Public Benefits Valuation of Green Roof Implementation in Milwaukee, Wisconsin

By

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ABSTRACT

This study evaluates the impact and performance of different green roof systems to manage and control stormwater runoff to prevent watershed pollution over the short and long term in a large urban MSA. A hybrid internet and mail-based stated-preference conjoint choice experiment was administered to residents of the Milwaukee MSA in order to ascertain the public benefits value of green roof infrastructure. This study contributes to the literature on the public benefits of green roofs. The full range of public benefits associated with green roofs, including improved air quality, water quality, biodiversity, and urban heat island effects are estimated. Estimation of all of these public values, allows for determination of the optimal public subsidy for supporting green roofs as a component of decentralized stormwater management in municipalities.

I. Introduction

Over 80% of the U.S. Population currently lives in urban areas and this percentage is expected to continue growing for the foreseeable future (Ando & Netusil, 2013). Ongoing urbanization creates an unsustainable use of natural systems and creates several problems within and outside of cities. One important example of this is urban hydrological systems have to deal with large fluctuations in surface water runoff (Mentens et al., 2004) as a result of the expansive coverage of impermeable surfaces in the urban environment. These fluctuations make it difficult for aging stormwater systems to comply with requirements of the Clean Water Act and often result in stormwater overflows (Niu et al., 2009). The traditional grey infrastructure corrections (steel or concrete engineered to manage stormwater) are costly, however many alternatives to reduce stormwater overflows exist that may be more cost effective. These include green infrastructure options, such as adding more pervious concrete, green roofs, ponds, green areas, or rain gardens all of which can help better manage water issues. In urban areas, rooftops often comprise 40-50% of the impermeable surface area, which provides an excellent opportunity in particular to replace these surfaces with vegetation (Rowe, 2011).

Green infrastructure includes bioretention basins, green roofs, and permeable pavement as oppose to grey infrastructure (which is a separate municipal stormwater sewer system). Green infrastructure employs natural solutions to minimize peak stormwater flows and improve runoff quality (Niu et al., 2009; Schroll et al., 2011; Stovin et al., 2012; Wang et al., 2013; Wolsch et al., 2014; Refahi et al., 2015; Karteris et al., 2016). Green roofs, as a subset of green infrastructure, basically entail growing plants on rooftops to partially replace the vegetation that was lost when a building was constructed (Rowe, 2011). Green roofs generally consist of a vegetation layer, a substrate layer (retention layer), and drainage layer (Mentens et al., 2004). They can contribute to reduction in runoff by delaying the initial time of runoff due to water absorption, retaining part of the rainfall, and distributing the water to the sewer system over a longer period of time through slow release mechanisms (Mentens et al., 2004).

Often times green roofs are preferred to ponds or other open channel system solutions because green roofs do not use up previously unused space (Mentens et al., 2004). Additionally, green roofs are often preferred to adding additional green space on the ground level, because of the large amount of impervious surface and high land prices. Green roofs provide an interesting alternative for stormwater management given the large amounts of unused roof space available in urban areas, as well as the additional public benefits they can provide (Mentens et al., 2004).

Green roofs have been widely used around the globe in varying contexts and locations. During the last couple of decades there have been numerous research studies published, especially in Germany on green roof benefits. The main goal of this paper will be to explore green roofs as a low impact development solution to managing stormwater overflow and estimating the value of the many other public and private benefits that green roofs offer more comprehensively and for a Midwestern, U.S. context.

In addition to stormwater management, mitigating the urban heat island (UHI) effect is another public benefit that green roofs offer (Rowe, 2011; Schroll et al., 2011; Stovin et al., 2012; Wolsch et al., 2014; Refahi et al., 2015; Karteris et al., 2016). Urban areas have higher air temperatures and lower air humidity, which is referred to as the UHI (Mentens et al., 2004). Green roofs have the ability to reduce ambient air temperatures, which also reduces energy demand and therefore helps mitigate emissions from electricity resulting in improved UHI effects (Niu et al., 2009). Reducing the UHI effect can also lead to health benefits (Niu et al., 2009). Urban areas see an increase in respiratory illness and heat-related deaths in part as a result of the UHI (Sproul et al., 2014). Apart from mitigating the UHI, green roofs can also provide a more aesthetically pleasing environment to work or live in which provides public health benefits as well (Getter & Rowe, 2006; Schroll et al., 2011; Rowe, 2011). Seeing greens can help reduce stress, release muscle tension, increase positive feelings and lower blood pressure which all translates into improved health (Getter & Rowe, 2006).

Green roofs also help reduce air pollution in urban areas (Niu et al., 2009; Schroll et al., 2011; Ando & Netusil, 2013; Wolsch et al., 2014; Karteris et al., 2016), which is often viewed as both a public and private benefit. Nearly one in ten people in the U.S. population live where there are unhealthy pollution levels year round (Rowe, 2011). Air pollution can lead to respiratory illness such as asthma and cardiovascular disease (Rowe, 2011). Green roofs have the ability to filter and break down pollution in the air resulting in improved air quality (Rowe, 2011). Additionally, reducing the air temperatures leads to reductions in emissions produced by buildings (Ando & Netusil, 2013).

Another important public benefit of green roofs is their ability to increase biodiversity by providing habitat for insects and other wildlife in urban areas (Rowe, 2011; Schroll et al., 2011; Stovin et al., 2012; Claus & Rousseau, 2012; Refahi et al., 2015; Karteris et al., 2016), green roofs are often inhabited by spiders, beetles, bats, bees, birds, leafhoppers and more (Claus & Rousseau, 2012).

Green roofs also reduce noise pollution (Rowe, 2011; Wolsch et al., 2014; Refahi et al., 2015), which is often seen as both a public and private benefit. The substrate, drainage layers and sedum plants that make up a green roof are often heavier compared to the parts that make up a traditional roof, these heaver materials can lead to noise muffling (Claus & Rousseau, 2012), and have an ability to absorb sound waves to a greater degree compared to traditional hard surfaces (Rowe, 2011).

Additional public benefits that green roofs provide include: improving aquatic habitat, improving ground water recharge (process where surface water moves downward to groundwater), flood mitigation (Ando & Netusil, 2013), and reducing the effects of acid rain (Karteris et al., 2016) and carbon dioxide (CO_2) in the environment (Rowe, 2011). For example, if Michigan State University were to replace all of their conventional roofs with green roofs this would avoid 3,640,263 kg of CO_2 emitted in electricity and natural gas consumption per year, which is the equivalent of removing 661 vehicles off the road annually (Rowe, 2011). This is a significant reduction in CO_2.

Private benefits that green roofs provide include energy savings from the reduction in energy demanded (Niu et al., 2009; Claus & Rousseau, 2012; Refahi et al., 2015; Karteris et al., 2016); decreases in cost of repairs and renovation (Refahi et al., 2015); improved property values (Claus & Rousseau, 2012; Bianchini & Hewage, 2012; Wolsch et al., 2014); and improved roof life (Rowe, 2011; Schroll et al., 2011; Bianchini & Hewage, 2012). Green roofs improve the roof life due to their ability to absorb UV and IR radiation, which allows the construction underneath the green roof to last longer than a conventional roof would otherwise (Claus & Rousseau, 2012). Additionally, green roofs tend to have a lower membrane temperature compared to traditional roofs, which results in a decrease in expansion and contraction (Rowe, 2011). When roof membrane expands and contracts it leads to eventual failure of the roof (Rowe, 2011). Green roofs also provide a protection benefit from extreme weather conditions such as frost or hailstorms (Claus & Rousseau, 2012). Green roofing systems ability to increase the life span of a roof can really help improve the return on investment compared to a traditional roofing system (Rowe, 2011).

An often mentioned limitation of green roofs in urban metropolitan statistical areas (MSA's) is the amount of water capture and retention that a traditional green roof is capable of supplying during storm events. Because of traditional basin and soil medium volume, there have been limits to the mitigation of peak rainfall events which green roofs are able to offer. Recently, new green roofs with the ability to dynamically react to weather conditions have been developed. This study evaluates the impact and performance of these dynamic green roof systems in addition to more traditional options for managing and controlling stormwater runoff to prevent watershed pollution. This study contributes to the literature on the public and private benefits of green roofs in two ways. First, the public benefits value of dynamic stormwater retention facilitated through the use of "smart" green roofs with access to real-time weather data as well as traditional extensive green roofs is estimated. Second, a wider and more comprehensive range of public benefits associated with green roofs, including improved air quality, water quality, biodiversity, and urban heat island effects are estimated. Estimation of these public values, allows for determination of the optimal public subsidy for supporting green roofs as a component of decentralized stormwater management in municipalities.

A hybrid internet and mail-based stated-preference conjoint choice experiment was administered to residents of the Milwaukee MSA in order to ascertain the public benefits value of green roof infrastructure. A utility difference model is estimated using the conditional and random parameters logit estimators. Results provide evidence that Milwaukee MSA residents prefer improvements in all of these categories of public benefits, but improvements to biodiversity and water quality seem to be more important to residents followed by improvements in air quality; little evidence is found to support residents are much concerned regarding urban heat island effects. Results for water retention were inconsistent amongst the mail-based and internet based residents.

The remainder of the article is organized as follows: section 2 is a detailed literature review; section 3 discusses the data and methods employed, specifically survey design and administration, as well as the conjoint choice experiment used to establish preferences; section 4 presents the empirical results and welfare analysis; section 5 concludes.

II. Literature Review

The benefit provided by green roofs of most interest to this paper is stormwater runoff reduction. Increased impervious surface area, which results from increased urbanization, drastically increases the amount of runoff from storms (Horowitz, 2012). Stormwater that would previously have been able to soak into the ground, evaporate, or become absorbed by plants becomes runoff water when areas become urbanized (Horowitz, 2012). An example of this is when runoff water travels over impervious surfaces it picks up waste, trash, bacteria, automotive fluids, debris, pathogens and other contaminants and carries them into nearby lakes, rivers, and beaches (Horowitz, 2012). Additionally, this runoff can lead to combine sewer overflows (CSOs) (Montalto et al., 2007). Combined sewer systems are relatively common in urban areas and are designed to convey sewage as well as a limited amount of stormwater (Montalto et al., 2007). CSOs are estimated to be a leading cause of pollution in rivers and lakes in the United States (Montalto et al., 2007).

