# Recommendations for Bank and Bluff Erosion Monitoring Using Citizen Science in Walkerton, Ontario

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## Abstract

The Saugeen River flows directly through downtown Walkerton, Ontario and it is cutting into its valley across from Riverbend Park. The river has encroached into the valley walls, resulting in consistent and considerable bank and bluff erosion over the last few decades. This study explores the ways in which the erosion across from Riverbend Park could be better understood and monitored using citizen science – a suite of tools and methods that rely on non-scientists and local citizens to produce scientific data. Because bank and bluff erosion in general is complex and variable in time and space, citizen science methods could be critical for provide observation and reports for qualitative assessment of erosion. In addition, image-based methods such as 3D photogrammetry have been used to produce high-resolution quantitative information that could allow for better understanding of the specific process, rates, patterns, and locations of erosion in Walkerton. The success of citizen science is often dependent on the presence of motivated citizens, which may be more likely to exist in Walkerton due to its infamous history of a water-related *E. coli* outbreak. The Walkerton bluff is also the location of protected bird species, with further complicates efforts to abate erosion yet could be another focus of citizen science. The results of this study are a series of discussions and recommendations for possible monitoring and erosional assessment programs using citizen science methods.

## Introduction

Non-scientists are better equipped than ever to provide and produce meaningful geographic data using mobile devices and new technologies (Dehnen-Schmutz et al., 2016; Scardino et al., 2022; Harley & Kinsela, 2022; Kim et al., 2011). This methodology, called citizen science, harnesses community strength and social cohesion to solve complex research questions through the collection of data (Grootjans et al., 2022; Harley & Kinsela, 2022). Community members (citizen scientists) can also contribute through their findings and in some cases can also help develop new technologies (Grootjans et al., 2022; Scardino et al., 2022). Citizen science has been shown to provide data to researchers when and where data is otherwise difficult to obtain – in particular, citizens are effective at providing data over large areas and during unpredictable events (Theuerkauf et al., 2022; Harley & Kinsela, 2022). All citizen-science based research requires non-scientists to be interested enough in the project goals to spend time and potentially money to aid the research group while simultaneously reducing barriers for first-time participants (Zhang et al., 2023). Therefore, citizen science projects must provide benefits to those participating in some way. Much training and learning is also required, although specific learning outcomes depend on the discipline, facets of the project itself, and tasks required (Golumbic et al., 2022). It is therefore important to consider learning outcomes for every stage or activity conducted by participants of the project (Golumbic et al., 2022). The extent to which the average citizen is willing to participate in citizen science projects is not well known, but recent research suggests socioeconomic status and stakeholder impact are correlated with public participation (Allf et al., 2022).

Landscape erosion, in particular coastal and fluvial bluff and bank erosion, is difficult to predict and measure. High flow events and storm events often have short prediction times and could result in dangerous conditions near the location of interest. Technological difficulties can also arise from the episodic and unpredictable nature of these sites, and each specific field site can present unique challenges to install or operate scientific equipment. Direct human observation and imagery is therefore often necessary for successful active monitoring of erosional sites and the collection of useful data.

Local non-scientists could be particularly effective at improving the understanding of these rapid erosion events by using citizen science. Citizen science allows for members of a community to personally interact with their environment and the resources and sites they regularly benefit from (Kim et al., 2011; Albagli & Iwama, 2022). In addition, citizen science can affect citizen perspectives on the local environment and water resources, as well as build better trust between scientists and locals (Albagli & Iwama, 2022). Citizen science also allows the participants to feel emotionally involved, which supports a deeper sense of meaning and place in their local communities, whether they have resided there for their entire lives, or even a couple of months (Albagli & Iwama, 2022; Allf et al., 2022). The feeling of involvement, or social cohesion, has also shown to be linked with better health and wellbeing, and participants often reflect on their personal lives and habits when working as a part of a citizen science-based project (Kim et al., 2020; Grootjans et al., 2022). Finally, citizen science can also help improve scientific literacy for participants, and research using citizen science methods continue to expand educational opportunities for participants and encourage participation in future studies (Scardino et al., 2022; Kim et al., 2011).

The town of Walkerton is situated in Bruce County, Ontario. Walkerton is located approximately 70 kilometres south of Wiarton and the Bruce Peninsula, and 90 kilometres northwest of Kitchener-Waterloo. Walkerton neighbours the towns of Hanover and Mildmay and was home to 4,724 inhabitants in 2021 (Statistics Canada, 2022). The town of Walkerton also rests along the Saugeen River, which flows directly downtown. The river plays a key role in the town's history and will continue to influence Walkerton for years to come: one critical way this is happening is through river erosion. The glacial valley in which the Saugeen River travels through is the focus of considerable erosion, especially at Riverbend Park, located in downtown Walkerton. The town has commissioned an engineering firm to study the stability of the eroding slope in addition to other concerns.

One of these additional concerns is the potential removal or disruption of a bird species, the Bank Swallow (*Riparia riparia*), where there are at least seven known colonies along the Saugeen River ('Bank Swallow,' 2014; Cadman & Lebrun-Southcott, 2013). Nesting within the bluff by carving out burrows, these unique birds are threatened in Ontario ('Bank Swallow,' 2014). The Walkerton Bank Swallow colony alone had around 400 unique burrows, according to a 2013 study (Cadman & Lebrun-Southcott). The primary nesting area of the Walkerton colony is directly within the eroding cliff on the west side of the river's meander (Cadman & Lebrun-Southcott, 2013). It is clear from this that the combination of an obvious water-related hazard – that being the eroding cliff – and these additional concerns (and Walkerton's historical struggle with environmental issues) make for a unique opportunity for a study on citizen science and its usefulness in complex spaces.

The town of Walkerton is well known in Canadian history for a deadly *E. coli* and *C. jejuni* outbreak in May 2000 which has been deemed “the worst public health disaster involving municipal water in Canadian history,” and one of the world’s largest recorded *E. coli* outbreaks (Salvadori et al., 2009, p.S33). The outbreak killed at least 7 people and infected thousands with *E. coli* O157:H7 disease, gastroenteritis, and caused acute kidney failure in some (Salvadori et al., 2009; Cote et al., 2017). The outbreak was caused by heavy rainfall (134 mm) in the area over a span of 4 days, leading to high surface runoff into a municipal drinking water well from the surrounding agricultural landscape (Salvadori et al., 2009). The bacteria and organic matter within the manure used in local agriculture overwhelmed the chlorination of the well, which had been lower than usual due to fraud within the chlorination tracking system for over 20 years (Salvadori et al., 2009). With this unfortunate history of water crisis, the citizens of Walkerton have a deepened psychological connection to water-related issues and environmental hazards (Cote et al., 2017). Today, the town of Walkerton’s tourism website boasts “clean water living” despite a longstanding tainted reputation for unclean water (Walkerton: Bruce County, Ontario, 2018).

To summarize, the aim of this thesis is to assess the potential for using citizen science methods to monitor erosion from the Saugeen River in Walkerton, and to provide a synthesis of actionable recommendations for the municipality. A secondary aim is to determine the willingness and availability of local participation in citizen science efforts in Walkerton, which can serve as the focus of future work as recommendations from this thesis begin to be implemented.

## Background

### *The Saugeen River Watershed*

The Saugeen River is 160 km long and flows from the village of Badjeros to the town of Southampton, Ontario (‘The Saugeen River’, n.d.). The river’s source is at one of the highest elevations in southern Ontario at the Osprey Wetland Conservation Lands, and the mouth is at a shore of Lake Huron, south of Sauble Beach. The name “Saugeen” is derived from the Ojibway word *Zaagiing*, which means “at the river’s outlet” or “mouth of the river”. The Saugeen First Nation is located just north of Southampton, with some territory along the bank of the Saugeen River. The river is known for its good fishing of Rainbow Trout, Brook Trout, Salmon, Pike, and Saugeen Musky (endemic to the Saugeen).

The Saugeen River watershed (Fig. 1) is 4,675 square km in area and is located across Bruce, Dufferin, Grey, Huron, and Wellington counties in Ontario (‘About Us,’ 2022). The watershed area is largely dominated by rural areas with agricultural land usage (63%), followed by swamp wetlands (20%) (‘Ontario Flow Assessment Tool [OFAT hereafter]’, n.d.). The remaining 17% of land uses are split between deciduous, coniferous, and mixed forests (9%), urbanized areas and communities (3%), and a variety of other natural or cultivated land uses (5%) (OFAT, n.d.).

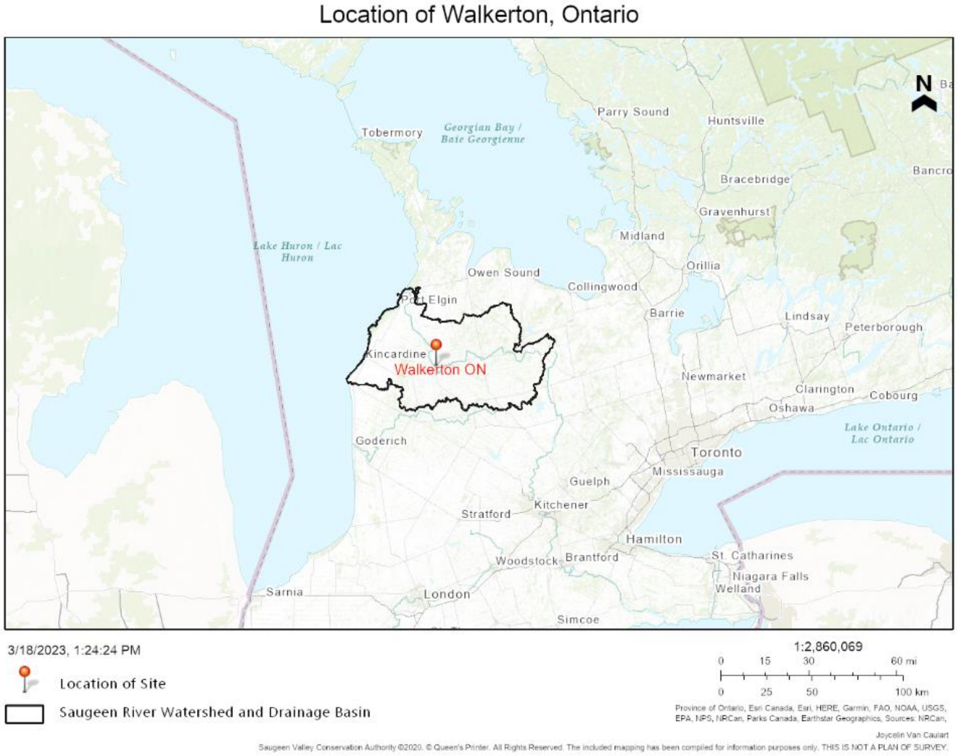


*Figure 1: Relative Location of Walkerton, Ontario, and the Saugeen River Watershed*

In 2018, Saugeen Conservation conducted a "Watershed Report Card" assessment of the watershed's health through four categories: groundwater quality, surface water quality, forest conditions, and wetland conditions. First, the assessment found that the watershed's groundwater quality was high, and that chloride and nitrate concentrations were above the provincial guideline level at monitored wells ('Saugeen Conservation Watershed Report Card [SCWRC, 2018 hereafter]', 2018). In terms of surface water quality, most areas within the watershed were ranked within the "A" to "C" ("excellent" to "fair") range, indicating a generally good surface water quality (SCWRC, 2018). More specifically, the "Lower Main Saugeen River" section of the watershed (where Walkerton is located) was ranked as a "B" category, indicating “good,” showing improvement since the previous report (SCWRC, 2018). The SCWRC (2018) also indicated that areas further away from agricultural areas, with more wetlands, and a higher percentage of forest cover had higher water quality. In this watershed, those spaces are generally found upstream. Forest cover was another category in the report, with the watershed having 27.5% of land categorized as “forest cover” overall (SCWRC, 2018). In Walkerton’s section of the watershed, forest cover is categorized to be “fair,” likely indicating the region’s heavier focus on agriculture land uses (SCWRC, 2018). Saugeen Conservation also reports that 761,249 trees were planted between 2013-2018, demonstrating a local effort to increase forest cover in their jurisdiction (SCWRC, 2018). Finally, wetland conditions were reported as well. The watershed contains 17.5% of land cover classified as wetland, and the report indicates a need for more wetlands constructed in “strategic locations” (SCWRC, 2018, p.2). Saugeen Conservation also goes on to explain that more “commitment to conserving wetlands is needed across the SVCA jurisdiction” overall (SCWRC, 2018, p.2).

### ***Walkerton Study Site***

The area of interest (Fig. 2) is located directly adjacent to Riverbend Park in Walkerton, Ontario, at approximately 44°08'16"N 81°08'59"W. The main section of the cliff is approximately 20 m high, and the entire eroding section spans around 250 m along the Saugeen River. Various angles of the site can be viewed from Riverbend Park.

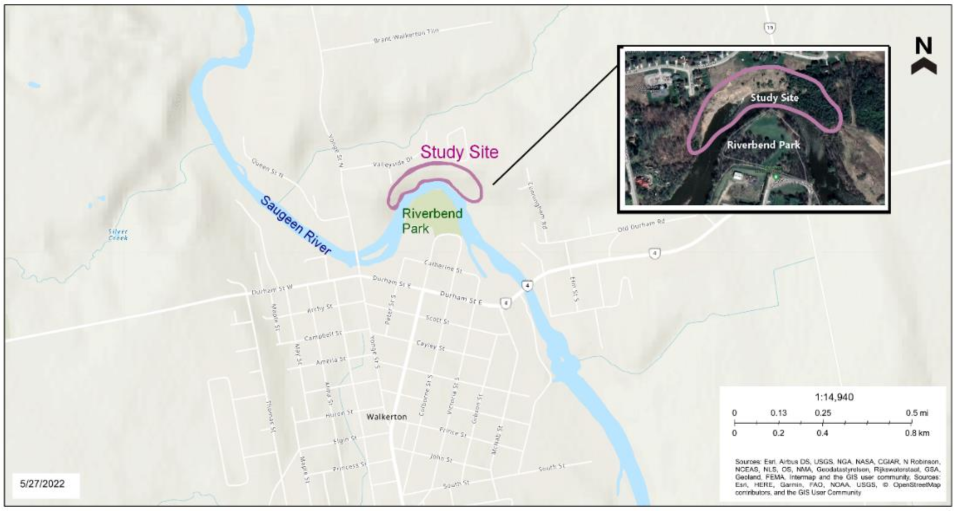


*Figure 2: Location of the eroding cliff in Walkerton*

This site has seen significant erosion over time, as demonstrated in Figure 3. This figure uses all obtainable air photo imagery from Google Earth Pro, which demonstrates the observable changes in the water's edge against the cliff from 2005 to 2021. The June 2005 aerial image serves as the background. The different coloured lines indicate different years of captured imagery, as provided by Google Earth's basic timeline feature.

