The Ohio State University
Campus as a Living Laboratory

# Establishing a Research Framework to Assess Permeable Pavement Sites at Ohio State

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## Executive Summary

Urban runoff is a ubiquitous problem in the United States. Runoff carries contaminants that alter the water quality and ecology of urban waters. In Columbus, the Olentangy River is not immune to these impacts.  Several strategies have been proposed to combat the issue of urban runoff, including permeable pavement systems. Permeable pavement is a paved surface that allows water to infiltrate the soil below. The pavement and subsurface soil layer act as a filter that catches contaminants before they enter the groundwater and nearby bodies of water.

Ohio State has several permeable pavement systems on campus. Although permeable pavement sites have been introduced on campus as part of Ohio State's ongoing sustainability and conservation initiatives, little research has been conducted to confirm the relative impact this technology has on water quality. Furthermore, University officials are hesitant to create new installations because of durability issues in freeze-thaw conditions and the possibility of chloride contamination from de-icing salts. In response to these concerns, the focus of this project is to create a framework for student-led research to evaluate Ohio State's current permeable pavement sites and assess the viability of permeable pavement for future storm water quality management on campus.

This research framework will address three questions: 1) Can permeable pavement withstand Ohio's freeze-thaw conditions, 2) Does permeable pavement's composition affect its durability, and 3) Does the use of de-icing salts on permeable pavement have a negative effect on soil and groundwater quality? To answer these questions, student researchers will conduct durability comparison studies in the field, laboratory composition and density tests, and soil chloride testing. This study will last approximately five years and will require two groups of students to complete the work. To find student researchers, several student organizations have been contacted, and two have already expressed interest. The students who take on this project will apply for and receive funding from applicable grants, such as the Coca-Cola Sustainability Grant. This project is an excellent opportunity for students to participate in research in their field and to influence Ohio State's and the City of Columbus' future sustainability policies.

## Introduction

Permeable pavement has been heralded as a promising technology in mitigating storm water impacts by reducing runoff that contributes to water pollution. However, because permeable pavement is still a relatively novel technology, little longitudinal research has been conducted to determine its effectiveness long-term. One of the particularly daunting challenges to installing permeable pavement is maintaining the pavement in freeze-thaw conditions, a frequent occurrence in Central Ohio. As a university that has several permeable pavement installations, Ohio State University has lacked a process by which to conduct follow-up research on existing permeable pavement on campus. To ascertain whether permeable pavement is a viable option for sustainable water quality control, and to determine whether further installation of permeable pavement is an option for campus sustainability, a structured proposal for future research is required. Working with Steve Volkmann, University Landscape Architect, and Laura Shinn, the Director of Planning, a proposal will be established for student-led research on current permeable pavement sites on campus. The goals of this research framework are to determine the practicality of permeable pavement on Ohio State's campus and to assess whether inclusion of permeable pavement in future sustainability initiatives could be used to meet storm water quality standards.

## Background

### *Urban Runoff at Ohio State*

Urban runoff is a major source of watershed impairment in the United States (United States Environmental Protection Agency [USEPA], 2012). Urbanized landscapes contain large areas of impervious surfaces, such as pavement, rooftops, and compacted soil. When rain falls in urbanized areas, large amounts of it cannot infiltrate the soil, so it flows directly into nearby water bodies, often carrying harmful pollutants. Examples of pollutants include sediment, organic contaminants from motor vehicles, pesticides and fertilizers from lawns, de-icing salts, and heavy metals from cars and rooftops (USEPA, 2013). Hydrocarbons from petroleum products have been shown to negatively impact larval fish growth (Milukaite, Sakalys, Kvietkus, Vosyliene, Kazlauskiene, & Karlaviciene, 2010), and urban runoff from roadways decreases the diversity of macroinvertebrate communities (Beasley & Kneale, 2004). In Columbus, the Olentangy River's water quality and in-stream communities have been negatively impacted by urban runoff (Ohio Environmental Protection Agency [OEPA], 2007).

Every five years, the Ohio Environmental Protection Agency (OEPA) surveys large watersheds. They use chemical water quality, habitat quality, and the diversity of aquatic macroinvertebrate and fish communities as measures of overall stream health. Because stream organisms have low migration rates and can inhabit a stream for up to five years, they are an indirect measure of a stream's current and historical water quality (OEPA, 2007).