Green roofs can absorb or transpirate rainfall which can reduce stormwater runoff by 26%-100% (Getter et al., 2006; Dietz, 2007; Evans & Associates, 2008; Van Seters et al., 2009; Berndtsson, 2010; Stovin et al., 2012; Saadatian et al., 2013; Porsche & Köhler, 2013; Sproul et al., 2014; Karteris et al., 2016) with an average of 63% (Dietz, 2007) depending on the type of green roof system and on the storm event (Stovin et al., 2012). Previous literature reviews have concluded average rainfall retention with a green roof varies between 0 – 22 millimeters (mm) (Stovin et al., 2012; Sproul et al., 2014). A green roof with a 3 – 4 inch (in) soil layer can generally absorb between ½ - 1 in of rainfall from a given storm event, preventing that volume of runoff from ever flowing to storm drains and contributing to surface water pollution (Horowitz, 2012).

Within the literature on green roofs there is a wide range of proposed values for the amount of rainfall that green roofs can retain. For example, in a controlled experiment in Estonia, located in Northern Europe, a green roof was found to effectively retain 85% of light rain from a 2.1 mm rainfall event; however, was unable to retain more water versus a bituminous membrane roof in a heavy rainstorm of 12.1 mm (Teemusk et al., 2007). A research study in Brussels estimated that if 10% of buildings in the region were covered with a green roof the individual buildings would see retention of 54% of rainwater while the region overall would see a reduction of 2.7% (Mentens et al., 2006). In Portland, green roofs are estimated to be able to retain 26-86% of rainfall per storm with an annual rainfall reduction of 56% (Evans & Associates, 2008). Data from Penn state shows that green roofs have the ability to capture 80% of rainfall during rainstorms compared to 24% for standard roofs (Rosenzweig et al., 2006). Green roofs can reduce stormwater runoff by tens of billions of gallons per year (Horowitz, 2012). For example, if green roofs were installed on 50% of existing roof surfaces in Southern California, stormwater runoff would be reduced by more than 36 billion gallons per year (Horowitz, 2012). Additionally, 40,000 square feet of green roof has a runoff of 406,000 gallons per year which is a reduction of 471,000 compared to a conventional roof (Evans & Associates, 2008).

The amount of stormwater retention from different roofing types certainly depends on the structure of the green roofs, the amount and depth of layers, climate conditions and the amount of precipitation. Additionally, stormwater retention depends on the season. Retention is actually significantly lower in winter months versus summer months (Mentens et al., 2004). Differences in retention rates in certain seasons is difficult to compare within the literature because different studies define seasons in different ways (Berndtsson, 2010). A number of studies in different climates including Portland, Michigan, North Carolina, Ontario and Germany have concluded that moisture content of the growing medium, different climates and different seasonal conditions can impact the ability of a green roof to reduce stormwater (Evans & Associates, 2008). Warmer seasons have higher evapotranspiration, which allows green roof retention capacity to increase (Berndtsson, 2010). During winter, or colder months, retention seems to be lower compared to warmer months (Mentens et al., 2004; Schroll et al., 2011; Horowitz, 2012). A study in Pennsylvania found that in summer nearly everything could be retained, whereas in winter only about 20% of stormwater was retained (Horowitz, 2012).

Many studies agree that the type and depth of substrate have a major influence on the amount of stormwater a green roof can retain, but not necessarily the vegetation (Mentens et al., 2006). However, some studies do find that vegetation does play a role in water retention but mostly in periods of warmer temperatures with lower water availability. Vegetation seems less important in winter months or when water availability is higher (Mentens et al., 2006).

Schroll et al. (2011) monitors stormwater performance over a one-year period of time for three different roof designs: a conventional impervious design, a medium (soil) only design and a typical extensive green roof including vegetation. Their results indicate that during winter rainy seasons the vegetation had no influence on stormwater retention, while medium-only and vegetated roofs reduced stormwater nearly the same as the conventional roof. During the summer months; however, the roof with vegetation was able to retain significantly more rainfall than the medium-only or conventional roof designs, but this depended strongly on the size of the rain fall event. Some variation was also found depending on irrigation, in the summer months irrigation significantly reduced summer retention in the medium only and planted roof but only during the largest dry season event. On average during wet seasons (late fall to spring), medium only and vegetated roofs were able to retain about 26.4% – 27.2% of total rainfall while during the dry months (summer time) planted roofs retained 64.7% while medium only roofs retained 51.9% (Schroll et al., 2011). These results are consistent with other literature suggesting that green roofs during cool or wet seasons don’t see as much stormwater retention.

Another factor that may affect stormwater retention in green roofs, besides season and vegetation, is the slope of the roof. The relationship found is often that the lower the slope, the higher the water retention (Berndtsson, 2010). Additionally, the age of the green roof may play a role in retention capabilities; however, research is inconclusive on this (Berndtsson, 2010). Additional green roof factors that may impact the amount of stormwater retention include: soil moisture, thickness and type, the number of layers, roof geometry and position (whether it is shadowed or not) (Berndtsson, 2010), as well as plant species (Getter et al., 2006). Weather conditions that may impact the amount of stormwater retained by green roofs includes the length of the proceeding dry period, the air temperature, wind conditions, humidity (Getter et al., 2006) and type of rain event (duration and intensity) (Getter et al., 2006; Berndtsson, 2010).

Apart from retaining stormwater runoff green roofs can delay the runoff (Teemusk et al., 2007; Berndtsson, 2010; Horowitz, 2012), which can prevent sewer systems from overflowing (Getter et al., 2006; Montalto et al., 2007; Horowitz, 2012). Green roofs can conservatively reduce combined sewer system overflows by 26% (Montalto et al., 2007). Even when saturated, green roofs have been able to significantly delay runoff as well as reduce erosion and flooding (Horowitz, 2012). Previous literature reviews have concluded that green roofs can delay the start of run off by an average of 5.7 hours (Berndtsson, 2010). However, other researchers have found that green roofs can delay run off up to 30 minutes but depending on the storm can result in runoff that is actually the same as a conventional roof (Teemusk et al., 2007).

Besides retaining and delaying stormwater, green roofs also have the ability to reduce the peak flow of a storm by 60 –95% (Evans & Associates, 2008; Berndtsson, 2010; Stovin et al., 2012; Sproul et al., 2014). Peak flow is the maximum rate of discharge during a runoff period. For an average rainfall intensity of 4.3 mm per hour a green roof is estimated to reduce peak flow intensity to about 2.4 mm per hour (Berndtsson, 2010). However, some authors conclude that this peak flow reduction estimate is arguably meaningless because it depends so much on the irregularity of natural rainfall patterns and other weather or green roof factors (Stovin et al., 2012). A German paper published by Jeroen Mentens, Dirk Raes and Martin Hermy (2006) found that green roofs are certainly effective at reducing overall stormwater volumes but are not so good at reducing storm flow peaks alone. They conclude that in order to provide a greater effect on overall runoffs green roofs should be paired with other means of runoff reduction, such as storage reservoirs, rainwater cisterns or an increase in green areas in nearby open space.

A green roof can be an effective tool for managing small storms in highly developed areas however green roofs alone cannot be relied on for storm water management at the watershed scale (Berndtsson, 2010). In a simulation study, Rosenzweig et al (2006) showed that runoff could be reduced up to 10% at the sewage-shed level with a 50% green roof scenario utilizing a simple box model and data from LaGuardia airport from a wet year, 1984, and a normal year, 1988 (Rosenzweig et al., 2006).

Green roofs can also provide benefits related to temperature. Standard roofs can have surface temperatures more than 72°F higher than green roofs midday during the summer months (Odefey et al., 2012; Rosenzweig et al., 2006). On a hot sunny day the surface immediately above a standard roof can actually exceed ambient air temperatures by 90°F or more, with much of that heat transmitted into the building below (Horowitz, 2012). Green roofs can decrease surface temperature of the roof by 86°F – 140°F (Saadatian et al., 2013). On average in July of 2003 in New York City, surface temperatures were 34°F higher on standard roofs during the day, and 14°F lower at night, compared to a green roof (Rosenzweig et al., 2006). Indoor temperatures were found to be on average 4°F lower during the day, and 0.5°F higher at nighttime in the buildings with a green roof (Rosenzweig et al., 2006). If 50% of the buildings in New York City had green roofs, the average surface temperature of the city could be reduced by 0.1°F - 1.4°F (Rosenzweig et al., 2006). When outdoor temperatures are between 77°F -86°F an extensive green roof can reduce room temperatures by at least 5.4°F- 7.2°F (Mullen et al., 2013). With this reduction in energy the air conditioner resizing benefits are estimated to be between $0.02 - $0.04 per meter squared per year with a green roof (Niu et al., 2010). The energy used for air conditioning can be reduced 25-80% (Saadatian et al., 2013). Historically, passive cooling practices in very hot and arid climates involved cooling a roof with wet soil and providing shade to that soil, green roofs provides similar benefits (Saadatian et al., 2013).

While reductions in temperatures can translate to lower energy bills for buildings they also provide a value of lowering the ambient temperatures in surrounding urban neighborhoods. As discussed in the introduction, this decrease in ambient temperatures results in a decrease in the urban heat island (UHI) effect. In the US, the majority of the building sector consists of impervious black (or dark) colored roofs, which absorb approximately 80% of incoming sunlight (Sproul et al., 2014). Literature consistently shows that installing green roofs in urban areas can play a significant role in reducing the urban heat island effect (Horowitz, 2012). Green roofs reduce the UHI by reducing the ambient air temperature through reduction in rooftop temperatures as well as through evapotranspiration of water into the air (Karteris et al., 2016). Previous literature has suggested that replacing 50% of an urban cities roof tops with a green roof could result in a citywide decrease in ambient temperature of 1.4°F - 3.8°F, depending on if the green roof is irrigated or not (Odefey et al., 2012; Horowitz, 2012). Installing green roofs on every building in a 300-block area of Portland, Oregon would result in a reduction during peak summer temperatures of 0.5°F -0.9°F or 0.0025°F per acre, per year) and would benefit the surrounding areas with a cooling effect and thus reducing the UHI by 1% (Evans & Associates, 2008).

