RESEARCH ARTICLE

Assessing the Social and Economic Barriers to Permeable Surface Utilization for Residential Driveways in Kitchener, Canada

Stephanie A. Cote, S.E. Wolfe

Urban stormwater runoff rates are expected to intensify with climate change. Permeable surfaces, a low-impact development (LID) stormwater management technology, can be used to mitigate the impacts of urban stormwater runoff. Permeable surfaces have demonstrable benefits for use in northern climates, but widespread use requires greater recognition of this potential. This article reports on the multiple barriers associated with the installation of a permeable surface in single-family residences, along with the characteristics and incentives associated with early adopters. Results from standardized, self-administered mail-back questionnaires distributed within a Kitchener, Canada, community identified awareness, cost, and technological acceptance as permeable surface adoption barriers. Other results indicate that Kitchener residents possess the necessary characteristics to support permeable surface adoption once technical and economic barriers are resolved. This article contributes insights on barriers to LID urban stormwater management practices to both the academic and applied literatures.

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Impervious surfaces prevent soil infiltration and force water to run over roads, parking lots, and residential driveways. Urban development increases the rate of impervious surface installation over natural landscapes and decreases water infiltration by quickly channeling water into sewer systems (Donofrio et al., 2009). This approach undermines local water regimes by depleting soil moisture and slowing groundwater recharge (Dietz, 2007). Impervious surfaces also contribute to overall increased stormwater quantities. Urban stormwater runoff originates as rainfall, snowmelt, or water from seasonal, domestic activities—for example, swimming pool drainage (Ontario Ministry of Environment, 2003).

A sudden or ongoing increase in urban stormwater will increase stream flow and flood risk, bank erosion, sedimentation, and water contamination (Burns et al., 2012; Frazer, 2005; Thurston et al., 2010). Urban stormwater, if not managed adequately and properly, can degrade surface water quality, diminish groundwater quantities, harm aquatic wildlife and fisheries, and impact drinking water supplies (Litman, 2011; McGuire et al., 2010; Thurston et al., 2010).

Researchers anticipate that climate change will intensify these concerns in Canada [Cunderlik and Ouarda, 2009; Government of Ontario (GO), 2011; He et al., 2011; Picketts et al., 2012]. For example, the province of Ontario may experience higher annual temperatures, greater-than-average spring and winter precipitation, and more intense summer dry periods (Crabbe and Robin, 2006; Expert Panel on Climate Change Adaption, 2009; Grillakis, Koutroulis, and Tsanis, 2011). The changes to precipitation amounts and runoff patterns may reduce recharge rates, generate more frequent flooding, and further degrade surface water quality (Elçi, 2011; GO, 2011; Yazicigil et al., 2011). In response to these anticipated climatic and hydrological changes, Hamin and Gurran (2009) argue that new approaches to urban design are required for society to adapt to such increased risks associated with climate change. This new urban design includes alternative forms of stormwater management by Canadian municipalities (Binstock, 2011; Donofrio et al., 2009; GO, 2011; Hamin and Gurran, 2009).

One option would be to embed low-impact development (LID) stormwater management practices (Binstock, 2011).

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LID practices are lot-level and cost-effective landscape features that attempt to mimic natural processes in order to manage precipitation events near their source (Coffman, 2000; Dietz, 2007). LID practices have many benefits—for example, flood, erosion, and pollution reduction; habitat and water quality improvement; and water conservation—and could serve as a climate change adaption (Coffman, 2000; GO, 2011; Hamin and Gurran, 2009; Mayer et al., 2012; McGuire et al., 2010). As climate change intensifies, adaption measures will be an important management strategy (Hamin and Gurran, 2009; Juhola and Westerhoff, 2011; Picketts et al., 2012).

Permeable surface installment is an LID practice allowing water to infiltrate the soil. These surfaces can be in many contexts, including urban residential driveways. Permeable surfaces can be installed in new residential developments or easily retrofitted to existing residential properties [Credit Valley Conservation and Toronto Region Conservation Authority (CVC and TRCA), 2010; Yong, McCarthy, and Deletic, 2012]. Encouraging the retrofit of LID practices, such as permeable surface use, is needed in order to manage increased stormwater generated by development intensification in urban areas (CVC and TRCA, 2010). Canada Mortgage and Housing Corporation (2013), expects Canadian housing starts to be at 190,300 units in 2013 and 194,100 units in 2014, and identifies a large potential market for permeable surface installation in new developments.

Permeable surfaces reduce stormwater quantities that can reach, and quickly overwhelm, urban wastewater infrastructure. By using permeable surfaces, urban municipalities can manage their legislative obligations, minimize wastewater capital and operating costs, and reduce negative environmental consequences (Coffman, 2000; CVC and TRCA, 2010; Frazer, 2005). However, for permeable surfaces to be adopted and widely installed, homeowners must easily recognize this practice as being beneficial.

In this study, we assessed the feasibility of permeable surface adoption in the Canadian residential sector. We focused on Kitchener (Ontario, Canada) residents' expressed social and economic objections to permeable surfaces. The results contribute insights on barriers to LID urban stormwater management practices to the academic and applied literatures. Section 2 is a brief review of stormwater management over time, permeable pavement technologies, and the innovation adoption literatures. Section 3 includes a case and methods description. The study results are summarized in section 4 and their implications discussed in section 5. Conclusions and recommendations for promoting urban permeable surface adoption are in section 6.

Literature Review

Evolution of Stormwater Management

Conventional stormwater management requires extensive drainage networks that are designed to transport stormwater quickly away from urban landscapes and into surrounding surface waters (Burns et al., 2012; Donofrio et al., 2009). Efficient drainage and flood control are used to address health, safety, and property concerns (Arnold and Gibbons, 1996; Zimmer et al., 2007). Prior to the 1980s, these conventional practices were based on *flat-earth planning*, an approach that encouraged urban development without consideration of landscape or ecosystem processes (Cowell, 1998; Ontario Ministry of Environment and Energy, 1994).

Contemporary urban stormwater management is more inclusive of landscape and ecosystem processes. Practices now include runoff flow-rate control, stream channel erosion control, and water quality protection (Zimmer et al., 2007). Stormwater management priorities shifted because of (a) recognition of the limitations, impacts, cost, and effectiveness concerns with the use of conventional management practices and (b) the development of expanded watershed protection objectives (Coffman, 2000; Donofrio et al., 2009).

LID, which emerged in the 1980s in Germany, France, and Japan, was first tried in the United States a decade later (Coffman, 2000; Dietz, 2007). Since then, LID use by Canadian municipalities has increased to improve stormwater management outcomes (McGuire et al., 2010; Podolsky and MacDonald, 2008). Cities like Toronto, St. Catherines, and Waterloo are using LID to reduce stormwater quantities and to prevent combined sewer overflows (CSOs), which are a major water pollution source in Canada (Binstock, 2011; He and Marsalek, 2009; Podolsky and MacDonald, 2008; Thurston et al., 2010). CSO occurs when large amounts of stormwater infiltrate pipes carrying both stormwater and sewage, overwhelms treatment plants' capacity, and forces the plant operators to release untreated wastewater into local creeks, rivers, and lakes. CSOs contaminate drinking and recreational waters with pathogens, active pharmaceutical ingredients, household chemicals, and other pollutants, risking human health (Binstock, 2011; Kessler, 2011; Podolsky and MacDonald, 2008). To avoid CSO scenarios and source water contamination, LIDs (e.g., permeable surfaces) can be used in Canadian municipalities (Binstock, 2011).

