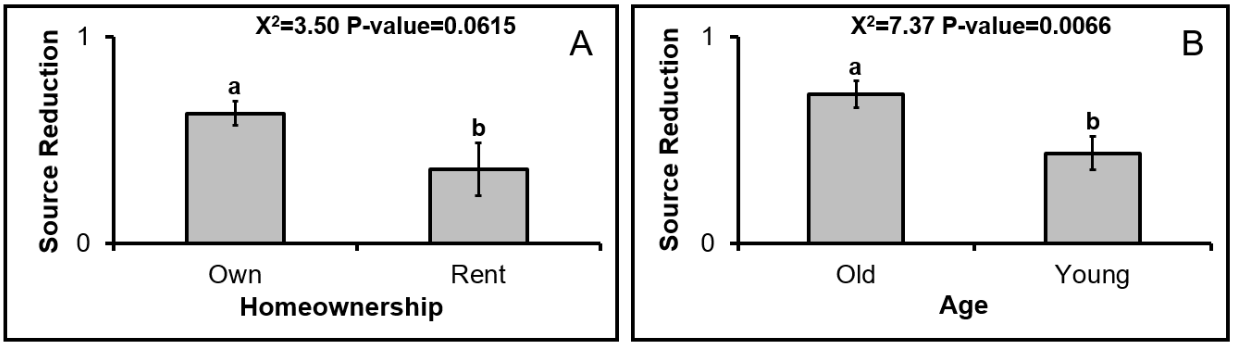
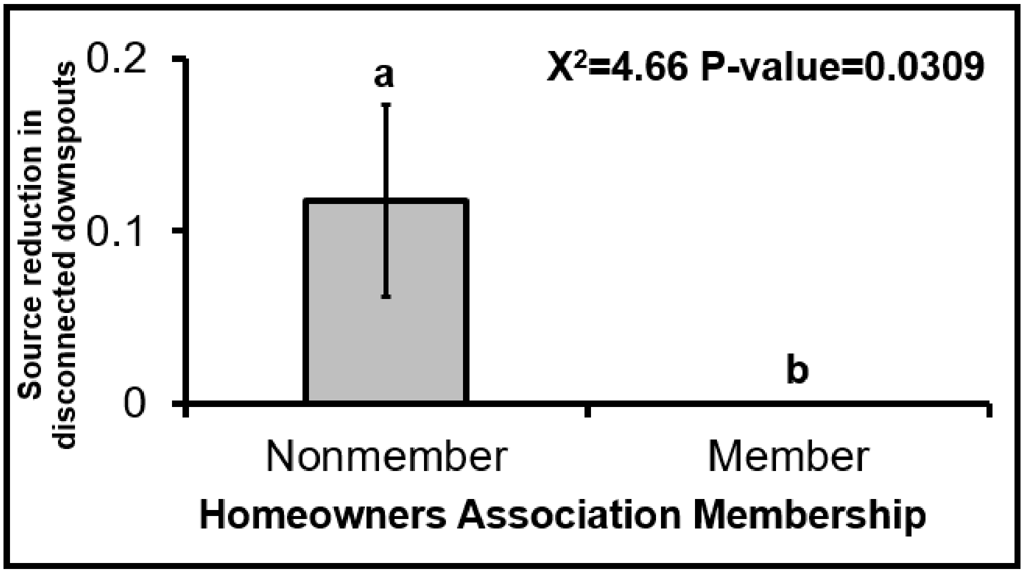

X²=3.50 P-value=0.0615
A
Source Reduction
1
0
a
b
Own
Rent
Homeownership
X²=7.37 P-value=0.0066
B
Source Reduction
1
0
a
b
Old
Young
Age

**Fig. 9**



X²=4.66 P-value=0.0309
Source reduction in disconnected downspouts
0.2
0.1
0
a
b
Nonmember
Member
Homeowners Association Membership