The public benefits of the mitigation of the urban heat island effect are not often quantified in literature because it is very difficult to quantify this benefit. One study quantified the UHI value to be $0.0083 - $0.017 per meter squared (Bianchini et al, 2012). Other literature has quantified the urban heat island effect based on air quality improvements. For example, considering the nitric oxide (NO_x) absorption resulting from the UHI reduction provides an estimated benefit of $0.01 - $0.59 with an average of $0.44 per meter squared per year (Claus et al., 2012).

In addition to mitigating the UHI effect through reduction in surface area temperatures and evapotranspiration, green roofs also have the ability to reduce the UHI effect by improving the air quality. For example, simulation studies have predicted that a reduction in the population-weighted smog amounts of 10-12% in the city of Los Angeles can result in a reduction of ambient temperature of a 2.7°F - 3.6°F (Horowitz, 2012). In some scenarios, this is actually comparable to the effect of replacing all gasoline-powered vehicles with electric models (Horowitz, 2012).

Improving the air quality in urban areas is important for many public health reasons, as discussed in the introduction. Green roofs' ability to provide cooling and insulation to buildings leads to a reduction in energy consumption which results in reductions in emissions of nitric oxide (NO_x), sulfur dioxide (SO_2), and carbon dioxide (CO_2). Reductions in these types of emissions can lead to reductions in health care costs that come from air pollution (Mullen et al., 2013). Plants grown in green roofs have the ability to reduce air pollution by absorbing pollutants such as CO_2 as well as generating oxygen and reducing pollutants through uptake of ozone, NO_2 and SO_2 (Claus et al, 2012; Karteris et al., 2016). The type of vegetation used in the green roof largely affects the magnitude and type of air quality improvements generated, and comparing air quality improvements across different green roofs can be very misleading (Carter & Keeler, 2008). Improved air quality benefits within the literature are estimated to be $0.00 - $0.59 per meter squared (Carter & Keeler, 2008; Claus et al., 2012; Bianchini et al, 2012). Annually the benefits are estimated to be $3,024 for a 40,000 square foot roof (Evans & Associates, 2008). A 40,000 square foot green roof has the ability to reduce particulates by 1,600 pounds annually; each square foot filters approximately 0.04 pounds of dust and particulate matter out of the air (Evans & Associates, 2008).

Previous research studies on the benefit of green roofs have employed a comprehensive range of methods to measure CO_2 benefits. For example, a study in Northern Greece concluded that if 50% of the buildings' blocks were covered with green roofs, then at least 35 tons of CO_2 would be sequestered, which would be the equivalent to 50 acres of forest. The annual savings in the entire city of Thessaloniki can reach approximately 65,000 tons of CO_2 (Karteris et al., 2016). In Southern California, CO_2 could be reduced by 162- 465 thousand metric tons per year if 30%-50% of rooftops were green roofs (Horowitz, 2012). Other studies have found that a 40,000 square foot green roof has the ability to reduce carbon emissions annually by 5 tons, which would be an annual carbon reduction benefit worth $29 ($5.75 per ton of CO2; Evans & Associates, 2008). Sproul et al. (2014) concluded, from a literature review of 22 studies, that annually green roofs can reduce CO_2 emissions by 5.7 kg per meter squared. Claus et al. (2012) claims that green roofs could impact CO_2 in two ways, directly through absorption by the plants and indirectly by reduction in energy used in the buildings. They stated that the monetary savings of the direct effect couldn't be estimated however they estimated the indirect effect to be $0.04 per meter squared. Niu et al. (2010) estimated CO_2 benefits on the low end to be between $1.20 – $7.40 per mg of CO_2, with a mean value of $3.80 per mg of CO_2, and a high end estimate between $17.40 – $46.20 per mg of CO_2 with a mean of $33.70 per mg of CO_2 (Niu et al., 2010). The variation in benefits from CO_2 reduction in the literature review can in part be attributed to the range of different plants that can make up a green roof (e.g. spices and aromatic plants can actually achieve higher CO_2 sequestration rates) (Karteris et al., 2016).

Considering another greenhouse gas, nitrogen dioxide (NO_x), the city of Chicago estimated that the economic benefits of greening only 10% of the city's roofs with green roofs could remove 17,400 mg of NO_x per year, which can result in avoided public health costs of $29.2 - $111 million annually (Odefey et al., 2012). In Sproul et al.'s literature review they concluded NO_x emissions can be reduced by an average of 0.011 kg per meter squared (Sproul et al., 2014). Considering only NO_x removal, the overall public health benefit of greening a 2000 meter squared roof is between $890 and $3390 per year (Mullen et al., 2013). This benefit would likely be higher if reduction of other greenhouse gases was considered (Mullen et al., 2013).

In addition to CO_2 and NO_x, benefits green roofs can provide other air quality benefits such as a reduction of sulfur dioxide (SO_2) emissions by 0.013 kg per meter squared (Sproul et al., 2014), a reduction of carbon dioxide equivalent (CO2e) of 34 kg (Sproul et al., 2014), and can also reduce the effects of acid rain by raising the pH value of water (Karteris et al., 2016).

Habitat creation can also be generated from green roofs, this can provide a benefit of $0.00 - $10.20 per meter squared (Bianchini et al., 2012), or a 40,000 square foot green roof can generate an enhanced habitat value of $25,300 which includes 10% of the avoided construction costs of generating habitat space (because generating a green roof is not the same as creating habitat elsewhere so only 10% of value is considered) (Evans & Associates, 2008).

Green roofs ability to retain stormwater helps prevent a substantial amount of pollution from reaching local waters (Horowitz, 2012). Stormwater precipitation can be filtered by the different layers in a green roof, which leads to improvements in runoff water quality; however, at this time there is no clear consensus on this in the literature (Claus et al., 2012). What has been agreed upon is stormwater should not be used for domestic use unless it has had further treatment (Claus et al., 2012).

Factors that affect runoff water quality include type of material used for the green roof, soil thickness, type of vegetation, wind direction, local pollution sources, season, precipitation dynamics (Berndtsson, 2010) and characteristics of the pollutants (Teemusk et al., 2007; Berndtsson, 2010). The largest influence on the quality of runoff water is from the soil material and added fertilizers (Berndtsson, 2010); however, even if green roofs have been fertilized they still have the ability to reduce pollutants in our waterways because the amount of runoff is reduced, and thus the amount of pollutants are reduced (Horowitz, 2012). Within the literature there seems to be design issues with the amount of fertilizer or if fertilizer is needed on green roofs (Berndtsson, 2010). Previous literature has found that several different types of chemicals have been reduced in green roof runoff versus conventional roof runoff with the exceptions of magnesium, calcium (Teemusk et al., 2007; Van Seters et al., 2009) and total phosphorus (Van Seters et al., 2009), which are either naturally present or added to promote growth of the plants. Water purification benefits have been estimated to be between $0.34 - $0.38 per meter squared (Claus et al., 2012).

As discussed briefly in the introduction, having a green roof instead of a conventional flat roof can lead to energy savings for buildings (Horowitz, 2012; Mullen et al., 2013). Energy savings vary with several factors related to building construction, insulation properties, green roof characteristics, season (Horowitz, 2012), or size of the roof (Mullen et al., 2013). Buildings with smaller roofs will realize greater energy savings compared to buildings with larger roofs (Mullen et al., 2013). The insulation values range depending on the warmth and dryness of the climate, the leaf area index (LAI), number of floors in the building (Rafahi et al., 2015), thickness of the soil (Wong et al., 2003; Rafahi et al., 2015), and type of plants (Wong et al., 2003). The difference in savings grows as the depth of the green roof effect increases, the relationship between the net private benefits and number of floors in a building seems to be quadratic, initially positive then negative (Mullen et al., 2013).

Green roofs can reduce the energy needed for building cooling on the floor directly below by 25% - 50%, and 10% on the second floor from the roof (Horowitz, 2012). For a one-story building a green roof can actually reduce the energy demand for cooling the entire building by upwards of 75% compared to a conventional roof (Horowitz, 2012). The direct electricity savings are estimated at 0.17 kWh per foot squared (Horowitz, 2012). To put this in perspective, in Southern California if 50% of the roofs were green roofs this would result in estimated energy savings of 625 thousand

MWh worth $211 million; if only 30% were green roofs, the energy savings could be 565 thousand MWh worth $73 million (Horowitz, 2012). Buildings with green roofs can expect to see an annual cost savings from reduction in their required cooling energy of 17% - 47% (Horowitz, 2012). This is conservative in the sense that it does not account for greenhouse gas savings, indirect electricity savings, savings from reduction in heating costs due to green roofs insulating effects or savings from increases in air conditioner efficiency (Horowitz, 2012). In general, air-conditioning systems begin to decrease in operational efficiency at about 95°F (Horowitz, 2012). Green roofs tend to maintain a localized air temperature below that of ambient air, allowing cooler air to enter the air-conditioning system and reducing costs and energy used for cooling (Horowitz, 2012).

Monetary savings from energy reduction with a green roof are estimated to be between $0.11 - $0.87 per meter squared per year (Carter & Keeler, 2008; Claus et al., 2012; Niu et al., 2012). Annual savings from decreases in energy costs for buildings that have a green roof range from $384.35 - $1,480 (Evans & Associates, 2008; Odefey et al., 2012; Rafahi et al., 2015), while the decreases in annual energy consumption ranges from 3568.2-7710.1 kWh (Rafahi et al., 2015). The cooling cost annual reduction is $680 (based on a value of $0.10 per kWh) and heating cost annual reduction is $800 (based on a value of $1.00 per therm; Evans & Associates, 2008). In a literature review by Sproul et al. (2014) they reviewed 22 studies and concluded the heat savings relative to a black roof range from $0.00-$0.70, with a median of $0.30 per meter squared, per year, while the cooling savings relative to a black roof range from $0.20 - $0.60 with a median of

$0.30 per meter squared per year, estimating an expected lifespan of a green roof to be 40 years.