In 2005, the OEPA conducted their most recent survey of the Olentangy River watershed. The Lower Olentangy, specifically the section south of I-270, was largely impaired by the effects of urbanization. Additionally, two sites near Ohio State were affected by urbanization, particularly urban runoff. One site, near Union Cemetery, had a partial attainment[1] status for aquatic life use. The other, upstream from the Fifth Avenue Dam, was considered a non-attainment site because of the combined effects of the dam and urban runoff. In response to the poor quality of these sites, the EPA recommended that Ohio State improve their storm water management program by implementing practices that reduce the volume and/or improve the chemical quality of urban runoff. They listed several storm water "best management practices", and permeable pavement was one of them (OEPA, 2007).

*Permeable Pavement*

The OEPA considers permeable pavement a watershed-based approach to storm water management (OEPA, 2007). Permeable pavement is a paved surface that allows water to infiltrate through the pavement to the soil below, and its main purpose is to decrease the amount of runoff that reaches urban bodies of water. Typically, a permeable pavement installation has a subsurface layer composed of sand, gravel, and clay. The pavement and subsurface layers filter out harmful contaminants that urban runoff carries before they reach nearby water bodies (Scholz & Grabowieki, 2007). Several types of permeable pavement are currently being used throughout the country.

*Types of Permeable Pavement*

The most common types are permeable concrete, permeable asphalt, and brick pavers. Permeable concrete and asphalt are very similar in their composition. The large difference between permeable concrete or asphalt and traditional concrete or asphalt is that they are mixed

[1] Attainment for aquatic life use is defined by the water and habitat quality of a site. An attaining site allows for diverse, resilient macroinvertebrate and fish communities. Partial and non-attainment sites have diminished water and/or habitat quality, causing fish and macroinvertebrate communities to be comprised of pollution-tolerant species, with very few sensitive or rare species (OEPA, 2007).

without fine particles (those less than 600 μm). This allows water to pass through the surface, but often at the expense of durability. These types of permeable pavement are meant for parking lots, light traffic roadways, bike paths, and sidewalks.

Brick or block pavers are another common type of permeable surface. The pavers are typically composed of impermeable concrete, and they interlock, leaving an open void space between the pavers to allow water to pass through. The space between the pavers is filled with sand, gravel, or grass. For this pavement type, areas of less traffic are recommended, such as overflow parking lots, sidewalks, and driveways. (McNally, Philo, & Joubert, 2005). Ohio State has all three types of permeable pavements on campus, which are described briefly in the next section.

### *Ohio State's Permeable Pavement Installations*

Ohio State has four installations of permeable pavement on campus. They are located at Neil Avenue, 11$^{th}$ Avenue, 17$^{th}$ Avenue, and Cunz Hall. The permeable asphalt site on Neil Avenue is the oldest site, and it was installed in 2008. There has been noticeable wear to this site because it has been through several severe winters. The parking lot on 11$^{th}$ Avenue is permeable concrete, and it was installed in 2010. It was strategically located in the center of the available parking space and near the sidewalks to decrease the amount of traffic on the pavement. The sites at 17$^{th}$ Avenue and Cunz Hall were installed in 2012, and they are both brick pavers with gravel. The only traffic that these sites experience is foot traffic; therefore, these sites have not shown signs of significant wear (S. Volkmann, personal communication, February 13, 2013).

### *Freeze-thaw Considerations*

Permeable pavements are being used as a storm water management technique throughout the country, but special considerations are needed for areas that experience wet, freeze-thaw conditions. During a precipitation event in the winter, water infiltrates the pavement, freezes, and expands. This may cause significant structural damage to the pavement, and is one of the primary concerns that Ohio State decision makers have about permeable pavement (Interlocking Concrete Pavement Institute, 2006; S. Volkmann, personal communication, February 13, 2013). The use of de-icing salts on permeable pavement is also a concern (S. Volkmann, personal communication, February 13, 2013). Permeable pavement efficiently captures some contaminants, such as heavy metals and hydrocarbons, but chloride ions from de-icing salts are not adsorbed by the pavement. Chloride ions pass through permeable pavement and could contaminate the soil and groundwater beneath an installation (Interlocking Concrete Pavement Institute, 2006). The mixture design of pavement, chloride ion monitoring, and the placement of permeable pavement installations can help combat these issues.

