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Using Mobile Technology and Social Networking to Crowdsource Citizen Science

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Using Mobile Technology and Social Networking to Crowdsource Citizen Science

by

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Professor Marti Hearst, Co-Chair
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Abstract

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This dissertation explores the application of computer science methodologies, techniques, and technologies to citizen science. Citizen science can be broadly defined as scientific research performed in part or in whole by volunteers who are not professional scientists. Such projects are increasingly making use of mobile and Internet technologies and social networking systems to collect or categorize data, and to coordinate efforts with other participants.

The dissertation focuses on observations and experiences from the design, deployment, and testing of a citizen science project, Creek Watch. Creek Watch is a collaboration between an HCI research group and a government agency. The project allows anyone with an iPhone to submit photos and observations of their local waterways to authorities who use the data for water management, environmental programs, and cleanup events.

The first version of Creek Watch was designed by a user-centered iterative design method, in collaboration with scientists who need data on waterways. As a result, the data collected by Creek Watch is useful to scientists and water authorities, while the App is usable by untrained novices. Users of Creek Watch submit reports on their local creek, stream, or other water body that include simple observations about water level, water flow rate, and trash. Observations are automatically time stamped and GPS tagged. Reports are submitted to a database at creekwatch.org, where scientists and members of the public alike can view reports and download data.

The deployment of Creek Watch provided several lessons in the launch of an international citizen science mobile App. Subsequent versions of the iPhone App solved emergent problems with data quality by providing international translations, an instructional walk-through, and a confirmation screen for first-time submissions.

This dissertation further examines how social networks can be used for recruitment and promotion of a crowdsourced citizen science project and compares this recruiting method to the use of traditional media channels. Results are presented from a series of campaigns

to promote Creek Watch, including a press release with news pickups, a participation campaign through local organizations, and a social networking campaign through Facebook and Twitter. This dissertation also presents results from the trial of a feature that allows users to post Creek Watch reports automatically to Facebook or Twitter.

Social networking was a worthwhile avenue for increasing awareness of the project, which increased the conversion rate from browsers to participants. The Facebook and Twitter campaign increased participation and was a better recruitment strategy than the participation campaign. However, targeting existing communities resulted in the largest increase in data submissions.

This dissertation is dedicated to the millions of citizen scientists who have helped with countless problems around the world. Thank you for giving of yourselves for our future.

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Chapter 1

Introduction

Long before the term crowdsourcing was coined, citizen scientists were successfully aiding professional scientists in distributed projects. Citizen science can be broadly defined as scientific research performed wholly or in part by volunteers who are not professional scientists. Citizen science projects encourage amateurs and hobbyists to work on real scientific problems—for example, by collecting or cataloging field data. This dissertation explores the application of computer science methodologies, techniques, and technologies to citizen science.

The ease of data collection and integration via the Internet presents great potential as a platform for citizen science. At the same time, increased interest in crowdsourcing has led to a variety of projects seeking to empower communities with the means to collect and analyze data of relevance to them, their neighborhoods, and the environment. The result is a dramatic increase in the number and scope of citizen science projects ongoing today. Many of these projects make use of technology such as mobile phones, which have potential to act as convenient data collection platforms. However, there remain many open questions about how best to use such technology to further scientific goals.

Social networking presents opportunities for empowering collaborative responses to community concerns. The Arab Spring has shown the power of organizing concerned citizens on Facebook and Twitter. Advertisers are already exploiting the networking power of Facebook to raise awareness about products, issues, and opportunities. Facebook Pages are an increasingly popular way to voice support for important issues. Parallel to the growth of social networking opportunities, a new data collection movement has emerged. Participatory sensing projects enable concerned citizens to not only voice their concerns but back their arguments up with hard data and take action. The emergence of such projects is partly due to the increasing instrumentation of mobile phones, which provide the means to easily collect data and allow citizens to integrate data collection into their daily activities. With such a multitude of technologies to empower users, project managers are often overwhelmed with choices.

Citizen science projects typically operate on limited resources with a small budget. Their time-constrained staff members often take on administrative duties in addition to the work they do as scientists in designing experiments and analyzing data. Often, trying a new method of recruiting or educating users comes at the expense of time to analyze data or take action on findings. The success of a project therefore depends upon knowing where to invest limited time and effort.

