CITIZEN SCIENCE:
THEORY AND PRACTICE

iWetland: A Community Science Platform for Monitoring Wetland Water Levels

RESEARCH PAPER

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ABSTRACT

iWetland is a community science wetland water level monitoring platform developed by the McMaster Ecohydrology Lab and tested from 2016 to 2019 in wetlands located east of Georgian Bay, Ontario, Canada. The goal of iWetland is to engage community members in wetland science while collecting data to better understand the spatiotemporal variability in water level patterns of wetlands. We installed 24 iWetland water level monitoring stations in popular hiking and camping areas where visitors can text the water level of the wetland to an online database that automatically collates the data. Here, we share our approach for developing the iWetland community science platform and its importance for monitoring all types of wetland ecosystems. From 2016 through 2019, almost 2,000 individuals recorded more than 2,600 water table measurements. The iWetland platform successfully collected accurate water table data for 24 wetlands. We discuss the successes and shortcomings of the community science platform with respect to data collection, community engagement, and participation. We found that forming mutually beneficial partnerships with community groups paired with strong outreach presence were key to the success of this community science platform. Finally, we recommend that those interested in adopting the iWetland platform in their community partner with community groups, recognize participant contributions, identify accessible sites, and host outreach activities.

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INTRODUCTION

Wetland ecosystems often occupy a transitional position between land and water and are typically grouped into five classes (i.e., bog, fen, marsh, swamp, and shallow open water) that are defined by their morphology (shape), nutrient dynamics, vegetation, soil characteristics, and hydrology (National Wetlands Working Group 1997). Wetlands can be highly biodiverse ecosystems and provide a suite of ecosystem services that include carbon storage (Gorham 1991; Loisel et al. 2017), water storage (Holden 2005; Mitsch et al. 2009), nutrient retention (Cheng et al. 2020), wildlife habitat (Markle et al., 2020), and can be refugia from environmental change (Stralberg et al. 2020). Despite the value of these wetland ecosystem services, over 80% of the world's wetlands have been lost, severely degraded, or threatened due to climate change, agriculture, industrial development, resource extraction, urban expansion, and other human activities over the past approximately 200 years (Rubec and Hanson 2009; Davidson 2014). Direct human impacts on wetlands are exacerbated by climate-mediated disturbances such as drought, wildfire, and sediment loading (Erwin 2008; Rubec and Hanson 2009).

One major impact of these disturbances is manifested through the alteration of wetland hydrological regimes, such as the variability of the wetland hydroperiod (Erwin 2008). Hydroperiod is defined as the duration and timing of saturated conditions (Brooks and Hayashi 2002) and is quantified by monitoring wetland water level dynamics. Wetland hydroperiod and the variability of water table depth are also important indicators of wetland class, hydrological function, ecological integrity, and habitat type and quality (Mitsch et al. 2009). Thus, characterizing wetland water level dynamics is critical to understand wetland ecosystems and the services they provide. With increasing stresses on wetland ecosystems there is a growing need to monitor wetland water levels, especially in areas prone to direct human impacts. The development of a community science platform that monitors wetland water table dynamics can help address this critical challenge and promote community engagement.

Wetland water levels are dynamic and often fluctuate rapidly, highlighting the need for frequent measurements (Díaz-Delgado, Cazacu, and Adamescu 2019) to capture the full range of variability. Monitoring wetland water levels can be done manually by staff gauge or continuously with pressure transducers and data logging systems, with a tradeoff between lower cost or increased measurement frequency, respectively. More recently, community science has been used to collect water level data to address the drawbacks of manual (e.g., lower measurement frequency) and continuous data collection (e.g., higher cost). Community science has been used successfully to monitor hydrological regimes across the USA and Europe, including stream discharge (e.g., CrowdWater; Seibert et al. 2019; Strobl et al. 2019; Etter et al. 2020) and water levels of streams and lakes (e.g., CrowdHydrology; Lowry et al. 2019). CrowdHydrology participants collect water levels using a staff gauge while CrowdWater participants collect stream water levels using a virtual staff gauge through a smartphone app (see Lowry et al. 2019 and Seibert et al. 2019 for details). However, a community science platform designed to collect water level data where water levels are often below the surface (regularly the case in bog and fen wetlands) has not been previously tested.

As a consequence of this gap in community science, our goal was to develop and test a community science wetland monitoring platform to better understand wetland ecosystems through the collection of water level data and involve the public with water research and stewardship. As such, we developed the iWetland community science platform to monitor water levels in a variety of wetland types, including peatlands (bog or fen) where the water table can be below the surface for parts of the year. Our first objective was to create a transferable monitoring platform that could be used to collect water level data in all wetland types. Second, we tested our community science platform in a range of wetland classes including coastal wetlands, ephemeral wetlands (i.e., wetlands that lose their water table during some portion of the year), shallow open water wetlands, swamps, and peatlands (bogs or fens). To assess the ability of the platform to collect water level data, we quantified (a) when each station had data collected at a frequency sufficient to calibrate hydrological models, and (b) the accuracy of the manual community science water level data by comparing it to continuously recorded water level data. Third, we assessed participation and engagement with our wetland water level monitoring community science program over a four-year period.

METHODS

STUDY AREA

We tested our iWetland wetland water level monitoring platform in 24 wetlands east of Georgian Bay, Lake Huron (Ontario, Canada). The 24 study wetlands are situated within Anishinaabek territory, including the Robinson-Huron Treaty and Williams Treaties, and are also within Métis Nation of Ontario Region 7, which is home to many diverse Indigenous peoples. The region east of Georgian Bay provides habitat for more than 50 species-at-risk, many of which use wetlands (GBB 2021). For example, wetlands provide overwintering habitat for many turtle and snake species (Markle et al. 2020). The study region has an abundance of wetlands of all classes and is a popular region for outdoor summer tourism, with several Provincial Parks and non-government organizations committed to environmental efforts, which offers high potential for environmental community science participation.

The region has a cool temperature and humid climate with 26-year daily average (1981–2010) maximum and minimum air temperatures for May–October of 25.5°C and 1.9°C, respectively (Government of Canada 2022). The 26-year average annual precipitation for the region is 1,118.2 mm (807.1 mm rainfall, 311.2 cm snowfall), where an average of 555.6 mm of rainfall occurs between May and October (Government of Canada 2022).

iWETLAND STATION DESIGN

Our iWetland platform had two different station types that can be installed depending on the wetland type and associated water level variability. First, the staff gauge design was installed in wetlands where the water table was above the surface throughout the year, or when there was open water (i.e., shallow open water and coastal wetlands, n = 7; Figure 1*a*). This design is similar to the CrowdHydrology gauge design (Lowry et al. 2019) and involved installing a piece of lumber (untreated 3.8 cm x 8.9 cm board with the end cut to a point) or a steel post (T-post with holes to bolt to) into the wetland substratum (e.g., peat, sediment, mineral soil). Once the lumber or pole was installed, a ruler was drilled or bolted on so that the zero mark was positioned at the top of the substratum. The participant read and recorded the water level from the position on the ruler.