Permeable Surfaces

Many permeable surface types are applicable to the urban, residential context:

- Permeable interlocking concrete pavers (PICPs): blocks, generally concrete, placed to create voids between adjacent units (Brown et al., 2009).
- Permeable asphalt and permeable concrete: standard asphalt or concrete mixtures with fine particles removed, creating voids (Brown et al., 2009; Houle et al., 2009).
- Permeable grid pavers (PGPs): concrete or plastic blocks with internal voids and gaps between adjacent units (Bean, Hunt, and Bidelspach, 2007).
- Crushed stone: loose stone composed of particles sized to allow for void space generation (Gilbert and Clausen, 2006).
- Grasspave and Gravelpave: a plastic grid, with virtually no impervious area, that is filled with sand and grass or gravel (Brattebo and Booth, 2003).

Surface design and performance researchers have quantified and evaluated permeable surfaces' infiltration and water quality management effectiveness [Bean et al., 2007; Brattebo and Booth, 2003; Collins, Hunt, and Hathaway, 2008; Gilbert and Clausen, 2006; Toronto and Region Conservation (TRC), 2008]. A surface's effectiveness is determined by measuring the infiltrated water quantity per hour compared with rainfall depth (Bean et al., 2007; Brattebo and Booth, 2003; Gilbert and Clausen, 2006). Permeable pavements can be very effective at infiltrating and reducing runoff. Collins, Hunt, and Hathaway (2008) reported minimum and maximum values of recorded infiltration rates for permeable concrete, PICP, and concrete grid pavers to be between 91.4% and 100% of rainfall (p. 1150). Gilbert and Clausen (2006) measured a 78% runoff reduction when PICPs were used and a 98% reduction when crushed stone was used (p. 829). Finally, Brattebo and Booth (2003) also observed infiltration of virtually all water when PGPs, PICPs, Grasspave, or Gravelpave were used. Huang et al. (2012) observed a major decrease in infiltration rate during the winter months in a study based in Calgary. This is believed to be a result of both cold temperatures and clogging from sanding material. Although reduced, infiltration in the winter was still found to be at acceptable levels for handling snowmelt and storm runoff during freeze–thaw periods (Huang et al., 2012).

Effectiveness may also be impeded or enhanced, depending on surface design and installation (Bean et al., 2007; Brattebo and Booth, 2003; Collins, Hunt, and Hathaway, 2008; Yong, McCarthy, and Deletic, 2012). For example, using a larger stone rather than sand to fill voids between concrete grid pavers and PICPs can improve infiltration because the larger aggregate creates wider drainage channels that limit the clogging of pore spaces (Bean et al., 2007). Permeable surface installation on low-infiltration-capacity soils such as clay may reduce effectiveness, but significant infiltration is possible in poorly drained or mechanically compacted soils (Bean et al., 2007; Collins, Hunt, and Hathaway, 2008; TRC, 2008).

Passive water quality treatment is possible through contaminants' removal by permeable surfaces. Conventional surfaces result in mass pollutant transport—for example, of heavy metals and of organic and inorganic compounds—into local water bodies as stormwater flushes contaminants off the urban landscape (Ball and Rankin, 2010; Roseen et al., 2012; Thurston et al., 2010). In contrast, permeable surfaces allow contaminants to be filtered through the permeable structure (Brown et al., 2009; Huang et al., 2012; Kwiatkowski et al., 2007). These are then retained within the pavement through filtration and sedimentation, or degraded within the porous media reservoir, subgrade soils, or geotextile filters (Brown et al., 2009; Kwiatkowski et al., 2007; Roseen et al., 2012). The effectiveness of contaminant removal is demonstrated by Huang et al.'s (2012) study, which found removal rates of 91% for total suspended solids, 78% for total phosphorus, 6% for total nitrogen, 68% for zinc, 69% for copper, and 55% for lead (p. 995). Infiltration rates and contaminant removal depend heavily on surface composition and installation, so permeable surfaces are recommended for low- to medium-traffic areas that receive low contaminant levels (CVC and TRCA, 2010; Scholz and Grabowiecki, 2007).

Contaminant filtration from stormwater, although important to improving water quality, can cause the permeable pavement to clog, reducing its infiltration rate (Kuang and Fu, 2013). Minimal maintenance practices are therefore required to remove particles from void spaces to ensure sustained infiltration rates. The types of maintenance and required frequency vary significantly across the research literature (Ball and Rankin, 2010; Bean et al., 2007; Brown et al., 2009). Vacuuming, sonicating, sweeping, high-pressure washing, and suction (Dietz, 2007) effectively remove clogged particles. For example, Sansalone et al. (2012) found that 96% of the initial hydraulic conductivity was recovered after either vacuuming or sonicating permeable concrete. Similarly, Kuang and Fu (2013) found that high-pressure washing followed by vacuuming was effective at removing clogged particles. The reported maintenance frequency varies, however. The results from Rowe et al.'s (2009) study, using a simulated six-year rainfall on PICPs, indicated that no maintenance was required in order to clear particle clogging; this finding was supported by Brattebo and Booth's study (2003). Other researchers have asserted that PICPs should be vacuumed at least once every 3–5 years (TRC, 2008) or vacuum swept every six weeks (Kwiatkowski et al., 2007).

Permeable surface durability and longevity in cold climates is another concern (Roseen et al., 2012). Houle et al. (2009) found that maintenance was required to preserve structural, visual, and hydraulic integrity of permeable asphalt after frost and freeze–thaw cycles. However, postinstallation assessments of the permeable surface parking lot at Seneca College (King City) demonstrated winter durability for 17 years and maintained permeability for 13 years (TRC, 2008). Roseen et al. (2012), after a four-year study indicated no negative freeze–thaw effects, concluded that the permeable pavement would last longer than conventional surfaces in northern climates. Newton (2005) notes the possible combinations of permeable and impermeable pavement into a system that assists with stormwater management and is durable and structurally sound.

Another permeable surface concern is that sodium and chloride—from winter deicing of driveways or parking lots—are potential groundwater contaminants (Kwiatkowski et al., 2007; Marsalek and Schreier, 2009). In the Waterloo Region, the chlorides contributed specifically from road salt applications are recognized as a threat to drinking water quality (Lake Erie Source Protection Region, 2011). Because of this threat, efforts are taken to avoid surface water infiltration from parking lots within wellhead protection areas. However, in small-scale residential contexts, the load contributed will be low and unlikely to harm groundwater supplies significantly. In addition, demand for salt application may be reduced overall because snow and ice melt faster on permeable asphalt than on conventional asphalt (Houle et al., 2009).

Permeable surfaces are an effective, innovative LID practice for northern climates and residential applications when installed and managed appropriately. Yet, even with extensive technical knowledge and the obvious benefits, more widespread social acceptance is required for greater installation. Some specific barriers may impede the adoption and installation of residential permeable surface use.

Barriers to the Adoption of Residential Permeable Surfaces

Any technical innovation must illustrate its compatibility with society's current needs, values, and norms in order to increase or ensure its adoption rate (Rogers, 1983). Numerous barriers to innovation adoption are identified in related subjects of water conservation, green building techniques, and LID in general (Barnhill and Smardon, 2012; City of Toronto, 2006; Earles et al., 2009; Hood, 2008; Jordaan and Stevens, 2007). Potential barrier examples include adopter's physical capacity, knowledge, awareness, attitudes, and perceptions; expense; uncertainty; and risk levels associated with the technical innovation (Barnhill and Smardon, 2012; Earles et al., 2009; Hood, 2008; Jordaan and Stevens, 2007).