Mix designs for permeable cement have been developed to increase the pavement's resistance to freeze-thaw damage. For example, adding sand to permeable concrete mixtures increases its freeze-thaw durability. Schaefer et al. (2006) created several permeable concrete mixtures with river gravel, pea gravel, or limestone as the main aggregate, and sand and/or latex were added to some mixtures. All samples were subjected to a freeze-thaw test. The mixture that contained river gravel and sand performed the best in the freeze-thaw test and maintained adequate permeability. Additionally, concrete mixtures that had a density between 127 and 132 $lbs/ft^3$ were adequately durable and permeable (Schaefer, Wang, Suleiman, & Kevern, 2006). Therefore, the aggregate composition and density of a permeable concrete mixture are important factors to consider when installing permeable pavements in cold climates.

Chloride contamination from de-icing salt applications is a concern for permeable pavement in cold climates, but some solutions have been proposed to decrease the likelihood of soil and groundwater contamination. During light (<2 inches) snow events, some permeable pavements do not require de-icing salt application. For example, permeable pavement installations with adequate sun exposure often require less de-icing salt because the sunlight melts the snow and ice on the surface before black ice can form. Unfortunately, during heavy snow events or in heavily shaded areas, large amounts of de-icing salt are required (Ballestero, Roseen, & Houle, 2011). If this is the case, then chloride testing of the soil or groundwater is needed on a regular basis (Interlocking Concrete Pavement Institute, 2006).

## Research Review

Methods already exist to test for the durability of permeable pavement, and we propose several of these previously tested methods for use in this research framework. One of these proposed methods, ASTM Standard C 666/666 M, tests the durability of concrete samples to repeated freezing and thawing cycles in a controlled laboratory setting (ASTM Standard C 666/666 M, 2008). The freezing-thawing apparatus is a chamber with the necessary refrigeration and heating equipment to continuously and automatically produce regulated freeze-thaw cycles. Samples for the test are cured concrete cylinders between 7.5 mm and 125 mm in width, depth, and diameter and between 275 mm and 405 mm in length.

For the freezing portion of the test, samples are placed in between 1 mm and 3 mm of water, and the temperature is lowered from 4° to -18°C. The freezing process lasts between two and five hours. During the thawing portion of the test, the samples remain in the water from the freezing cycle, and the temperature is raised from -18°C to 4°C. The thawing process must be 25% of the initial freeze time to achieve accurate results. Samples are removed every ten freeze-thaw cycles to determine mass, fundamental traverse frequency, and length change. After removal, specimens are returned to random positions in the freeze-thaw chamber, and ten more freeze-thaw cycles are completed. This process is repeated for 300 cycles, or until specimens fail. Passing metrics and equations to calculate those metrics are in the ASTM Standard C 666/666 M manual (2008).

Because of concerns of chloride contamination, soil chloride concentrations in the soil surrounding permeable pavement sites must be monitored. Soil samples should be collected from under and around permeable pavement installations using a soil probe. Each sample is mixed with deionized water, treated with a series of reagents, and centrifuged. The solution is decanted off, and 5 mL is analyzed in an Ion Chromatograph, which will determine the soil chloride concentration. For detailed instructions, reagents, and equipment, please refer to the California Department of Transportation's Test 422 (2006).

## Research Framework

### *Overview and Research Questions*

The aim of the proposed research framework is to determine whether permeable pavement is a viable option for improving storm water quality on Ohio State's campus. The primary barrier to permeable pavement's long-term effectiveness is central Ohio's rapid freeze-thaw climate conditions, which may cause considerable cracking and wear of permeable pavement sites in comparison to impervious forms of pavement. Additionally, permeable pavement could allow greater amounts of chemicals from de-icing salts to leach into the groundwater or combine with runoff in winter, causing elevated levels of chloride in campus storm water and further contaminating the Olentangy River.

Previous studies set in similar climate conditions as those experienced on Ohio State's campus indicate that increased wear and tear of permeable pavement sites and increased chloride levels in the water may not be inevitable outcomes of permeable pavement installations, as previously stated (Interlocking Concrete Pavement Institute, 2006; Schaefer et al., 2006). Given the unique nature of Ohio State's freeze-thaw conditions and traffic patterns, however, research for campus permeable pavement is necessary as part of the "Campus as a Living Laboratory" initiative. We therefore propose a student-led research project to be conducted over a period of five years, with oversight from OSU Sustainability officials, to determine the durability and impacts of Ohio State's permeable pavement installations in both laboratory and field settings. The data collected from this research will be used to answer three specific questions:

1. *Can permeable pavement withstand Ohio's rapid freeze-thaw conditions?*[2]
2. *How does the composition of permeable pavement affect the durability and permeability of the pavement?*
3. *Does permeable pavement significantly (negatively) affect water quality (in this case, with regard to chloride levels)?*

Data to assess the viability of permeable pavement will be collected using three different methods: 1) durability comparison studies in the field, 2) laboratory composition and density tests, and 3) soil chloride testing. This project will occur over a span of five years and will be conducted by two phases of undergraduate research teams. The program will have a built-in mentorship component, by which the first undergraduate team will mentor the new freshman team in the third year of the project. Each team will use their senior year to produce an independent thesis using data from the project, therefore further encouraging undergraduate research on campus. The methods for this study are detailed below.

*Durability Comparison Study*

To determine the durability of current permeable pavement sites on campus, students will track repairs recorded in maintenance records for all four permeable pavement sites on campus. In this part of the study, students will work closely with Facilities Management to determine the frequency of repairs and the level of wear and tear between permeable pavement sites and comparable non-permeable pavement sites on campus. These comparisons will then be analyzed

[2] Do permeable and impermeable pavements experience wear and tear at faster, slower, or relatively equal rates?

using ANOVA procedures to determine the presence of statistically significant differences in durability between permeable and comparable non-permeable sites. The results of this analysis will be used to draw conclusions about the relative durability of permeable pavement in Ohio's unpredictable freeze-thaw climate.

This durability comparison study will consist primarily, if not entirely, of document research. Students will review past maintenance records to aggregate data on maintenance across each of the four sites. Then, students will compare data from permeable sites and comparable non-permeable sites. When choosing non-permeable pavement sites for analysis, comparability is important for limiting confounding variables in the data. Considerations for comparability should include the level and type of traffic, type of pavement, year of installation, shade cover, proximity to trees, and location on a slope. After pairing each of the four permeable sites with a comparable non-permeable site, the number of repairs to each type of pavement and severity of repairs will be analyzed. A ranking from 1-5 will be used (1 being least severe, 5 being most severe) to gauge the severity of each type of repair. Students will work with Facilities Management to determine these metrics. As an illustration, the data could be recorded as presented in Table 1.

*Neil Avenue Pavement Data, 2008-2013*

| **Location** | **Number** | **1 Frequency** | **2 Frequency** | **3 Frequency** | **4 Frequency** | **5 Frequency** |
|---|---|---|---|---|---|---|
| **Neil Avenue perm paver** | 15 | 3 | 7 | 2 | 1 | 2 |
| **Neil Avenue nonperm** | 9 | 2 | 5 | 1 | 1 | 0 |

**Table 1.** Example of a data collection table. Please note that this table does not reflect actual measurements.

Once the data is aggregated, students will run an ANOVA to determine: a) whether there is a statistically significant difference in the *amount* of maintenance required for permeable pavement sites in comparison to non-permeable pavement sites, b) whether there is a statistically significant difference in the *level* of maintenance required for permeable pavement sites in comparison to non-permeable sites, and c) whether any significant differences found indicate a greater number or level of repairs for permeable or non-permeable sites (our hypothesis being that permeable sites would likely require more maintenance). Depending on student interest in the project, a small student team can also be delegated to tracking repairs and maintenance over the next five years, in conjunction with the proposed timeframe of the entire permeable pavement assessment project. This could provide an opportunity to compare current maintenance records with past maintenance records, to determine whether maintenance needs increase in frequency and/or severity level or time.

The contribution of the durability comparison study to the overall proposed project is providing researchers with "real-world" knowledge of permeable pavement durability in the variable and unpredictable freeze-thaw climate experienced by Ohio State. This segment of the research project would therefore be pertinent to OSU decision makers because the data gathered would be specific to campus. Including statistics-based document research is also important for researcher recruitment, as students more interested in mathematics and statistics rather than laboratory research would be given the opportunity to contribute.