Recently, there has been a trend in citizen science projects toward using social networking tools to promote projects and encourage community, but it is unclear how successful such tools are for citizen science projects. While several prominent projects have established presences on Facebook and Twitter (e.g., eBird, SETI), the success of social networking as a means for raising project awareness, recruiting participants, and encouraging participation has not been well explored.

This dissertation explores challenges and opportunities in citizen science, including real-world examples of successful projects, both old and new (Chapters 2 and 3). Current trends and open problems in citizen science are described in detail (Chapter 4). The work presented focuses on observations and experiences from the design, deployment, and testing of a citizen science project, Creek Watch. Creek Watch is collaboration between an HCI research group and a government agency. The project allows anyone with an iPhone to submit photos and observations of their local waterways to authorities, who use the data for water management, environmental programs, and cleanup events.

Creek Watch was designed using a user-centered iterative design method, in collaboration with scientists who need the data (Chapter 5). As a result, the data collected by Creek Watch is useful to scientists and water authorities, while the App is usable by untrained novices (Chapter 6). Users of Creek Watch submit reports of their local creek, stream, or other water body, along with simple observations about water level, water flow rate, and trash. Observations are automatically time stamped and GPS tagged. Reports are submitted to a database at creekwatch.org, where scientists and members of the public alike can view reports and download data.

The deployment of Creek Watch provided several lessons in the launch of an international citizen science mobile App (Chapter 7). Subsequent versions of the iPhone App solved emergent problems with data quality by providing international translations, an instructional walk-through, and a confirmation screen for first-time submissions. After the motivations of citizen science volunteers were examined (Chapter 8), a new version of the App was launched with a feature that allows users to post automatically to Facebook or Twitter. The results of the trial of this feature and a survey of its use suggest that social networks have the potential to be useful as recruiting tools, but that users can be wary of using them (Chapter 9).

This dissertation further examines how social networks can be used to recruit and promote a crowdsourced citizen science project and compares this recruiting method to the use of traditional media channels, including press releases, news stories, and participation campaigns. Results are presented from a series of campaigns to promote Creek Watch, including a traditional press release with news pickups, a participation campaign through local organizations, and a social networking campaign through Facebook and Twitter (Chapter 10).

We conclude with a discussion of lessons learned for applying computer science methodologies, techniques, and technologies to Citizen Science (Chapter 11). It is hoped that this work will provide guidance to the community of CS researchers, scientists, and volunteer coordinators who are working to engage citizen scientists in mobile crowdsourcing projects.

Chapter 2

Background

2.1 Origins of Citizen Science

Citizen science invites volunteers to participate in scientific research. Amateurs have participated in a variety of ways, from gathering information in the field to analyzing data, and across the spectrum of sciences, including math, physics, chemistry, and biology. Indeed, all science began as citizen science, for long before science was an established profession in the private and public sectors, individuals made great leaps in scientific advances through hobbyist research [137]. Consider Charles Darwin, the wealthy gentleman who accompanied the captain of Her Majesty's Ship, The Beagle, on his travels [23], or Gregor Mendel, the Christian priest who, along his path to becoming abbott of a monastery, conducted groundbreaking studies with pea plants [79].

However, with deference to the great achievements of these and other private individuals, it could be said that the true power of citizen science comes not from single individuals making great leaps, but from groups of volunteers working together. Citizen science can provide useful results when the whole of the data collected and analyzed by many people is greater than the individual parts.

Perhaps the oldest and most successful example of this type of citizen science is the Christmas Bird Count organized annually by the National Audubon Society in North America. Since Christmas of 1900, volunteers interested in birds have donated a few hours of their time over the holiday season to identify and count the number of birds of each species in an area. This data, aggregated across the continent and compared over the past century, forms one of the most important sources of information about bird population and migration in the world [110, 141].

The Christmas Bird Count has been so successful, in fact, that bird counts have been started all around the world and throughout the year. The United Kingdom's Big Garden Birdwatch, for which citizens record the bird populations in their backyards throughout the month of January, is in its 32nd year [134]. In Australia, the Atlas of Australian Birds is a multi-year bird count inviting citizen scientists to identify the species of birds found across the (largely unexplored) continent [103]. In North America, eBird [51] enables its more than three million members to report on bird sightings 24 hours a day. Section 3.1, a case study on eBird, will discuss why the project has been so successful and arrive at some lessons for success in felicitously pairing of a community (birdwatchers) with a problem (tracking bird populations).