These social barriers must be mitigated to encourage residential adoption of green technologies (Earles et al., 2009; Zhao et al., 2012). Barriers may be lessened through the efforts of public- and private-sector groups, including private firms, community nongovernmental organizations, and watershed groups (Earles et al., 2009; Genskow and Wood, 2011; Vachon and Menz, 2006). However, to encourage innovation adoption and implementation, government support is essential (Rodriguez et al., 2008). Government control mechanisms such as building infrastructure, funding research, and development can facilitate innovation adoption (Hendry, Harborne, and Brown, 2010). Different levels of government can also apply specific influential policies to encourage adoption (Carter and Fowler, 2008; Vachon and Menz, 2006). Barrier identification is essential for determining suitable mechanisms and approaches to encourage adoption (Earles et al., 2009; Jordaan and Stevens, 2007). Particularly for the development of context-dependent municipal policies and programs around permeable surface installation for urban driveways, the social and economic barriers must be identified and addressed directly.

The methodology outlined next was used to assess the influence of potential barriers within an urban case: Kitchener, Ontario. The goal was to identify barriers that need to be overcome to encourage residents' installation of permeable surfaces.

Methodology

Kitchener Case

Kitchener's population, which is approximately 223,715, is expected to grow by an estimated 100,000 in 2009–31 (City of Kitchener, 2011), an expansion that will increase impervious cover and stormwater, and entail more intensive—and expensive—management interventions (City of Kitchener, 2011; Heaney and Sansalone, 2009; Litman, 2011). Among the many challenges that Kitchener faces are inadequate drainage systems, and inspection and maintenance regimens, along with flooding and erosion hazards (Gollan and Corbett, 2011).

LID practices have the potential to lower design, construction, and maintenance costs by 25%–30% by decreasing the dependence on conventional infrastructure (Binstock, 2011; Coffman, 2000, p. 2). However, Kitchener uses LID stormwater ponds only to capture and treat stormwater runoff from 20% of developed land (AECOM, 2011); installation of permeable surfaces would be an appropriate LID practice to incorporate into Kitchener's stormwater management program.

As a foundation for a permeable surface program, Kitchener completed a parcel analysis (2008; reviewed 2010) for a stormwater user-fee program. Their assessment identified 44,600 large, medium, and small single-family units and duplexes comprising 11,102,406 m^2 of impervious cover. This assessment included all impervious surfaces—roofs, patios, and driveways—and demonstrated the large impervious area contributed by residential properties (AECOM, 2010, p. 2). Permeable surface driveways could substantively reduce this impervious cover and subsequent stormwater (Frazer, 2005).

Managing the city's stormwater quantity has required a major public investment—Kitchener's estimated stormwater management assets' total value is CDN $300 million (Siva, 2009, p. ii). However, these investment efforts have proven insufficient because of a lack of significant improvement in urban streams' water quality in 2006–10 (City of Kitchener, 2010a). Additional stormwater investment is necessary, but Kitchener's budgetary limitations indicate a CND $40 million funding shortfall over 10 years; current expenditures support only 59% of the proposed stormwater initiatives (Murphy and Gregory, 2009, p. 5).

To offset some of these anticipated expenses, Kitchener implemented an innovative stormwater user-fee program on January 1, 2011, that was designed to generate consistent funding designated for stormwater management (City of Kitchener, 2014). The user fees are calculated based on impervious area coverage or *impervious footprint*—that is, the combined surface area of roofs, patios, and driveways. This tiered, residential, flat-rate calculation allows the property owners' charges to be allocated accurately and fairly (AECOM, 2010; City of Kitchener, 2012; Gollan and Corbett, 2011). Owners of a semidetached property are charged a fixed fee based on the number of dwelling units (City of Kitchener, 2012).

To encourage residents' efforts to reduce their stormwater, the council also approved a stormwater credit policy beginning October 2012 (City of Kitchener, 2010b). Credits are allotted when residents provide evidence of using stormwater quality and/or quantity best management practices on their property. Depending upon the effectiveness of these best management practices, residents may receive up to a 45% reduction in their monthly stormwater utility bills. A signed completed registration form denotes resident agreement to limited, announced inspections by city staff to confirm that credit requirements are met and that credit calculation is accurate. The credit status will be maintained provided the best management practices are functioning as approved and as demonstrated by city inspections (City of Kitchener, 2013).

These financial incentives—based on existing stormwater production and efforts to reduce stormwater—enable Kitchener to encourage lot-level LID adoption (Carter and Fowler, 2008). But financial instruments may not always be sufficient for encouraging LID (Carter and Fowler, 2008; Rodriguez et al., 2008). Therefore, identification of all social and economic barriers to LID practices is important to encourage adoption (Carter and Fowler, 2008; Earles et al., 2009; Jordaan and Stevens, 2007; Rodriguez et al., 2008).

To explore these barriers to permeable surface use, we used the methodology outlined next in Kitchener's Forest Heights—an area in southwestern Kitchener bordered by Fisher Hallman Road, Highland Road West, Trussler Road, and Highway 7/8. Forest Heights was selected as the study site because it has housing-stock diversity within a small area.

Sampling Method

The LID, water efficiency, and green building literatures were used to identify possible social and economic barriers to residential permeable surface adoption. Possible barriers include awareness and perception of a problem, lack of ownership of the stormwater issues, cost, maintenance, permeable surface acceptance as the norm, and reluctance to use external expertise (Bester et al., 2006; Earles et al., 2009; Hood, 2008; Jordaan and Stevens, 2007). Lack of motivation—that is, the perception that individual effort will make no significant contribution to stormwater reduction—was also examined (Jordaan and Stevens, 2007). Not every barrier was considered in this study, but the survey does provide a foundation for distinguishing the efforts that are likely required to encourage permeable surface use by residents for driveways.

Standardized, self-administered mail-back surveys were used for sampling. Compared with other survey methods, such as face-to-face or telephone contact, mail-back is relatively inexpensive, simple, and brief to administer, allowing for greater sample sizes (Beebe et al., 2007; Dillman, 1991; Larson and Chow, 2003), and the researcher's absence may relieve unintended pressure to answer the questions in a certain way (Bryman, Teevan, and Bell, 2009; Larson and Chow, 2003). However, the researcher's absence increases potential for unanswered questions (i.e., lack of clarification) and nonreturned surveys (i.e., lack of supervision) (Bryman et al., 2009; Webster, 1997). To address these concerns, the survey was beta tested, reviewed by a colleague, and designed to include a limited number of short, well-defined questions (Bryman et al., 2009).

Sampling Materials

Packages delivered to random Forest Heights households contained a cover letter, the survey, and a stamped return envelope.

The survey included only 20 short-answer questions. Question 1 confirmed that the homeowner was a household member rather than an off-site landlord. The next 14 questions were designed to identify potential social and economic barriers (see the Survey Distribution section that follows) to permeable pavement use by Kitchener residents for their driveways. Open-ended question 16 was intended to identify barriers not addressed by the survey. The remaining four questions were to cover basic demographics that were used to characterize the study respondents. Of the 20 questions, 19 were closed-ended to reduce answer variability, limit misinterpretation, and enable data analysis that is more straightforward (Bryman et al., 2009).