The second station type was our groundwater well design and was installed where there was no open water, or in wetlands where the water table was expected to be below the surface for at least a portion of the year (i.e., bog, swamp, ephemeral wetland, n = 17; Figure 1*b*). The

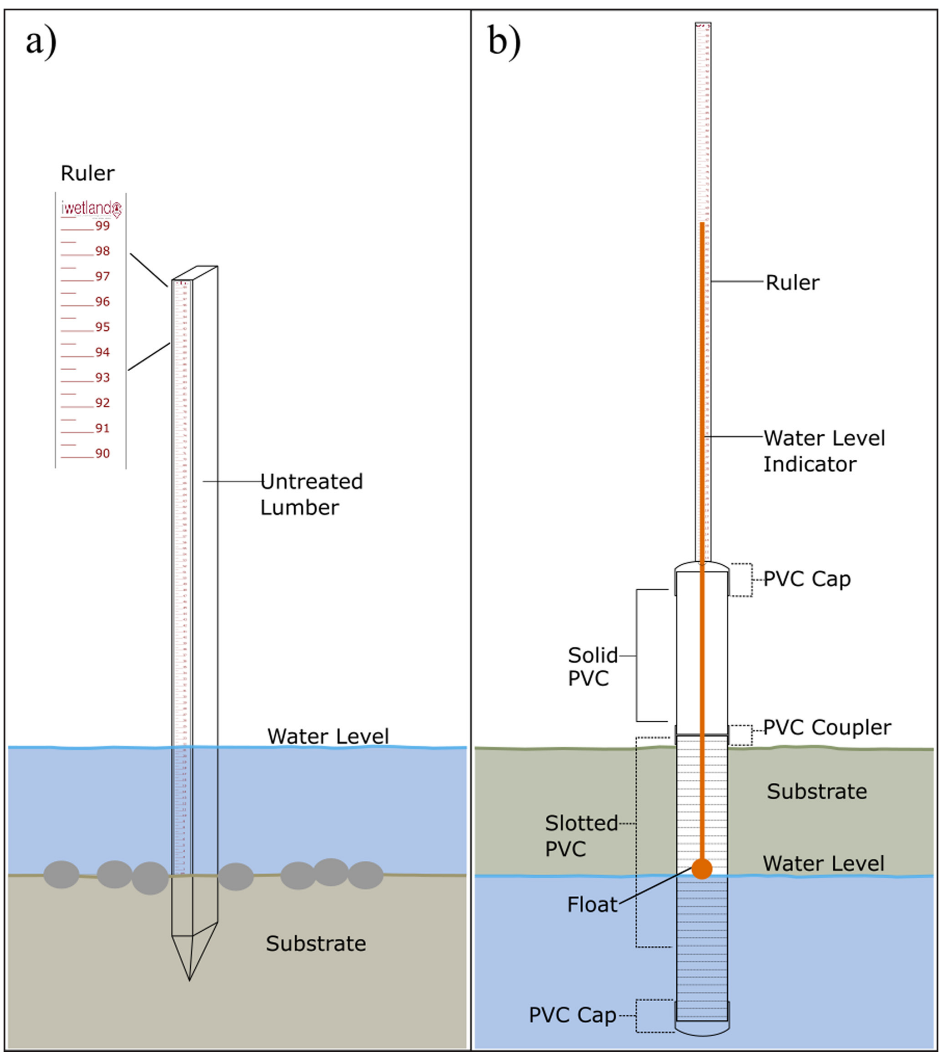

Figure 1 Diagram of **(a)** the staff gauge and **(b)** groundwater well iWetland stations.

groundwater well (1–2 m in length with ~0.5 m above surface) was made of 5-cm inner-diameter polyvinyl chloride (PVC) pipe. The below-ground portion was a slotted PVC pipe covered with a geotextile fabric sock to keep out sediment. The above-ground portion was solid PVC, with a cap that had an approximately 2 cm diameter hole drilled in the top that a float indicator rod emerged from. The float indicator consisted of a closed-cell foam float affixed to the bottom of an orange fiberglass dowel protruding through the pre-drilled hole in the well cap. A ruler was installed behind the well to act as a relative water level gauge, with the bottom of the ruler bolted near the top of the well. The participant used the ruler to read and record the height of the float indicator rod, which fluctuated as the water level changed. We measured the overall length of the well, noted the starting position of the float indicator, and made a manual water table depth measurement to convert the participant's data to a water table position relative to the wetland surface.

Each iWetland station was located in an area with good cellular network service and equipped with an information sign adjacent to the staff gauge or groundwater well that provided instructions detailing how to collect the wetland water level data (Supplemental File 1: Figure S1). The sign was specific to the station type (staff gauge or groundwater well) and included information on how to accurately read the water level from the ruler and how to submit the data by SMS text. Our information signs also included the name of the station, the funding source, a description and purpose of the platform, and a link to the iWetland website (http://ecohydrology.mcmaster.ca/iwetland.html) where the participant can view the data that have been collected to date. Individuals can also submit information on the condition of wells and send photos of any damage that they record.

Once the participant sends an SMS text containing water level data, an automated workflow is initiated that (a) sends a reply to the participant confirming receipt of the text, (b) parses information from the SMS text to identify the date, time, station name, and water level, and (c) stores water level data in a database (Figure 2). For simplicity and ease of interoperability, the iWetland platform uses a suite of Google services, where (a) Gmail is used to receive the SMS texts, (b) Google Scripts is used to monitor for incoming texts, parse SMS text information, and update the database, and (c) Google Sheets is used to store water level data and plot data that can be shared/linked directly to the iWetland website and updated in real time. To receive SMS texts as an email, the iWetland platform uses Twilio for a cloud-based virtual phone number that receives the SMS text. The Twilio service costs C$0.0075/SMS text (C$0.015 per water level with auto-reply) plus C$1/month for the virtual phone number. Within the Twilio service, all SMS messages are set up to be automatically forwarded to the iWetland email address. Step-by-step instructions to set up the iWetland automated workflow, including Google Scripts and Twilio code, can be found at https://github.com/pmoore82/iWetland.