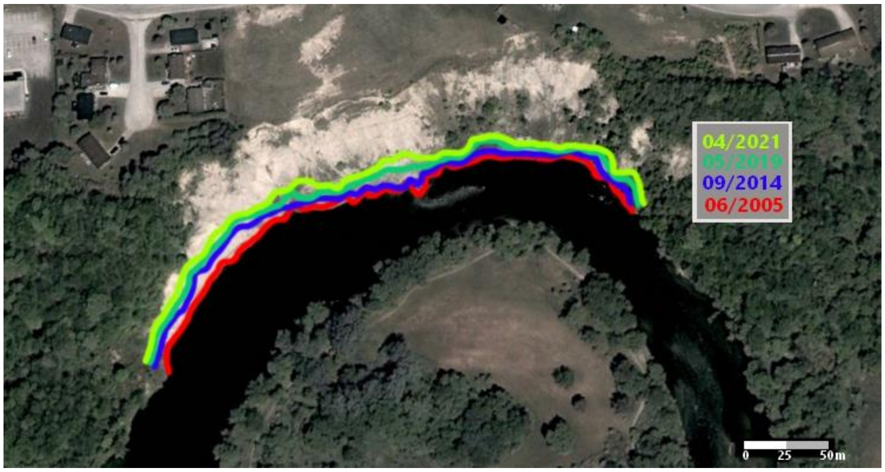


*Figure 3: Erosion from 2005-2021 at the study site*

It is shown in this image that the cliff edge has generally been receding northward, indicating significant erosion along this section of the river. Although this simplified image is useful for seeing some basic changes, changes to other aspects of the cliff face are not clear from an aerial image at this resolution and quality. Cliff overhangs, new vegetation patterns, bank swallow nesting sites, deposits of fallen debris, and more important aspects to this site are not visible in this figure. These types of information, which are critically important to better understand the patterns and rates of erosion, are difficult to obtain from simple, relatively low-resolution aerial photographs. In addition, the specific patterns of bank and bluff erosion can only be successfully interpreted with imagery of high temporal resolution, so these images make understanding the specific processes that are dominating bank erosion in this location challenging.

### *Studying Fluvial Erosion*

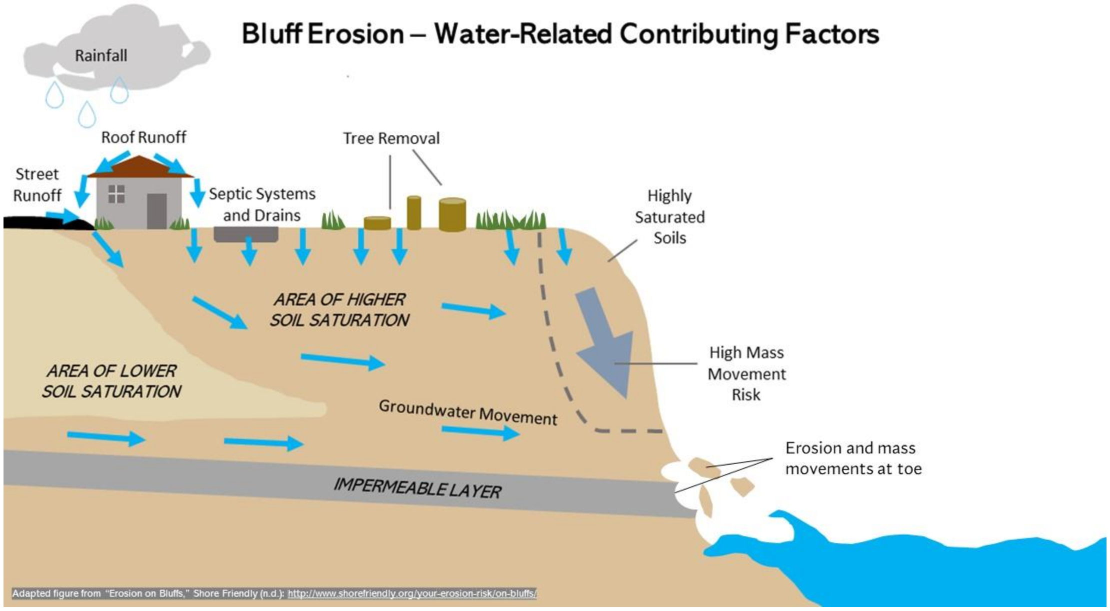
As previously mentioned, bank and bluff erosion are critically important processes, yet are difficult to directly measure in the field because of their episodic and unpredictable nature. Couper et al. (2002) provide an example of this in their work on bank erosion in three rivers in the United Kingdom. They found that the results of studies of bank erosion are heavily dependent on methodology used, with certain methods yielding vastly different results (Couper et al., 2002). They also found that a variety of factors in their own study (using erosion pins) contributed to changes in the resulting data – these factors included: high-flow depositions of sediment; soil fallout onto erosion pins from the upper banks; loosening of soils; expansion/contraction of the soil mass from temperature and moisture changes; movement of the erosion pin within the bank, and finally, human interferences (Couper et al., 2002). Considering the Couper et al. (2002) example, measuring erosion directly in the field is clearly difficult, with many possible factors affecting the collection of quality data that is representative of the site. Human interference is another large problem that studies of bank and bluff erosion face, in addition to natural factors affecting the stability of the slope, such as temperature changes (especially freeze-thaw cycles) and inclement weather.

River erosion rates and patterns are measured typically in either direct or indirect methods, or a combination of the two. The simplest direct method is the use of erosion pins, as used in Couper et al. (2002), where metal rods are placed into the eroding bank and the bank's position can be measured along the rods over a period of time. The use of photoreceptors is also commonly combined with this method, where the amount of rod exposed is measured through voltage in a data logger (Lawler, 1992). Another direct method is to conduct simple cross-section stream measurements at the site of interest, to measure both bank geometry and the rate of erosion over time (Doty, 2023; Park & Jung, 2010). This is not always realistic for all grades of rivers, however, and accessibility can pose a considerable issue in certain cases, such as that found at the site in Walkerton. Installing permanent or semi-permanent equipment can be dangerous because of the inherent instability of the slope, and equipment can be damaged, or their effectiveness reduced when major erosional events occur. In Walkerton, the protected Bank Swallow habitat also limits the amount of physical disturbance that is acceptable to install and monitor bank erosion directly.

A way around these challenges has been developed in recent years due to technological advances such as the proliferation of small unoccupied aerial systems (sUAS/UAV, or drones) and image-based “Structure from Motion” (SfM) photogrammetry. These methods have allowed for many new insights into erosion (Wernette et al., 2022; Pucino et al., 2021; Ierodiaconou et al., 2022; Theuerkauf et al., 2022; Hemmelder et al., 2018). These methods can also be useful for larger or more dangerous banks where direct methods may not be as effective or feasible.

Bluff erosion (like what we find in Walkerton) is complicated as a process. There are many factors that contribute to it, but water-related factors are the most important (Fig. 4). In Walkerton, much of the erosion is likely due to mass movements at the “toe” of the bank or bluff, where the water of the Saugeen River meets with the slope itself. During flooding events, elevated flow depth and velocity along the outer bank of the river (which coincides with the eroding face of the bluff) cause increased shear stresses on the channel bed and banks. This elevated shear stress has the capacity to loosen and carry sediment that is located along the bank toe, which can over-steepen the banks and destabilize them (Howard, 2009). In locations where flow depth and velocity are highest, consistent over-steepening of the bank due to this sediment movement will lead to small mass movements of sediment as it moves from higher up the bank to replace the eroded toe material. Over time, this process of “cutting” and removing sediment leads to consistent movement of the toe of the bank in the lateral direction (Howard, 2009). In Walkerton’s case, this means towards the already eroding bluff (Fig. 3).

Mass movements can also happen farther up the slope, particularly when the soils are unstable and highly saturated. Highly saturated and wet soils are weaker and therefore are prone to more mass movement. Tree removal, street and roof runoff, septic systems, municipal drains, and high levels of rainfall all contribute to highly saturated soil. Groundwater flow is another component to note – groundwater movement towards the bluff edge can also contribute to highly saturated soils.



Adapted figure from "Erosion on Bluffs," Shore Friendly (n.d.): http://www.shorefriendly.org/your-erosion-risk/on-bluffs/

*Figure 4: Conceptual diagram of bluff erosion processes and factors. [Note that there are many factors at play, and that every location is unique. This diagram provides an example of some of the considerations to make when designing policies and plans around bluff erosion.]*

The spatial distribution, magnitude, and frequency of mass movements on bluffs are difficult to understand and predict because they are the interaction among highly variable ground and surface water hydrology, the presence, absence, and type of vegetation, and the characteristics of the soil and near-surface bedrock material (Kelly & Belmont, 2018). Their occurrence is also highly transient in time and space, because one movement may reduce local bluff slope, thereby stabilizing it, or remove vegetation and roots from a section of the slope and thus destabilizing it. The same rainfall event might not cause a mass movement during summer, when vegetation is dense, but might do so earlier in the season before significant leaf area and biomass density can slow the movement of surface water downslope. Additional complications, such as the freezing and thawing of bluff sediment, has been shown to also have an impact on erosion patterns and rates (Roland et al., 2021).

Due to the complications discussed above, studies of bank and bluff erosion would certainly benefit from high spatial and temporal resolution imagery that could be used to qualitatively assess erosional patterns. For example, imagery with dates could be tied to nearby weather stations to connect the occurrence of a mass movement to the previous rainfall magnitude and duration – if that same rainfall event occurs at another time without a mass movement, one can ascertain that factors other than rainfall are clearly an important control on mass movement.

### Past Work Conducted at the Walkerton Site

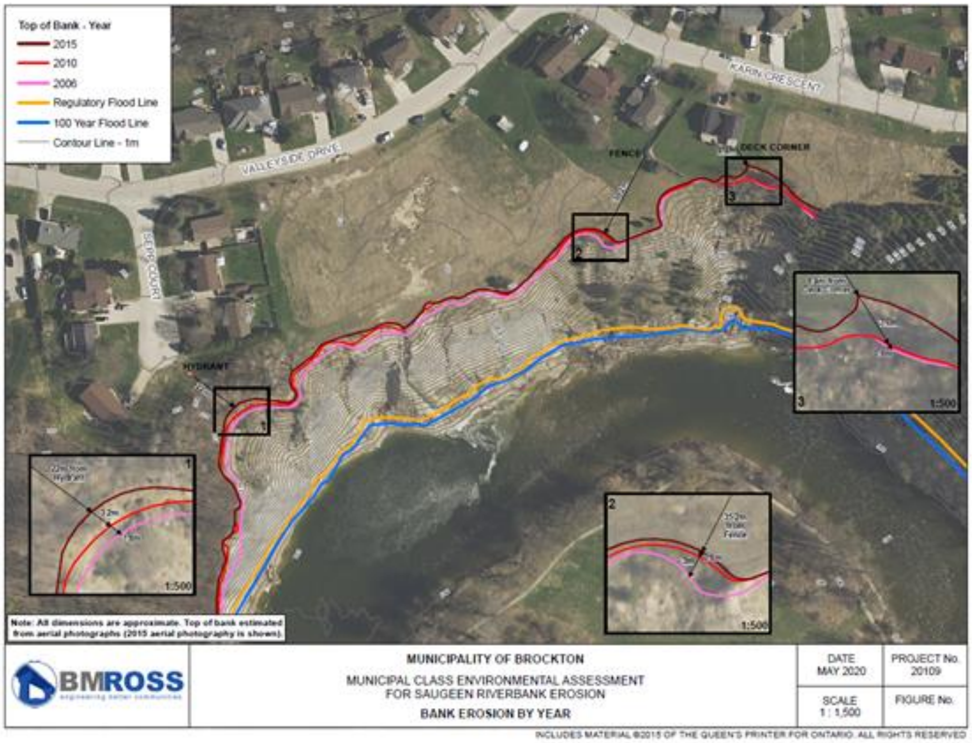


*Figure 5: Study Site Environmental Assessment by BMROSS*

BMROSS engineering has been actively monitoring the eroding bank/bluff across from Riverbend Park since 2019 and have produced detailed reports and site assessments (Fig. 5). There has also been both recent (2020) and older (1970s-2000s) geotechnical measurements of the bluff area which have produced information on sediment characteristics at borehole locations. The BMROSS site assessment has found that there are significant concerns that the erosion rates are high enough to put infrastructure, including fences, hydrants, and homes, at risk in the near future (Fig. 5). However, this assessment has been hampered by the lack of high temporal and spatial resolution information. For example, if active monitoring suggests that toe-of-bank erosion is the most important driver of bluff retreat, BMROSS would be able to make and assess plans to slow the flow along the Saugeen River’s outer bank with methods such as installing submerged vanes to physically disrupt and recirculate flow (Bhuiyan et al., 2010). Traditional engineering-based assessments, and ultimately solutions, are tried-and-true methods for slowing erosion like what is occurring at Walkerton. The additional of citizen science could act as either a supplement to these efforts, or a lower-cost alternative. Citizen science could be attractive because it can begin as a low-cost method, then later in the site assessment process be used to provide additional data and context to engineering assessments like that done by BMROSS.