Survey Distribution

A total of 200 surveys were distributed in Forest Heights over two days in January 2011. To ensure that random sample surveys were distributed to a house on each side of every street, the houses selected were at the approximate street center according to a Forest Heights street map and cross-referenced to the Kitchener city map. If the street center had no houses, the next houses in the direction being traveled were sampled. Housing circles were treated as dead ends, with the center considered to be between the street's start and the circle's furthest side. The remaining 30 surveys were distributed to houses on both sides of the neighborhood's longest streets at the approximate quarter and three-quarter distances.

Results

Response Rate

Mail-back surveys often yield low response rates (Bryman et al., 2009; Larson and Chow, 2003; Tivesten et al., 2012). However, some strategies will improve response rates to 50%–70% (Bryman et al., 2009, p. 205; Dillman, 1991, p. 234). Many strategies—including the personalization of all cover letters, a financial incentive provision, replacement survey delivery, and reminder notifications after the initial mailing—were unfeasible due to time and funding constraints. We provided a cover letter detailing the study's importance, guaranteed response confidentiality, included a stamped return envelope, folded materials to contrast with advertising mail, and ensured that the survey was short and the questions were clear (Bryman et al., 2009; Dillman, 1991; Larson and Chow, 2003). Our final response rate was 30%: 59 of 200 surveys were returned.

Respondents' Demographic Characteristics

All 59 respondents confirmed that a household member owned the residence. The demographic questions describing age and gender demonstrate an evenly distributed sampling population (Tables 1 and 2).

One survey did not indicate the respondent's gender, and four did not indicate age. Of the respondents, 47 indicated that they were married, 7 were in a common-law relationship, and 3 were widowed, were divorced, or had never married. The majority (39) declared a high household income (CND $80,000–150,000 or more), 14 declared a moderate income (CND $40,000–79,999), and 5 declared a low income (CND < $10,000 to 39,999). The respondents' self-reported income was used to identify any potential relationship between income and barriers. Survey results are presented next.

Social and Economic Barriers to Residential Permeable Surface Use

Respondents' answers to question 2 identified that residents lacked stormwater impact awareness. Of the 59 respondents only 7 (12%) correctly recognized all five issues (Figure 1) as stormwater impacts.

Another 7 respondents incorrectly identified stormwater as being treated and not a cause of environmental concerns. The least recognized issue was the stormwater burden on Kitchener's financial resources; the most recognized issue was surface water pollution.

All respondents answered question 5 gauging residents' permeable surface awareness: 26 (44%) knew what permeable surfaces were prior to receiving the survey, whereas 33 (56%) did not know.

Respondents indicated, through responses to question 3, that they saw a need to improve stormwater management (Table 3). The majority of respondents considered improving stormwater management in Kitchener to be at least somewhat important. One respondent did not answer.

The majority (77%) of answers to question 4 demonstrated a sense of ownership or responsibility for contributing to stormwater reduction (Table 4). Two respondents did not answer.

Table 1. Respondents' gender

Gender	No. of responses
Female	26
Male	32
Total	58

Table 2. Respondents' age

Age (years)	No. responses
25–44	12
45–64	24
65 or older	19
Total	55

Through question 15, the respondents also indicated that they were motivated to help address urban stormwater issues (Table 5). Six did not answer this question.

Of the respondents, 57 answered question 13 identifying willingness to actively seek information regarding permeable driveways (2 did not answer); 41 (72%) claimed to be willing to seek out information, whereas 16 (28%) were unwilling to do so.

Current permeable surface acceptance was assessed with question 14, which asked residents whether they would consider using permeable surfaces (Table 6).

The financial investment that residents were willing to make was assessed in comparison to the expense incurred while installing a conventional asphalt driveway. Households with higher incomes were willing to spend a greater percentage than were those with low or medium household incomes (Table 7).

Of the respondents, 54 answered question 6, whereas 5 did not. Within the responses, 15 people (28%) would spend no more than they would on conventional asphalt, whereas 31 (57%) would spend 1%–15% more. Another 5 (9%) would spend 16%–30% more, whereas 3 (6%) would spend 31%–49% more. No one was willing to spend 50% or more to install permeable surfaces on their driveways. Of all respondents, 50 (85%) indicated that they would be willing to pay more if incentive programs were available.

All respondents, through question 8, indicated their likeliness to perform annual maintenance on their permeable surface driveways (Table 8).

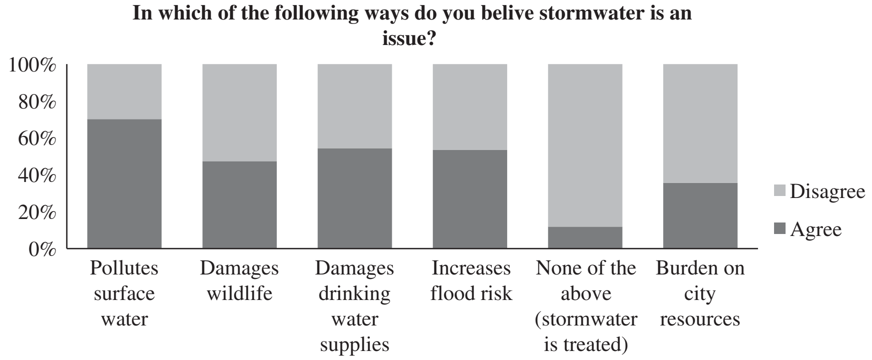

Figure 1. Response percentages to survey question 2.

Table 3. Respondent belief in the need to improve stormwater management in Kitchener

	No. responses	% Total responses
Very important	19	33
Somewhat important	34	59
Not very important	4	7
Not at all important	1	1
Total	58	100

Table 4. Respondents' belief in the importance of their contribution to stormwater management

	No. responses	% Total responses
Very important	11	19
Somewhat important	33	58
Not very important	12	21
Not at all important	1	2
Total	57	100

Table 5. Respondents' belief that permeable surfaces on their property would make a difference

	No. responses	% Total responses
Strongly agree	6	11
Agree	40	76
Disagree	7	13
Strongly disagree	0	0
Total	53	100

Table 6. Respondents' potential consideration of installing a permeable surface driveway

	No. responses	% Total responses
Would consider	25	42
Might consider	30	51
Would not consider	4	7
Total	59	100

Of these individuals, 58 responded (1 did not respond) to question 9, which asked whether they would be more likely to perform annual maintenance if incentive programs were available: 44 (76%) agreed, whereas 14 (24%) disagreed.

Permeable surface maintenance also involves consistent limitation of winter salt and/or sand application. The majority (86%) of respondents already limited use of salt and/or sand during the winter (Table 9).

Of the respondents, 22 (37%) wrote comments for the open-ended question 16. These comments identified other social, economic, and technological concerns that might prevent permeable surface use for residential driveways. Aesthetic attractiveness, including weed growth and ant-hill establishment, was one concern. Many technical concerns were mentioned, including these regarding the surface material:

- Life span
- Durability
- Strength
- Capacity
- Abrasion
- Effectiveness on specific property types (i.e., sloping driveways and clay soils)
- Resilience to heaving and shifting caused by freeze–thaw cycles

Risk perception was a barrier identified through expressed concern for potential basement flooding, incorrect installation, and groundwater contamination. Respondents also questioned how permeable surface installation would negatively affect their home's resale value. Even with these questions and concerns, 45 (76%), in response to question 12, demonstrated interest in learning more about permeable pavements.