The insulation properties of green roofs that can help with energy savings can also provide noise reduction benefits. Green roofs have the ability to reduce noise by 2 to 3 dB compared to gravel roofs (Porsche & Köhler, 2013). The benefit of noise reduction savings has been estimated at $0.33- $0.36 per meter squared per year with an estimated 50 year life span (Claus et al., 2012). For example, a three-story office building could expect noise reduction saving benefits of $17.28 per meter squared over the life span of a green roof (Claus et al., 2012). These noise reduction benefits alone can increase building values by 13.8% (Clark et al., 2012).

Within the literature, fee based storm water benefits range from $0 – $0.38 per meter squared in savings that building owners benefit from by having a reduction in impervious area (Carter & Keller, 2008; Niu et al., 2010; Bianchini et al, 2012). Some cities offer incentives to encourage green roof adoption, such as best management practice (BMP) discounts on stormwater fees. The literature values these fee based incentives between $9.06 - $44.70 per meter squared (Carter & Keeler, 2008, Sproul et al., 2014), or aggregated to the city level in Washington DC, BMP benefits are estimated to be $0.22 - $0.32 million per year (Niu et al., 2010). Additional private benefits for avoided stormwater benefits combined with avoided construction and demolition waste benefits for an extensive green roof are estimated at $39 - $100 per meter squared, and $100 - $324 per meter squared for an intensive green roof (Bianchini et al., 2012). The annual benefit for a building owner just from stormwater volume reduction benefits is estimated at $1,330; for 5 years the accrued benefited is $6,822; and for 40 years is $45,866 (Evans & Associates, 2008). The results of a net present value (NPV) analysis in Washington DC showed that stormwater infrastructure benefits totaled $1.04 million (Niu et al., 2010).

As demonstrated throughout this literature review thus far, green roofs have the ability to provide many benefits. For building owners they can actually increase property values from $132 - $174 per meter squared (Bianchini et al, 2012). Intensive green roofs can increase property values even more, for example property values could increase from $181.5 - $678 per meter squared with an intensive green roof (Bianchini et al., 2012). Part of these property value benefits include providing additional aesthetic value of $2.60 - $8.30 per meter squared (Bianchini et al., 2012). Owners can also see a tax reduction benefit, for example in the city of New York if 50% of roof tops were covered in green roofs, tax reduction benefits of $48 per meter squared would be expected, with a maximum tax abatement of $100 thousand (Bianchini et al., 2012). In Portland, Oregon green roof projects actually offer building owners and developers an incentive of up to $5 per square roof to install green roofs, while in Philadelphia, Pennsylvania, there is a 25% rebate offered for green roof costs up to $100,000 (Odefey et al., 2012). Green roofs can also reduce system management costs and infrastructure costs (Evans & Associates, 2008). Additionally they can provide an avoided landfill cost (that a standard roof has) of $0.0089 to $0.20 per meter squared (Bianchini et al., 2012). Additionally, covering 1% of all large buildings with green roofs in America's medium to large cities was estimated to create over 190,000 jobs as well as provide billions in revenue to manufactures and suppliers that produce or distribute green roof materials (Hewes, 2008).

The wealth of literature on green roofs concludes that the biggest challenges in implementation are perceived high costs, as well as inadequate or incorrect understanding of the benefits green roofs provide (Tsang et al., 2011). Installation costs for extensive green roofs are estimated at about $306 per meter squared (Niu et al., 2010). A literature review of 22 studies by Sproul et al. (2014) found that the average first installation cost ranged from $108 - $226 (with a median of $172) per meter squared, while other studies have shown the installation costs are around $306 per meter squared (Niu et al., 2010). These variations can be explained by the different roof characteristics discussed earlier. Differences in installation costs between conventional versus green roofs range from $40.61 to $72 per meter squared (Claus et al., 2012; Wong et al., 2003).

Maintenance costs for green roofs ranged from $0.30 - $2.90 per meter squared per year (using 50 as the average years in a green roof life cycle) (Sproul et al., 2014); however, other findings show that maintenance costs could range from $13 - $21 per meter squared (Niu et al., 2010; Bianchini et al, 2012) again, depending on many roof characteristics. Avoided infrastructure costs range from $39-$100 per meter squared (Bianchini et al, 2012). Construction and maintenance costs were found to be $155.41 per meter squared (Carter & Keeler, 2008).

The life span of a green roof is estimated to be between 40-55 years (Saadatian et al., 2013) compared to a conventional roof, which is 20 years (Evans & Associates, 2008). The longevity benefit from having a green roof over a 40-year period of time is estimated to provide a one-time benefit of $600,000 (Evans & Associates, 2008) or $161.46 per meter squared (Bianchini et al, 2012).

Net public benefits have been found to be highly stable across different scenarios ranging from $32.49-$32.90 per meter squared, depending on the installation costs and number of floors the building has (Claus et al., 2012). The total private benefits are $0.52 per meter squared while the total public benefits are found to be about $9.54 per meter squared (for a 929 meter squared roof; Carter & Keeler, 2008). When considering only a limited set of factors, green roofs may not be cost-effective at the individual building level; however, when considering the full range of benefits at both the private and public levels green roof infrastructure is found to be cost-effective (Rosenzweig et al., 2006).

If subsidies are granted, the net present value (NPV) of green roof investment is estimated to be $12.37 per meter squared of green roof construction costs. Without subsidies granted, the NPV drops to negative $21.57 per meter squared (Claus et al., 2012). Without subsides, private incentives are insufficient to convince investors to install a green roof (Claus et al., 2012).

Probabilistic analysis shows that the most probable private net present value (NPV) is $291 per meter squared, the maximum private NPV is estimated at $3606 per meter squared. The most probabilistic social NPV is $21 per meter squared, while the maximum is $184 per meter squared (Bianchini et al, 2012). When combining private and social values, the most probable NPV is $400 per meter squared, while the maximum is $3802 per meter squared. A study in Washington DC concluded the NPV of storm water infrastructure benefits totaled $1.04 million over the lifetime of a green roof (which was estimated to be 40 yrs.), considering both private and public benefits. The NPV of green roofs are 30-40% less than that of conventional roofs, not including the green roof maintenance costs (Niu et al., 2012). Additionally, the earliest breakeven period for green roofs occurs when the lower bound NPV of green roofs is less than the mean NPV of conventional roofs, which is estimated at 7 years (Niu et al., 2010).

Life cycle cost (LCC), not including energy costs, for a flat roof have been estimated at approximately $226,500 while for an extensive green roof the LCC is approximately $231,905. When considering energy benefits, extensive greens roofs are more cost effective than exposed flat roofs in terms of LCC (Wong et al., 2003). LCC increases to $632,948 for a flat roof and $579,121 for an extensive green roof when factoring in energy benefits. At around year 10, the LCC of a conventional flat roof exceeds that of an extensive green roof. When considering both private and social benefits, payback period probabilistic analysis shows that the most probable payback period is 4.2 years with a maximum of 10 years (Bianchini et al, 2012). Cost benefit analysis show that the breakeven period of a green roof is 7 years (Niu et al., 2012).

Prior research has been done to try and evaluate the trade-offs between water quality improvements and the economic costs and resources of implementing green infrastructures. One particular example is a consequential life cycle assessment (LCA) in 2013 completed by Raran Wang, Matthew J. Eckelman and Julie B. Zimmerman where the incremental climate, resource and economic costs of implementing green versus gray infrastructures was thoroughly evaluated. The authors identify a gap in the previous literature; few studies have looked at the environmental trade-offs in the life cycle of gray and green infrastructure between water quality gains and incremental energy and material cost for green and/or gray infrastructure expansion in an attempt to reduce combined sewer overflows. The goal of their research is the help close this gap by looking at the marginal economic and environmental costs and benefits of expanding stormwater infrastructure under various patterns while also considering forecasted climate change effects in rainfall.

The LCA allows for a comparison of different trade-offs and quantifies the environmental benefits and impacts in order to choose the most appropriate stormwater management system. Their paper compares 3 potential infrastructure expansion options: (1) one of the three green infrastructures: bioretention basin, green roof or permeable pavement; (2) a gray infrastructure solution that directly discharges stormwater runoff to receiving water bodies (MS4) and (3) a combination of one of the green infrastructures with MS4. These options resulted in a total of 7 alternatives that were modeled and compared to a baseline combined sewer system with combined sewer overflows in a typical Northeast US watershed for typical dry and wet years. Six midpoint indicators were used to compare the environmental impacts of the base case and the stormwater management alternatives under different precipitation scenarios: climate change, freshwater eutrophication, marine eutrophication, freshwater eco-toxicity, marine eco-toxicity, and fossil fuel depletion.

The main results show that all 7 alternatives generate additional greenhouse gas emissions (compared to the base case) since they all require some additional infrastructure; however, there are large differences between these alternatives in potential climate change impacts. The bioretention basin yields the lowest greenhouse gas emissions and the permeable pavement yields the highest. All of the alternatives also result in a considerable reduction in freshwater eutrophication compared to the base case. The highest eutrophication reduction (greatest water quality improvement) is achieved with the integration of green and gray systems (regardless of the type of green system that is paired with the MS4). Implementation of green infrastructure can significantly improve water quality by reducing eutrophication impacts by more than 40%. Additional cost benefit analyses show that bioretention basins were the most financially cost-effective solution and demonstrated the smallest climate footprint. MS4 was the most effective at eutrophication reduction for the smallest resource depletion. All alternatives result in reduction of phosphorus. These results contribute to the extensive literature on costs and benefit of green roofs.