## Rationale

Investigating what citizen science methods work best in active monitoring of the cliff at Riverbend Park will provide the town of Walkerton with a stronger understanding of their own abilities to conduct high quality active monitoring of the Saugeen River within their jurisdiction. By providing the town with a continual gathering of visual and numerical data through citizen science, the town of Walkerton is provided with a greater quantity and higher quality of information from which respective governments and decision-making organizations can conduct proper environmental management of the site. Future work at this site (whether academic or not) can also benefit by using these data, and other studies in similar contexts can use this study as a reference for pushing the agenda of citizen science and its associated benefits associated with citizen science methods for studying erosional hazards.

## Methods

Citizen science can be used as a method within a variety of studies in many different topics and fields. The following five case studies explore some methods and their uses for different topics of research, relevant to the Walkerton site.

### *Case Study I: Drone, UAV, and Photo-Based Citizen Science*

Citizen science methods using UAVs (commonly called drones) have proven to be effective in large scale studies. An example of this is found in Theuerkauf et al. (2022), where researchers conducted a review of a novel citizen science coastal change monitoring program in the Great Lakes Basin region. They found that drone-based monitoring was one helpful monitoring and data collection method, but even the simple uploading of photos was of use as well (Theuerkauf et al., 2022). In this project, those participating either submitted photos of perceived coastal changes or hazards via a web app or collected aerial imagery using drones which would later be developed into DEMs (Theuerkauf et al., 2022). Examples such as this demonstrate the potential for improving bank erosion (and other environmental hazard) monitoring efforts with the use of citizen science methodologies.

Another example is found in Hemmelder et al. (2018), where UAVs were used to map the geomorphological characteristics of two dynamic sections of the Buëch river floodplain in southeastern France. Apart from being easy to learn and use, UAVs are able to collect accurate imagery of floodplains and specific sites (Hemmelder et al., 2018). In this study, the images acquired were then processed using the SfM algorithm, which allowed for the creation of a digital elevation model (DEM) with a strong resulting accuracy of centimeters to decimeters for eroding banks (Hemmelder et al., 2018).

Similar studies have also shown that these methods are so simple that untrained citizens could easily partake in them (Pucino et al., 2021). Some advantages to UAV, drone, and photo-based citizen science are a relatively low cost, high precision in output products, ease in reproducing the study over different time periods, and overall simplicity (Pucino et al., 2021). Finally, citizens are better equipped than ever to capture imagery and data with their personal devices, and sharing imagery, location, and other information is now a part of many people’s everyday lives (Graham et al., 2011; See, 2019). This too adds to the accessibility and availability of these methods.

### ***Case Study II: Citizen Science for Active Flood Monitoring***

During flood events and other natural hazards, social media is a common ground for citizens to come together to actively report on the event (See, 2019). Twitter, as found in See (2019), was the most popular reportedly used social media platform for real-time flood monitoring. In some cases, social media platforms also allow for flood maps to be made in real-time, which can be a great advantage to emergence response teams and locals impacted by the flood event (See, 2019). A more specific example of one of these applications is PetaJakarta, which can be defined as an "active source of flood reports" that uses data collected from Twitter in Jakarta, Indonesia (See, 2019, p.4). Instead of using social media feeds for data mining, the use of applications such as these allows for decision makers and citizens to find all relevant information and reports quickly (See, 2019).

### ***Case Study III: Citizen Science for Fluvial Bank Erosion Studies***

Citizen science can provide municipalities and other governing bodies with incredibly useful information about erosion. For example, in collaboration with the District Municipality of Muskoka, the consulting company Water's Edge Environmental Solutions Inc. developed a citizen science project to "educate the public" on topics such as: the types, causes, and impacts of erosion (Gazendam et al., 2022, p.3). The project also educated the public on the "ecological impacts of erosion" within the Muskoka River Watershed bounds (Gazendam et al., 2022, p.3). The aim of the project in general was to create an application, called Muskoka E-Rode, which will serve as a reporting platform for erosional sites (Gazendam et al., 2022). This application and the associated citizen science project also helped district staff members make well-informed decisions about erosional hazards within their watershed with the use of the E-Rode platform data (Gazendam et al., 2022).

### ***Case Study IV: Citizen Science for Water Quality Studies***

Citizen science can be incredibly useful for water quality studies as well. Kim et al. (2011) provides an example of a mobile application (called CreekWatch) that was created for locals to monitor river pollution (levels of garbage) and water clarity (based on subjective categories). Although very limited, CreekWatch was an early example of a water quality-based citizen science platform. Similarly, another example is River Watch, a community-based water monitoring program in the Red River Basin (located between Manitoba, Minnesota, and North Dakota) (Sheppard & Terveen, 2011). River Watch uses many different parameters for water quality monitoring, including subjective descriptions of river appearance, *in-situ* measurements (such as pH and dissolved oxygen) using an electronic probe, and water samples collected by participants to be later analyzed in a lab (Sheppard & Terveen, 2011). Over its years of use, River Watch has provided crucial data on water quality issues, although it is mostly field based, which can create some data quality issues (Sheppard & Terveen, 2011).

### ***Case Study V: Citizen Science for Avian Habitat Studies***

Birding and avian citizen science projects are particularly popular among members of the public, with many different websites, apps, and community volunteering projects being used to monitor bird migration patterns, counts, and more (Silvertown, 2009). Some of these platforms are based upon a research hypothesis, whereas others are based purely on volunteerism in local communities towards the shared cause of monitoring (Silvertown, 2009). In other cases, avian monitoring is done unintentionally through applications such as iSpot and the Electronic Field Guide, where users simply use the provided resources to help identify and learn about birds and other species, without the goal of monitoring in mind (Silvertown, 2009). For avian monitoring and habitat studies specifically, a huge number of platforms exist for citizen science projects. Harnessing the capabilities of these platforms is one way to engage locals in intentional and unintentional citizen science.

### *Application to Walkerton Site*

As previously mentioned, these case studies are relevant to the site in Walkerton. For one, the use of drones/UAVs in this area would allow for detailed monitoring and mapping of the eroding cliff face. Flood monitoring methods could be beneficial for areas of the Saugeen River that are prone to floods and could increase flood hazard preparedness for locals. Next, bank and bluff erosion studies are particularly relevant due to the current erosional hazards at the site and could apply to other areas of the Saugeen River where erosion occurs.

Methods for monitoring water quality and avian habitat are less directly relevant to the erosion problem, although they still play large roles as secondary issues that could be addressed effectively with citizen science. The Bank Swallow habitat at the eroding cliff is one example of a location for potential avian monitoring. Another example is the ongoing monitoring of water quality in the Walkerton stretch of the Saugeen River, especially considering the many recreational activities practiced in and along the river, and Walkerton’s commitment to “Clean Water Living” (Walkerton: Bruce County, Ontario, 2018).

### ***Other Methods***

Quite a few other methods for citizen science studies exist in the literature. Apart from those listed in the previous sections, interviews, digitization, community workshops, and social media are some other methods that work particularly well in citizen science-based projects.

Table 1 outlines some of the general methods used for environmental citizen science-based studies. The references provided in this table are non-exhaustive but provide a general idea of methods and approaches to environmental citizen science. Although disciplines of environmental studies vary throughout this table, the general themes here are geomorphology, water quality, health studies, and ecology.

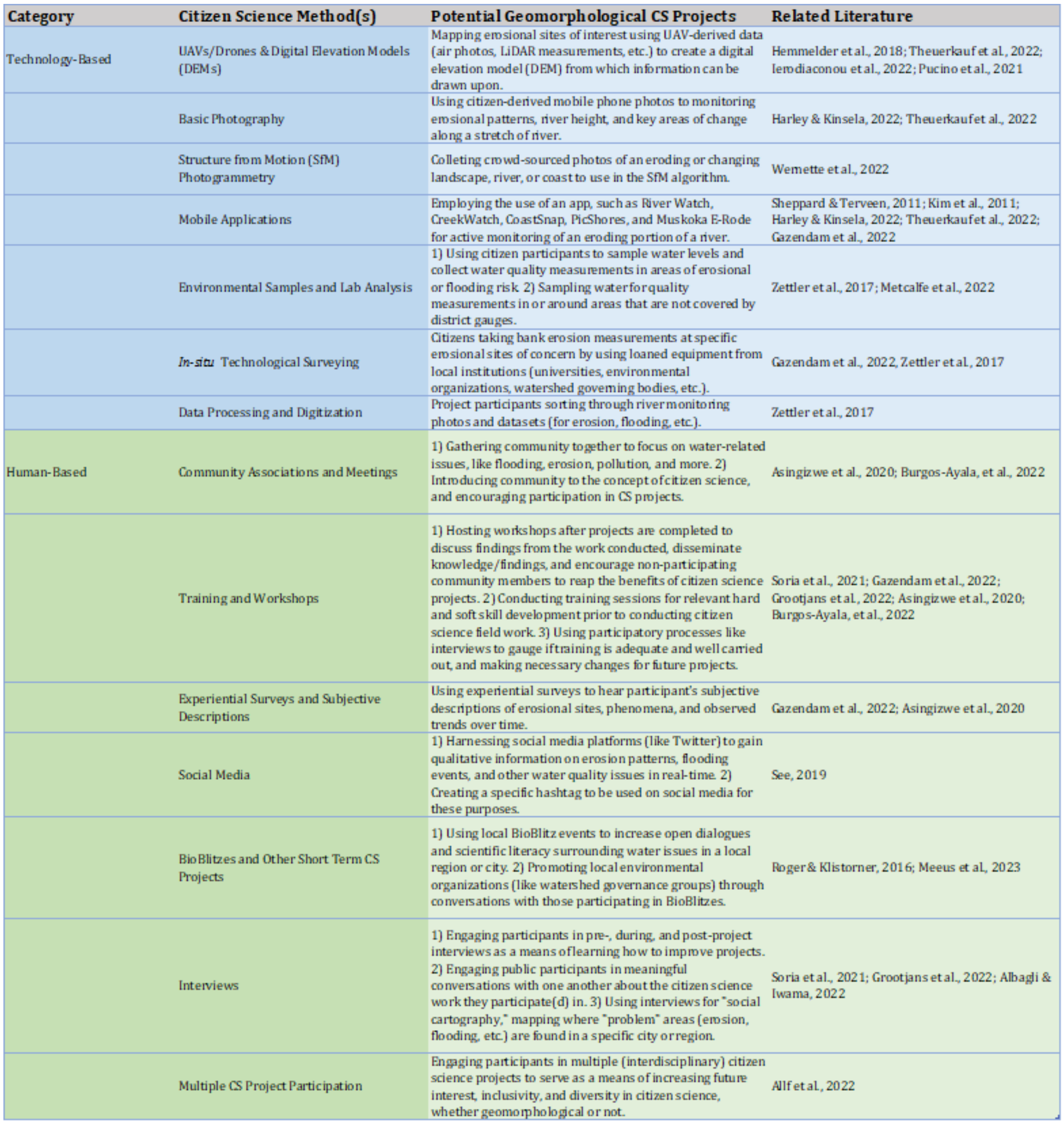
*Table 1: General Citizen Science Methods*
*[see in greater detail in List of Figures and Tables]*

| **Category** | **Citizen Science Method** | **Examples** | **Literature Evidence** |
|---|---|---|---|
| Technology-Based | UAVs/Drones | Mapping sites using UAV data; creating DEMs from UAV data; capturing and using air photos for mapping; capturing air photos to be used in the SfM algorithm; monitoring river dynamics and erosion cases using UAV imagery and/or UAV-derived data | Hemmelder et al., 2018; Theuerkauf et al., 2022; Ierodiaconou et al., 2022; Pucino et al., 2021 |
| | Basic Photography | Citizen-derived mobile phone photography for monitoring coasts and monitoring shore erosion; mobile phone photos for species identification on apps (like iNaturalist) | Harley & Kinsela, 2022; Callaghan et al., 2022; Theuerkauf et al., 2022 |
| | Digital Elevation Models (DEMs) | DEMs created for shore/coastal erosion and river erosion studies providing quantitative data that can be used for active monitoring and data analysis | Hemmelder et al., 2018; Theuerkauf et al., 2022 |
| | Structure from Motion (SfM) Photogrammetry | Crowd-sourced photos of a landscape for use in the SfM algorithm | Wernette et al., 2022 |
| | Mobile Applications | River Watch, CreekWatch, nauticAttiva, CoastSnap, PicShores, iNaturalist, Muskoka E-Rode, iSpot, eBird, Electronic Field Guide, PetaJakarta | Sheppard & Terveen, 2011; Kim et al., 2011; Scardino et al., 2022; Harley & Kinsela, 2022; Theuerkauf et al., 2022; Callaghan et al., 2022; Gazendam et al., 2022; Silvertown, 2009; See, 2019 |
| | Environmental Samples and Lab Analysis | Sampling seawater for plastics; sampling plastic beach debris and categorizing the samples; sampling freshwater from remote locations (where gauges are not installed) during storms; dust samples from homes to search for mycobiomes | Zettler et al., 2017; Metcalfe et al., 2022; Martin-Sanchez et al., 2021 |
| | *In-situ* Technological Surveying | Taking site measurements at erosional sites in Muskoka; towing nets from personal watercraft to collect and count plastics from surface water; surface trawling using loaned equipment | Gazendam et al., 2022, Zettler et al., 2017 |
| | Data Processing and Digitization | Sorting through river monitoring trail camera photos and datasets (for erosion, floods, wildlife, herring migration, etc); specimen digitization in museum contexts | Zettler et al., 2017; Ballard et al., 2017 |
| Human-Based | Community Associations and Meetings | Local meetings conducted among community members; community-led project education for training and better communication | Asingizwe et al., 2020; Burgos-Ayala, et al., 2022 |
| | Experiential Surveys and Subjective Descriptions | Citizens describing erosional sites using lay terminologies; apps that provide citizen science surveys of various kinds for those interested in contributing further; surveys to gauge perceptions of community members over time | Gazendam et al., 2022; Scardino et al., 2022; Asingizwe et al., 2020 |
| | Interviews | Using interviews as a means to engaging public participants; interviews for participants to voice their experiences, opinions, and more; interviews for "social cartography" | Soria et al., 2021; Grootjans et al., 2022; Albagli & Iwama, 2022 |
| | Social Media | Twitter feeds for natural hazard monitoring and active local updates during disaster events | See, 2019 |
| | Training and Workshops | Relevant workshops to discuss findings from studies after projects are over; training sessions for relevant hard and soft skill development prior to conducting citizen science field work; using participatory processes like interviews, workshops, and educational activities in engaging citizens; raising awareness, and adapting processes for future work; dissemination workshops to encourage non-participating members of the community to participate and reap the benefits of citizen science projects; community-led project education for training and better communication | Soria et al., 2021; Gazendam et al., 2022; Grootjans et al., 2022; Asingizwe et al., 2020; Burgos-Ayala, et al., 2022 |
| | "Adopt a..." Programs | "Adopt a beach" program; "Adopt a tree" program in Miami | Merlino et al., 2021; Hunsberger et al., 2003 |
| | BioBlitzes and Other Short Term CS Projects | Monitoring coastal marine fish using a national "BioBlitz" event; increasing open dialogues and scientific literacy through BioBlitz events; creating a species inventory using BioBlitz data; promoting local environmental organizations through BioBlitzes | Agersnap et al., 2022; Roger & Klistorner, 2016; Meeus et al., 2023 |
| | Multiple CS Project Participation | Engaging participants in multiple (interdisciplinary) citizen science projects serves as a means of increasing inclusivity, diversity, and broad learning objectives | Allf et al., 2022 |