Discussion

The survey data indicated both the barriers to permeable surface adoption for residential driveways and characteristics of likely adopter's.

One barrier was the residents' insufficient awareness of stormwater and permeable surface options. Because problem recognition and subject knowledge influence adoption, Kitchener residents' limited understanding impedes permeable surface installation (Chawla, 2008; Hood, 2008; Maibach, 1993). Investment in outreach and information dissemination—focused on stormwater and permeable surfaces—will be essential for wider use (Coffman, 2000; CVC and TRCA, 2010; Genskow and Wood, 2011).

However, awareness does not guarantee adoption because there are many other significant factors (Rogers, 1983), such as personal attitudes (Dolnicar and Hurlimann, 2010; Freeman et al., 2012). For example, the majority of respondents who demonstrated favorable attitudes about

Table 7. Price for asphalt is greater than residents are willing to pay

No. residents	No price difference	1%–15%	16%–30%	31%–49%	≥50%	No. total respondents
Low income	0	3	1	0	0	4
Middle income	5	6	1	0	0	12
High income	5	17	3	2	0	27
Unknown income	5	5	0	1	0	11
Total	15	31	5	3	0	54

Table 8. Respondents' likeliness to perform annual maintenance

	No. responses	% Total responses
Very likely	25	42
Somewhat likely	20	34
Not very likely	10	17
Not likely at all	4	7
Total	59	100

Table 9. Respondents' frequency of salt/sand application substances

	No. responses	% Total responses
Never	20	34
During severe storms	31	52
Every snowfall	7	12
Every day	1	2
Total	59	100

the need for improved stormwater management, issue ownership, and motivation indicated openness to permeable surface adoption. Issue ownership may be particularly influential in generating environmentally responsible behavior because it makes the matter part of one's expressed identity and, therefore, is valued by that individual (Hungerford and Volk, 1990). Motivation—that is, the perception that an individual effort will make a difference—has also been found to influence environmentally beneficial practice adoption significantly (Chawla, 2008; Jordaan and Stevens, 2007). Finally, a majority of respondents demonstrated their willingness to actively seek permeable surface information. Information seekers are more likely to initially adopt an innovation (Rogers, 1983).

Although there was substantial evidence of individuals' characteristics that would support permeable surface adoption, the results also indicated that this technology currently is neither accepted as a social norm nor widely accepted. This assessment was inferred by the respondent majority, who claimed they *might*, rather than *would*, consider permeable surface use. Increased interest in permeable surfaces is evidenced, though: for example, Hanson Hardscapes in Cambridge (Ontario) reports an increase in requests for specifications and an increase in sales for LID permeable paving within municipalities (D. Stuebing, personal communication, February 23, 2012). Interest in permeable surfaces is important because an interested individual will be more likely to seek out information about permeable surfaces, remember it, and act toward adopting a new technology or approach (Maibach, 1993).

Although potential for permeable surface adoption was demonstrated, barriers remain for residential applications. Installation cost remains a major barrier. Although higher-income households were willing to spend more, no respondents were willing to pay 50% more than for conventional asphalt. A Kitchener–Waterloo company estimated conventional asphalt costs $5 CND per square foot, whereas permeable surfaces (e.g., PICPs) would be $12–$20 CND (D. Lippert, personal communication, February 23, 2012). The additional costs associated with permeable surfaces exist because a thicker aggregate base is needed (CVC and TRCA, 2010).

Respondents identified a willingness to spend more if municipal incentive programs were available. Financial incentives, even at low levels, often encourage adoption of new environmental technologies (Carter and Fowler, 2008; Dolnicar and Hurlimann, 2010; Mayer et al., 2012). For example, Portland (Oregon) initiated the Clean River Incentive and Discount Program, which offered up to a 35% discount to residents on their stormwater utility fee based on the effectiveness of lot-level efforts to manage stormwater (Carter and Fowler, 2008, p. 156). In the first year in which green roofs (a lot-level LID practice) were accepted within this program, 23 were constructed to earn the credit (Carter and Fowler, 2008). This program is comparable to Kitchener's, which offers up to a 45% discount on residents' utility fee based on the effectiveness of lot-level quality and quantity stormwater controls. These examples suggest that advertising permeable pavements as eligible for the Kitchener stormwater credit policy would encourage residential permeable surface installation. Informing residents that any cost differential can be reduced or eliminated when total life-cycle expenses are considered may further increase the adoption of permeable pavements (CVC and TRCA, 2010; Houdeshel et al., 2009; Maibach, 1993; Rogers, 1983).

Because the regional drinking water supplies are primarily groundwater, winter salt application to permeable surfaces is another central concern for Kitchener. Approximately 10%–60% of road salts will infiltrate groundwater (Bester et al., 2006; Fay and Shi, 2012; Sanderson et al., 1995). However, results indicate that residents are already limiting their application of winter salt on their driveways, which suggests that salt use on permeable residential driveways would have a minimal impact on groundwater compared with the current widespread salt use on roads (Bester et al., 2006; Fay and Shi, 2012). However, permeable surfaces might not be appropriate for residential driveways on the Waterloo Moraine, which serves as the region's major aquifer and is exceptionally vulnerable to contamination (Sanderson et al., 1995).

Potential permeable surface maintenance was not found to impede permeable surface use, since the majority of respondents claimed to be at least somewhat likely to perform annual maintenance. Furthermore, literature demonstrates that maintenance may not be required for many years, further reducing the potential influence of maintenance on permeable surface adoption (Brattebo and Booth, 2003; Rowe et al., 2009; TRC, 2008).

The identification of awareness, cost, technological acceptance, and perhaps salt use as barriers is valuable because it enables the recommendation of the efforts required to encourage permeable surface adoption by Kitchener residents.

Conclusions and Recommendations

Urban development has resulted in many negative environmental consequences, including impacts by climate change and stormwater runoff. Urban areas must now be modified to adapt to and manage these effects. One potential method is permeable surface use.

Barriers identified in this study that prevent permeable surface use for driveways by Kitchener residents include awareness, cost, and technological acceptance. Salt use may also pose a barrier to adoption in some areas; further research is needed to examine the interaction between permeable surfaces and salt infiltration in sensitive moraine and groundwater recharge areas.

Residents' characteristics that favored adoption included a perceived need for improved stormwater management, issue ownership, and motivation, as well as willingness to actively seek information and perform maintenance. The nature of barriers identified compared with those negated suggests that Kitchener residents possess the necessary characteristics that will support permeable surface adoption once technical and economic barriers are resolved.

Efforts to overcome impediments and encourage permeable surface adoption are viable and likely cost effective. Based on study findings, urban decision makers, along with the City of Kitchener, should consider how stormwater credit policies may be used and extended to minimize residents' cost concerns and provide incentives for permeable surface adoption. Promotional and educational efforts are also required in order to improve stormwater issue awareness and knowledge related to permeable surface benefits, costs, and characteristics. Kitchener should be involved with mitigating the barriers to residential permeable surface awareness and adoption. These minimal interventions will benefit all concerned with reduced stormwater generation and management obligations.

References

AECOM. 2010. *Memorandum on City of Kitchener Stormwater Rate Implementation*. Project 60148170. AECOM, Kitchener, Canada, 7 pp. Formerly available at http://www.kitchener.ca/en/ (accessed September 3, 2012).