III. Data & Methods

The Milwaukee MSA provides a unique location for green roof implementation. The watershed has significant water quality impairments due to nonpoint urban runoff and combined sewer overflows. In addition, it experiences air quality health warnings an average of 10 days per year. Biodiversity and green space within the downtown portion of the MSA and across the sewer shed are limited. Lastly, there exists significant potential for green roof implementation in the downtown MSA. These factors combine to meet many of the conditions which would make green roof implementation on a widespread scale attractive as an alternative to additional grey infrastructure investment in order to combat the area's water quality problems.

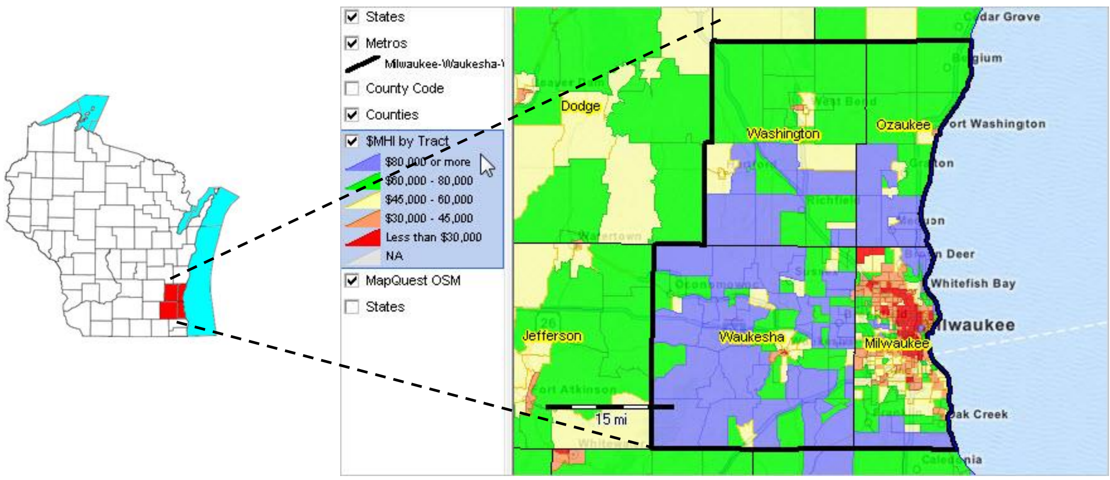


Figure 1: State of Wisconsin & Milwaukee MSA

To establish public preferences regarding any publically supported green roof program, a stated preference survey with mail and internet samples was designed and administered to Milwaukee MSA residents in 2016. The Milwaukee MSA is 241.10 square miles in size and contains a population of 951,448 individuals in 381,715 households.

For the mail component, 7,000 residents within the MSA were randomly selected who were older than 18. An initial mailer describing the study, indicating selection into the sample and asking for participation was sent with an instruction to look for the survey itself to arrive in 1 week. The survey was then sent to each resident in the sample, with a follow up reminder card sent two weeks later. After another two weeks, a reminder card was sent to each resident. The list accuracy was approximately 90% with around 700 surveys returned undeliverable (~6300 viable addresses). This generated a sample of 511 responses out of the 6,300 viable addresses, yielding an effective response rate of 8.11%.

The internet component was also done in collaboration with Survey Sampling International (SSI). They provided a sample of respondents drawn from their internet panel who lived in the Milwaukee MSA and met the study requirements. For the internet survey design, the survey was coded into Qualtrics Survey Software and distributed to a panel of respondents via SSI who tracked progress participation and incentivized completion. An additional 542 responses were obtained through the Internet survey sample from 643 individuals asked to participate (84.3%). Ultimately, this yielded 1053 usable responses (15.93% response rate) from residents located within the Milwaukee MSA boundary.

Combined internet and mail survey samples, as well as population statistics are presented in Table 1. In Milwaukee population, 51.7% of individuals are female, with a mean age of 34.2 years. Of the population, 86.5% have completed a high school education or higher, with 29.1% having completed a bachelor's degree or higher. The median income is $43,873. 61.5% of the population is white and 49.9% are homeowners.

In the mail-based sample, 42% of the respondents are female, with a median age of 65 years. Of the respondents, 98% have completed a high school education or higher, with 57% having completed a bachelor's degree or higher. The median household income is $70,000. 90.6% of respondents are white and 83% are homeowners. The mail survey sample is older and wealthier, as well as more educated, male, white and likely to own their home than Milwaukee area population averages.

In the internet-based sample, 68% of respondents are female, with a median age of 40.8 years. Of the respondents, 99% have completed a high school education or higher, with 41% having completed a bachelor's degree or higher. The median household income is $63,797. 84.9% of respondents are white and 58.5% are homeowners. The internet survey sample is a better reflection of Milwaukee population averages in regards to the most important socio-demographic characteristics however both samples are significantly different from the population in regards to many characteristics.

Table 1: Socio-demographic Characteristics

Variable	Sample Mean (Mail)	Sample Mean (Internet)	Sample Mean (Combined)	Population Mean
Age				
(Median)	65***	40.8***	49.6***	34.2
Income				
(Household)	$81,293***	$63,797***	$71,980***	$43,873
Gender				
(Female)	42%***	68%***	55%**	51.7%
Race				
(White)	90.6%***	84.9%***	87%***	65.1%
(Indian)	1.5%	0.9%	1.2%	1.0%
(Black)	4.8%***	7.7%***	6%***	27.1%
(Asian)	1.5%***	2.6%**	2.03%***	4.2%
(Hawaiian)	0.0%*	0.6%	0.3%	<0.5%
(Latino)	2.3%***	3.2%***	2.7%***	14.5%
Education				
(HS<)	98%***	99%***	98.5%***	86.5%
(BS<)	57%***	41%***	49%***	29.1%
Homeowner	83%***	58.5%***	70%***	49.9%

a.) T-tests indicate significantly different from the population at the 90% level (*), 95% level (**), and 99% level (***).

In order to get the survey respondents to begin thinking about green roof infrastructure and to gauge their experience regarding water related topics, they were asked several “lead in” questions. Of the combined internet and mail sample, only 4.5% of respondents live in a flood plain; but 23.5% of respondents had experienced issues with flooding at their residence in the last 5 years. 36% had knowledge of green infrastructure prior to taking the survey and 86% thought use of green infrastructure was very or somewhat important for helping with issues of water management. 27% of respondents believed combined sewer overflows are currently the greatest threat to local water quality, while 39.8% thought the greatest threat was polluted stormwater runoff. 87.6% of respondents believe everyone has a role to play in maintaining or improving water quality, while 4% believe it is the government’s responsibility and 2.4% believe they have no impact. Mean and median water/sewer payments are $57.84 and $100.00 per month respectively.

To ascertain residents’ preferences over the public benefits generated by green roof installations as well as willingness to support public investment, a conjoint choice experiment was administered as part of the survey. A series of choice scenarios were designed to estimate trade-offs between the attributes describing different green roofs and the public benefits that would be generated from their installation. In order to obtain the benefits presented, these roofs would need to be installed on a sufficient surface area of roofs (estimated at 30%) of the Milwaukee MSA (focused in the urban downtown) and would result in increased water/sewer fees. A “choice scenario” consists of three possible alternatives: two of which represent different potential green roofs (or water retention programs) and a third “opt-out” alternative for simply maintaining the current, status quo outcomes associated with bare roofs. The alternatives are defined over six attributes: water retention, air quality, urban heat island impact, biodiversity, water quality and payment.

The first attribute, water retention, takes on 4 levels: 4%, 73%, 95% and 99%. These levels were chosen to correspond to actual bar and green roof water retention levels. A standard (bare) roof is described as being made of shingles, tile, concrete or steel and captures virtually no water when it rains. Water is discharged directly to the sewer system which can overburden sewers when it rains causing sewer overflows, erosion, property damage and the release of pollutants into nearby lakes and rivers. Different green roofs are described as having different water retention abilities based on their components. For example, green roof is described as being made of plants, soil, and a water storage layer, where 73% of water falling on the roof is captured when it rains and water is released over a few hours to the sewer system. This process helps to relieve the burden on sewer system by extending the time over which water enters the system. Most water is captured and stored in the soil, with only a small amount of water kept in the storage layer. Another green roof on-the-other-hand is made of plants, soil, and a larger water storage layer, where 95% of water falling on the roof is captured when it rains and water is slowly released at a controlled rate to sewers; this extends release time from a few hours to a few days, reducing volume of water to sewers during rain events. Some water is permanently captured in the storage layer to irrigate the plants above for longer periods of time. Lastly, a different green roof is described as being made of plants, soil, a large water storage layer and a computer control mechanism for water release, where 99% of water falling on the roof is captured when it rains and this roof uses weather predictions to decide when to release water. When rain is predicted, the roof releases water from its storage layer before it rains to maximize storage for upcoming rain. Virtually no water is sent to the sewer system when it rains. All captured water is stored and used to irrigate the plants.

The second attribute, water quality also takes on 4 values: lowest, lower, higher, and highest quality. The lowest water quality level is described as having water which is very murky and where algae have spread . In addition, no fish are present or can survive and few birds live in this habitat. Importantly, the water isn't safe for swimming, fishing, boating or pets and water contact can be hazardous to human and animal health. Lower water quality levels contain water which is murky and slightly green, with some algae; no game fish (like trout) are present, and a few coarse fish (which are not suitable for eating) are present. The water does provide a habitat for common, local birds. The water is not safe for swimming, but is safe for fishing, boating and pets. Higher water quality levels contain water which is less clear, but no algae is present. Few game fish are present, but coarse fish are abundant. The water provides a habitat for common, local birds and is safe for boating, fishing, swimming and pets. The highest level of water quality has water which is clear with healthy plants and no algae. Game fish are present and few coarse fish are present. The water provides a habitat for common, local birds and is again safe for boating, fishing, swimming and pets.

The third attribute is air quality which takes on 4 levels. Green roofs could eliminate unhealthy air quality days by reducing pollution through absorption by plants.

Fewer unhealthy air quality days reduce health risks associated with air pollution. This attribute describes green roofs as being able to reduce the number of days with air quality classified as “Unhealthy for Sensitive Groups” by an average of no days, 1 day, 2 days, or 3 days per year.