Birdwatchers are only one group of successful citizen scientists; another is amateur astronomers. The American Association of Variable Star Observers (AAVSO) was founded in 1911 to coordinate amateur astronomers in the observation of stars that change in brightness. For over a century, hobbyists with telescopes have been coordinating the observation of these stars and gathering valuable data for understanding the nature of variable stars [5]. This is another example of an excellent pairing between an existing hobbyist community and a scientific problem.

Citizen science astronomy has become increasingly popular in recent years, largely because digital imaging telescopes can now provide high-resolution images to the public [25]. Now it is possible for nearly anyone with an interest in the skies to contribute to astronomy, whether or not they own a small telescope themselves. The Galaxy Zoo project presents images from NASA's Hubble Space Telescope archive to the public, and asks volunteers to help identify and classify galaxies. More than 250,000 people have taken part in generating one of the largest and most important classification data sets in astronomy [178].

These examples, and many more, illustrate a widespread new approach to citizen science that seeks to make it as easy as possible for volunteers to contribute, often without even leaving their homes.

2.1.1 Armchair Citizen Science

Beyond astronomy, a wide range of citizen science projects cater to people who wish to help further science from the comfort of their home computers rather than in the field. These projects require various degrees of commitment from volunteers. Perhaps the most hands-off are volunteer computing projects such as SETI@home [152] and Folding@home [116]. Both projects enable volunteers to contribute to science simply by running software on their home computer when they are not otherwise using them, the former to process signals from space as part of the Search for Extra-Terrestrial Intelligence (SETI), and the latter to compute protein folding to study diseases. While these and other projects like them are undoubtedly examples of citizen science, they are a far cry from spending Christmas morning in a swamp counting birds.

More recently, some projects have tried to bring the challenge of field work to the comfort of the armchair. The Collaborative Observatories for Natural Environments (CONE) project enables volunteers to observe and identify birds by means of remote robotic cameras that can be viewed and controlled on the Web [140]. An accompanying game encourages users to make positive identifications and species counts, enabling round-the-clock observation of key bird hot spots [63].

Other disciplines lend themselves more directly to Internet-based citizen science. The Polymath Project [74] is an example of citizen mathematics. In 2009, over 37 days, a group of volunteers came together on the Internet to prove the density Hales-Jewett theorem (DHJ). The project has had an interesting side effect: it has provoked intense discussions about authorship within the mathematics community. Establishing the author of the proof was complicated. A diverse group of 27 volunteers, from high school teachers to Fields medalists, all took part in the proof; there was no specific leader. The compromise they reached was to publish under a group pseudonym, “DHJ Polymath.” However, getting the academic community to accept this notion of authorship has been a challenge [75, 38].

The ease with which volunteers can now contribute to projects they find meaningful is one reason citizen science is increasingly popular and successful [85]. Modern technologies, most notably the Internet, have enabled a vast number of projects that assemble disparate teams of amateurs to work toward a common goal. When this goal is scientific, we refer to the project as citizen science, but science is not the only discipline to take advantage of the new phenomenon that has come to be known as crowdsourcing.

2.2 Crowdsourcing

The term “crowdsourcing” was coined by Jeff Howe in 2006 to describe the then-new trend of outsourcing work to the “crowd,” or the increasingly talented public [80]. Crowdsourcing, by Howe’s definition [81], overlaps with citizen science, particularly for the data analysis portion of citizen science. NASA Clickworkers [165] is a canonical example of crowdsourced data analysis. In 2000, NASA had a collection of images of craters on Mars which they presented to the public to see if amateur astronomers (“clickworkers”) could successfully identify and classify the age of the craters. A few checks were put in place, including showing each image to multiple clickworkers. The results of the clickworkers’ analysis were compared to the results of the analysis that had already been performed by NASA. The results were stunning. The distributed amateurs did just as good a job as trained Ph.D. students [89].