AECOM. 2011. *Five-Year Stormwater Report Card* 2010 *Technical Report*. Project 60118433. AECOM, Kitchener, Canada, 44 pp. Available at http://www.kitchener.ca/en/livinginkitchener/resources/2010StormwaterManagementAudit5YearReportCardTechnicalReport.pdf (accessed September 3, 2012).

Arnold, C.L., and J.C. Gibbons. 1996. Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association* 62(2):243–258.

Ball, J.E., and K. Rankin. 2010. The Hydrological Performance of a Permeable Pavement. *Urban Water Journal* 7(2):79–90.

Barnhill, K., and R. Smardon. 2012. Gaining Ground: Green Infrastructure Attitudes and Perceptions from Stakeholders in Syracuse, New York. *Environmental Practice* 14(1):6–16.

Bean, E.Z., W.F. Hunt, and D.A. Bidelspach. 2007. Field Survey of Permeable Pavement Surface Infiltration Rates. *Journal of Irrigation and Drainage Engineering* 133(3):249–255.

Beebe, T.J., S.M. Stoner, K.J. Anderson, and A.R. Williams. 2007. Selected Questionnaire Size and Color Combinations Were Significantly Related to Mailed Survey Response Rates. *Journal of Clinical Epidemiology* 60(11):1184–1189.

Bester, M.L., E.O. Frind, J.W. Molson, and D.L. Rudolph. 2006. Numerical Investigation of Road Salt Impact on an Urban Wellfield. *Ground Water* 44(2):165–175.

Binstock, M. 2011, June. *Greening Stormwater Management in Ontario: An Analysis of Challenges and Opportunities*. Canadian Institute for Environmental Law and Policy, Toronto, 30 pp. Available at http://cielap.org/pdf/GreeningStormManOntario.pdf (accessed September 3, 2012).

Brattebo, B.O., and D.B. Booth. 2003. Long-Term Stormwater Quantity and Quality Performance of Permeable Pavement Systems. *Water Research* 37(18):4369–4376.

Brown, C., A. Chu, B. van Duin, and C. Valeo. 2009. Characteristics of Sediment Removal in Two Types of Permeable Pavement. *Water Quality Resources Journal of Canada* 44(1):59–70.

Bryman, A., J.J. Teevan, and E.A. Bell. 2009. *Social Research Methods*, 2nd Canadian edition. Oxford University Press, Don Mills, Canada, 392 pp.

Burns, M.J., T.D. Fletcher, C.J. Walsh, A.R. Ladson, and B.E. Hatt. 2012. Hydrologic Shortcomings of Conventional Urban Stormwater Management and Opportunities for Reform. *Landscape and Urban Planning* 105(3):230–240.

Canada Mortgage and Housing Corporation (CMHC). 2013. *Housing Market Outlook*, Canada edition. CMHC, Ottawa, 32 pp. Available at http://www.cmhc-schl.gc.ca/odpub/esub/61500/61500_2013_Q01.pdf?fr=1367032490584 (accessed April 25, 2013).

Carter, T., and L. Fowler. 2008. Establishing Green Roof Infrastructure through Environmental Policy Instruments. *Environmental Management* 42(1):151–164.

Chawla, L. 2008. Participation and the Ecology of Environmental Awareness. In *Participation and Learning: Perspectives on Education and the Environment, Health and Sustainability*, A. Reid, B.B. Jensen, and J. Nikel, eds. Springer-Verlag, New York, 98–110.

City of Kitchener. 2010a. *Kitchener's Stormwater Management Program: 2010 Report Card*. 6 pp. Available at http://www.kitchener.ca//en/livingin kitchener/resources/2010StormwaterManagementAudit5YearReportCard pamphlet.pdf (accessed September 3, 2012).

City of Kitchener. 2010b. *Stormwater Credit Policy*. 413 pp. Available at http://www.kitchener.ca/en/livinginkitchener/Stormwater_Credit_Policy.asp (accessed September 3, 2012).

City of Kitchener. 2011. *Fast facts about Kitchener*. 4 pp. Available at http://www.kitchener.ca/en/insidecityhall/resources/2011_01_Fast_Facts.pdf (accessed August 16, 2012).

City of Kitchener. 2012. *Important: Stormwater Utility Rate Change*. 1 p. Available at http://www.kitchener.ca/en/livinginkitchener/resources/SWM_UtilityInsert_2012_EPOST.pdf (accessed September 3, 2012).

City of Kitchener. 2013. *Residential Stormwater Credit Application*. 11 pp. Available at http://www.kitchener.ca/en/businessinkitchener/resources/SWM_Stormwater_Credit_Application_-_Mar_1_2013.pdf (accessed April 24, 2013).

City of Kitchener. 2014. *Stormwater Utility*. Available at http://www.kitchener.ca/en/livinginkitchener/Stormwater_Utility.asp (accessed January 29, 2014).

City of Toronto. 2006, June. *Making a Sustainable City Happen: The Toronto Green Development Standard* 2006. 86 pp. Available at http://www.toronto.ca/legdocs/2006/agendas/committees/ren/ren060710/it003.pdf (accessed September 3, 2012).

Coffman, L.S. 2000. Low Impact Development Design: A New Paradigm for Stormwater Management Mimicking and Restoring the Natural Hydrologic Regime. In *National Conference on Tools for Urban Water Resource Management and Protection: Proceedings*, February 7–10, Chicago. US Environmental Protection Agency, Cincinnati, OH, 158–167.

Collins, K.A., W.F. Hunt, and J.M. Hathaway. 2008. Hydrologic Comparison of Four Types of Permeable Pavement and Standard Asphalt in Eastern Northern Carolina. *Journal of Hydrologic Engineering* 13(12):1146–1157.

Cowell, D.W. 1998. Ecological Landscape Planning Techniques for Biodiversity and Sustainability. *Environmental Management and Health* 9(2):72–78.

Crabbe, P., and M. Robin. 2006. Institutional Adaption of Water Resource Infrastructures to Climate Change in Eastern Ontario. *Climate Change* 78(1):103–133.

Credit Valley Conservation (CVC) and Toronto Region Conservation Authority (TRCA). 2010. *Low Impact Development Stormwater Management Planning and Design Guide*, version 1.0. CVC, Mississauga, and TRCA, Toronto, Canada, 12 pp. Available at http://www.creditvalleyca.ca/wp-content/uploads/2012/02/lid-swm-guide-intro.pdf (accessed September 12, 2012).

Cunderlik, J.M., and T.B.M.J. Ouarda. 2009. Trends in the Timing and Magnitude of Floods in Canada. *Journal of Hydrology* 375(3–4): 471–480.

Dietz, M.E. 2007. Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions. *Water, Air, & Soil Pollution* 186(1–4):351–363.

Dillman, D.A. 1991. The Design and Administration of Mail Surveys. *Annual Review of Sociology* 17:225–249.

Dolnicar, S., and A. Hurlimann. 2010. Australians' Water Conservation Behaviours and Attitudes. *Australian Journal of Water Resources* 14(1):43–53.

Donofrio, J., Y. Kuhn, K. McWalter, and M. Winsor. 2009. Water-Sensitive Urban Design: An Emerging Model in Sustainable Design and Comprehensive Water-Cycle Management. *Environmental Practice* 11 (3):179–189.