The fourth attribute presented is average ambient air temperature reductions and is defined over 4 levels. Green roofs reflect heat away from the surface, which could reduce urban temperatures and impact the urban heat island effect as well. This lowers health risks and energy use, as well as improves the general standard of living in urban areas by making outdoor activities more enjoyable. This attributes describes green roofs as being able to reduce average ambient air temperature in the Milwaukee area by 2°, 4° or 6° Fahrenheit (F).

The fifth attribute relates to biodiversity and aesthetics takes on 2 levels. Green roofs could improve biodiversity and aesthetics by restoring habitat for birds and other species and adding visible green space. Residents may benefit psychologically as studies have found that more green space corresponds to lower levels of depression, anxiety, and stress. Views of green space relieve stress, which may reduce the number of poor mental health days.

Lastly, the payment attribute is defined over 8 levels. Respondents are informed an increase in water/sewer fees would be necessary to install, operate, support and/or maintain green roofs in order to receive the benefits. Depending on the program, the increase in their monthly payment could be $1.00, $1.50, $2.00, $2.50, $5.00, $7.50 or $10.00. These amounts would correspond to an annual increase in water/sewer fees of

$12.00, $18.00, $24.00, $30.00, $60.00, $90.00 or $120.00 respectively. These payment attribute levels were determined from previous research and percentage change in average water payment.

The possible levels these attributes can take on are summarized in Table 2. Each respondent examined the alternatives they were presented and was asked to then choose his or her most preferred alternative, given the attribute levels received and payment required under each. The status quo alternative fits the current profile for these variables in the Milwaukee MSA: low to no water retention, no change in number of unhealthy air days, no change in average ambient air temperature, no change in habitat or visible greenery, lowest water quality rating (red), with no resulting change in water/sewer payment.

Table 2: Choice Experiment Attributes and Levels

Attribute	**Levels**
Roof Type & Water Retention	99% water retention 95% water retention 73% water retention 4% water retention
Air Quality	3 Day reduction in unhealthy air days/year 2 Day reduction in unhealthy air days/year 1 Day reduction in unhealthy air days/year No Change in number of unhealthy air days
Temperature (Urban Heat Island)	6°F reduction in average ambient air temp. 4°F reduction in average ambient air temp. 2°F reduction in average ambient air temp. No Change in average ambient air temp.
Biodiversity	Restores habitat & provides visible greenery No change in habitat or visible greenery
Water	Highest Quality (Blue) Higher Quality (Green) Lower Quality (Yellow) Lowest Quality (Red)

Payment	\$0.00, \$12.00, \$18.00, \$24.00, \$30.00, \$60.00, \$90.00 or \$120.00 per year

The conjoint choice experiment was conducted to elicit residents' relative preferences regarding these different attributes which make-up the change in public benefits associated with green roof implementation. By observing residents' choices among the alternatives, the preference relationship regarding each attribute can be established. In an ideal setting, each respondent would face all possible choices between alternatives described by the attributes in Table 2. Unfortunately, a 4x4x4x4x2x8 experimental design would result in 4,096 possible combinations of attributes to describe all of the different possible green roof programs. A survey representing all possible combinations is practically impossible to administer and presents a cognitively difficult task for respondents. The well-established experimental design literature was used to simplify the experiment, without loss of information. The experimental design relates the designated attributes and their different levels using a systematic and planned process through which the attributes and their levels are pre-defined without measurement error and then varied to create choice alternatives (Louvierre, Hensher, & Swait, 2000). Each resulting choice alternative represents a different potential green roof program.

A C-optimal design was constructed using the Ngene software to maximize recovery of willingness-to-pay estimates (DeShazo and Fermo, 2006). C-optimality results in a set of choices for residents that would be dissimilar enough, and non-overlapping, so respondents could more easily decide which program they would prefer. Some trade-offs were made between orthogonality and statistical efficiency in order to maximize the information obtained in each choice scenario and prevent duplicate or dominated alternatives from occurring. Inclusion of a “baseline” scenario is another necessary trade-off which allows individuals to have an “opt-out” or “no-change” option within the choice set. This is important in maintaining unbiased parameter estimates (Johnson, Kanninen, Bingham, & Ozdemir, 2007).

The experimental design results in 24 choice scenarios, which is still too large to reasonably expect any single individual resident to be able to complete consistently. As such, the design was divided into 6 blocks with each block containing 4 of the choice scenarios. Each respondent was then presented with 1 of the 6 blocks containing that block’s 4 selected choice scenarios from the 24 available. This was a reasonable number of choice scenarios for a single individual to complete based on the survey and experimental design literatures and still allow for population level parameters to be estimated (DeShazo & Fermo, 2002; Kuhfeld, 2009). An example choice question format is seen in Figure 2.

DIRECTIONS

In the scenario below, you are asked to consider different green roof programs. Your task is to decide whether you prefer Program A, Program B, or neither, and to place an "X" in the box for your preferred option.

Scenario 10

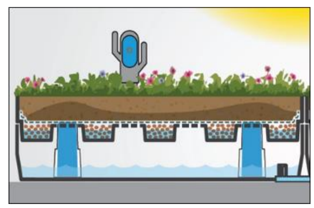
Program Features	**Program A**	**Program B**	**Status Quo**
Roof Type	 Green Roof A	 Green Roof C	 Bare Roof
Water Capture	73%	99%	4%
Air Quality	2 Day Reduction in Unhealthy Air Days	1 Day Reduction in Unhealthy Air Days	No Reduction in Unhealthy Air Days
Temperature	6°F Reduction	2°F Reduction	0°F Reduction
Biodiversity / Aesthetics	No Change	Restored Habitat Visible Green Space	No Change
Water Quality	Lower Quality 	Higher Quality 	Lowest Quality 
Water / Sewer Fee Change	Increase $30/year *($2.5/month)*	Increase $60/year *($5/month)*	No Change $0/year *($0/month)*
I would choose:	Program A: ☐	Program B: ☐	Neither Program: ☐

Figure 2: Conjoint Choice Analysis Question format

Theoretical and Statistical Framework

Residents' responses to the questions in the choice experiment yield the preference structure for the attributes. The choice between alternatives was assumed to be driven by respondents' underlying utility. The utility function has two components (deterministic $\overline{V}(x_{ij}, \beta)$ and stochastic ε_{ij}) and is therefore embedded in a standard random-utility framework (Louvierre, Hensher, & Swait, 2000; Train, 2009) denoted by (1),

$$U_{ij} = \overline{V}(x_{ij}, \beta) + \varepsilon_{ij} \quad (1)$$

where subscript *i* denotes the individual, subscript *j* denotes the alternative, *x* is the vector of attributes that vary across alternatives and ε_{ij} is a stochastic error term capturing individual and alternative specific factors influencing utility unobservable by the researcher. The model is further formalized by assuming the deterministic portion of utility can be approximated as a linear function of attributes, is additive over individuals, and can be represented by (2),

$$U_{ij} = \beta_0 + x_{ij}\beta_1 + (M_i + p_{ij})\beta_M + \varepsilon_{ij} \quad (2)$$

Where M_i is individual i's income and p_{ij} is the payment faced by respondent i under alternative profile j. The coefficient on residual income, β_M, is the marginal utility of income. The marginal price for a specific attribute is derived solely with respect to a change in that attribute. After estimating the common utility function, marginal price for attribute *l* is obtained by normalizing the marginal utility estimate of attribute *l* by the negative inverse of the marginal utility of income to yield,

$$MP_l = -\frac{\hat{\beta}_l}{\hat{\beta}_M} \quad (3)$$

where MP_l represents marginal price of attribute *l*, $\hat{\beta}_l$, is the estimated coefficient on attribute *l*, and $\hat{\beta}_M$, is the estimated marginal utility of income.

The probability, P_{ij}, of a respondent, *i*, choosing an alternative, *j*, is given by $U_{ij} > U_{ik}$ and can be denoted as,

$$P_{ij} = \Pr(V_{ij} + \varepsilon_{ij} > V_{ik} + \varepsilon_{ik}) = \Pr(\varepsilon_{ij} - \varepsilon_{ik} > V_{ik} - V_{ij}) \quad (4)$$

Statistical analysis of the choice experiment proceeds by estimating the utility difference model using the conditional and random parameters logit estimators. The random parameter logit model assumes stochastic variation in the preference structure (whereas the conditional does not), so that each individual, *i*, has a unique β_i for one, some, or all of the attributes and these parameters are distributed in accordance with certain conditions in the population. When the generalized extreme value distribution is assumed to be the probability distribution of the error term, and f(β|θ) is the density function for a given distribution of β with parameter θ (i.e. means and distributions) the choice probability can be expressed as,

$$P_{ij} = \int \frac{\exp V_{ij}}{\sum \exp V_{ik}} (\beta)\, f(\beta|\theta)\, d\beta \quad (5)$$

A continuous distribution, such as the normal, is assumed for f(β). The selection probability becomes P^* using simulated maximum likelihood procedures. R represents the number of draws with β^r representing the r^{th} draw from the density function. This results in a simulated probability of,

$$P^{*}_{ij} = \frac{1}{R}\sum_{r} P_{ij}(\beta^{r}) \tag{6}$$

which is used to estimate the simulated log likelihood function (LL^*) and the parameter θ which defines the distribution that maximizes this function. Given d_{ij} is a dummy variable representing respondents' choices and is set to 1 when alternative *j* is chosen, the simulated log likelihood is estimated as,

$$LL^{*} = \sum_{i}\sum_{j} d_{ij} \ln(P^{*}_{ij}) \tag{7}$$

The distribution function which quantifies the variability in preferences found between respondents can be derived from these calculations (Train, 2009). Since the random parameters logit does not guarantee global concavity, multiple starting values were evaluated to determine whether the final estimated coefficients were true maximums.

IV. Results

Given each of the 1053 respondents faced 4 choice scenarios, a maximum of 4,212 possible choice scenarios can be recovered. After cleaning the data and eliminating scenarios where a respondent failed to make a choice, 3,753 complete choice scenarios comparing 11,259 alternatives remain.