Due to the unconstrained nature of text messages, the automated parsing of data from the SMS text relies on

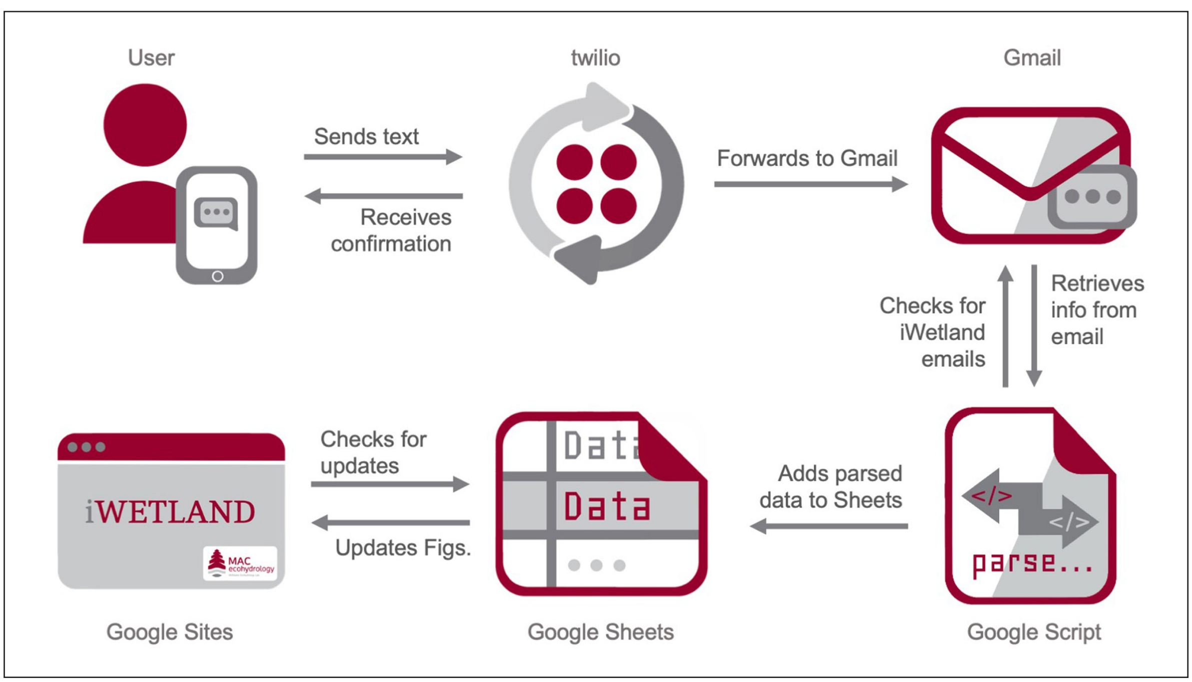

Figure 2 iWetland workflow diagram.

the participant following the instructions from the sign at the iWetland station (Supplemental File 1: Figure S1). Nevertheless, the scripts used to parse the SMS texts can be updated to recognize common site name typos. SMS texts that cannot be automatically parsed are flagged for manual assessment. To minimize inclusion of erroneous data, only water level data that fall within an acceptable range are automatically added to the database, otherwise the SMS text is flagged for manual assessment.

A groundwater well station can be installed for approximately C$50 (material costs only) and a staff gauge station for about C$20 (material costs only). The custom signage costs approximately C$30 per station. The cost of maintenance was variable depending on local climate and weather conditions, and the person-hours required to complete repairs.

iWETLAND SITES

We installed water level monitoring stations (hereafter referred to as iWetland stations) in 24 wetlands from 2016 to 2019 including in Provincial Parks, on recreational trails, private but accessible lands, and First Nation lands (Figure 3; Supplemental File 2: Table S1). iWetland site selection was based on three main criteria: facilitating partnerships,

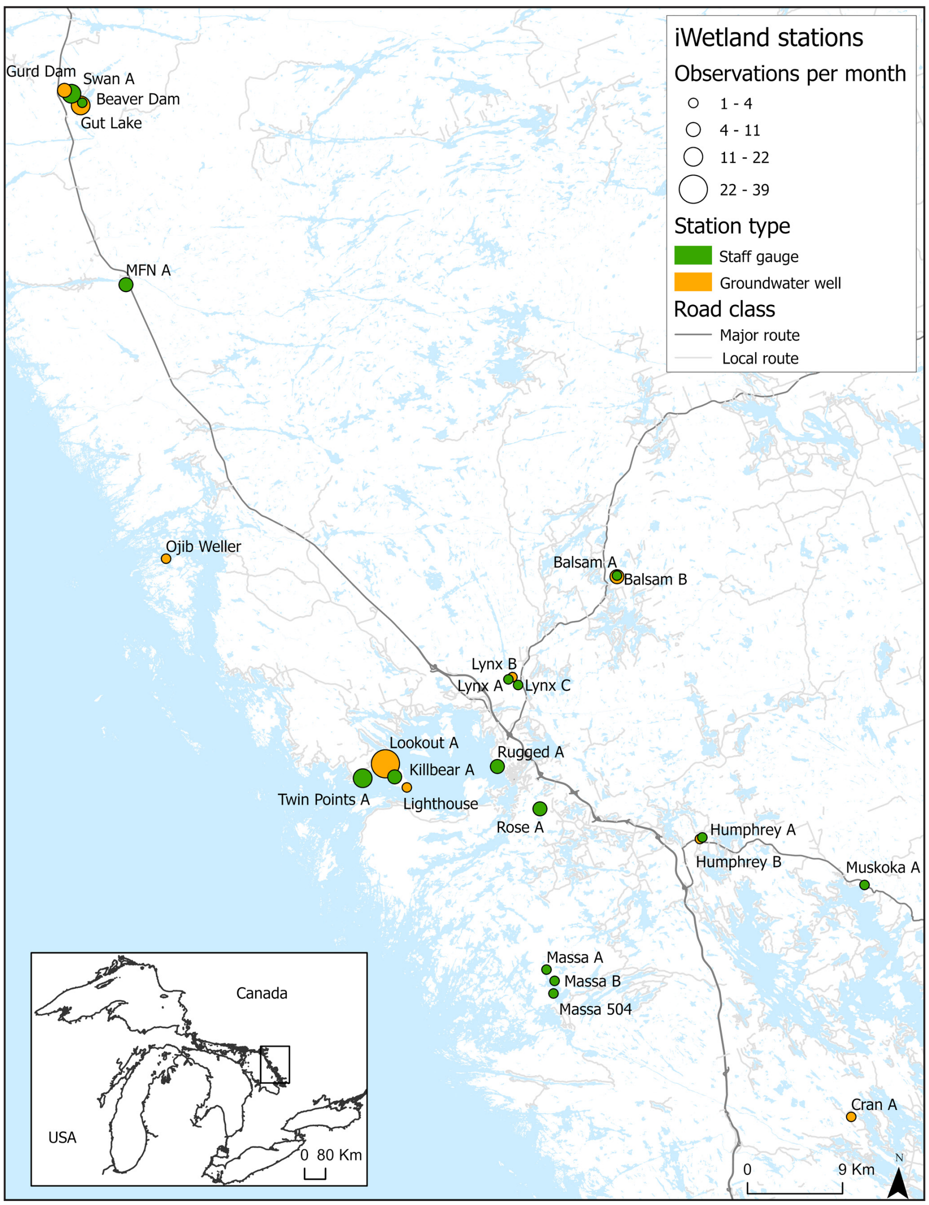

Figure 3 The 24 iWetland stations span ~150 km along Georgian Bay in South-Central Ontario, Canada. The stations consist of 15 surface water monitoring sites (staff gauge) and 9 groundwater monitoring sites (groundwater well). iWetland stations were active for 1–4 years between 2016–2019 (See Supplementary File 5: Table S1). Waterbody and road shapefiles licensed under the Open Government Licence – Ontario.