As demonstrated in Table 1, there is a large variety of studies that use a combination of methods for citizen science. Another trend to note is the prevalence of certain citizen science methods for environmental purposes, those being: UAVs/drones, environmental sampling and lab analysis, training and workshops, experiential surveys and subjective descriptions, and mobile applications. Each method provided has its own advantages and disadvantages, which are not outlined here, but are available in the literature.

For more specificity, Table 2 outlines some of the potential geomorphological citizen science projects that are associated with each method, as well as relevant literature. Please note that the literature included here is not necessarily explicitly related to the provided project, but that the work done in the literature is relevant in inspiring said projects.

*Table 2: Potential Geomorphological Citizen Science Projects and Methods [see in greater detail in List of Figures and Tables]*

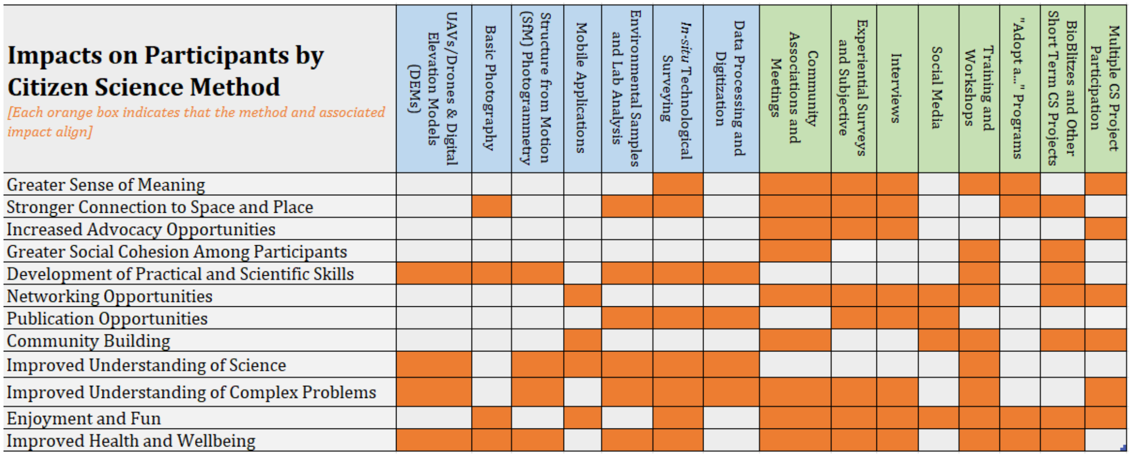


| Category | Citizen Science Method(s) | Potential Geomorphological CS Projects | Related Literature |
|---|---|---|---|
| Technology-Based | UAVs/Drones & Digital Elevation Models (DEMs) | Mapping erosional sites of interest using UAV-derived data (air photos, LiDAR measurements, etc.) to create a digital elevation model (DEM) from which information can be drawn upon. | Hemmelder et al., 2018; Theuerkauf et al., 2022; Ierodiaconou et al., 2022; Pucino et al., 2021 |
| | Basic Photography | Using citizen-derived mobile phone photos to monitoring erosional patterns, river height, and key areas of change along a stretch of river. | Harley & Kinsela, 2022; Theuerkauf et al., 2022 |
| | Structure from Motion (SfM) Photogrammetry | Colleting crowd-sourced photos of an eroding or changing landscape, river, or coast to use in the SfM algorithm. | Wernette et al., 2022 |
| | Mobile Applications | Employing the use of an app, such as River Watch, CreekWatch, CoastSnap, PicShores, and Muskoka E-Rode for active monitoring of an eroding portion of a river. | Sheppard & Terveen, 2011; Kim et al., 2011; Harley & Kinsela, 2022; Theuerkauf et al., 2022; Gazendam et al., 2022 |
| | Environmental Samples and Lab Analysis | 1) Using citizen participants to sample water levels and collect water quality measurements in areas of erosional or flooding risk. 2) Sampling water for quality measurements in or around areas that are not covered by district gauges. | Zettler et al., 2017; Metcalfe et al., 2022 |
| | *In-situ* Technological Surveying | Citizens taking bank erosion measurements at specific erosional sites of concern by using loaned equipment from local institutions (universities, environmental organizations, watershed governing bodies, etc.). | Gazendam et al., 2022, Zettler et al., 2017 |
| | Data Processing and Digitization | Project participants sorting through river monitoring photos and datasets (for erosion, flooding, etc.). | Zettler et al., 2017 |
| Human-Based | Community Associations and Meetings | 1) Gathering community together to focus on water-related issues, like flooding, erosion, pollution, and more. 2) Introducing community to the concept of citizen science, and encouraging participation in CS projects. | Asingizwe et al., 2020; Burgos-Ayala, et al., 2022 |
| | Training and Workshops | 1) Hosting workshops after projects are completed to discuss findings from the work conducted, disseminate knowledge/findings, and encourage non-participating community members to reap the benefits of citizen science projects. 2) Conducting training sessions for relevant hard and soft skill development prior to conducting citizen science field work. 3) Using participatory processes like interviews to gauge if training is adequate and well carried out, and making necessary changes for future projects. | Soria et al., 2021; Gazendam et al., 2022; Grootjans et al., 2022; Asingizwe et al., 2020; Burgos-Ayala, et al., 2022 |
| | Experiential Surveys and Subjective Descriptions | Using experiential surveys to hear participant's subjective descriptions of erosional sites, phenomena, and observed trends over time. | Gazendam et al., 2022; Asingizwe et al., 2020 |
| | Social Media | 1) Harnessing social media platforms (like Twitter) to gain qualitative information on erosion patterns, flooding events, and other water quality issues in real-time. 2) Creating a specific hashtag to be used on social media for these purposes. | See, 2019 |
| | BioBlitzes and Other Short Term CS Projects | 1) Using local BioBlitz events to increase open dialogues and scientific literacy surrounding water issues in a local region or city. 2) Promoting local environmental organizations (like watershed governance groups) through conversations with those participating in BioBlitzes. | Roger & Klistorner, 2016; Meeus et al., 2023 |
| | Interviews | 1) Engaging participants in pre-, during, and post-project interviews as a means of learning how to improve projects. 2) Engaging public participants in meaningful conversations with one another about the citizen science work they participate(d) in. 3) Using interviews for "social cartography," mapping where "problem" areas (erosion, flooding, etc.) are found in a specific city or region. | Soria et al., 2021; Grootjans et al., 2022; Albagli & Iwama, 2022 |
| | Multiple CS Project Participation | Engaging participants in multiple (interdisciplinary) citizen science projects to serve as a means of increasing future interest, inclusivity, and diversity in citizen science, whether geomorphological or not. | Allf et al., 2022 |

## Significance

Citizen science programs are very helpful for a variety of research contexts and other reasons. Without a citizen science program, the town of Walkerton is missing out on numerous positive impacts to participants resulting from strong citizen science programs and methodologies.

*Table 3: Impacts on Participants*
*[see in greater detail in List of Figures and Tables]*



| **Impacts on Participants by Citizen Science Method** *[Each orange box indicates that the method and associated impact align]* | UAVs/Drones & Digital Elevation Models (DEMs) | Basic Photography | Structure from Motion (SfM) Photogrammetry | Mobile Applications | Environmental Samples and Lab Analysis | *In-situ* Technological Surveying | Data Processing and Digitization | Community Associations and Meetings | Experiential Surveys and Subjective | Interviews | Social Media | Training and Workshops | "Adopt a..." Programs | BioBlitzes and Other Short Term CS Projects | Multiple CS Project Participation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Greater Sense of Meaning | | | | | | 🟧 | | 🟧 | 🟧 | 🟧 | | 🟧 | 🟧 | | 🟧 |
| Stronger Connection to Space and Place | | 🟧 | | | 🟧 | 🟧 | | 🟧 | 🟧 | 🟧 | | | 🟧 | 🟧 | |
| Increased Advocacy Opportunities | | | | | | | | 🟧 | 🟧 | 🟧 | | | | | 🟧 |
| Greater Social Cohesion Among Participants | | | | | | | | 🟧 | | | | 🟧 | | 🟧 | |
| Development of Practical and Scientific Skills | 🟧 | 🟧 | 🟧 | | 🟧 | 🟧 | 🟧 | | | | | 🟧 | | 🟧 | |
| Networking Opportunities | | | | 🟧 | | | | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | | 🟧 | 🟧 |
| Publication Opportunities | | | | | 🟧 | 🟧 | 🟧 | | 🟧 | 🟧 | 🟧 | | | | |
| Community Building | | | | 🟧 | | | | 🟧 | | | 🟧 | 🟧 | | 🟧 | 🟧 |
| Improved Understanding of Science | 🟧 | | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | | | | | 🟧 | | | |
| Improved Understanding of Complex Problems | 🟧 | | 🟧 | | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | | 🟧 | | | 🟧 |
| Enjoyment and Fun | | 🟧 | | 🟧 | | 🟧 | | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 | 🟧 |
| Improved Health and Wellbeing | 🟧 | 🟧 | 🟧 | | 🟧 | 🟧 | | 🟧 | 🟧 | 🟧 | | 🟧 | 🟧 | 🟧 | |

Citizen science has the capacity to provide many beneficial impacts to participants. For one, participants feel a greater sense of meaning and a stronger connection to space and place. These are intrinsic and not completely certain in all citizen science projects, but in interviews, surveys, personal experiences and descriptions, and community meetings for example these are clear benefits (Soria et al., 2021; Grootjans et al., 2022; Asingizwe et al., 2020; Burgos-Ayala et al., 2022). Citizen science programs also provides participants with a variety of unique opportunities, from networking to publication of their work and contributions, and advocacy for what matters most to them. Community associations and meetings are one great way that these types of opportunities present themselves (Asingizwe et al., 2020; Burgos-Ayala et al., 2022). In community associations and meetings, participants can advocate for their work, their rights, and their opinions on things that matter to them in their local contexts, such as environmental protection, water quality, and more. Next, citizen science programs bring people together in the community and local context, which then improves community building and social cohesion with one another. One great example of this is through BioBlitzes and other short-term citizen science projects like the National Audubon Society's Annual Christmas Bird Count (Roger & Klistorner, 2016; Meeus et al., 2023). To continue, citizen science programs improve understanding of science and complex problems. Some examples of this are *in-situ* monitoring opportunities and lab work or using photography and algorithms for developing models (Zettler et al., 2017; Metcalfe et al., 2022). Finally, citizen science programs are fun, enjoyable, and get participants outside, which improves mental health and physical wellbeing (Jackson et al., 2021). Many of the methods presented in Table 3 align with these great positive impacts.

Some difficulties and challenges do exist, however. Access to equipment and the necessary technology, having enough time, running training sessions effectively, and encouraging locals to participate are some of the key difficulties in what we suggest for Walkerton. As is shown in Table 4 under the "Recommendations" section, our suggested citizen science methods for Walkerton have a variety of pros and cons associated with them, which are worth full consideration for the future.

By implementing a citizen science program in Walkerton, the town will have more data (quantitative and qualitative) to work with for research and future program development. This is not only beneficial for urban and environmental planning, but for other aspects of governance. Future studies at this site (and similar sites along the Saugeen River, should they appear or currently exist) can and will also benefit from the development of a citizen science program for this reason. With more citizen science programming available, more data is collected, and the larger the database becomes from which decisions and future plans can be made.