**Fig. 10**

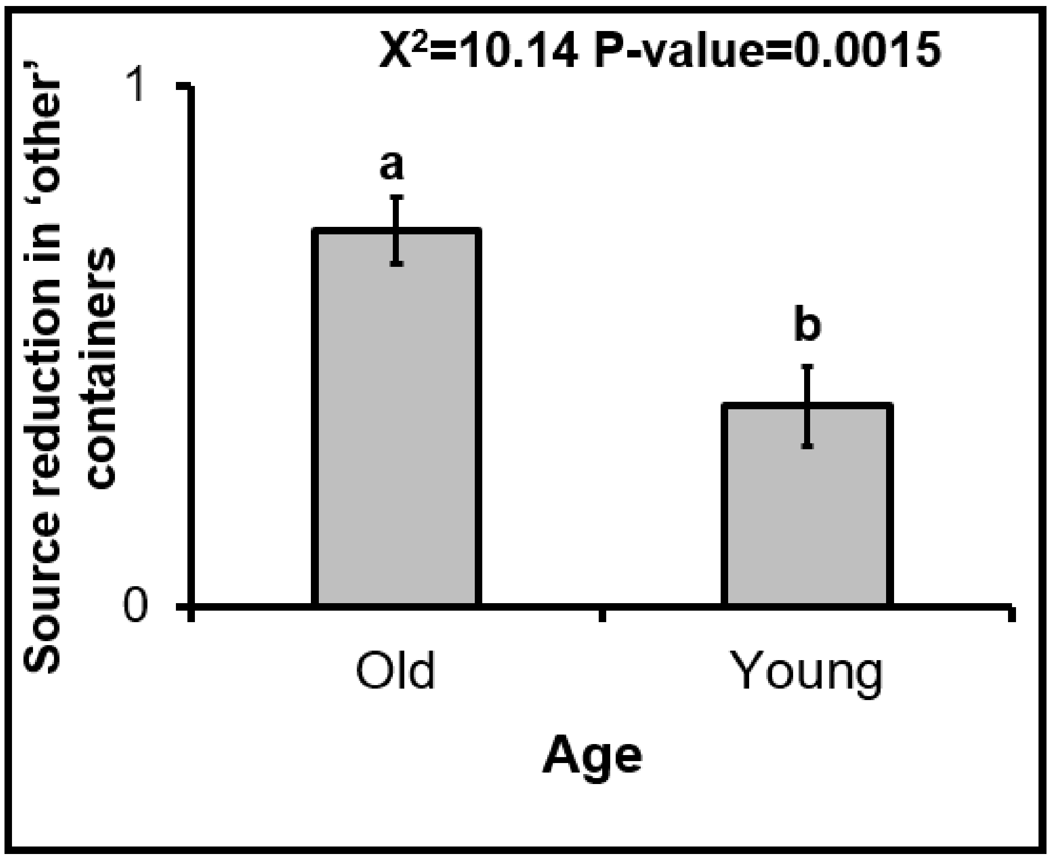

X2=10.14 P-value=0.0015
Source reduction in 'other' containers
1
0
a
b
Old
Young
Age

**Fig. 11**

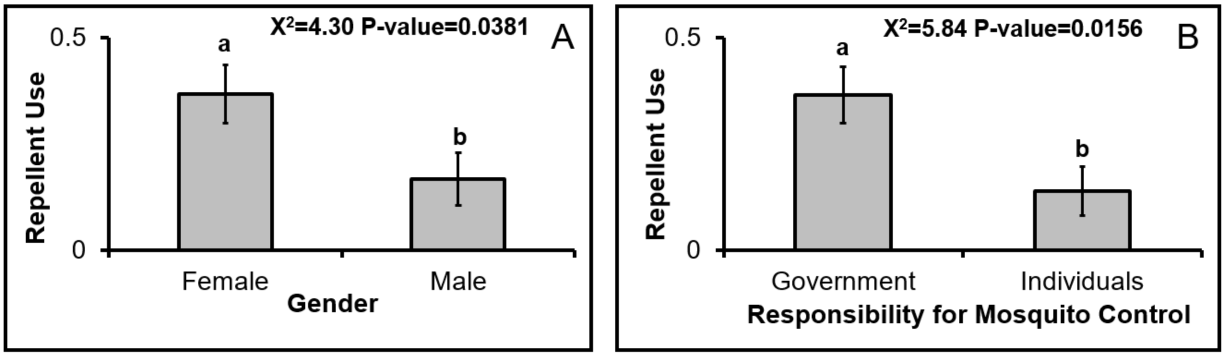

X2=4.30 P-value=0.0381
A
0.5
0
Repellent Use
a
b
Female
Male
Gender
X2=5.84 P-value=0.0156
B
0.5
0
Repellent Use
a
b
Government
Individuals
Responsibility for Mosquito Control

**Fig. 12**

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# Appendix A: Stormwater Questionnaire

Dear Resident,

We need your help. A partnership of University of Maryland, the Columbia Association, Groundwork DC, and the Anacostia Watershed Society is conducting a survey about managing stormwater in neighborhoods in Maryland and Washington, D.C.