Another astronomical project, SETI-Live [179], takes the SETI@home project to a new level—rather than merely enabling volunteers to do distributed computation to process signals from space, SETI-Live asks volunteers to listen directly to the signals and flag anomalies themselves. A human ear, with its innate knack for filtering signals out of background sounds, can hear patterns and distortions that machine algorithms miss. SETI is opening up the job of listening to signals to anyone who wants to lend an ear. While they are citizen science projects at heart, NASA Clickworkers and SETI-Live are identical to crowdsourcing—a job which formerly needed trained experts was thereafter outsourced to the crowd [81].

Indeed, there is evidence that the crowd can do the job not just as well as experts, but in some cases, better. In Suroweicki’s *Wisdom of Crowds* [145], he argues that if you need an answer to a question, polling a group of amateurs usually provides a more accurate answer than asking one expert. This wisdom of the crowds can most easily be seen in prediction markets such as those described by Wolfers and Zitsewitz [173] and by Dye [46]. These are markets in which participants can bet or vote on any kind of predictive question, such as "Who will be the next U.S. president?" These markets have shown consistent accuracy, but it has been repeatedly shown that the adage of "putting one's money where one's mouth is" holds true here—prediction markets where real money changes hands are more accurate [145].

This evidence that aggregating the analyses or predictions of amateurs provides highly accurate information suggests that citizen science should work. While the error rate of any individual's contribution may be higher than the expected error rate of an expert, the aggregate information produced by a group of people can have excellent accuracy [145]. This suggests, broadly, that citizen science projects should seek to have as large an amateur user base as possible.

This is certainly the case for the large and famous crowdsourcing project, Wikipedia [95]. Wikipedia is a free online encyclopedia with more than 16 million authors ("Wikipedians") [169], which has grown to be one of the most extensively utilized websites on the Internet [168]. The motivations of online volunteers such as Wikipedians will be discussed later, in Chapter 8, but the sheer success of the project provides good evidence that volunteers can do great things when sufficiently motivated.

2.2.1 Lessons from Monetized Crowdsourcing and Games with a Purpose

When Howe coined the term "crowdsourcing," he did not extend its meaning to paid microtasking [80]. But, Amazon's Mechanical Turk has since become the most well-known example of crowdsourcing today [131]. Mechanical Turk is a relatively simple idea: workers ("turkers") sign up to complete short work tasks online for small amounts of money. Requestors submit the tasks they would like completed (called HITs, Human Intelligence Tasks) and the price they will pay. The result is a marketplace of work where, among other things, HCI researchers conduct a large number of experiments [27, 77, 82, 96, 106, 131].

It is unclear if the model of paid micro-task crowdsourcing can apply directly to citizen science, but there are still many lessons to be learned. For example, the HCI community has observed with interest that Mechanical Turk is a useful environment in which to conduct user studies [96] and assess visualization designs [77]. This use of Mechanical Turk has been criticized, however, as there are issues with both data quality and sample demographics when turkers are used as user-study subjects [131]. Still, for many citizen science projects where cost is a primary concern, Mechanical Turk can provide a means of evaluating interfaces quickly and cheaply.

Mechanical Turk has also proven to be a reliable and very inexpensive means of evaluating translations [27]. Since internationalization is a challenge for many citizen science projects, using Mechanical Turk could be an effective alternative to expensive translation services.

Some recent studies on optimizing Mechanical Turk have implications beyond the paid crowdsourcing market. In particular, a number of recent crowdsourcing papers have explored the question of how to encourage good-quality output from workers. Mason and Watts [106] have shown that monetary incentives do not affect quality of work, but rather merely affect the number of times a worker is willing to do a task. Huang et al. [82] expand on this work to show that varying the design of the work to be done (e.g., the design of the Mechanical Turk task) has a positive effect on quality. While the task that crowdsourcers were asked to perform was simple (tagging images), the implications for more complex crowdsourced projects are intuitive: workers will do a better job on more interesting and varied work.

Some crowdsourcing research takes the notion of more interesting tasks one step further—by incentivizing participants not with monetary compensation but through games. Louis von Ahn's work on games with a purpose [158] has repeatedly shown that making work into a game spurs people to complete even challenging tasks. Some of the more successful examples involve image recognition—something that humans are good at but that often presents a major challenge in computation. Crowdsourced image tagging with the ESP game [157] and crowdsourced image captioning to facilitate search using Phetch [156] are two of the most successful of these projects. One consistent element in von Ahn's game work is penalty—a point reduction—for incorrect data.