## Recommendations

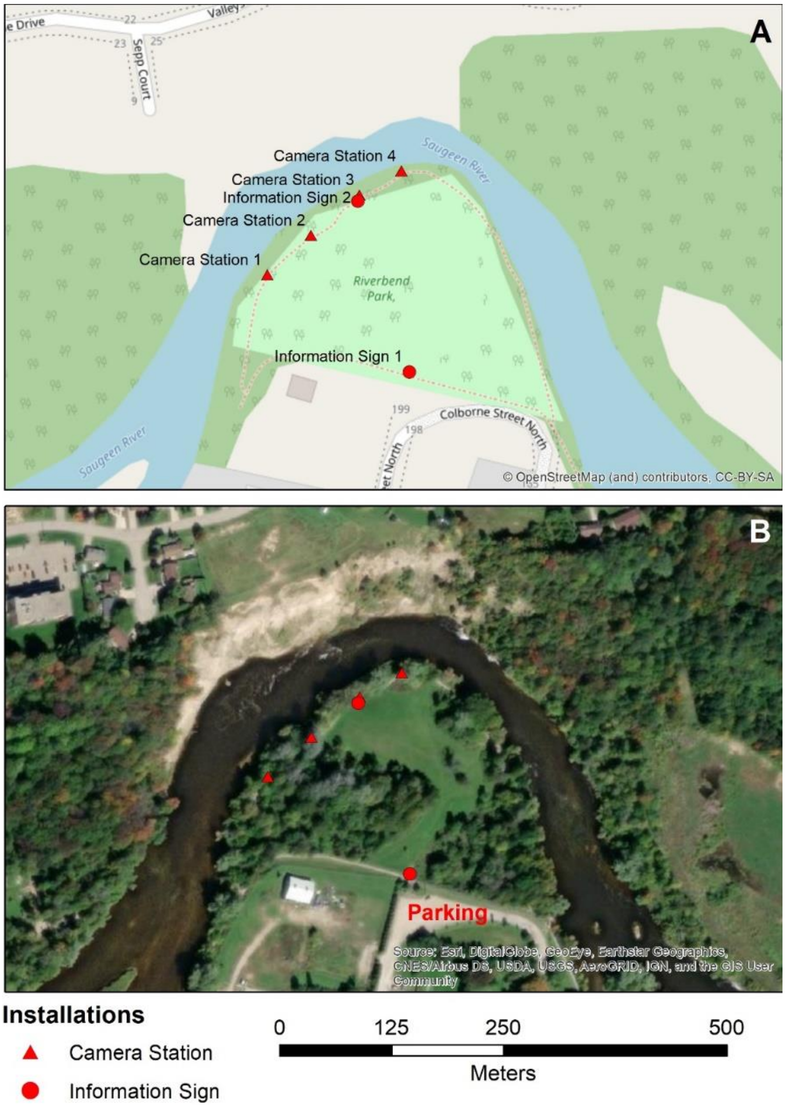
When it comes to the unique situation of the Walkerton site, we recommend the following citizen science methods for implementation in the future (Table 4).

*Table 4: Recommendations for Implementing a Citizen Science Program in Walkerton [see in greater detail in List of Figures and Tables]*

| CS Method | Recommendation Summary | Pros | Cons |
|---|---|---|---|
| Mobile Applications | Create a mobile application (supported on iOS and Android) for documenting qualitative data, site descriptions, experiences, and photos of the site in Walkerton. | Is easy for most participants to access on their personal devices; links electronic data collection with other suggested methods, like *In-situ* Technological Monitoring; has a variety of positive impacts on participants (see Table 3). | Can be inaccessible for some participants without access to the Internet, or a mobile device that supports mobile applications. |
| *In-situ* Technological Surveying | Provide particpants with equipment to collect water samples, water level measurements, soil samples, and more in order to take accurate quantitative data at (and surrounding) the study site. | Allows for accurate and site-specific quantitative data collection; has a variety of positive impacts on participants (see Table 3). | Can be difficult for those with mobility issues; can be difficult to achieve without proper equipment, which can be expensive. |
| Environmental Sampling and Lab Analysis | Provide participants with equipment to analyze previously-collected water samples and soil samples, in order to ensure accurate data, and find out more about the site over time (changes in water dissolved oxygen or soil pH, for example). | Allows for samples to be processed in-lab to ensure high quality data and decreases human error; has a variety of positive impacts on participants (see Table 3). | Can be difficult without access to a lab space; can be difficult without access to the proper equipment, which can be expensive. |
| Basic Photography | Collect photographs of the site in conjunction with the developed mobile application to store images of the site over time, to be used in SfM algorithm or elsewhere. | Is easily accessible for most participants either using personal cameras or mobile devices equipped with a camera; allows for creativity; has a variety of positive impacts on participants (see Table 3). | Can be inaccessible for some participants without access to a camera, or similar mobile device. |
| Structure from Motion (SfM) Photogrammetry | Provide a training session for using the SfM algorithm with photos of the site collected from other CS participants. Then, create DEMs from this algorithm, and use them to monitor changes to the site over time. | Is highly accurate; can use photos from many different angles and positions above the ground and around the site; algorithm is easy to train and learn; has a variety of positive impacts on participants (see Table 3). | Has a larger learning curve for some participants; requires the proper software and technological skillset to complete; can be time-consuming; requires detail-oriented participants. |
| Community Associations and Meetings | Get community environmental associations and clubs involved with the CS projects proposed here. Then, conduct meetings with members of each organization and participants from the local population to discuss findings, insights, ideas, and areas for improvement moving forward. | Brings the community together in a meaningful way; encourages participants to interact with one another; encourages participants to associate with other local organizations and city boards and councils; has a variety of positive impacts on participants (see Table 3). | Regular meeting times and the frequencies of meetings are not always possible for everyone to attend. |
| Experiential Surveys and Subjective Descriptions | Collect experiential surveys and site descriptions from participants in CS projects in the mobile application to gain qualitative and categorical data from various areas of the site ("What sections of the cliff are looking more or less unstable today?" is an example question). | Personal experiences can be explained for qualitative data purposes; descriptions of the site include details otherwise missed; has a variety of positive impacts on participants (see Table 3). | Can provide inaccurate data due to human error. |
| Training and Workshops | Provide training sessions and workshops for members of the community at a local event location in Walkerton. Then, promote the CS projects about the Walkerton site using social media, local news, and websites. Finally, get locals involved in specific branches of the project they want to participate in after they have completed trainings and/or workshops. | Both training and workshops allow for continued learning and skill development; awareness of issues is increased; more participants are gained through proper training; data is more accurate; has a variety of positive impacts on participants (see Table 3). | Regular trainings and workshops are not always possible for everyone to attend. |
| Interviews | Conduct interviews with participants in the CS projects at the site about their experiences, to improve CS work here in the future, and to gain other insights about observed changes. | Interviews provide an additional space for participants to share their experiences at the site and what they have seen changing over time; has a variety of positive impacts on participants (see Table 3). | Can provide inaccurate data due to human error. |

### *Recommendation I: Ground Equipment*

Ground equipment would be placed along the shoreline of Riverbend Park in downtown Walkerton (Fig. 6).



© OpenStreetMap (and) contributors, CC-BY-SA

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

*Figure 6: Plans for Ground Equipment*

Two informational sign boards, as well as several camera stations, make up the necessary equipment for this recommendation. The informational sign boards would include a detailed outline of the citizen science project, the ways locals can get involved, and email addresses and/or phone numbers that can be used for troubleshooting and other inquiries. The camera stations would consist of a metal stand for a cellphone camera, similar to what is shown in Harley & Kinsela (2022) with their global coastal erosion monitoring project called CoastSnap (Fig. 7).

*Figure 7: A potential camera station design, as found in Harley & Kinsela (2022)*

This camera station model (Fig. 7) can be replicated for use in Walkerton, as it keeps the device level, allows for the same view to be replicated among crowd-sourced photos from different participants, and is cost-effective and weatherproof. Harley & Kinsela's (2022) example d) (Fig. 7) is on a simple pole, which could work well in Walkerton's Riverbend Park context as well.

Please recall that Figure 6 displays the locations of the cameras and informational sign boards to be set up in Riverbend Park. However, concerns may arise about whether these camera stations would capture all angles and viewpoints of the eroding cliff. With the use of a viewshed (Fig. 8), this view is more clearly demonstrated. With a viewshed, we can determine what part of the landscape is visible to the camera stations based only on the topography from the digital elevation model (DEM) provided.

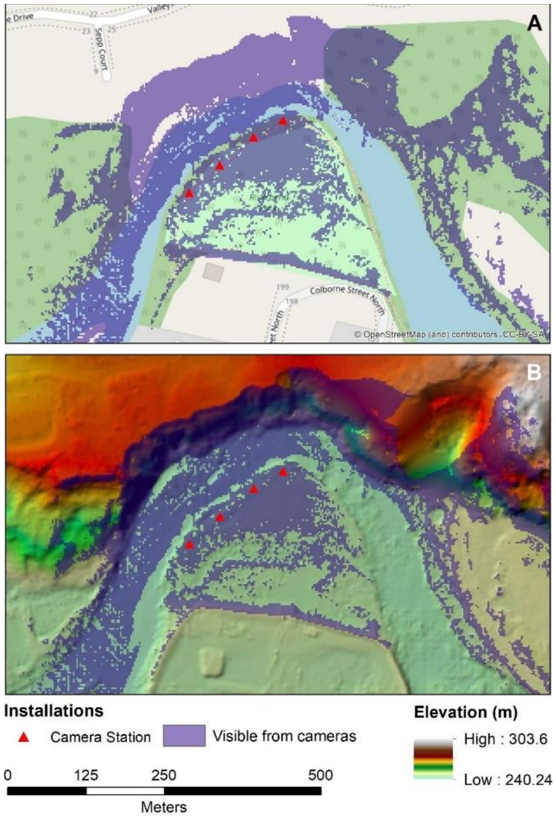


*Figure 8: Viewshed from camera stations*

For this figure, 2015 2m DEM data was used. This figure does not include trees, buildings, and other potential blocks to the camera viewshed, but provides a general idea of what areas could be captured well by cameras placed on the planned camera stations. In this case, the camera stations do indeed allow for capture of the eroding bank from our chosen points. To fully determine compatible locations, building plans will need to be made in Riverbend Park in Walkerton.

### *Recommendation II: Mobile Application, Photography, and Structure from Motion (SfM) Photogrammetry*

The second recommendation for Walkerton's specific context is to create a mobile application (supported on iOS and Android) for documenting qualitative data, site descriptions, experiences, and photos of the site in Walkerton. An application, as demonstrated in various studies, is very effective for monitoring sites over time, provided there is enough foot traffic and use of the application for crowd-sourcing data (Sheppard & Terveen, 2011; Kim et al., 2011; Harley & Kinsela, 2022; Theuerkauf et al., 2022; Gazendam et al., 2022). Having an application where photos and data (qualitative and quantitative) are stored is especially useful for Walkerton, as a database of photos over time can be used for Structure from Motion (SfM) Photogrammetry, which can provide many insights into erosional changes at the site over time (Wernette et al., 2022). The application could also have small surveys that participants and users could fill out when submitting a photo, as was used in Kim et al. (2011). Having an application is also useful as it can be continuously updated, with more features and possibilities added over time as the site continues to change. For example, if there are new and different concerns about the eroding bluff in the future, in-app surveys and prompts for participant descriptions can be edited so that the data being collected suits the ever-changing nature of concerns at the site.

### *Final Recommendations and Considerations*

If possible, it would be very effective to pair the photography and mobile application work previously discussed with some *in-situ* measurements and laboratory analyses. We suggest that participants can be equipped with the necessary tools to collect, store, and analyze water samples and soil samples in and around the site. Not only is this useful for scientific development and data to back up decision making in Walkerton and along the Saugeen River, but it encourages participants to become more scientifically literate, provides them with new skills, and can be more engaging than some of the more “hands-off” activities previously discussed, like simple photography or an in-app survey. To ensure accurate data, having citizen scientists work in a quality assurance or laboratory setting (with proper trainings) would be a good addition as well.

Finally, we recommend that the developers of the application host regular community meetings with various members of different associations (municipal government, NGOs, local clubs, and businesses, etc.) for discussion, increased learning opportunities, and community building. Community associations and meetings were some of the citizen science methods with the greatest positive impacts on participants, so they are very valuable to consider using. Trainings and workshops can stem from these meetings, as shown in Table 4. These methods all further help promote citizen science programs around the region and town, and ultimately will get more locals involved.

Alongside hosting regular discussion meetings about the application and the site itself, conducting interviews with participants and non-participating locals is another strong suggestion. Interviews not only help decision makers to hear a local perspective about local changes, but they can provide insight into future improvements as well.

## Conclusion

The eroding bank of the Saugeen River across from Riverbend Park in Walkerton, Ontario is an exemplary location to attempt citizen science-based methods of erosion monitoring. Walkerton has a unique history of water-related crisis, which suggests its citizens might be more concerned about current this current water-related hazard. This site has also been the focus of a traditional engineering assessment and study, so a citizen science program can be used as a data supplement as well as a comparison between traditional and newer methods. Bank and bluff erosion are not expected to slow or stop in the near future, so successfully monitoring erosion, constraining erosion rates, understanding whether the erosion in mainly caused by mass movement or bank toe erosion, and determining the location of erosional hotspots are critical for the safety of Walkerton’s citizens and infrastructure.

Image-based methods that can produce both qualitative and quantitative monitoring data have matured enough to allow for citizen-led monitoring efforts. Five case studies are discussed herein, and a series of suggestions and recommendations for implementing similar programs are discussed. Overall, citizen science should be considered as a priority approach for improving understanding of bank erosion rates and patterns of the Saugeen River in Walkerton, while also providing many meaningful benefits to local participants.