This study will help us understand how to work with residents to manage stormwater in neighborhoods in an affordable way. This is particularly important given the various stormwater impact fees implemented by some jurisdictions.

It is only with the generous help of people like you that we will be able to understand better attitudes and approaches to stormwater management.

Your participation in this research study is voluntary. You may choose not to participate. If you decide to participate in this research survey, you may stop at any time.

The procedure involves filling out a survey that will take approximately 10 minutes.

Your responses will be kept confidential. All data will be stored in a password protected electronic database. The results of this study will be used for scholarly purposes only.

SAMPLE QUESTION:
How frequently does your street flood? (Please choose one of the following options)
a) Never
b) Once every month
c) Every time it rains

RISKS: There are no psychological, social, legal, financial or physical risks to subjects in this study.

BENEFITS: There are no direct benefits to participants. However, the project may benefit your neighborhood and other communities by addressing barriers and incentives to stormwater management.

If you have any questions about the research study, please contact Assistant Professor Vikki Chanse, Department of Plant Science & Landscape Architecture, University of Maryland, College Park at (301) 405-4345 or via email at vchanse@umd.edu.

All survey responses will be in a password protected file. Only Dr. Chanse and trained co-investigators will have access to the survey responses. Survey data will be kept through 2017 and then deleted. Survey results will be kept indefinitely.

This research has been reviewed according to the University of Maryland IRB procedures for research involving human subjects. If you have questions about your rights as a research participant or wish to report a research-related injury, please contact:

University of Maryland College Park
Institutional Review Board Office
IRB Protocol 11-0513
1204 Marie Mount
College Park, Maryland, 20742
E-mail: irb@umd.edu
Telephone: (301) 405-0678

If you would like a copy of this letter that explains the benefits, risks, and how the information will be used, a copy is available.

By moving forward and participating in the survey you are indicating that you are at least 18 years of age; you have read this consent form or have had it read to you; and you voluntarily agree to participate in this research study. Please be assured that your responses to the survey questions are confidential. Your name will not be disclosed to anyone or linked to the data in any way. This survey is being conducted for research purposes, only. We are not selling anything and we will not provide your name to any other person or organization.

Thank you,
Victoria Chanse, Ph.D.
Assistant Professor University of Maryland

Section I: Stormwater Where You Live

A few things before you begin:
Stormwater, also called runoff, is the rainfall that drains off the surface of the land. Stormwater BMPs stands for best management practices. These practices may either be:
A) structural, such as a rain barrel or a raingarden or replacing your lawn with drought-tolerant plants, or they may be
B) nonstructural, such as disposing of pet waste or reducing your use of fertilizers.
Thank you very much for sharing your opinions and your valuable time!

1. Which watershed do you live in (Please check all that apply)?
- ❑ Patapsco
- ❑ Patuxent
- ❑ Wilde Lake
- ❑ Potomac
- ❑ Watts Branch
- ❑ Anacostia
- ❑ Northwest Branch of the Anacostia
- ❑ Chesapeake Bay
- ❑ Don't know
- ❑ Other ____________________

2. As far as you know, is the water that runs down your local storm drain treated before it is released into the area waterways (such as streams, rivers, and the Chesapeake Bay)?
- ❍ Definitely yes
- ❍ Probably yes
- ❍ Probably not
- ❍ Definitely not
- ❍ I am not certain

3. My county, city, town, Columbia Association, or homeowner's association gives me rebates for implementing stormwater management practices (such as building rain gardens or incorporating conservation landscaping).
- ❍ Yes
- ❍ No
- ❍ I am not certain

Section II: Stormwater Fees

4. I (or my household) assume financial responsibility for my stormwater impacts in the following ways (please select all that apply):

- ❑ I (or my household) pay a stormwater fee to my local utility.
- ❑ I (or my household) pay a stormwater fee through my homeowner's association or Columbia Association fee or through my City.
- ❑ I (or my household) have used the stormwater rebates available through my county, HOA, Columbia Association, or in DC.
- ❑ None of the above.
- ❑ I am not certain