The conjoint choice experiment results shown in Table 3 and Table 4 give important insight into which attributes are relevant to residents' decision-making regarding green roofs and their associated public benefits. All of the variables have well-defined expectations regarding sign. Respondents are expected to prefer higher levels of water capture to lower (indicating an expected positive sign on water retention). Respondents are expected to prefer greater reductions in poor air days or alternatively higher levels of air quality (indicating an expected positive sign on air quality). Respondents are expected to prefer greater reductions in ambient air temperature or alternatively less urban heat island effect (indicating an expected positive sign on temperature). Respondents are expected to prefer more biodiversity and visible greenery to less (indicating an expected positive sign on biodiversity). Respondents are expected to prefer higher levels of water quality (indicating an expected positive sign on water quality). Lastly, respondents are expected to prefer lower payment levels (indicating an expected negative sign on payment).

The results of 4 conditional logit estimators are presented in Table 3 below. Well known limitations to conditional logit estimators (such as the IIA property) often necessitate the use of more flexible models. These include the random parameters logit, which relaxes restrictions on the error term imposed by the conditional logit. Results of the random parameters model are presented in 4 specifications in Table 4 below.

Results across all model specifications and data sets generally conform to these expectations – with one significant exception. Improvements in water quality and biodiversity are uniformly positive, and statistically significant at the 99% level regardless of model specification. These results indicate residents have strong preferences for improvements in water quality in the region, as well as improvements in biodiversity and green space. Air quality is also positive and statistically significant across many of the model specifications (although it is insignificant in some as well). Temperature is positive and statistically significant in a couple of the models that consider only the mail-based survey results, but otherwise it is statistically insignificant. These results provide evidence that residents prefer improvements in all of these categories of public benefits, but improvements to biodiversity and water quality seem to be more important to residents followed by improvements in air quality; little evidence is found to support Milwaukee MSA residents are much concerned regarding urban heat island effects. Payment is negative and statistically significant across all specifications, indicating residents prefer lower payment levels.

Table 3: Conditional Logit Estimates

Variables	Model 1 Estimate (Standard Error)			Model 2 Estimate (Standard Error)			Model 3 Estimate (Standard Error)			Model 4 Estimate (Standard Error)		
	a	b	c	a	b	c	a	b	c	a	b	c
Water Retention	-0.006***	0.008***	0.002**				-0.007***	0.008***	0.001***			
(base:4%)	(0.001)	(0.001)	(0.001)				(0.001)	(0.001)	(0.001)			
73%				-0.447***	0.0594***	0.132				-0.561***	0.636***	0.111
				(0.153)	(0.153)	(0.010)				(0.173)	(0.151)	(0.112)
95%				-0.536***	0.933***	0.272***				-0.674***	0.954***	0.226*
				(0.154)	(0.154)	(0.098)				(0.180)	(0.157)	(0.117)
99%				-0.614***	0.763***	0.150*				-0.729***	0.764***	0.105
				(0.139)	(0.139)	(0.088)				(0.153)	(0.128)	(0.096)
Air Quality	0.064**	0.075***	0.064***	0.062*	0.060**	0.056**	0.049	0.064**	0.051**	0.053	0.043	0.041*
(base: no change)	(0.030)	(0.026)	(0.020)	(0.033)	(0.029)	(0.022)	(0.031)	-0.027	(0.020)	(0.035)	(0.030)	(0.023)
Temperature	0.013	0.002	0.004	0.011	-0.007	-0.001	0.006	-0.003	-0.002	0.006	-0.010	-0.005
(base: no change)	(0.015)	(0.014)	(0.010)	(0.016)	(0.015)	(0.011)	(0.016)	(0.014)	(0.010)	(0.016)	(0.015)	(0.011)
Biodiversity	0.577***	0.026***	0.384***	0.581***	0.026***	0.385***	0.552***	0.229***	0.355***	0.562***	0.203***	0.344***
(base: no change)	(0.060)	(0.050)	(0.038)	(0.064)	(0.054)	(0.041)	(0.065)	(0.061)	(0.042)	(0.072)	(0.061)	(0.046)
Water Quality	0.424***	0.301***	0.345***	0.423***	0.290***	0.339***						
(base: lowest quality)	(0.031)	(0.026)	(0.020)	(0.032)	(0.027)	(0.021)						
Lower Quality							0.723***	0.468***	0.561***	0.731***	0.354***	0.505***
							(0.120)	(0.116)	(0.077)	(0.133)	(0.116)	(0.086)
Higher Quality							1.157***	0.832***	0.959***	1.162***	0.810***	0.950***
							(0.123)	(0.113)	(0.082)	(0.124)	(0.113)	(0.083)
Highest Quality							1.293***	0.891***	1.031***	1.303***	0.823***	0.997***
							(0.098)	(0.089)	(0.062)	(0.108)	(0.089)	(0.068)
Payment	-0.006***	-0.009***	-0.007***	-0.006***	-0.009***	-0.007***	-0.006***	-0.009***	-0.008***	-0.006***	-0.009***	-0.008***
(base: $0)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
N	5214	6045	11259	5214	6045	11259	5214	6045	11259	5214	6045	11259
Likelihood Ratio Test	333.7***	480.46***	701.58***	334***	485.8***	705.5***	344***	486.1***	717.08***	344.24***	491.59***	717.08***
McFadden's Pseudo R^2	0.0874	0.1085	0.0851	0.0875	0.1097	0.0865	0.0901	0.1098	0.087	0.09	0.111	0.087
Log-Likelihood	-1742.5404	-1973.47	-3773.3	-1742.39	-1970.81	-3770.34	-1737.39	-1970.66	-3764.55	-1737.27	-1967.91	-3764.55

a. Mail-based results are indicated in columns labeled "a", internet-based results in columns labeled "b" and combined sample results labeled "c".
b. Alternative specific constant on the status quo was tested and was not significant.
c. Coefficients are the marginal effects with Standard Errors in parentheses below.
d. Significant at the 90% level (*), 95% level (**), and 99% level (***).

Table 4: Random Parameters Logit Estimates

Variables	Model 5 Estimate (Standard Error)			Model 6 Estimate (Standard Error)			Model 7 Estimate (Standard Error)			Model 8 Estimate (Standard Error)		
	a	b	c	a	b	c	a	b	c	a	b	c
Water Retention	-0.003^{C}	0.008***^{C}	0.004**^{C}	-0.004^{C}	0.010***^{C}	0.003*^{C}	-0.005*^{C}	0.018***^{C}	0.004***^{C}			
(base:4%)	(0.002)	(0.001)	(0.002)	(0.002)	(0.003)	(0.002)	(0.003)	(0.007)	(0.002)			
73%										-0.592***	0.699***	0.086
										(0.192)	(0.183)	(0.125)
95%										-0.725***	1.020***	0.174
										(0.217)	(0.198)	(0.135)
99%										-0.764***	0.849***	0.075
										(0.176)	(0.162)	(0.109)
Air Quality	0.150***	0.075***	0.092***	0.153**^{C}	0.056^{C}	0.078**^{C}	0.181*^{C}	0.074^{C}	0.107***^{C}	0.056^{C}	0.034^{C}	0.040^{C}
(base: no change)	(0.053)	(0.027)	(0.030)	(0.060)	(0.040)	(0.032)	(0.095)	(0.062)	(0.037)	(0.038)	(0.038)	(0.026)
Temperature	0.048**	0.002	0.016	0.044*^{C}	0.003^{C}	0.013^{C}	0.041^{C}	-0.011^{C}	0.015^{C}	0.004^{C}	-0.020^{C}	-0.011^{C}
(base: no change)	(0.024)	(0.014)	(0.014)	(0.026)	(0.020)	(0.015)	(0.039)	(0.032)	(0.018)	(0.018)	(0.021)	(0.013)
Biodiversity	0.695***	0.257***	0.417***	0.737***	0.253***	0.415***	0.805***^{C}	0.234*^{C}	0.436***^{C}	0.564***^{C}	0.187**^{C}	0.340***^{C}
(base: no change)	(0.082)	(0.050)	(0.047)	(0.119)	(0.074)	(0.059)	(0.185)	(0.125)	(0.066)	(0.078)	(0.082)	(0.055)
Water Quality	0.527***	0.301***	0.376***				0.660***^{C}	0.629***^{C}	0.457***^{C}			
(base: lowest quality)	(0.057)	(0.026)	(0.032)				(0.177)	(0.193)	(0.060)			
Lower Quality				1.028***	0.546***	0.665***				0.778***	0.511***	0.608***
				(0.197)	(0.135)	(0.106)				(0.171)	(0.156)	(0.115)
Higher Quality				1.566***	0.919***	1.083***				1.212***	1.003***	1.065***
				(0.238)	(0.151)	(0.121)				(0.166)	(0.170)	(0.117)
Highest Quality				1.747***	1.022***	1.194***				1.369***	1.040***	1.134***
				(0.238)	(0.168)	(0.125)				(0.181)	(0.151)	(0.115)
Payment	-0.010***	-0.009***	-0.009***	-0.011***	-0.010***	-0.009***	-0.011***	-0.017***	-0.010***	-0.006***	-0.011***	-0.008***
(base: $0)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)	(0.002)	(0.004)	(0.005)	(0.002)	(0.001)	(0.002)	(0.001)
N	5214	6045	11259	5214	6045	11259	5214	6045	11259	5214	6045	11259
Likelihood Ratio Test	6.28**	0.02	1.43	9.27**	5.82	2.47	10.47*	11.74**	6.77	0.41	4.99	3.16
McFadden's Pseudo R2												
Log-Likelihood	-1739.398	-1973.46	-3771.589	-1732.753	-1967.746	-3763.319	-1737.304	-1967.61	-3768.921	-1737.061	-1965.415	-3761.376

a. Mail-based results are indicated in columns labeled "a", internet-based results in columns labeled "b" and combined sample results labeled "c".
b. Alternative specific constant on the status quo was tested and was not significant;
c. Coefficients are the marginal effects with Standard Errors in parentheses below.
d. Significant at the 90% level (*), 95% level (**), and 99% level (***).
e. "^{C}" Indicates variable was specified as a random parameter.