Earles, A., D.P.E. Rapp, J. Clary, and J. Lopitz. 2009. Breaking Down the Barriers to Low Impact Development in Colorado. In *World Environmental and Water Resources Congress* 2009, *Great Rivers: Proceedings of the Congress*, May 17–29, Kansas City, MO, S. Starrett, ed. American Society of Civil Engineers, Reston, VA, 914–923.

Elçi, A. 2011. Assessing the Impact of Climate Change on Groundwater Resources Using Groundwater Flow Models. In *Climate Change and Its Effects on Water Resources: Issues of National and Global Security*, A. Baba, G. Tayfur, O. Gündüz, K.W.F. Howard, M.J. Friedel, and A. Chambel, eds. NATO Science for Peace and Security Series C: Environmental Security, volume 3. Springer, New York, 63–75.

Expert Panel on Climate Change Adaption. 2009. *Adapting to Climate Change in Ontario*. Queens Printer for Ontario, Toronto, 88 pp.

Fay, L., and X. Shi. 2012. Environmental Impacts of Chemicals for Snow and Ice Control: State of the Knowledge. *Water, Air, & Soil Pollution* 223(5):2751–2770.

Frazer, L. 2005. Paving Paradise: The Peril of Impervious Surfaces. *Environmental Health Perspectives* 113(7):A456–A462.

Freeman, S., E. Vigoda-Gadot, H. Sterr, M. Schultz, I. Korchenkov, P. Krost, and D. Angel. 2012. Public Attitudes towards Marine Aquaculture: A Comparative Analysis of Germany and Israel. *Environmental Science & Policy* 22:60–72.

Genskow, K.D., and D.M. Wood. 2011. Improving Voluntary Environmental Management Programs: Facilitating Learning and Adaptation. *Environmental Management* 47(5):907–916.

Gilbert, J.K., and J.C. Clausen. 2006. Stormwater Runoff Quality and Quantity from Asphalt, Paver, and Crushed Stone Driveways in Connecticut. *Water Research* 40(4):826–832.

Gollan, N., and N. Corbett. 2011. *Memorandum on Credit Policy Development: Memorandum #1: Introduction, Background (including Research) and Purpose*. City of Kitchener and City of Waterloo, Kitchener, Canada, 7 pp. Available at http://www.kitchener.ca/en/livinginkitchener/resources/SWCPFINALMemo1.pdf (accessed January 29, 2014).

Government of Ontario. 2011. *Climate Ready: Ontario's Adaptation Strategy and Action Plan* 2011–2014. Queens Printer for Ontario, Toronto, 120 pp.

Grillakis, M.G., A.G. Koutroulis, and I.K. Tsanis. 2011. Climate Change Impact on the Hydrology of Spencer Creek Watershed in Southern Ontario, Canada. *Journal of Hydrology* 409(1–2):1–19.

Hamin, E.M., and N. Gurran. 2009. Urban Form and Climate Change: Balancing Adaptation and Mitigation in the U.S. and Australia. *Habitat International* 33(3):238–245.

He, C., and J. Marsalek. 2009. Hydraulic Optimization of a Combined Sewer Overflow (CSO) Storage Facility Using Numerical and Physical Modeling. *Canadian Journal of Civil Engineering* 36(2):363–373.

He, J., C. Valeo, A. Chu, and N.F. Neumann. 2011. Stormwater Quantity and Quality Response to Climate Change Using Artificial Neural Networks. *Hydrological Processes* 25(8):1298–1312.

Heaney, J.P., and J.J. Sansalone. 2009. Urban Stormwater Management in 2050. In *World Environmental and Water Resources Congress* 2009*, Great Rivers: Proceedings of the Congress*, May 17–29, Kansas City, MO, S. Starrett, ed. American Society of Civil Engineers, Reston, VA, 2336–2344.

Hendry, C., P. Harborne, and J. Brown. 2010. So What Do Innovating Companies Really Get from Publicly Funded Demonstration Projects and Trials? Innovation Lessons from Solar Photovoltaics and Wind. *Energy Policy* 38(8):4507–4519.

Hood, I. 2008. *Green Building in North America. Paper 4c: Residential Building in North America: The benefits of a North American Strategy—A Perspective from Canada*. Sheltair Group, Vancouver, Canada, 52 pp. Available at http://www.cec.org/Storage/61/5383_GBPaper4c_en.pdf (accessed September 12, 2012).

Houdeshel, C.D., C.A. Pomeroy, L. Hair, and R. Goo. 2009. Cost Estimating Tools for Low-Impact Development Best Management Practices. In *World Environmental and Water Resources Congress* 2009*, Great Rivers: Proceedings of the Congress*, May 17–29, Kansas City, MO, S. Starrett, ed. American Society of Civil Engineers, Reston, VA, 991–1003.

Houle, K.M., R.M. Roseen, T.P. Ballestero, J.F. Briggs, and J.J. Houle. 2009. Examinations of Pervious Concrete and Porous Asphalt Pavements Performance for Stormwater Management in Northern Climates. In *World Environmental and Water Resources Congress* 2009*, Great Rivers: Proceedings of the Congress*, May 17–29, Kansas City, MO, S. Starrett, ed. American Society of Civil Engineers, Reston, VA, 1105–1122.

Huang, J., C. Valeo, J. He, and A. Chu. 2012. Winter Performance of Interlocking Pavers—Stormwater Quantity and Quality. *Water* 4(4):995–1008.

Hungerford, H.R., and T.L. Volk. 1990. Changing Learner Behavior through Environmental Education. *Journal of Environmental Education* 21(3):8–22.

Jordaan, S., and C.M.A. Stevens. 2007. *Overcoming Barriers on the Path to Water Conservation*. Water Soft Path Lexicon, volume 1. Friends of the Earth Canada, Ottawa, 1–13.

Juhola, S., and L. Westerhoff. 2011. Challenges of Adaptation to Climate Change across Multiple Scales: A Case Study of Network Governance in Two European Countries. *Environmental Science & Policy* 14(3):239–247.

Kessler, R. 2011. Stormwater Strategies: Cities Prepare Aging Infrastructure for Climate Change. *Environmental Health Perspectives* 119(12):A514–A519.

Kuang, X., and Y. Fu. 2013. Coupled Infiltration and Filtration Behaviours of Concrete Porous Pavement for Stormwater Management. *Hydrological Processes* 27(4):532–540.

Kwiatkowski, M., A.L. Welker, R.G. Traver, M. Vanacore, and T. Ladd. 2007. Evaluation of an Infiltration Best Management Practice Utilizing Pervious Concrete. *Journal of the American Water Resources Association* 43(5):1208–1222.

Lake Erie Source Protection Region (LESPR). 2011, June. *Drinking Water Threat: The Application of Road Salt; Drinking Water Threat: The Handling and Storage of Road Salt*. Final Discussion Paper. LESPR, Cambridge, Canada, 53 pp. Available at http://www.sourcewater.ca/plandevelopment/12_13_Salt_DiscussionPaper_Final.pdf (accessed April 23, 2013).

Larson, P.D., and G. Chow. 2003. Total Cost/Response Rate Trade-offs in Mail Survey Research: Impact of Follow-up Mailings and Monetary Incentives. *Industrial Marketing Management* 32(7):533–537.

Litman, T. 2011. Why and How to Reduce the Amount of Land Paved for Roads and Parking Facilities. *Environmental Practice* 13(1):38–46.

Maibach, E. 1993. Social Marketing for the Environment: Using Information Campaigns to Promote Environmental Awareness and Behavior Change. *Health Promotion International* 8(3):209–224.