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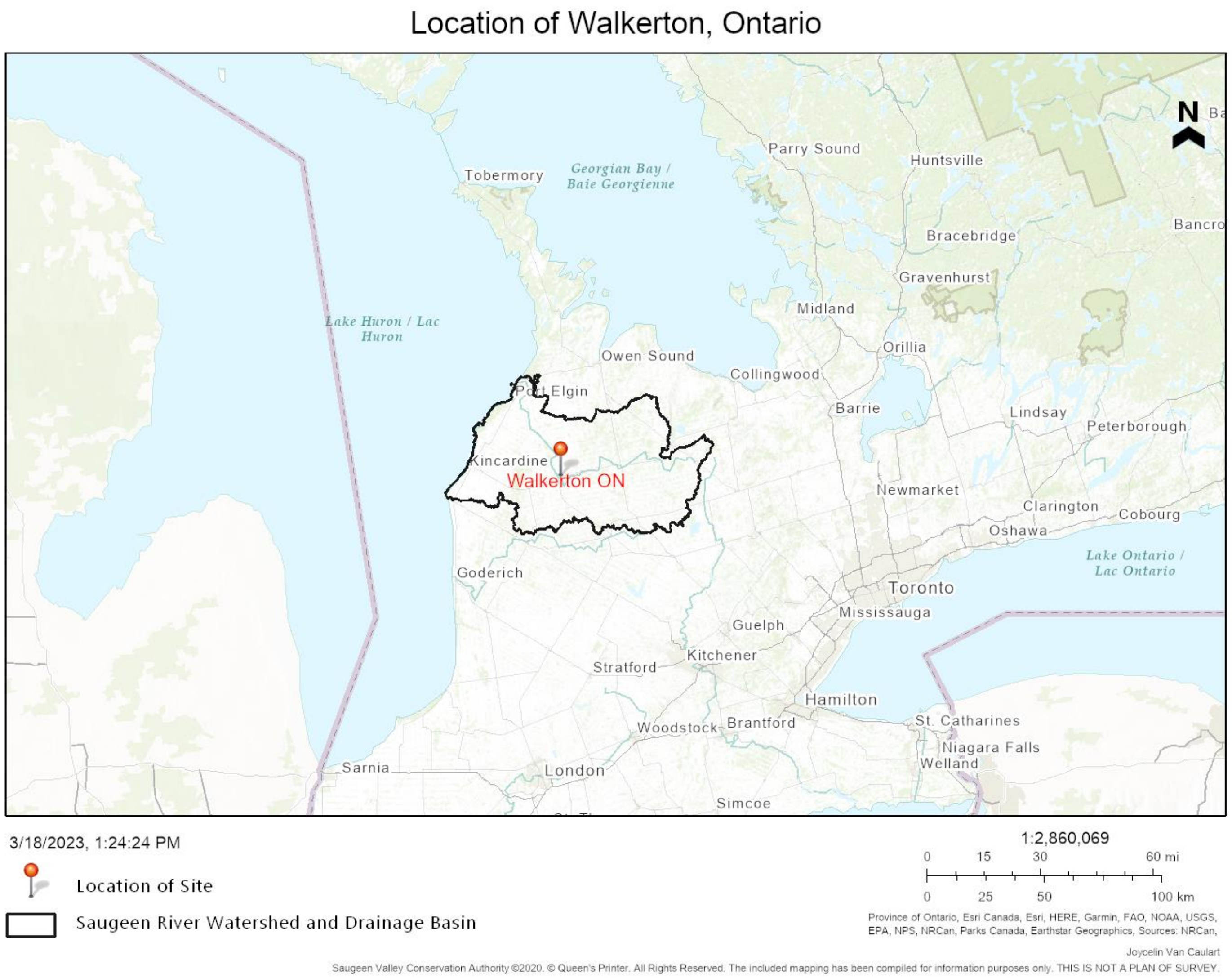
## List of Figures

Figure 1



Location of Walkerton, Ontario

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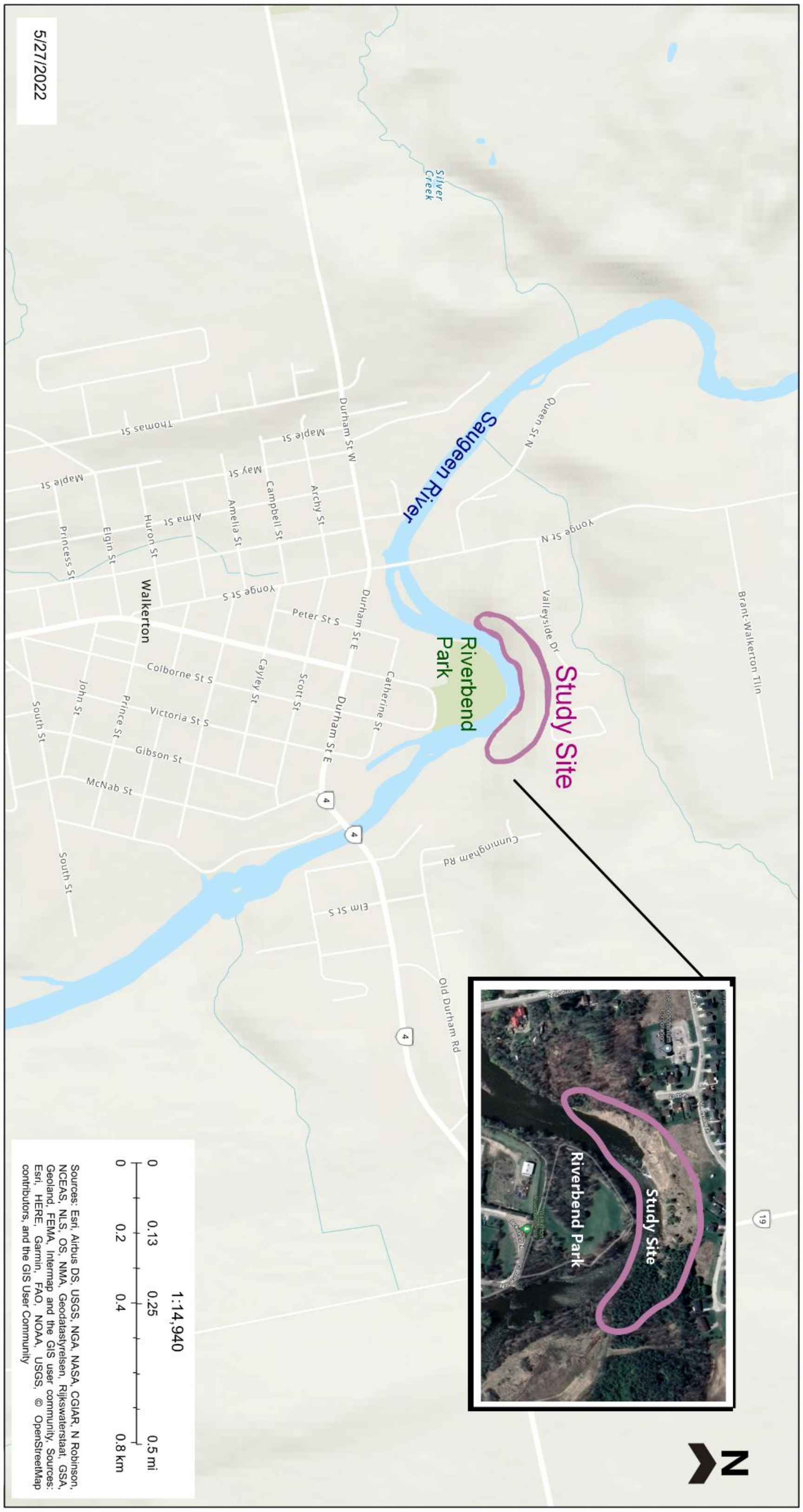
Province of Ontario, Esri Canada, Esri, HERE, Garmin, FAO, NOAA, USGS, EPA, NPS, NRCan, Parks Canada, Earthstar Geographics, Sources: NRCan,

Joycelin Van Caulart

Saugeen Valley Conservation Authority ©2020. © Queen's Printer. All Rights Reserved. The included mapping has been compiled for information purposes only. THIS IS NOT A PLAN OF SURVEY.

Figure 2



Sources: Esri, Airbus DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstaat, GSA, Geoland, FEMA, Intermap and the GIS user community, Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community

Figure 3

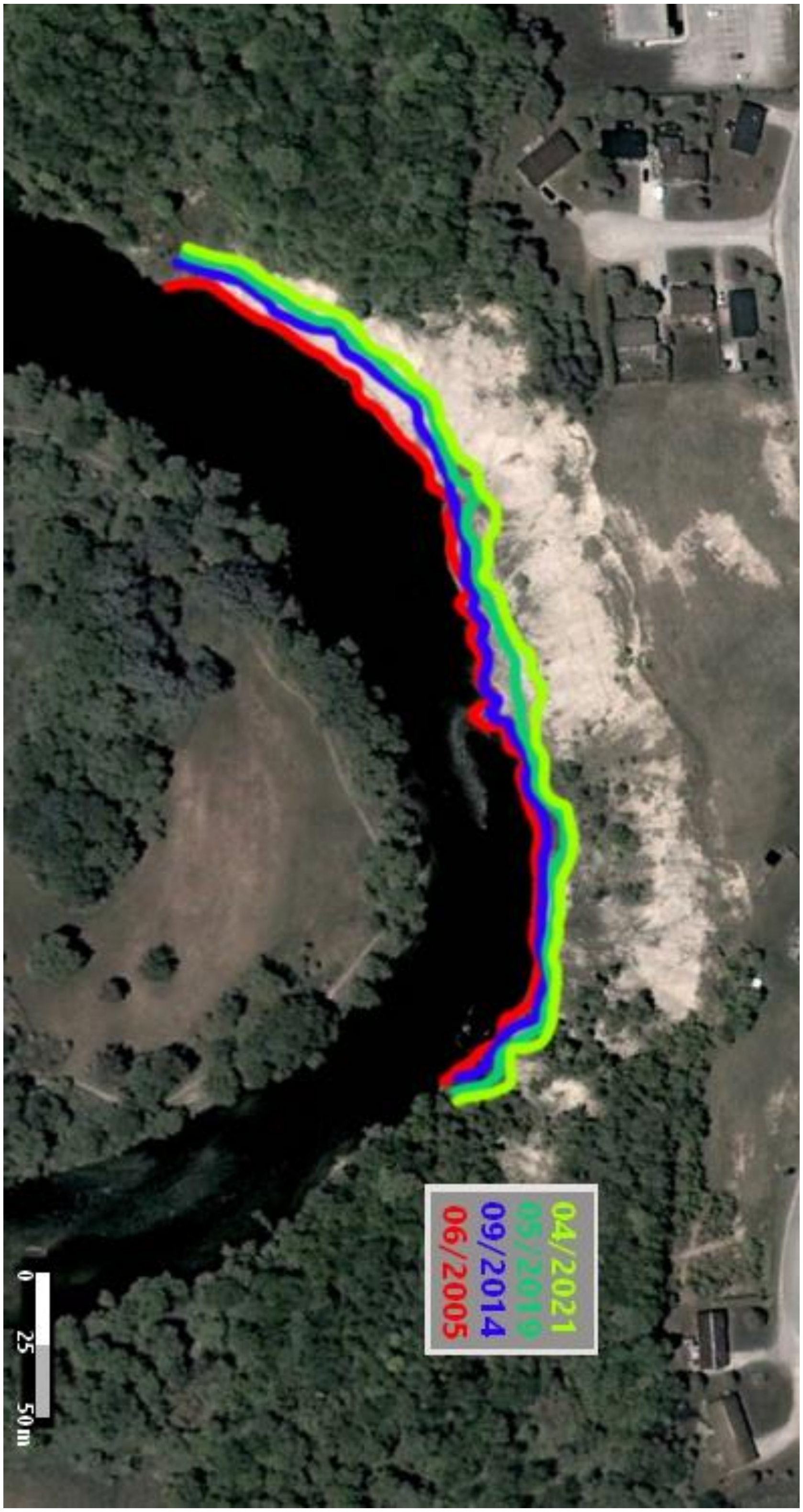
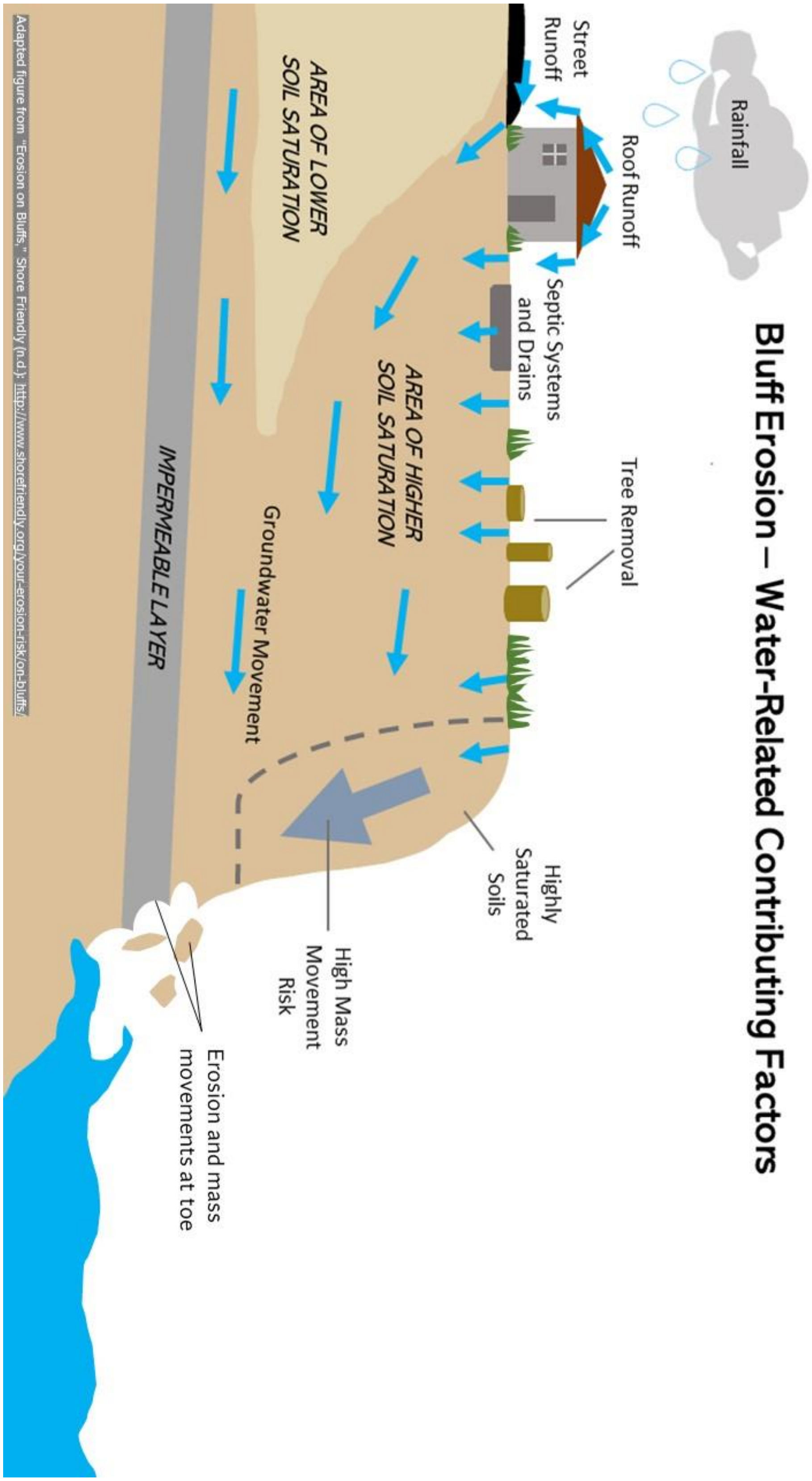


Figure 4 (Adapted from Shore Friendly, n.d.)