The most interesting result comes in the water retention estimates. With the mail-based survey results, the coefficients were found to be negative and statistically significant. Given that the base value for the variable is 4% and is linked with a bare roof and each subsequent value is a green roof type with specified amounts of water capture, this indicates that these residents dislike green roofs themselves (*ceteris paribus)*. The respondents have strong, positive preferences for the public benefits green roofs generate, but dislike the roofing medium itself. This appears to be related to the fact that these respondents were thinking primarily in terms of installation and maintenance of green roofs *on their own homes*. A significant number of mail survey respondents commented at the end of the survey that they didn't believe these roof types could be installed on their own sloped roof. They were also concerned about maintenance and upkeep if a green roof were installed on their home. Other concerns, which were repeated were that residential homes would need to be retrofitted to support the weight and there were concerns about green roofs resulting in water leakage and mold buildup into homes. This is an interesting and important result. Respondents like the public benefits generated by green roofs and appear broadly willing to support and pay for those benefits, but green roof installation and implementation would need to be done on public or private flat roof buildings. This was explained as part of the choice exercise, but it appears it was not well emphasized enough.

Considering the internet survey data as well as the combined data most model specifications show roof type is positive and statistically significant. This suggests that residents do prefer green roofs. It seems that the internet-based sample had a better focus on public program element compared to the mail-based sample. The remainder of the results will be discussed in terms of the combined mail and internet sample as it provides the largest sample size.

Considering all models, model 6 is the preferred to the alternatives because it models the preferences for changes in water quality in a non-linear way. For example, the value of moving from lowest to lower quality is different than the value of moving from lowest to higher quality. Additionally, the value of moving from lower quality to higher quality, or higher quality to highest quality, is also different. Utilizing a single parameter causes the effect to be averaged so moving from lowest quality to lower quality to higher quality to highest quality has the same value. Model 6 results show that moving from lowest to lower or higher quality has a much higher value compared to moving from higher to highest quality (where both qualities are essentially good). These results are expected, individuals are willing to pay a larger amount to move from lowest to lower or higher quality, but aren't willing to pay as much for a smaller improvement of moving from higher to highest quality.

To establish the willingness-to- pay (WTP) for residents to choose a green roof program over the status quo, the indirect utility function described in (2) is calculated for different potential programs and then equated to the indirect utility associated with the status quo option of no program (with attribute values denoted as x_0) and solved for WTP in (8)

$$x_j\hat{\beta} + (M - WTP_j)\hat{\beta}_M = x_0\hat{\beta}_l + (M)\hat{\beta}_M \qquad (8)$$

Here, x_j represents the vector of attribute values describing the listed green roof programs, $\hat{\beta}_l$ is the vector of estimated attribute parameters, and $\hat{\beta}_M$ is the estimated marginal utility of income. Solving for WTP_j yields (9), where Δx is the difference between the proposed green roof program and status-quo attribute levels.

$$WTP_j = \frac{(\Delta x)\hat{\beta}_l}{\hat{\beta}_M} \tag{9}$$

The WTP in dollars for implementation of particular programs are listed in Table 5 using the parameter estimates from the preferred model, Model 6 in Table 4. These values indicate the average resident's WTP, in dollars, to support implementation of the indicated water retention program when it results in the stated benefits. WTP for each green roof type (relative to the status quo) is explored. Each green roof type results in different levels of improvement in the public benefits attributes because of its underlying properties as described earlier in the paper. Each water retention column in Table 5 below indicates one program. Average WTP per person per year as well as average population benefits are also included in Table 5.

Table 5: Willingness-To-Pay

			Water Retention		
Attribute	**Est. Parameter**	**Marginal Price ($)**	**Advanced**	**Expanded**	**Traditional**
Water Retention	0.003	0.333	95%	91%	75%
Air Quality	0.078	8.667	3 day reduction	2 day reduction	1 day reduction
Temperature	0.000	0.000	6 degree	4 degree	2 degree
Biodiversity	0.415	46.111	Improved	Improved	Improved
Water Quality					
:lower	0.665	73.889			Lower quality

:higher	1.083	120.333		Higher quality	
:highest	1.194	132.667	Highest Quality		
Payment	-0.009				
		Ave.WTP/Per Person/Per Year:	**$236.44**	**$214.11**	**$153.67**
		Population (951,448) = Total Benefits:	**$224,964,593.78**	**$203,715,588.44**	**$146,205,842.67**

The marginal price of water retention is estimated at $0.33 indicating that Milwaukee residents value each additional percentage point of water retention increase beyond the status quo (4% retention) at $0.33. The marginal price of air quality is estimated at $8.67 for every additional day of improved air quality per year, beyond the status quo (no change in air quality days). Since the coefficient on temperature was insignificant the marginal price is estimated at $0.00, we find no evidence that Milwaukee residents find value in having reduction in the urban heat island effect (*ceteris paribus)*. The marginal price of biodiversity is estimated at $46.11, which is the value that Milwaukee residents place on having an increase in biodiversity (versus no increase, the status quo). Marginal price of increasing from the status quo (lowest) quality of water to the lower quality of water is valued at $73.89; increases from the status quo to higher quality of water is $120.33; and increases from the status quo to highest quality of water is valued at $132.67. These results show us that individuals do have a higher willingness to pay for bigger improvements in water quality, which reinforces that the results are reliable and respondents answered survey questions rationally.

Considering all of these public benefits, the average willingness to pay per person per year for the advanced water retention program is $236.44 with a total population benefit of $224,964,593.78 per year. For the expanded water retention program the average WTP per person per year is $214.11, which equates to a total population benefit per year of $203,715,588.44. Lastly, the average WTP per person per year for the traditional water retention program is $153.67 with a total population benefit estimated at $146,205,842.67. The total population benefits are calculated by multiplying the WTP per person per year by the total population of 951,448 residents. These WTP estimates are gross benefits if the Milwaukee MSA were able to achieve the public benefits considered. The limitation to this is that these are gross benefits, not net benefits, so in order to determine if this is feasible what would need to be done is compare these gross benefits to the public cost of implementation of these water retention programs in the Milwaukee MSA.

The weighted average water and sewer bill in combined sampled data set is $57.97 per month. To calculate WTP per person per month these yearly WTP calculations were divided by 12. This allows for calculation of the percentage increase that Milwaukee MSA residents are willing to pay per person per month in their water and sewer bills. This results in a 33.99% increase for the advanced water retention program, a 30.78% increase for the expanded water retention program, and a 22.09% increase for the traditional green roof program.

VI. Conclusion

This article provides empirical estimates of several of the most important public benefits associated with green roof implementation. Specifically examined here are the potential gains in water capture available with green roofs. The increase in water capture may make green roofs a more attractive low impact development option to replace grey infrastructure. Results provide evidence that Milwaukee MSA residents prefer improvements in all of these categories of public benefits, but improvements to biodiversity and water quality seem to be more important to residents followed by improvements in air quality; little evidence is found to support residents are concerned about urban heat island effects. Results for water retention were inconsistent amongst the mail-based and internet based residents, likely due to a difference in focus on public program elements between the two samples. The WTP estimates arrived at can provide useful policy information to municipal governments and the water utility in setting subsidies for installation and/or constructing a program to embark on public installation and maintenance of green roofs in the urban downtown.

Within the green roof literature authors suggest that a policy focused on information dissemination and technical assistance may be more cost-effective than a direct subsidy payment (Mullen & Colson, 2013). Optimal policy may require new commercial developments to manage a minimum amount of rainfall for storms. Additionally, optimal policy may require private stormwater management by taxing stormwater runoff at a price equal to the marginal external cost (MEC) associated with the runoff (Ando & Netusil, 2013). This could encourage landowners to install their own low impact development options to help manage runoff and reduce their total fee. Many cities do have similar stormwater fees but they are too low to result in any socially optimal stormwater control solution (Ando & Netusil, 2013). Another cost effective policy could be a tradable system of runoff permits where landowners would be given permits to ensure their properties would not produce more stormwater runoff than the permit allows. This may encourage landowners to reduce their runoff more than necessary in order to sell the extra permits to other landowners who may struggle with higher cost runoff solutions. In this tradable system the MEC would need to be equal to the marginal cost for a landowner to reduce the stormwater (Ando & Netusil, 2013).

Around the country many different types of policies are being used to try to manage stormwater runoff. Chicago has an ordinance requiring that the first inch of rainfall during a storm is managed onsite for all new construction (Ando & Netusil, 2013). Portland, Oregon has an incentives-based approach and regulations that result in fees to cover the costs of stormwater management, however the fees are waved 100% for residential or commercial properties that manage their own runoff (Ando & Netusil, 2013). Additionally Portland has installed green street facilities and incentives to purchase the restoration of open spaces or trees (Ando & Netusil, 2013). Philadelphia, Pennsylvania has a 25-year plan (which is the largest green roof infrastructure program in the U.S.), which includes the use of green infrastructure on public and private land as well as a street tree program, open space acquisition and stream restoration project (Ando & Netusil, 2013). Cities in the U.S. without combined sewer systems are also developing some of these approaches including Pelham and Greenland, New Hampshire; Burnsville, Minnesota; Kansas City, Missouri; Orlando, Florida and more (Ando & Netusil, 2013). In some highly urbanized areas outside of the U.S., such as Germany, Belgium, Japan and

Singapore, the advantages of green roofs have already resulted in government encouraging and/or imposing the use of green roofs (Mentens et al., 2004).

Decentralized approaches to stormwater management such as green roofs do generate several benefits as highlighted throughout this paper. There are many factors that slow down or prevent such low impact development options including the costs of construction, training personnel, changing local business codes, construction on private property, monitoring and enforcement changes and fear that these solutions will provide insufficient protection during extreme storms. Future research would be wise to consider these factors and help find more sustainable practices.

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