*Composition and Density Tests*

Students will work in the lab to replicate the composition and density tests conducted by researchers at the University of Iowa's Center for Transportation Research and Education (Schaefer et al., 2006). Composition tests will focus on using sand and river gravel aggregates in different levels and combinations within various replicated pavement samples. Sand and river gravel will be the primary aggregates used because the research by Schaefer et al. (2006) previously indicated these substances to be the most effective at ensuring durability in rapid freeze-thaw conditions. However, students will also be able to suggest other aggregate materials for further testing, with the possibility of completing independent theses as a result of this work. The samples created by students in the lab will then be subjected to laboratory freeze-thaw tests using the ASTM Standard C 666/666 M test and running samples through 300 trials in the freeze-thaw chamber, or until the specimens fail (2008)[3]. Density of each sample will also be recorded as a function of these various combinations of aggregates across each trial in this particular series to measure the rapidity of degradation for each particular sample. The data from each trial phase of 300 trials will be used to create samples for the next trial phase that

[3] The ASTM Standard C 666/666 M protocol requires 300 freeze-thaw cycles for a statistically significant amount of data (2008).

approximate the concentrations of the most successful samples in the previous trial. In this way, student researchers will be able to determine the optimal aggregate mixture for permeable pavements in rapid freeze-thaw conditions (Schaefer et al., 2006).

In separate tests, students will keep the composition of permeable pavement samples constant (in regards to different combinations of sand and river gravel) while alternating the density of permeable pavement samples. Density will be measured among two different sample trial series, one in which density is varied by adding and subtracting sand, and one in which density is varied by adding and subtracting river gravel (Schaefer et al., 2006). Schaefer et al. (2006) had previously found that permeable pavement density between 127 and 132 lbs/ft$^3$ was optimal for freeze-thaw conditions typically found within Iowa. Students will also run these samples through freeze-thaw ASTM Standard C 666/666 M tests (2008). By comparing the data from the density test trials with the data from the composition test trials, student researchers will be able to determine whether density independently affects durability of permeable pavement, or whether density as a function of particular aggregate compositions create optimum pavement samples for withstanding rapid freeze-thaw conditions (Schaefer et al., 2006; ASTM Standard C 666/666 M, 2008).

Pavement samples fabricated in the lab can range in size between 7.5 and 125 mm in width, depth, and diameter and 275 and 405 mm in length according to convention, but the specific size parameters chosen for samples by the research team should be kept constant across all trials (ASTM Standard C 666/666 M, 2008). Following the procedure for pavement fabrication outlined by Schaefer et al. (2006) to ensure adequate bondage between the cement mixture and the aggregate(s), students will mix a small amount of standard cement mixture (less than 5% mass) with the particular aggregate until thoroughly coated, or for approximately one minute. Then, the remaining cement and water is added, mixed for three minutes, and allowed to rest for three additional minutes. After resting, the sample should be mixed for two more minutes and then cast (Schaefer et al., 2006). Researchers at Iowa State found that a binder-to-aggregate ratio of 0.21 was optimal, as was a water-to-cement ratio of 0.27 (Schaefer et al., 2006), so students will be instructed to follow these guidelines while mixing their samples.

The final stage will combine the data gathered from both the composition and density tests and apply these findings to a real-world setting. If time and funding permits, student researchers will recommend a permeable pavement installation for campus that combines optimal sand/gravel composition with optimal density, as determined in the lab setting. These students will then help coordinate and oversee the installation of a small permeable pavement test site on campus, in an area with low- to moderate-foot traffic.[4] Students will then work with Facilities Management to monitor the pavement site for frequency of repairs and level of degradation over time. This final stage will likely require a two- to three-year research period to track significant changes over time. It is therefore recommended that students complete laboratory composition and density tests within the first two to three years of the five-year proposed project timeframe.[5] The five-year timeframe can most likely be met if multiple student teams are assigned to conduct multiple trials at once. Therefore, composition and density testing will likely require the greatest number of student researchers.

Composition and density tests are integral to the overall pavement assessment project because the data from these tests will allow OSU officials to identify optimal permeable pavement types for future use on campus. The ultimate goal of these tests is to ensure that any future permeable pavement installations will be able to withstand Ohio's rapid freeze-thaw conditions better than the permeable pavement installations currently on campus, some of which have experienced significant wear in comparison to regular pavement sites (T. Ekegren, personal communication, February 11, 2013). Compaction testing will also benefit student researchers interested in getting involved with rigorous research and leadership positions, as these tests will require many trials and tightly coordinated management of several student teams to achieve favorable results. The allowance for creativity in proposing different aggregates for testing also provides the added opportunity for students to create their own independent projects which may lead to undergraduate theses.