ease of public access, and water level dynamics. Sites were selected in collaboration with supporting partners, and installation permissions were provided by landowners and managing bodies (e.g., governments, recreation organizations, and small businesses). To ensure maximal public participation, 19 iWetland stations were located along an established hiking trail, two were adjacent to a campsite, two were located near a feature of interest (i.e., a winery and a historical lodge), and one was roadside near a community centre. Stations were selected to capture the water level dynamics of a range of wetland classes and included coastal wetlands (n = 3), ephemeral wetlands (n = 10), shallow open water (n = 4), swamps (n = 3), and peatlands (bogs or fens; n = 4). The iWetland stations were operational from May to October (during ice-free conditions) of each year from 2016 to 2019 (Supplemental File 2: Table S1).

To assess iWetland station use, we quantified the duration of time the iWetland stations were receiving adequate frequency of measurements. We considered a water level observation recording at least once per week to be adequate, which is considered almost as good as continuous data to calibrate hydrological models for streamflow, even with assumed errors (Etter et al. 2018, 2020). To assess the accuracy of community science wetland water level observations, three coastal iWetland stations with direct surface water connections to Georgian Bay were compared using Kendall correlation to hourly water level data collected from this waterbody at Parry Sound Station 11375 (DFO 2021).

PARTICIPATION AND OUTREACH

We quantified participation at each iWetland station as the total number of submitted water level observations. Data were also standardized by the total number of months stations were operational to account for variations among stations and years. A Wilcoxon rank-sum test was used to discern differences in participation between the two station types (staff gauge and groundwater well) while a Kruskal-Wallis test was used to compare participation among station types (park, private, public) and among the individual stations located in Provincial Parks (i.e., Grundy, Killbear, Massasauga).

We conducted regular outreach programming to increase engagement with the iWetland platform. We considered an individual a participant if they submitted a water level observation at an iWetland station, while we considered an individual to have engaged with the platform if they attended an event or lecture. We primarily used interactive public lectures in Provincial Parks, classrooms, and summer camps to engage with community members. We also spoke with local news and radio outlets and discussed the iWetland project in academic settings through poster sessions and presentations. We used social media to share information, hosted contests with prizes (e.g., Provincial Park gift certificates), and encouraged participants to share photos at the stations.

RESULTS

PARTICIPATION

From 2016 to 2019, 1,934 individual participants recorded 2,638 water level observations during the 336 total combined months all 24 iWetland stations were operational. In the first year of operation in 2016, the total number of observations (as text messages received) was 60 for the initial 5 iWetland stations installed (6 observations per station-month). In subsequent years, as the number of iWetland stations increased, the total number of observations increased to 895 in 2017 (n = 21 stations, 9 observations per station-month), 938 in 2018 (n = 24 stations, 7 observations per station-month), and then dropped to 745 in 2019 as the number of iWetland stations dropped to 18 (8 observations per station-month; Supplemental File 2: Table S1). Eighty percent of participants (n = 1,545) recorded one-time observations, while less than 1% (n = 7) recorded observations greater than ten times. In general, participants who recorded ten or more observations revisited the same station each time. In one instance, a single participant collected up to 30% of the observations at one station.

Participation per station ranged from 3 to 700 total measurement observations and an average of 7 observations per month (range of 1 to 39 observations per month; Supplemental File 2: Table S1; Figure 4). From May to October, we received 0 to 27 observations (mean = 3.5 observations) per day among the 24 stations, but this varied throughout the year. The peak month for water level observations across the four years for all stations was August (910 total observations, 15 observations per month), followed by July (559 total observations, 10 observations per month) and September (458 total observations, 8 observations per month; Figure 5*a*). We received at least 100 measurement observations from participants seasonally during the spring (May–June), summer (July–August), and fall (September–October) each year, with the exception of 2016 and spring 2019. Nearly twice as many participants recorded observations on Saturdays or Sundays (573 and 533 observations total, respectively) than any given weekday (254–291 observations total) from 2016 to 2019. Participation was consistent among week days (Monday–Friday) and between weekend days (Saturday and Sunday; Figure 5*b*). Participants were approximately 20% less likely

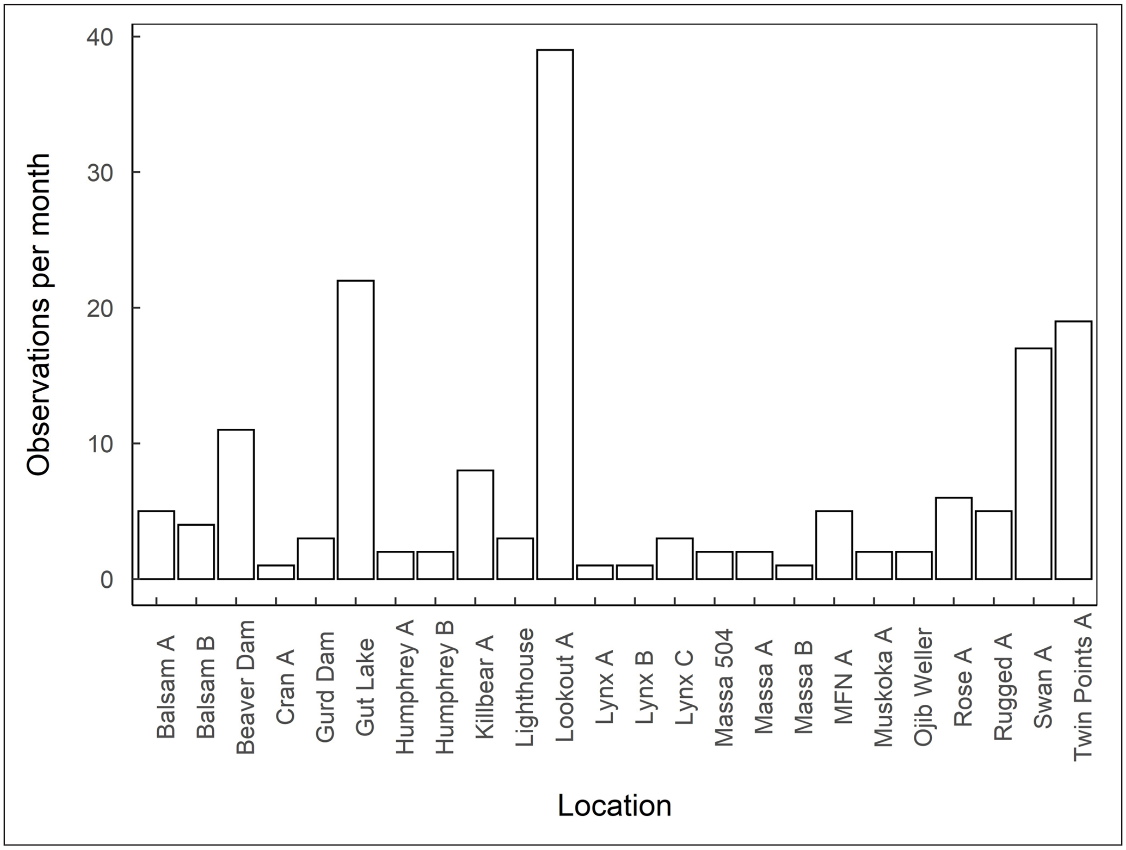

Figure 4 Average number of observations per month for each iWetland location.