5. My stormwater fee is assessed according to the following (please choose one):

- ❍ Equivalent residential unit, based on squared ft of impervious surfaces or lot size (tiered according to the unit type)
- ❍ Assessed property value
- ❍ Flat rate
- ❍ None of the above
- ❍ I am not certain

6. Are you aware of any of the incentive programs that exist to promote adoption of stormwater BMPs in your local area?

- ❍ Yes
- ❍ Not sure/maybe
- ❍ No

7. Which incentive program(s) are you aware of in your area?

Section III: Tell Us What You Think

8. Which of the following statements do you agree with the most?
- ❍ Phosphorus is most responsible for polluting the Chesapeake Bay.
- ❍ Potassium is most responsible for polluting the Chesapeake Bay.
- ❍ Nitrogen is most responsible for polluting the Chesapeake Bay.
- ❍ I don't know what is most responsible for polluting the Chesapeake Bay.

9. Which of the following statements do you agree with the most?
- ❍ The amount of stormwater running off the land is more important to the health of streams, rivers and bays.
- ❍ The cleanliness of the stormwater running running off the land is most important to the health of streams, rivers, and bays.
- ❍ The amount and cleanliness of the stormwater running off the land are both important to the health of streams, rivers, and bays.
- ❍ None of the above
- ❍ I am not certain

10. Which of the following statements do you agree with the most?
- ❍ Protecting the Chesapeake from stormwater runoff from homes is the sole responsibility of individuals.
- ❍ Protecting the Chesapeake from stormwater runoff from homes is somewhat more the responsibility of the individual but also the responsibility of government.
- ❍ Protecting the Chesapeake from stormwater runoff from homes is equally the responsibility of individuals and the government/homeowners association/County/State.
- ❍ Protecting the Chesapeake from stormwater runoff from homes is somewhat more the responsibility of the government/homeowners association/County/state but also the responsibility of the individual.
- ❍ Protecting the Chesapeake from stormwater runoff from homes is the sole responsibility of the government homeowners association/County/State.

11. Please rate your level of agreement about the following statements.

| | 1=Strongly Disagree (1) | 2=Disagree (2) | 4=agree (3) | 5=Strongly Agree (4) | 6=Don't know/Not Applicable (5) |
|---|---|---|---|---|---|
| a. There are many things I can personally do to help restore the Chesapeake Bay. | ❍ | ❍ | ❍ | ❍ | ❍ |
| b. There are many things that I can personally do to help improve the stream/river/pond where I live. | ❍ | ❍ | ❍ | ❍ | ❍ |
| c. Blue crabs, oysters, and other seafood are important symbols of Maryland culture. | ❍ | ❍ | ❍ | ❍ | ❍ |
| d. I enjoy outdoor recreation on the Bay, such as going to the beach, fishing, boating, bird and marine life watching and swimming. | ❍ | ❍ | ❍ | ❍ | ❍ |
| e. The stream/river/pond where I live is very important to me personally. | ❍ | ❍ | ❍ | ❍ | ❍ |
| f. I go fishing or crabbing in my local waterbody. | ❍ | ❍ | ❍ | ❍ | ❍ |

12. Please tell us your opinion about each of the following stormwater BMPs. For each of the 9 BMPs, please select all the opinions that apply. For example, if you are both unfamiliar with the rain garden approach and think that the maintenance is too difficult, please select both.

| | Am unfamiliar with this approach. | I don't think it looks attractive | Difficult to install | Expensive to install | Maintenance is too difficult | Is cost-effective | Is easy to maintain | Will save money on my utility bill by reducing imperviousness |
|---|---|---|---|---|---|---|---|---|
| a. Rain Barrels/ Cisterns | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| b. Rain Gardens | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| c. Downspout disconnect | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| d. Lawn Infiltration | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| e. Lawn depression | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| f. Replacing some of the lawn with low-maintenance plants | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| g. Reducing fertilizer use | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| h. Pervious pavers | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |
| i. Installing a pet waste station | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ | ❑ |

Section IV: Your Stormwater Practices

13. What approaches have you already installed or do you use? Please check all that apply.

- ❑ Rain barrels
- ❑ Rain gardens
- ❑ Downspout disconnection
- ❑ Lawn infiltration
- ❑ Lawn depression
- ❑ Replacing some of the lawn with low-maintenance plants
- ❑ Reducing fertilizer use
- ❑ Pervious pavers
- ❑ Other ____________________
- ❑ None

13b. What influenced you to decide on the particular BMPs you currently use or would consider using in the future? Please check all that apply.