*Soil Chloride Testing*

Soil chloride testing will be conducted to determine whether there is a significant difference in soil chloride levels between permeable and non-permeable sites on campus. Steve Volkmann expressed concern that de-icing salts used in winter on permeable pavement sites

[4] A note on compaction tests: Because all compacted samples performed poorly in the Iowa State University test (Schaefer et al., 2006), and because University officials are already aware that high compaction reduces permeable pavement performance (T. Ekegren, personal communication, February 11, 2013), compaction tests will not be performed in a lab setting. Rather, students will focus on replicating freeze-thaw tests on samples with varying compositions and densities and use these results to make recommendations on future permeable pavement installations.

[5] Student turnover for the proposed research project will be discussed in the Time Requirement section, page 13.

could percolate into the soil and groundwater, elevating chloride levels (Personal communication, February 13, 2013). Tests will therefore be used to verify whether or not permeable pavement sites significantly contribute to higher, or at least more greatly fluctuating, chloride levels.

Using a soil probe, students will take three to five soil samples from the four permeable pavement sites on campus and compare them to soil samples from comparable non-permeable sites (see previous section on the durability comparison study to determine what constitutes "permeable sites"). These samples will be drawn on a weekly basis, and the location of each sample will remain constant across the study (for optimal results, students could take samples from each cardinal direction surrounding the site). Samples will then be analyzed using an Ion Chromatograph,[6] as previously detailed, and the concentration of chloride across comparable permeable and impermeable sites will be recorded. The recorded data for permeable sites and impermeable sites will then be tracked on overlapping line graphs across each of the four permeable/impermeable comparison couplings each month. Average chloride levels for each month will then be used to construct an overlapping line graph for each pair of comparison sites for the entire year. At the end of the five-year pavement assessment, students will be able to determine whether permeable pavement links to elevated chloride levels in the soil, and whether these levels warrant discontinuation of permeable pavement installations.

Soil chloride testing, much like the other tests detailed in this section, is important for decision making on campus and for student researcher recruitment. Because Ohio State is considering the use of permeable pavement to mitigate storm water contamination, soil chloride testing is critical to determine that permeable pavement does not actually *degrade* water quality. Additionally, providing "basic science" research for students interested in environmental science could allow students to get involved in applied research without having to agree to the more rigorous commitment of researching on the laboratory teams studying pavement composition and density[7].

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[6] The Earth Sciences Department on Ohio State's campus houses an Ion Chromatograph. Therefore, this test will not pose a significant cost to the University ("School of Earth," n.d.)

[7] Refer to the section entitled "Research Review" on page 6 for more details on the methods described above.

*Time Requirement*

This framework proposes a longitudinal study with a minimum time frame of five years. Given the predictable turnover rate of undergraduate students and the "long-term" nature of this study, we therefore propose the implementation of an informal mentorship program to ensure the continuation of the study across two sets of "research cycles." High-achieving students in the areas of environmental science, engineering, and statistics will be recruited during their freshman year to work with Steve Volkmann and Facilities Management to commence the study. Student organizations related to the fields named above will be informed of this opportunity to recruit student researchers for the study. These researchers will continue to collect data throughout their freshman, sophomore, and junior years of college. After three years of research, "second cycle" freshmen researchers will be recruited and trained by the outgoing "first cycle" researchers (now juniors) to continue the study for two years. During their fourth year, "first cycle" researchers will be encouraged to complete an undergraduate thesis in conjunction with their work on the pavement assessment project. This proposed mentorship system will allow students to complete the proposed long-term study while also having time to complete independent thesis projects.

## Student Involvement

Student involvement is vital to completing the research outlined in the above framework. The framework offers a unique research opportunity for students at Ohio State. In this manner, the research opportunity lies at the heart of Ohio State's "Campus as a Living Laboratory" initiative by promoting the involvement of students in campus research. To ensure success of the framework, educational outreach and communication are necessary.

Educational outreach is an important motivator to promote student involvement. Because many people are unaware of the pre-existing permeable pavement sites on campus, signs should be introduced to these areas. Signs are a cost-effective communication technique, bringing awareness to the existing permeable pavement sites on campus. Therefore, these signs may intrigue Ohio State's students to learn more about this novel technology.