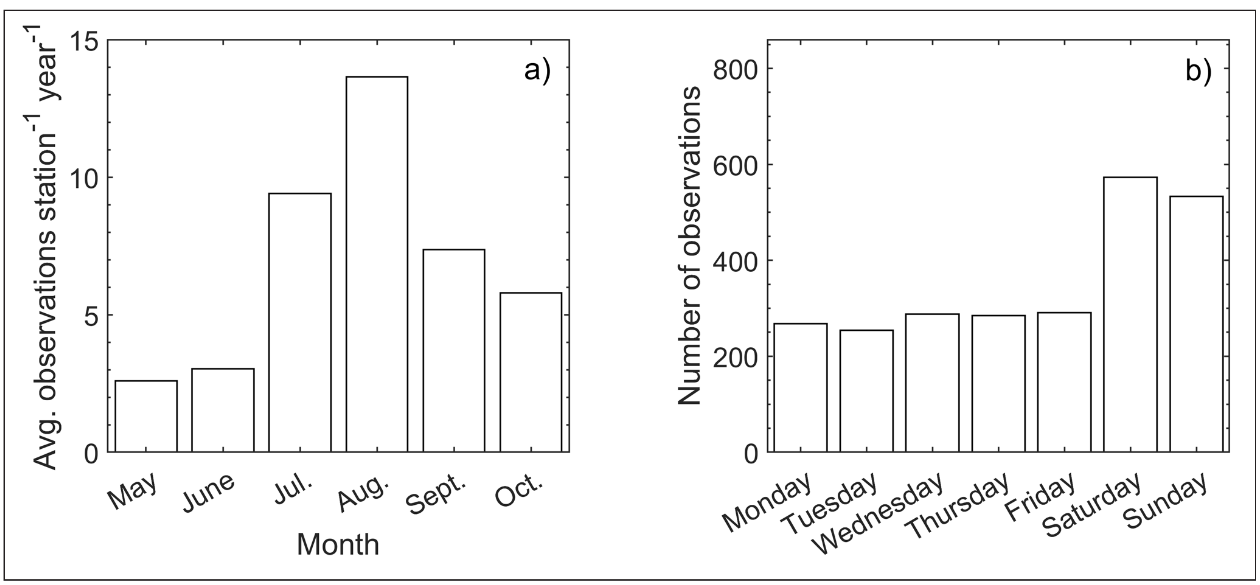

Figure 5 (a) Average number of observations per active station per month received among all 24 iWetland stations from 2016 to 2019, and **(b)** total number of observations by day of week.

to record a water level observation on the day of a rain event or the following day compared with periods with no rainfall (Figure 6).

Largely by design to promote participation, half of the iWetland stations were located within 1 km of parks, campgrounds, and other recreation areas, and the majority (19 of 24 sites) were readily accessible from roads (< 1 km from a road; Supplemental File 3: Figure S2). There was no significant difference in participation between the staff gauge and groundwater well stations (Wilcoxon rank sum = 185.5, p = 0.93), though there was more variability in participation among the groundwater well stations (Figure 7*a*). There was greater participation among the stations installed in parks compared with other public and private locations (χ^2= 8.35, p = 0.02, df = 2; Figure 7*b*). In addition, there were significant differences in participation between parks (χ^2 = 6.00, p = 0.05, df = 2, Figure 7*c*), where Grundy (n = 4 stations) and Killbear (n = 4 stations) Provincial Parks saw considerably more participation (13–14 observations per month and 19–25 observations per month, respectively) than the Massasauga Provincial Park (n = 3 stations, 1–4 observations per month), which is consistent with annual attendance for these parks during 2017–2019 (Supplemental File : Figure S3).

FREQUENCY OF OBSERVATIONS

The percentage of weeks an iWetland station was being used adequately (recording at least one water level observation per week) throughout a given summer ranged from 0% to 95%. The stations at Killbear and Grundy Lake Provincial Parks received the highest frequency of observations and received adequate frequency of observations throughout the majority of the summer (n = 8 stations, mean 60% of weeks with adequate use, range 14%–95%). The stations that received the lowest frequency observations were often located on privately owned but publicly accessible land (n = 6 stations, mean 12% of weeks with adequate use, range 0%–52%). Within a given week, the frequency of measurements ranged from 0 to 85 observations across all

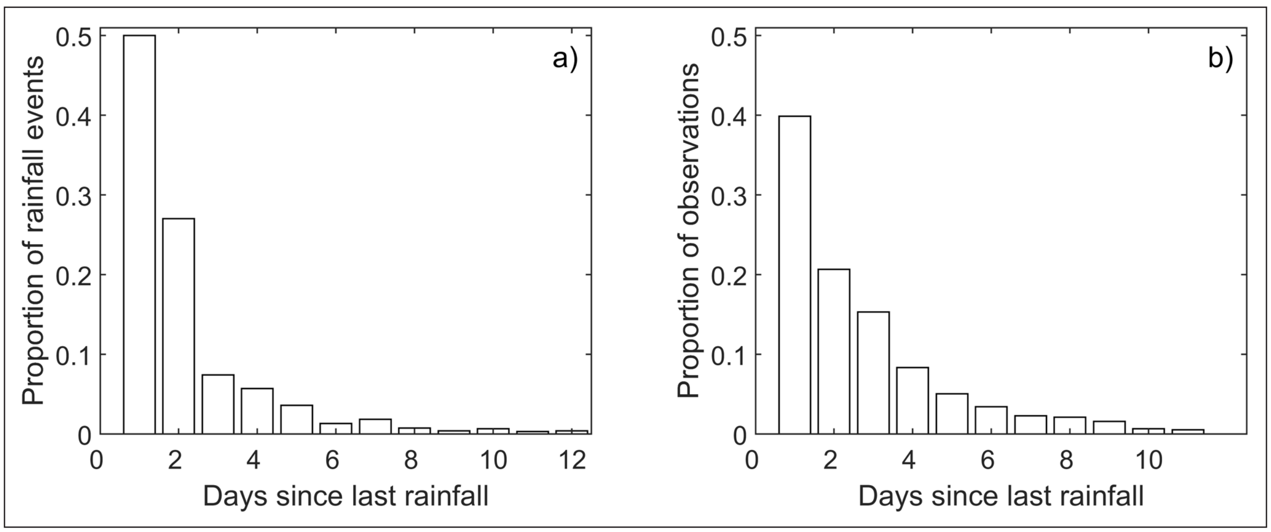

Figure 6 (a) Distribution of number of days between rainfall events measured at Beatrice, ON, and **(b)** distribution of time since last rainfall and receipt of observation.