Adapted figure from "Erosion on Bluffs," Shore Friendly (n.d.): http://www.shorefriendly.org/your-erosion-risk/on-bluffs/

Figure 5 (BMROSS Engineering)

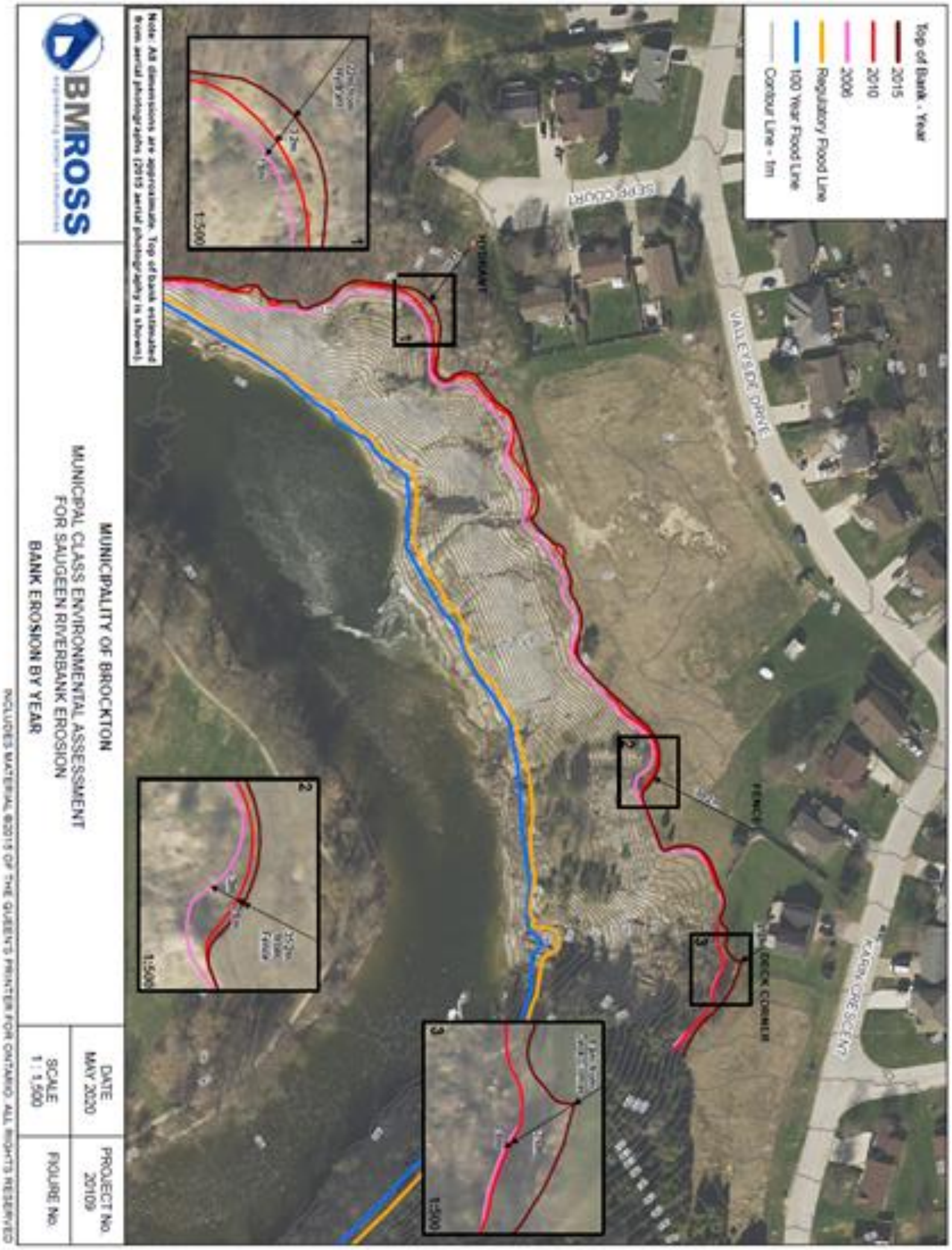
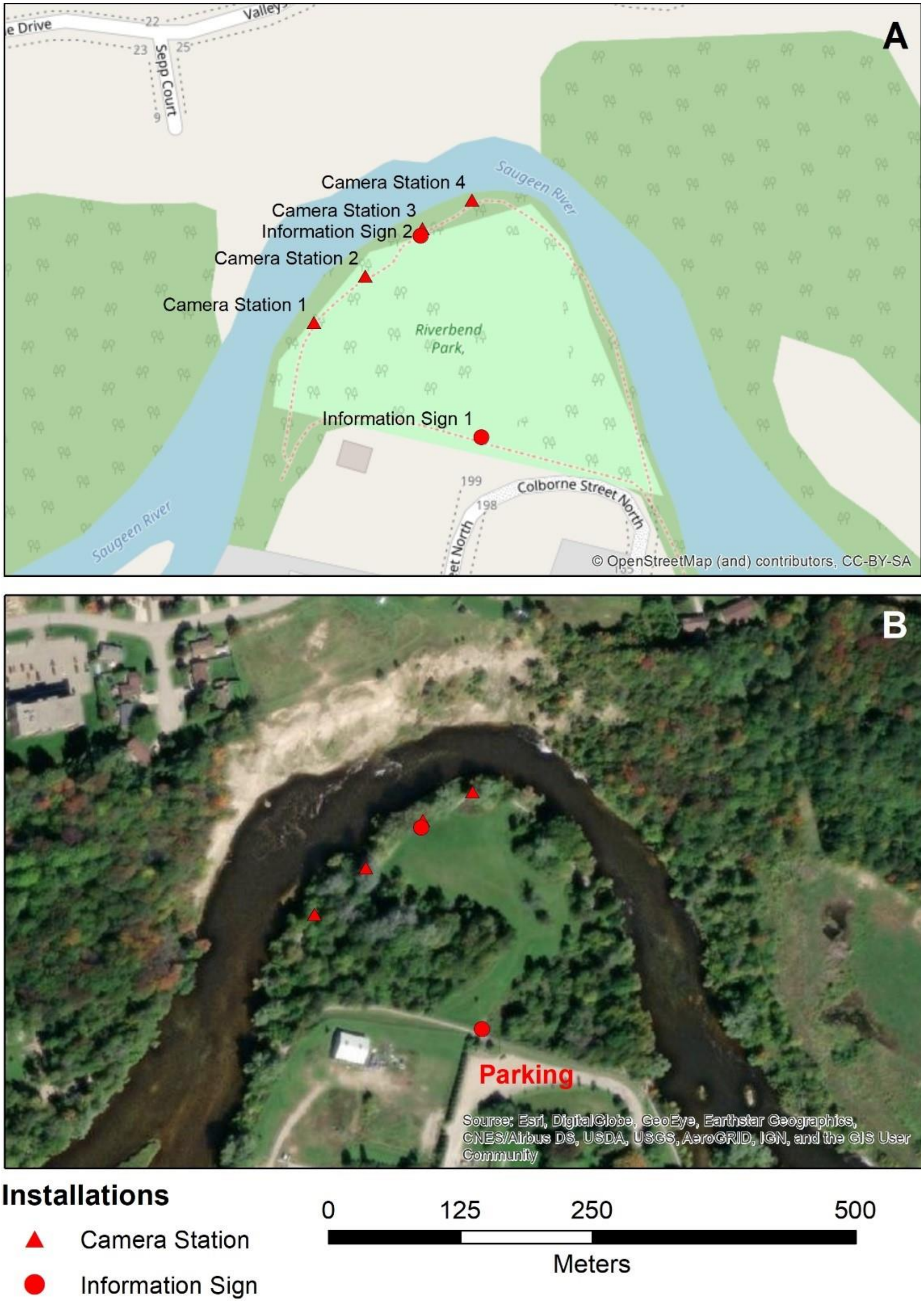


Figure 6



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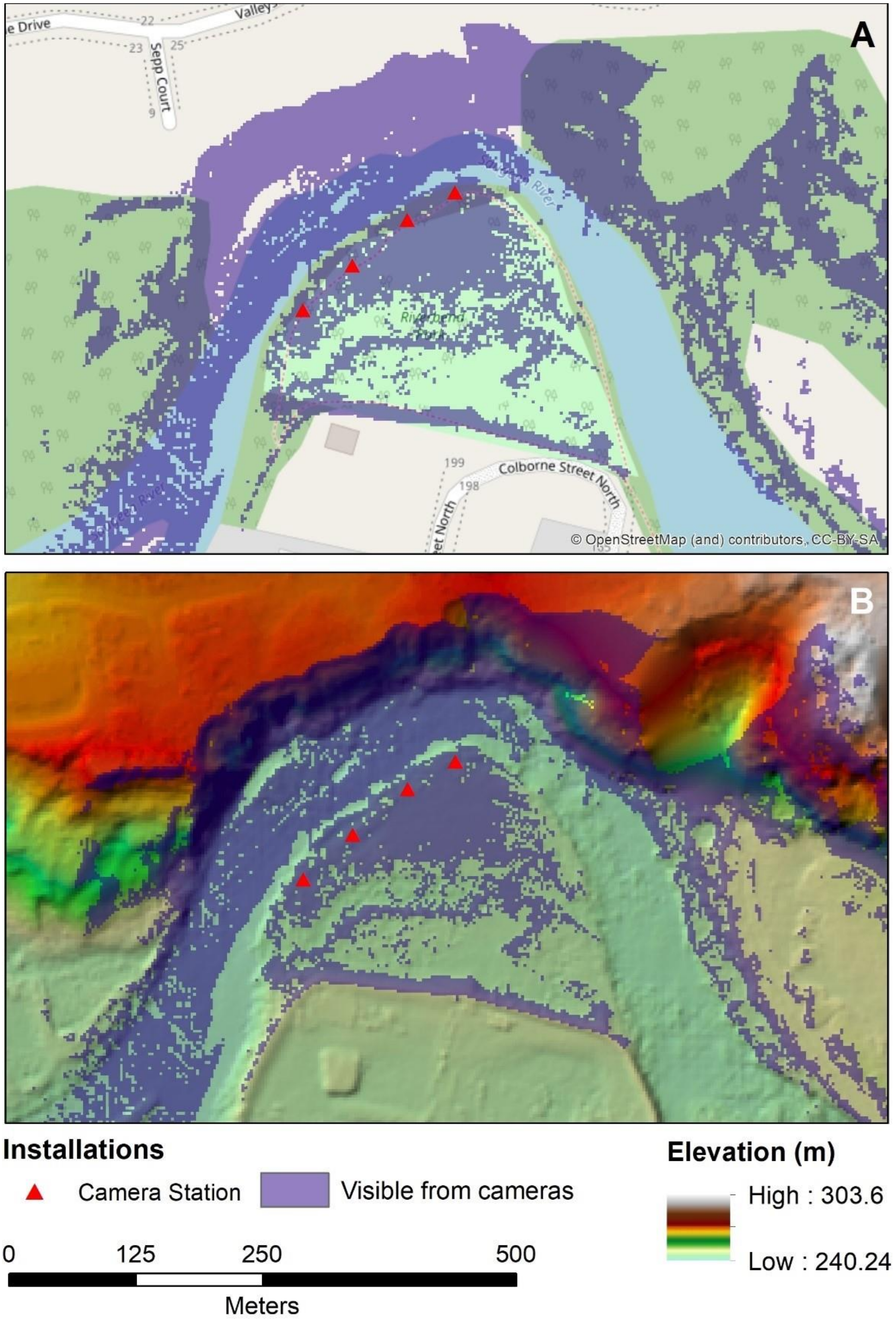
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 7 (Taken from Harley & Kinsela (2022))

Figure 8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© OpenStreetMap (and) contributors, CC-BY-SA
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Installations
Camera Station
Visible from cameras
Elevation (m)
High : 303.6
Low : 240.24
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## List of Tables