- ❑ A friend or neighbor used a similar BMP (and showed me how).
- ❑ I attended an educational training event sponsored by my local watershed group.
- ❑ I attended a local training at my local community center or library or garden.
- ❑ Other (please explain) ____________________

14. Whom would you choose to have install a raingarden in your home?

- ❍ A government contractor.
- ❍ An independent contractor that you choose.
- ❍ I will install it myself.
- ❍ None of the above. I do not need a raingarden.

15. Have you been contacted by a Watershed Steward?

- ❍ Yes
- ❍ No
- ❍ Maybe

16. Please check all that apply to you:

- ❑ I like to garden.
- ❑ I am a member of my local watershed organization.
- ❑ I volunteer at environmental events.
- ❑ I enjoy fishing and crabbing.
- ❑ I consider myself an environmentalist.
- ❑ I am concerned about the overall health of the Chesapeake Bay.
- ❑ I am concerned about mosquito breeding in stormwater BMPs.
- ❑ I am concerned about safety issues related to stormwater BMPs. Please briefly describe here: ____________________
- ❑ None of the above.

Section IV: Information About You

17. If you are interested in additional information on stormwater best management practices, which type of educational approach would you prefer (please check all that apply)?

- ❑ Pamphlet
- ❑ YouTube video showing a "how to"
- ❑ Local educational event at nearby library or school or community center
- ❑ Having a watershed volunteer recommended by your local watershed group come by to examine your yard and provide a recommendation.
- ❑ Have a "how to" training session at home or neighbor's home.
- ❑ Have a county or government personnel come to my residence.
- ❑ Have my local watershed organization conduct a training.
- ❑ Other (please describe) ____________________
- ❑ I am not interested in additional information on stormwater best management practices.

18. Would you be willing to participate in a focus group for stormwater incentives if offered by Dr. Chanse (the researcher of this project)?

- ❍ Yes, I am willing to participate and to be contacted by Dr. Chanse about any potential focus groups on this topic.
- ❍ No, I am not willing to participate.
- ❍ Not sure. I am willing to be contacted by Dr. Chanse about any potential focus groups on this topic.

**Thank you! I just wanted to quickly remind you that your information will be given to Dr. Chanse and protected in a password protected database.**

19. I, personally, make approximately half or more of all the household financial decisions about stormwater management.

- ❍ Always (100% of the time)
- ❍ Most of the Time (about 75% of the time)
- ❍ Sometimes (about half the time)
- ❍ Rarely (only about 25% of the time)
- ❍ Never

20. What is your age?
- ❍ 18-29 years old
- ❍ 30-49 years old
- ❍ 50-64 years old
- ❍ 65-75 years old
- ❍ Over 75 years old

21. Are there any children under the age of 18 who live in your home?
- ❍ Yes
- ❍ No
- ❍ Prefer not to answer/Not sure

22. Are you part of a homeowners' or neighborhood association?
- ❍ Yes
- ❍ Maybe/Not sure
- ❍ No

23. Do you currently rent or own your home?
- ❍ Rent
- ❍ Own
- ❍ Other arrangement, please describe: ____________________

24. What was the highest level of education you have completed?
- ❍ Some high school
- ❍ High school graduate or GED
- ❍ Some college or associate's degree
- ❍ Bachelor degree
- ❍ Graduate or professional degree
- ❍ Prefer not to answer

25. Which of these categories best describe your ethnicity?
- ❍ Asian/Pacific Islander
- ❍ Black/African American
- ❍ Hispanic or Latino
- ❍ Native American or American Indian
- ❍ White/Non-Hispanic
- ❍ Other
- ❍ Prefer not to answer

26. What was the total income before taxes of all members of your household last year?

- ❍ Less than $25,000
- ❍ $25,000-$49,000
- ❍ $50,000-$74,999
- ❍ $75,000 and over
- ❍ Prefer not to answer

27. What is your gender?

- ❍ Male
- ❍ Female

Almost done!
Was there anything that we did not ask you about in this survey that you would like to add?

Thank you for your participation!

# Appendix B: Mosquito Questionnaire

QUESTIONNAIRE

Researchers from the University of Maryland and are investigating mosquito ecology, pest problems, and control strategies in Maryland and Washington, D.C.