Marsalek, J., and H. Schreier. 2009. Innovation in Stormwater Management in Canada: The Way Forward. *Water Quality Research Journal of Canada* 44(1):v–x.

Mayer, A.L., W.D. Shuster, J.J. Beaulieu, M.E. Hopton, L.K. Rhea, A.H. Roy, and H.W. Thurston. 2012. Building Green Infrastructure via Citizen Participation: A Six-Year Study in the Shepherd Creek (Ohio). *Environmental Practice* 14(1):57–67.

McGuire, G., N. Wyper, M. Chan, A. Campbell, S. Bernstein, and J. Vivian. 2010, February. *Re-inventing Rainwater Management: A Strategy to Protect Health and Restore Nature in the Capital Region*. Environmental Law Clinic, University of Victoria, Victoria, Canada, 107 pp. Available at http://www.elc.uvic.ca/press/documents/stormwater-report-FINAL.pdf (accessed September 3, 2012).

Murphy, G.K., and M. Gregory. 2009. *Stormwater Management Program and Funding Review*. 18 pp. Formerly available at http://www.kitchener.ca/en/ (accessed January 12, 2011).

Newton, D.B. 2005. *The Effectiveness of Modular Porous Pavement as a Stormwater Treatment Device* (unpublished PhD dissertation). Griffith

University, Nathan, Australia, 73 pp. Available at https://www120.secure.griffith.edu.au/rch/items/a98c0848-dec8-1f19-6609-03bd818ae830/1/02Main.pdf (accessed September 3, 2012).

Ontario Ministry of Environment. 2003, March. *Stormwater Management Planning and Design Manual*. Queen's Printer for Ontario, Toronto, 372 pp. Available at http://www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/std01_079721.pdf (accessed September 3, 2012).

Ontario Ministry of Environment and Energy. 1994, June. *Stormwater Management Practices Planning and Design Manual*. Queens's Printer for Ontario, Toronto, 260 pp. Available at https://archive.org/stream/stormwatermanage00marsuoft#page/n1/mode/2up *and* https://archive.org/stream/stormwatermanage00marsuoft/stormwatermanage00marsuoft_djvu.txt.

Picketts, I.M., A.T. Werner, T.Q. Murdock, J. Curry, S.J. Déry, and D. Dyer. 2012. Planning for Climate Change Adaptation: Lessons Learned from a Community-Based Workshop. *Environmental Science & Policy* 17:82–93.

Podolsky, L., and E. MacDonald. 2008, August. *Green Cities, Great Lakes: Using Green Infrastructure to Reduce Combined Sewer Overflows*. Ecojustice, Toronto, 51 pp. Available at http://www.blue-economy.ca/sites/default/files/reports/green%20cities.pdf (accessed September 3, 2012).

Rodriguez, J.M., J.J. Molnar, R.A. Fazio, E. Sydnor, and M.J. Lowe. 2008. Barriers to Adoption of Sustainable Agriculture Practices: Change Agent Perspectives. *Renewable Agriculture and Food Systems* 24(1):60–71.

Rogers, E.M. 1983. *Diffusion of Innovations*, 3rd edition. Free Press, New York, 524 pp.

Roseen, R.M., T.P. Ballestero, J.J. Houle, J.F. Briggs, and K.M. Houle. 2012. Water Quality and Hydrologic Performance of a Porous Asphalt Pavement as a Storm-Water Treatment Strategy in a Cold Climate. *Journal of Environmental Engineering* 138(1):81–89.

Rowe, A.A., M. Borst, T.P. O'Connor, and E.K. Stander. 2009. Pervious Pavement System Evaluation. In *World Environmental and Water Resources Congress* 2009, *Great Rivers: Proceedings of the Congress*, May 17–29, Kansas City, MO, S. Starrett, ed. American Society of Civil Engineers, Reston, VA, 1–8.

Sanderson, M., P.F. Karrow, J.P. Greenhouse, G.V.R. Paloschi, G. Schneider, G. Mulamoottil, C. Mason, E.A. McBean, P.N. Fitzpatrick, B. Mitchell, D. Shrubsole, and E. Child. 1995. Groundwater Contamination in the Kitchener-Waterloo Area Ontario. *Canadian Water Resources Journal* 20(3):145–160.

Sansalone, J., X. Kuang, G. Ying, and V. Ranieri. 2012. Filtration and Clogging of Permeable Pavement Loaded by Urban Drainage. *Water Research* 46(20):6763–6774.

Scholz, M., and P. Grabowiecki. 2007. Review of Permeable Pavement Systems. *Building and Environment* 42(11):3830–3836.

Siva, S. 2009. Appendix A: Executive Summary of Draft Final Report. In *Stormwater Management Program and Funding Review: Study Recommendation*. City of Waterloo, Waterloo, Canada, i–v. Available at http://www.waterloo.ca/en/contentresources/resources/living/report_stormwater_program_funding_review_april_2009.pdf (accessed January 29, 2014).

Thurston, H.W., M.A. Taylor, W.D. Shuster, A.H. Roy, and M.A. Morrison. 2010. Using a Reverse Auction to Promote Household Level Stormwater Control. *Environmental Science & Policy* 13(5):405–414.

Tivesten, E., S. Jonsson, L. Jakobsson, and H. Norin. 2012. Nonresponse Analysis and Adjustment in a Mail Survey on Car Accidents. *Accident Analysis & Prevention* 48:401–415.

Toronto and Region Conservation. 2008, November. *Performance Evaluation of Permeable Pavement and a Bioretention Swale—Seneca College, King City, Ontario*. Toronto and Region Conservation Authority, Toronto, 120 pp. Available at http://sustainabletechnologies.ca/wp/clean-water/stormwater-management/permeable-pavement/performance-evaluation-of-permeable-pavement-and-a-bioretention-swale-seneca-college-king-city-ontario/ (accessed September 3, 2012).

Vachon, S., and F.C. Menz. 2006. The Role of Social, Political, and Economic Interests in Promoting State Green Electricity Policies. *Environmental Science & Policy* 9(7–8):652–662.

Webster, C. 1997. Effects of Researcher Presence and Appeal on Response Quality in Hand-Delivered, Self-Administered Surveys. *Journal of Business Research* 38(2):105–114.

Yazicigil, H., K.K. Yilmaz, B.U. Erdemli, and O. Yagbasan. 2011. Impacts of Decreasing Recharge Rates on Sustainable Groundwater Management. In *Climate Change and Its Effects on Water Resources: Issues of National and Global Security*, A. Baba, G. Tayfur, O. Gündüz, K.W.F. Howard, M.J. Friedel, and A. Chambel, eds. NATO Science for Peace and Security Series C 3: Environmental Security, volume 3. Springer, New York, 43–50.

Yong, C.F., D.T. McCarthy, and A. Deletic. 2012. Predicting Physical Clogging of Porous and Permeable Pavements. *Journal of Hydrology* 481:48–55.

Zhao, T., L. Bell, M.W. Horner, J. Sulik, and J. Zhang. 2012. Consumer Responses towards Home Energy Financial Incentives: A Survey-Based Study. *Energy Policy* 47(3):291–297.

Zimmer, C.A., I.W. Heathcote, H.R. Whiteley, and H. Schroeter. 2007. Low-Impact Development Practices for Stormwater: Implications for Urban Hydrology. *Canadian Water Resources Journal* 32(3):193–212.