Table 1

| **Category** | **Citizen Science Method** | **Examples** | **Literature Evidence** |
|---|---|---|---|
| Technology-Based | UAVs/Drones | Mapping sites using UAV data; creating DEMs from UAV data; capturing and using air photos for mapping; capturing air photos to be used in the SfM algorithm; monitoring river dynamics and erosion cases using UAV imagery and/or UAV-derived data | Hemmelder et al., 2018; Theuerkauf et al., 2022; Ierodiaconou et al., 2022; Pucino et al., 2021 |
| | Basic Photography | Citizen-derived mobile phone photography for monitoring coasts and monitoring shore erosion; mobile phone photos for species identification on apps (like iNaturalist) | Harley & Kinsela, 2022; Callaghan et al., 2022; Theuerkauf et al., 2022 |
| | Digital Elevation Models (DEMs) | DEMs created for shore/coastal erosion and river erosion studies providing quantitative data that can be used for active monitoring and data analysis | Hemmelder et al., 2018; Theuerkauf et al., 2022 |
| | Structure from Motion (SfM) Photogrammetry | Crowd-sourced photos of a landscape for use in the SfM algorithm | Wernette et al., 2022 |
| | Mobile Applications | River Watch, CreekWatch, nauticAttiva, CoastSnap, PicShores, iNaturalist, Muskoka E-Rode, iSpot, eBird, Electronic Field Guide, PetaJakarta | Sheppard & Terveen, 2011; Kim et al., 2011; Scardino et al., 2022; Harley & Kinsela, 2022; Theuerkauf et al., 2022; Callaghan et al., 2022; Gazendam et al., 2022; Silvertown, 2009; See, 2019 |

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| | Environmental Samples and Lab Analysis | Sampling seawater for plastics; sampling plastic beach debris and categorizing the samples; sampling freshwater from remote locations (where gauges are not installed) during storms; dust samples from homes to search for mycobiomes | Zettler et al., 2017; Metcalfe et al., 2022; Martin-Sanchez et al., 2021 |
| | *In-situ* Technological Surveying | Taking site measurements at erosional sites in Muskoka; towing nets from personal watercraft to collect and count plastics from surface water; surface trawling using loaned equipment | Gazendam et al., 2022, Zettler et al., 2017 |
| | Data Processing and Digitization | Sorting through river monitoring trail camera photos and datasets (for erosion, floods, wildlife, herring migration, etc.); specimen digitization in museum contexts | Zettler et al., 2017; Ballard et al., 2017 |
| Human-Based | Community Associations and Meetings | Local meetings conducted among community members; community-led project education for training and better communication | Asingizwe et al., 2020; Burgos-Ayala, et al., 2022 |
| | Experiential Surveys and Subjective Descriptions | Citizens describing erosional sites using lay terminologies; apps that provide citizen science surveys of various kinds for those interested in contributing further; surveys to gauge perceptions of community members over time | Gazendam et al., 2022; Scardino et al., 2022; Asingizwe et al., 2020 |
| | Interviews | Using interviews as a means to engaging public participants; interviews for participants to voice their experiences, opinions, and | Soria et al., 2021; Grootjans et al., 2022; Albagli & Iwama, 2022 |

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|  |  | more; interviews for "social cartography" |  |
|  | Social Media | Twitter feeds for natural hazard monitoring and active local updates during disaster events | See, 2019 |
|  | Training and Workshops | Relevant workshops to discuss findings from studies after projects are over; training sessions for relevant hard and soft skill development prior to conducting citizen science field work; using participatory processes like interviews, workshops, and educational activities in engaging citizens; raising awareness, and adapting processes for future work; dissemination workshops to encourage non-participating members of the community to participate and reap the benefits of citizen science projects; community-led project education for training and better communication | Soria et al., 2021; Gazendam et al., 2022; Grootjans et al., 2022; Asingizwe et al., 2020; Burgos-Ayala, et al., 2022 |
|  | "Adopt a..." Programs | "Adopt a beach" program; "Adopt a tree" program in Miami | Merlino et al., 2021; Hunsberger et al., 2003 |
|  | BioBlitzes and Other Short Term CS Projects | Monitoring coastal marine fish using a national "BioBlitz" event; increasing open dialogues and scientific literacy through BioBlitz events; creating a species inventory using BioBlitz data; promoting local environmental | Agersnap et al., 2022; Roger & Klistorner, 2016; Meeus et al., 2023 |

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| | | organizations through BioBlitzes | |
| | Multiple CS Project Participation | Engaging participants in multiple (interdisciplinary) citizen science projects serves as a means of increasing inclusivity, diversity, and broad learning objectives | Allf et al., 2022 |

Table 2

| **Category** | **Citizen Science Method(s)** | **Potential Geomorphological CS Projects** | **Related Literature** |
|---|---|---|---|
| Technology-Based | UAVs/Drones & Digital Elevation Models (DEMs) | Mapping erosional sites of interest using UAV-derived data (air photos, LiDAR measurements, etc.) to create a digital elevation model (DEM) from which information can be drawn upon. | Hemmelder et al., 2018; Theuerkauf et al., 2022; Ierodiaconou et al., 2022; Pucino et al., 2021 |
| | Basic Photography | Using citizen-derived mobile phone photos to monitoring erosional patterns, river height, and key areas of change along a stretch of river. | Harley & Kinsela, 2022; Theuerkauf et al., 2022 |
| | Structure from Motion (SfM) Photogrammetry | Colleting crowd-sourced photos of an eroding or changing landscape, river, or coast to use in the SfM algorithm. | Wernette et al., 2022 |
| | Mobile Applications | Employing the use of an app, such as River Watch, CreekWatch, CoastSnap, PicShores, and Muskoka E-Rode for active monitoring of an eroding portion of a river. | Sheppard & Terveen, 2011; Kim et al., 2011; Harley & Kinsela, 2022; Theuerkauf et al., 2022; Gazendam et al., 2022 |
| | Environmental Samples and Lab Analysis | 1) Using citizen participants to sample water levels and collect water quality measurements in areas of erosional or flooding risk.<br>2) Sampling water for quality measurements in or around areas that are not covered by district gauges. | Zettler et al., 2017; Metcalfe et al., 2022 |
| | *In-situ* Technological Surveying | Citizens taking bank erosion measurements at specific erosional sites of concern by using loaned equipment from local | Gazendam et al., 2022, Zettler et al., 2017 |

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| | | institutions (universities, environmental organizations, watershed governing bodies, etc.). | |
| | Data Processing and Digitization | Project participants sorting through river monitoring photos and datasets (for erosion, flooding, etc.). | Zettler et al., 2017 |
| Human-Based | Community Associations and Meetings | 1) Gathering community together to focus on water-related issues, like flooding, erosion, pollution, and more.<br>2) Introducing community to the concept of citizen science, and encouraging participation in CS projects. | Asingizwe et al., 2020; Burgos-Ayala, et al., 2022 |
| | Training and Workshops | 1) Hosting workshops after projects are completed to discuss findings from the work conducted, disseminate knowledge/findings, and encourage non-participating community members to reap the benefits of citizen science projects.<br>2) Conducting training sessions for relevant hard and soft skill development prior to conducting citizen science field work.<br>3) Using participatory processes like interviews to gauge if training is adequate and well carried out, and making necessary changes for future projects. | Soria et al., 2021; Gazendam et al., 2022; Grootjans et al., 2022; Asingizwe et al., 2020; Burgos-Ayala, et al., 2022 |
| | Experiential Surveys and | Using experiential surveys to hear participant's subjective descriptions of | Gazendam et al., 2022; Asingizwe et al., 2020 |

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| | Subjective Descriptions | erosional sites, phenomena, and observed trends over time. | |
| | Social Media | 1) Harnessing social media platforms (like Twitter) to gain qualitative information on erosion patterns, flooding events, and other water quality issues in real-time.<br>2) Creating a specific hashtag to be used on social media for these purposes. | See, 2019 |
| | BioBlitzes and Other Short Term CS Projects | 1) Using local BioBlitz events to increase open dialogues and scientific literacy surrounding water issues in a local region or city.<br>2) Promoting local environmental organizations (like watershed governance groups) through conversations with those participating in BioBlitzes. | Roger & Klistorner, 2016; Meeus et al., 2023 |
| | Interviews | 1) Engaging participants in pre-, during, and post-project interviews as a means of learning how to improve projects.<br>2) Engaging public participants in meaningful conversations with one another about the citizen science work they participate(d) in.<br>3) Using interviews for "social cartography," mapping where "problem" areas (erosion, flooding, | Soria et al., 2021; Grootjans et al., 2022; Albagli & Iwama, 2022 |

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| | | etc.) are found in a specific city or region. | |
| | Multiple CS Project Participation | Engaging participants in multiple (interdisciplinary) citizen science projects to serve as a means of increasing future interest, inclusivity, and diversity in citizen science, whether geomorphological or not. | Allf et al., 2022 |

Table 3

| **Impacts on Participants by Citizen Science Method** *[Each orange box indicates that the method and associated impact align]* | UAVs/Drones & Digital Elevation Models (DEMs) | Basic Photography | Structure from Motion (SfM) Photogrammetry | Mobile Applications | Environmental Samples and Lab Analysis | *In-situ* Technological Surveying | Data Processing and Digitization | Community Associations and Meetings | Experiential Surveys and Subjective | Interviews | Social Media | Training and Workshops | "Adopt a..." Programs | BioBlitzes and Other Short Term CS Projects | Multiple CS Project Participation |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Greater Sense of Meaning | | | | | | ■ | | ■ | ■ | ■ | | ■ | ■ | | ■ |
| Stronger Connection to Space and Place | | ■ | | | ■ | ■ | | ■ | ■ | ■ | | | ■ | ■ | |
| Increased Advocacy Opportunities | | | | | | | | ■ | ■ | ■ | | | | | ■ |
| Greater Social Cohesion Among Participants | | | | | | | | ■ | | | | ■ | | ■ | |
| Development of Practical and Scientific Skills | ■ | ■ | ■ | | ■ | ■ | ■ | | | | | ■ | | ■ | |
| Networking Opportunities | | | | ■ | | | | ■ | ■ | ■ | ■ | ■ | | ■ | ■ |
| Publication Opportunities | | | | | ■ | ■ | ■ | | ■ | ■ | ■ | | | | |
| Community Building | | | | ■ | | | | ■ | | | ■ | ■ | | ■ | ■ |
| Improved Understanding of Science | ■ | | ■ | ■ | ■ | ■ | ■ | | | | | ■ | | | |
| Improved Understanding of Complex Problems | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | | | ■ |
| Enjoyment and Fun | | ■ | | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| Improved Health and Wellbeing | ■ | ■ | ■ | | ■ | ■ | | ■ | ■ | ■ | | ■ | ■ | ■ | |

Table 4

| **CS Method** | **Recommendation Summary** | **Pros** | **Cons** |
|---|---|---|---|
| Mobile Applications | Create a mobile application (supported on iOS and Android) for documenting qualitative data, site descriptions, experiences, and photos of the site in Walkerton. | Is easy for most participants to access on their personal devices; links electronic data collection with other suggested methods, like *In-situ* Technological Monitoring; has a variety of positive impacts on participants (see Table 3). | Can be inaccessible for some participants without access to the Internet, or a mobile device that supports mobile applications. |
| *In-situ* Technological Surveying | Provide particpants with equipment to collect water samples, water level measurements, soil samples, and more in order to take accurate quantitative data at (and surrounding) the study site. | Allows for accurate and site-specific quantitative data collection; has a variety of positive impacts on participants (see Table 3). | Can be difficult for those with mobility issues; can be difficult to achieve without proper equipment, which can be expensive. |
| Environmental Sampling and Lab Analysis | Provide participants with equipment to analyze previously-collected water samples and soil samples, in order to ensure accurate data, and find out more about the site over time (changes in water dissolved oxygen or soil pH, for example). | Allows for samples to be processed in-lab to ensure high quality data and decreases human error; has a variety of positive impacts on participants (see Table 3). | Can be difficult without access to a lab space; can be difficult without access to the proper equipment, which can be expensive. |
| Basic Photography | Collect photographs of the site in conjunction with the developed mobile application to store images of the site over time, to be used in SfM algorithm or elsewhere. | Is easily accessible for most participants either using personal cameras or mobile devices equipped with a camera; allows for | Can be inaccessible for some participants without access to a camera, or similar mobile device. |

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| | | creativity; has a variety of positive impacts on participants (see Table 3). | |
| Structure from Motion (SfM) Photogrammetry | Provide a training session for using the SfM algorithm with photos of the site collected from other CS participants. Then, create DEMs from this algorithm, and use them to monitor changes to the site over time. | Is highly accurate; can use photos from many different angles and positions above the ground and around the site; algorithm is easy to train and learn; has a variety of positive impacts on participants (see Table 3). | Has a larger learning curve for some participants; requires the proper software and technological skillset to complete; can be time-consuming; requires detail-oriented participants. |
| Community Associations and Meetings | Get community environmental associations and clubs involved with the CS projects proposed here. Then, conduct meetings with members of each organization and participants from the local population to discuss findings, insights, ideas, and areas for improvement moving forward. | Brings the community together in a meaningful way; encourages participants to interact with one another; encourages participants to associate with other local organizations and city boards and councils; has a variety of positive impacts on participants (see Table 3). | Regular meeting times and the frequencies of meetings are not always possible for everyone to attend. |
| Experiential Surveys and Subjective Descriptions | Collect experiential surveys and site descriptions from participants in CS projects in the mobile application to gain qualitative and categorical data from various areas of the site | Personal experiences can be explained for qualitative data purposes; descriptions of the site include details otherwise missed; has a variety of | Can provide inaccurate data due to human error. |

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| | ("What sections of the cliff are looking more or less unstable today?" is an example question). | positive impacts on participants (see Table 3). | |
| Training and Workshops | Provide training sessions and workshops for members of the community at a local event location in Walkerton. Then, promote the CS projects about the Walkerton site using social media, local news, and websites. Finally, get locals involved in specific branches of the project they want to participate in after they have completed trainings and/or workshops. | Both training and workshops allow for continued learning and skill development; awareness of issues is increased; more participants are gained through proper training; data is more accurate; has a variety of positive impacts on participants (see Table 3). | Regular trainings and workshops are not always possible for everyone to attend. |
| Interviews | Conduct interviews with participants in the CS projects at the site about their experiences, to improve CS work here in the future, and to gain other insights about observed changes. | Interviews provide an additional space for participants to share their experiences at the site and what they have seen changing over time; has a variety of positive impacts on participants (see Table 3). | Can provide inaccurate data due to human error. |