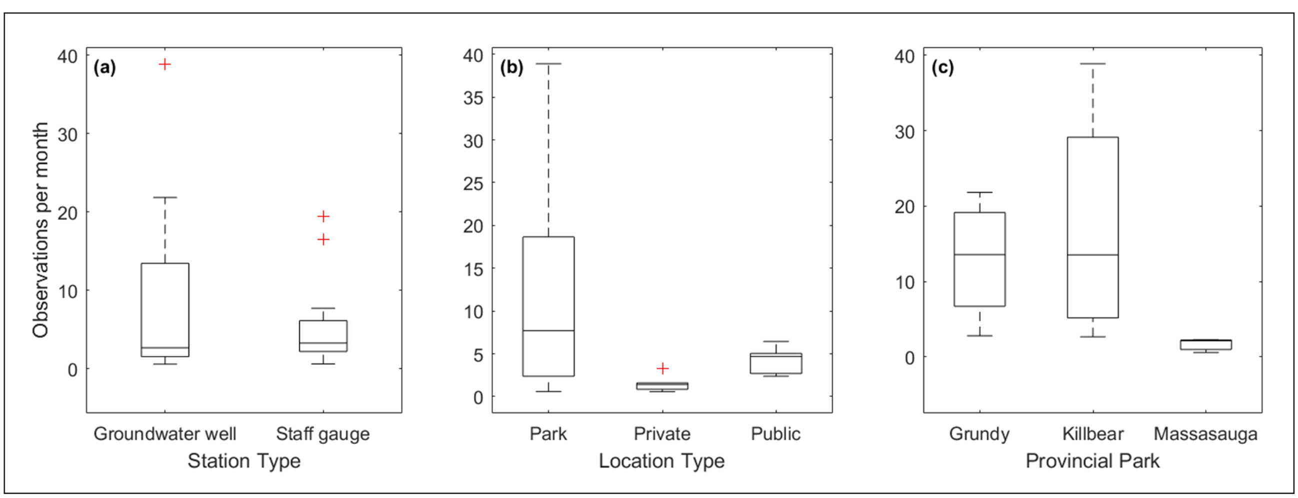

Figure 7 Median number of observations per month (25 and 75 percentiles; whiskers represent most extreme non-outliers, red plus sign indicates outliers) for **(a)** iWetland station type, **(b)** location type *(Park = Provincial Park , Private = privately owned but publicly accessible lands, Public = lands outside of a park that are available to the community, including hiking trails and First Nations lands)*, and **(c)** among the three Provincial Parks with iWetland stations.

stations, and 0 to 36 observations for a single station. Thus, some of the iWetland stations experienced large temporal gaps in which the station went days to even months without participant engagement.

WATER LEVEL PATTERNS

The first year of operation (May–October 2016) was the hottest (mean 16.5°C) and driest (325 mm of precipitation) of all four years (2016–2019) (ECCC 2021; Supplementary File 5: Table S2) and had the lowest mean water table position when all iWetland stations were pooled (29.5 cm; SD = 27.6 cm). In 2017, conditions were cooler (mean 15.7°C) and wetter (558 mm of precipitation; Supplementary File 5: Table S2) (ECCC 2021) with a mean water table position of 38.4 cm (SD = 18.1 cm). Fourteen of the 24 stations (58%) recorded the highest mean water table position during this year. The highest mean wetland water levels were in 2018 (50.3 cm; SD = 37.0 cm), even though weather conditions were relatively warm and dry (16.4°C, 486 mm of precipitation; Supplementary File 5: Table S2; ECCC 2021). In 2019, conditions were cool and wet (mean 15.1°C, 503 mm precipitation; ECCC 2021; Supplementary File 5: Table S2) and the mean water level was 37.2 cm (SD = 26.9 cm). Eleven of the 24 stations (46%) recorded their lowest mean water table position during this year.

Regardless of year, mean seasonal wetland water level (relative to the top of the substratum for staff gauge stations and relative to the base of the well for groundwater well stations) was highest in the spring (May, June) and lowest in the summer (July, August) for 14 of the 24 iWetland stations (58%). Six of the iWetland stations (25%) had a mean seasonal water table position that decreased from spring to fall. The remaining four wetlands either had a peak seasonal water table position during the summer (n = 2), or the mean seasonal water level increased from the spring to the fall (n = 2). The mean water level ranged from 9.9 cm to 35.6 cm for coastal wetlands, 21.7 cm to 78.4 cm for ephemeral wetlands, 30.0 cm to 39.1 cm for shallow open water, 8.5 cm to 75.0 cm for peatlands, and 17.1 cm to 62.8 cm for swamps. On average, peatlands had the lowest water level variability (range = 22.3 cm), whereas swamps and shallow open water wetlands had the greatest water level variability (range = 71.2 cm and 73.8 cm, respectively). Most ephemeral wetlands (90%) and peatlands (75%) had a lower mean water table position in the summer than in the spring and fall (e.g., Figure 8*a*). While the water levels of shallow open water and coastal wetlands tended to decrease from spring to fall, the response was more variable (e.g., Figure 8*b*). The seasonal water level patterns of swamps were similar, but