***Please help us*** (and your neighborhood) learn about problems and control strategies by answering these questions. The entire questionnaire should take 5-10 minutes. Personal information will be kept confidential.

**1. In 2014-15, we surveyed residents in this area on their attitudes towards storm water management practices, such as rain gardens and reducing fertilizer use. Do you recall being surveyed?** Yes No I'm not sure

**2. What mosquitoes do you find in this area?**

______________________________________________________________________

_______________

**3. What diseases can mosquitoes give you here in DC and Maryland?**

______________________________________________________________________

_______________

**4. What kinds of animals can get these diseases from mosquitoes?**

______________________________________________________________________

_______________

**5. Where do mosquitoes lay eggs and grow?**

______________________________________________________________________

_______________

**6. Are you ever bothered by mosquitoes? Yes No**
**If yes, how often are you bothered by mosquitoes in the summer?**

Never A few days a week A few days a month Less than a few days a month

Every day Other (please describe):_____________________

**7. Are there mosquitoes on your property?** Yes No

**8. If yes, do they alter your behavior?** Yes No
**If yes, how?**

Stay indoors Avoid certain areas Don't garden Don't socialize outdoors

Don’t go for walks Other (please describe):____________________

**9. On a scale of 0-5, how concerned are you about diseases carried by mosquitoes?**

0 1 2 3 4 5

Not at all concerned Very concerned

**10. Do you regularly do anything to keep the numbers of mosquitoes down on your property?** Yes No

**If yes, what?**

______________________________________________________________________

______________

**11. Do you do anything to keep the numbers of mosquitoes down in either of the following stormwater structures on your property?** Yes No

**If yes, which of the following?**

- ☐ Rain barrels/cisterns (structures at the end of downspouts that collect rainwater for later use)
- ☐ Disconnected downspouts/gutters (downspouts that redirect water from hard surfaces to planted areas)
- ☐ Other (please describe)

  ______________________________________________________________

  __________

**12. Who do you think should be responsible for mosquito control?**

District Health Department Residents Landlords

Prefer not to answer

Other (please describe):____________________________________

**13. I (or my household) assume financial responsibility for my stormwater impacts in the following ways (please select all that apply):**

- ☐ I (or my household) pay a stormwater fee to my local utility.
- ☐ I (or my household) pay a stormwater fee through my homeowner's association or Columbia Association fee or through my City.
- ☐ I (or my household) have used the stormwater rebates available through my county, HOA, Columbia Association, or in DC.
- ☐ None of the above.
- ☐ I am not certain

**14. My stormwater fee is assessed according to the following (please choose one):**

- ☐ Equivalent residential unit, based on squared ft of impervious surfaces or lot size (tiered according to the unit type)
- ☐ Assessed property value

- ☐ Flat rate
- ☐ None of the above
- ☐ I am not certain

**15. Are you aware of any of the incentive programs that exist to promote adoption of stormwater BMPs in your local area?** Yes Not sure/maybe No

**16. Almost done! Was there anything that we did not ask you about in this survey that you would like to add?**

______________________________________________________________________________

_______________

## DEMOGRAPHICS

The next set of questions will collect basic demographic information. Please circle best answer.

---

**1. I, personally, make approximately half or more of all the household financial decisions about stormwater management.**

Always (100% of the time) Most of the Time (about 75% of the time)

Sometimes (about half the time) Rarely (only about 25% of the time)

Never

**2. What is your age?** 18-49 years old 50+ years old

**3. Are there any children under the age of 18 who live in your home?**

Yes No Prefer not to answer/Not sure

**4. Are you part of a homeowners' or neighborhood association?** Yes

Maybe/Not sure No

**5. Do you currently rent or own your home?**

Rent Own Other arrangement, please describe:________________________

**6. What was the highest level of education you have completed?**

Some high school High school degree or GED Some college or associate's degree

Bachelor degree Graduate or professional degree Prefer not to answer

**7. Which of these categories best describe your ethnicity?**

Asian/Pacific Islander Black/African American Hispanic or Latino

Native American or American Indian White/Non-Hispanic Other

Prefer not to answer

**8. What was the total income before taxes of all members of your household last year?**

Less than $25,000 $25,000-$49,000 $50,000-$74,999 $75,000 and over

Prefer not to answer

**9. What is your gender?** Male Female

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