Promoting student involvement requires communication. Campus organizations are being contacted and informed of the research opportunity provided by the framework. These key organizations include Engineers for a Sustainable World, Friends of the Lower Olentangy Watershed, TerrAqua, The Materials Science and Engineering Club, and The Society of

Environmental Engineers. This promotion of the framework has provided promising results. TerrAqua, the student chapter of the Soil and Water Conservation Society, has expressed interest in the project. Furthermore, Holly Lorton, the Secretary of The Society of Environmental Engineers, has posted this research proposal on the organization's ListServ for any members who may be interested.

**Funding**

Any organization willing to utilize the framework will need financial support. Financial support is required to provide laboratory and field equipment needed for research purposes. A few key grants are available for any organization with interests in the project, including the Battelle Endowment for Technology and Human Affairs, Coca-Cola Sustainability Grants, and SEEDS: OARDC Research Enhancement Competitive Grants Program. Interested students or organizations are encouraged to apply for these grants and to continue searching for other grants that may not be listed above.

The Battelle Endowment for Technology and Human Affairs is a well-suited grant opportunity for the project. The grant is managed through the Office of Research with an overall goal to "gain a better comprehension of the capabilities and limitations of science and technology" (Office of Academic Affairs, 2013). The proposed research framework corresponds to this goal by analyzing the advantages and disadvantages of permeable pavement on campus. Another core goal of the Battelle Endowment for Technology and Human Affairs Grant is to pursue scientific research in a manner that coincides with societal needs. Pursuing a better standard of living by improving the environment is an important societal need. Our proposed research framework would meet this requirement by providing empirical data to determine the usefulness of permeable pavement to enhance water resources in Columbus.

Coca-Cola Sustainability Grants are also a potential funding opportunity for student-led initiatives.[8] A primary requirement for this grant opportunity is for students to lead on-campus research promoting sustainability and conservation, which fits the description of our proposed research framework (Office of Student Life, 2013). Financial support also may be satisfied

[8] Coca-Cola Sustainability Grants are provided to registered student organizations at Ohio State, but the organization must have the assistance of a faculty member. A list of faculty members through the School of Environment and Natural Resources who may assist with the application process for these grants can be found at the school's website, senr.osu.edu.

through the SEEDS: OARDC Research Enhancement Competitive Grants Program. The grant stems from The Ohio Agricultural Research and Development Center and encourages innovative research proposals with the potential to enhance research on a broader scale (Kaser, 2010). The proposed research framework offers a unique opportunity to impact all areas in the United States with temperate climates by determining the durability and effectiveness of permeable pavement in rapid freeze-thaw conditions like those found in Columbus. Furthermore, the research may identify permeable pavement as a technology with the potential to meet storm water quality standards for the city.

**City and Campus Implications**

The research framework proposed in this paper will give students an opportunity to participate in on-campus research and allow permeable pavement to be included in Ohio State's sustainability initiatives. Ohio State is a research institution, and the University regularly encourages students to participate in research-related activities. Research into permeable pavement sites on campus is the perfect opportunity for students with an interest in civil or environmental engineering, materials science, or soil science to become involved in research related to their field of interest. The results of this research will also inform decision makers on the feasibility of permeable pavement in Ohio's climate. If permeable pavement is found to be adequately durable and effective with regards to freeze-thaw conditions, then the University could install more permeable pavement sites to help to improve the Olentangy River's water quality. The results of this research might also allow for greater collaboration with the City of Columbus with regards to city-wide sustainability initiatives.

The City of Columbus currently treats permeable pavement as traditional pavement in their storm water regulations (T. Ekegren, personal communication, February 11, 2013). The results of this research might convince the City of Columbus to change their storm water requirements to include permeable pavement as a mitigation technique. If the results of this project do convince Columbus to revise their storm water regulations, then this could allow for the installation of new permeable pavement sites throughout the city. As a result, Columbus could become a model for other Midwestern cities considering installing permeable pavement, and the work of the student-led research could provide a foundation for future studies in other areas.

**Conclusion**

Permeable pavement is a promising technology used to reduce runoff and to enhance water quality in urban settings; however, Ohio State decision makers have stressed strong concerns regarding the viability of permeable pavement in Ohio's climate. For this reason, student-led research is required to collect valuable data pertaining to the ability of permeable pavement to endure freeze-thaw conditions on campus. The proposed framework will analyze pre-existing permeable pavement sites on Ohio State's campus with regard to their durability and their potential contribution to soil chloride levels. Ultimately, the aim of this research will be to determine the viability of permeable pavement as a storm water quality management technology for future campus construction.

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