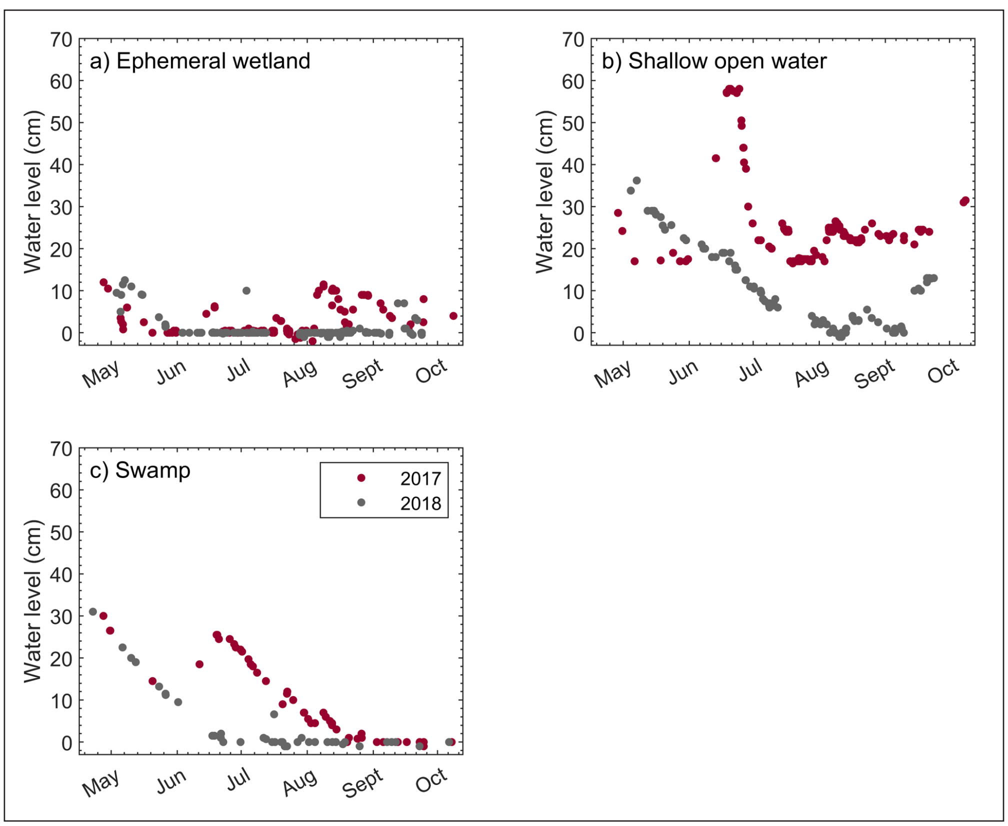

Figure 8 Example of summer relative water level position (cm) at **(a)** an ephemeral wetland using a groundwater well, **(b)** shallow open water wetland using a staff gauge, and **(c)** swamp using a groundwater well in 2017 and 2018.

experienced a decreasing water table at different times in the summer (e.g., Figure 8c).

Where there were considerable (n = 54) community water level observations using the staff gauge in a coastal wetland, they were well correlated with hourly water level data from Georgian Bay (n = 57, $p < 0.01$ Kendall tau = 0.66, Supplemental File 6: Figure S4*a*), indicating that water level data were accurate at this iWetland station. Even at a station with a lower number of observations (n = 16), the community water level observations were significantly correlated with the continuous water level data ($p < 0.05$, Kendall tau = 0.71, Supplemental File 6: Figure S4*c*). However, at the station with the lowest number of observations (n = 9), the community water level observations were not significantly correlated (p = 0.68, Kendall tau = –0.14, Supplemental File 6: Figure S4*b*).

DISCUSSION

DATA QUALITY

We created the iWetland community science platform as a relatively simple program to engage people in wetland conservation through participation in community science. This platform can be implemented to monitor wetland water levels across all wetland classes and in different regions. Similar to other community science initiatives (e.g., Walker et al. 2016; Weeser et al. 2018; Lowry and Fienen 2013; Lowry et al. 2019), iWetland collected reliable hydrological data to monitor wetland water level dynamics and provided or supplemented existing hydrological data for our partners and research program. The iWetland platform captured wetland water table dynamics across a range of wetland classes over multiple years with appropriate levels of accuracy and frequency to allow for interannual and seasonal comparisons of water level and water level variability. The strong correlation between two of our iWetland stations and the continuous water table data (Fisheries and Oceans Canada 2021; Supplemental File 6: Figure S4) indicates that the iWetland design is effective, and that community scientists are capable of collecting accurate water level data. There was one iWetland station with water level data that were not correlated with the continuous data. However, this iWetland station had very few observations, suggesting that measurement frequency is an important part of accurately capturing water level dynamics, especially in coastal wetland systems that experience fluctuating water levels.

The wetland water level data collected by community scientists aligned reasonably well with regional wetland water level patterns. These trends are expected due to the moisture retention properties of *Sphagnum* mosses (Moore et al. 2021; Waddington et al. 2015), which moderate water level fluctuations in peatlands, the variability of shallow open water wetlands that can range from being permanently flooded to intermittently losing their standing water during droughts or low flow periods, and the varying water levels of swamps influenced by seasonal flooding and precipitation (National Wetlands Working Group 1997). Furthermore, community science water level measurements reflected annual and seasonal climatic trends. In general, participants recorded lower water level measurements during years with warmer mean air temperatures and lower precipitation from May through October. The reduction in water levels during the summer for 14 of 24 iWetland stations is consistent with studies in the region on water level dynamics in deep and shallow peatlands (Moore et al. 2021). Additionally, all three coastal iWetlands stations (Rugged A, Massasauga B, Massasauga 504) recorded the lowest water levels in the fall, which is consistent with the seasonal water level cycle within the Great Lakes (Quinn 2002).

DATA QUANTITY

Stations in Grundy Lake (n = 4 stations) and Killbear (n = 4 stations) Provincial Parks had the highest participation. These eight stations (25% of the iWetland stations) made up 76.6% of total observations from 2016 through 2019. Grundy Lake and Killbear Provincial Parks are highly visited, attracting between 90,000 and 325,000 visitors each year, respectively (Supplemental File 4: Figure S3). Here, park staff can recommend hiking trails with iWetland stations, and park lectures provide an opportunity to directly engage with potential participants. We also installed stations in the Massasauga Provincial Park, but two of three were water access only (e.g., canoe, kayak) and were not as successful as stations in Grundy Lake and Killbear Provincial Parks. In general, the most successful stations were located along a walking trail in highly visited areas. Since location is a critical determinant of station success (Lowry and Fienen 2013; Lowry et al. 2019), identifying areas that are frequented by community members or are tourist hotspots will help maintain an adequate frequency of water level observations when locating stations for future projects. Each selected site must strike a balance between ecohydrological relevance and the likelihood of community members passing by. A site with high relevance to the research question, but with little public visibility would not be suitable for a community science project.

Even if a site is located in a high traffic area, if people are not encouraged to stop and participate, the number of observations may be low (Lowry and

Fienen 2013; Lowry et al. 2019). This occurred at Rose Point and Humphrey nature trails, where the stations were located along popular trails but there were few observations. In these instances, it may be beneficial to direct outreach programming to these areas or to identify an individual who frequents the area and can reliably record observations as a part of their regular activities (Jollymore et al. 2017; Lowry and Fienen 2013; Lowry et al. 2019). Alternatively, a water level logger would be useful in remote areas that would not receive high participation. Since the iWetland platform is sustained almost exclusively by one-time participants (80% of participants submitted only one observation and less than 1% of participants submitted more than 10 observations) identifying individuals who are able to visit a station often may be beneficial to ensure an adequate frequency of observations. The high number of one-time participants may be partially explained by the relatively low year-round population and high level of summer tourism within the eastern Georgian Bay region. The method of data collection may also influence participation trends. Community science projects sustained by one-time participants (e.g., iWetland, CrowdHydrology: Lowry et al. 2019) are often designed so that no prior training or application download is required. Conversely, programs where most observations are submitted by relatively few participants (e.g., FreshWater Watch: Scott and Frost 2017; CrowdWater: Etter et al. 2020) often require volunteers to attend detailed training sessions or collect multiple observations. This higher commitment lends itself to more dedicated volunteers, compared with programs that allow for one-time participants.

Further, temporal trends in participation impact the consistency of wetland water level observations. For example, we received more observations on weekends than weekdays (Figure 5*a*), which is a common bias in community science (Courter et al. 2013). Etter et al. (2020) found that pen-and-paper submissions to their CrowdWater program occurred more often on the weekends compared to the weekdays, whereas application submissions were even across all days of the week, except Saturday which was slightly lower. For iWetland, the number of water level observations recorded during the summer months greatly exceeded those collected in the spring (Figure 5*b*). This is consistent with the seasonal increase in tourism in the region. Additionally, colder weather conditions may have deterred participation in early spring, biasing the data towards the drier months and capturing lower water levels. CrowdWater also found a data collection bias towards warmer air temperatures, with most measurements taking place between May and September (Etter et al. 2020). Increasing engagement with potential participants at the start of the spring could boost participation during the early season and help mitigate the challenges of low-frequency data collection during this time. iWetland participation was lower on the day of and the day after a rain event compared with days with no rain (Figure 6). This bias has also been demonstrated in volunteer behaviour in species monitoring programs (e.g., Bas et al. 2008). Conversely, Weeser et al. (2018) found that the number of water level observations did not change between the wet and dry months in their community science project.

EASE OF IMPLEMENTATION

We partially attribute the success of iWetland to its simple, user-friendly design. No training, downloaded application, or data plan is required prior to data collection, which are common requirements in community science (e.g., CrowdWater: Kampf et al. 2018; Creekwatch: Kim et al. 2011). The only requirement for iWetland is a cell phone and network service. Previous studies have also had success using text messages for data reporting because participants are generally familiar with the technology (Lowry and Fienen 2013; Weeser et al. 2018). That said, a cell phone is necessary for participation and may be a barrier for those without access to a cell phone. We did not collect demographic information of participants, so the extent that cell phone access hindered participation within our platform is unknown. Thus, appropriate site selection with respect to location, accessibility, cellular service coverage, and relevance to the research question is important to maximize participation and quality of data collected.

Maintaining iWetland stations in working order has been a challenge of the platform. Since stations remain in wetlands year round, they can become damaged from exposure to harsh weather conditions. In particular, we found that the groundwater well stations require yearly maintenance because the closed-cell foam floats were damaged over winter (likely due to ice/freezing) causing the floating indicator to sink, which if not replaced would lead to inaccurate water level observations. Moreover, stations are often installed in areas that are unmonitored by the iWetland team, which makes them susceptible to vandalism. This occurred once where the information sign was stolen during the winter and had to be replaced in the spring. Together, weather and vandalism result in the need to periodically inspect, repair, or replace the station, where applicable. Sporadic visits to each station were beneficial to minimize damage but were time consuming due to the spatial distribution of the iWetland stations. Improving the signage to encourage participants to report damaged stations could prevent unnecessary inspections by the iWetland team.

LEVERAGING COMMUNITY KNOWLEDGE AND ENGAGEMENT

Through community engagement initiatives, we directly connected with approximately 400 individuals of all ages across the study region and indirectly connected with many more. For example, in 2018 we ran an advertisement in the Killbear Provincial Park newspaper and 50,000 copies were distributed to park visitors. The success of this engagement is partially evidenced by the high participation at the Killbear stations. Future engagement could include virtual or in-person workshops for community scientists that are hosted by researchers with the goal of connecting with participants, sharing the outcomes of data collection, data interpretation, and acknowledging participant efforts (Rotman et al. 2014; Walker et al. 2016; Weeser et al. 2018). These events can increase data quality and long-term participant satisfaction and retention (e.g., Weeser at al. 2018; Walker et al. 2016).

We have four recommendations for those interested in implementing the iWetland platform in their community. First, create mutually beneficial relationships with local organizations, governments, and landowners. Giving sufficient recognition, directing participants to further resources available from our partners, and collaborating towards a mutual goal have enhanced the success of the iWetland platform. Second, recognize that participants are doing a service by reporting data and celebrate their contributions. Uploading the data to the iWetland website, sending an automatic text in response to a water level observation, planning giveaways and contests, and engaging with participants on social media are methods we have used to acknowledge participants and receive feedback. Providing channels for communication and data sharing are critical factors to ensure long-term participation and overall volunteer satisfaction (Lowry et al. 2019; Rotman et al. 2014; Walker et al. 2016; Weeser et al. 2018; Peter et al. 2021). Third, identify areas with high pedestrian traffic before site selection. Locating these areas can be challenging and highlights the importance of building relationships with local stake- and rights-holders (e.g., Indigenous Nations) who may be willing to share insight and knowledge. Further, involving community members in the site selection process can foster a feeling of ownership and increase observation frequency (Walker et al. 2016). Finally, we recommend conducting regular outreach activities to highlight the purpose of monitoring wetland water levels and provide updates on the platform status (e.g., results, new stations), as this can introduce new participants and increase long-term participation (Devlin, Waterhouse and Brodie 2001; Rotman et al. 2014; Lowry et al. 2019).

CONCLUSION

We support and encourage the expansion of the iWetland platform into new regions to enhance the relationship between researchers and the public and to engage the community with respect to relevant local research questions. In our region, iWetland provided water table data for 24 unique wetlands across multiple years that were not previously monitored, filling important data gaps on the water table dynamics of sensitive wetland ecosystems. Together with other research projects, water table data are being used to examine wetland response to changing weather conditions to help inform wetland management decisions. iWetland can be a standalone platform or complement an existing community science project (e.g., combining iWetland water level data with community science observations of species-at-risk). We have provided the workflow and code for implementing the end-to-end automation of the iWetland database. The resources provided as supplementary material provide a ready-made solution for groups with limited resources as no coding expertise is needed and all platforms apart from Twilio are cost-free. Through iWetland's simple, collaborative design, the platform provides a multifaceted approach to educate the public on wetland types, science, and management and to engage communities in wetland monitoring.

SUPPLEMENTARY FILES

The supplementary files for this article can be found as follows:

- **Supplemental File 1.** Figure S1. DOI: https://doi.org/10.5334/cstp.448.s1
- **Supplemental File 2.** Table S1. DOI: https://doi.org/10.5334/cstp.448.s2
- **Supplemental File 3.** Figure S2. DOI: https://doi.org/10.5334/cstp.448.s3
- **Supplemental File 4.** Figure S3. DOI: https://doi.org/10.5334/cstp.448.s4
- **Supplemental File 5.** Table S2. DOI: https://doi.org/10.5334/cstp.448.s5
- **Supplemental File 6.** Figure S4. DOI: https://doi.org/10.5334/cstp.448.s6

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COMPETING INTERESTS

The authors have no competing interests to declare.

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