Another approach to improving the quality of data gathered in games is to award extra points based on the number of other players who answer in agreement, as in Chamberlain et al.'s Phrase Detectives Game [29]. However, as Robertson et al. [127] have shown in the ESP game, strategies for increasing data quality by cross-checking with other players tend to produce more predictable and less unique results. They recommend rewarding players explicitly for novel answers.

All of these approaches rely on structured incentives for the user which can be modified according to the quality of the work. For certain types of citizen science, this approach can apply. One example is the FoldIt project [66], which engages citizen scientists in the challenge of protein folding. FoldIt uses an online video game with structured scoring that encourages users to compete at folding proteins. The proteins presented to players all have known solutions and are scored according to difficulty, with partial scores for getting close to the optimal solution. One of the goals of the project is to prove that humans can find optimal protein folds as well as computers, with the hope that unsolved protein structures will someday be presented to game players [65]. The project has recently proven successful at decoding the structure of retrovirus enzymes, in particular for an AIDS-like virus that had been an open problem for more than a decade. This result contributes to research into a cure for AIDS [135].

Another less direct example of structured competition can be found in many regional Audubon Societies during the Christmas Bird Count (CBC) [110]. Several teams of volunteers compete to see who can spot the most birds in a single day. While the goal of the CBC is to catalog the number of each type of bird in an area—which competition participants still count—the team that sights the highest number of distinct species wins. This competition differs from the above "games with a purpose." Players are not scored according to the true "purpose" of the game, nor is there a ground truth. Since scores are determined by the records kept in each team, the competition operates on an honor code. While the competition winner will not necessarily be the team who contributes the most useful data to the CBC, adding a layer of team competition has been shown to increase participation, since members recruit teammates [141].

Though structured incentives and competition can increase participation in many citizen science projects, they can also create myriad problems. Users have been known to "game the system" to increase their score or ranking in most games throughout history. Furthermore, there is some evidence that participants in citizen science and other volunteer programs are not motivated by competition, and may shy away from participating in competitive projects. We will discuss the motivations of citizen scientists in Chapter 8.

2.2.2 Location-based Crowdsourcing

If the Internet has brought citizen science into the home of every would-be volunteer, then mobile technology has brought it to every pocket. The penetration of mobile phones is truly astonishing— by the end of 2011, nearly 6 billion of the world's 7 billion people had mobile phones. Of those, almost 1.2 billion had active mobile-broadband subscriptions. [150]

What this means for citizen science is that billions of people in every country on earth are technologically enabled to participate in real-time location-based information gathering. The potential for crowdsourcing in the field is huge. Many initial use cases of this technology have demonstrated how useful on-the-ground information can be. The TxtEagle project [47] was started by Nathan Eagle to bring the power of crowdsourcing to people in developing nations. The project used SMS-based information to report on a variety of topics. The project initially targeted users in Africa, particularly taxi drivers with cell phones, who could report on real time traffic or roadway conditions in their areas. Another key use case in Africa was in translation to local dialects. In Nigeria, the TxtEagle crowdsourcing network was even used very successfully by blood banks. By creating a just-in-time blood supply alert system, that alerts paid volunteers when blood is urgently needed, nurses were able to use TxtEagle to help maintain the blood supply. [41]

TxtEagle, now rebranded and commercialized as Jana [48], has demonstrated some of the challenges for location-based crowdsourcing in the developing world, most notably, the difficulty in engaging people with different levels of technology (e.g., SMS-based communication on feature phones vs. smart phones).

Next-Drop is another real-time location-based crowdsourcing project aimed at the developing world—in this case, India [151]. Unreliable water services mean that millions of households across the world do not have regular access to clean water, despite plumbing infrastructure in their areas. Next-Drop is a mobile crowdsourcing solution that lets community members notify each other whenever water becomes available in the pipes, typically for only a few hours at a time. This system, like Txt Eagle, uses SMS for notification.

As the use of mobile phones expands, and more people begin to have access to smart phones, the potential for location-based tracking has increased. More smart phones are being equipped with sensors such as GPS, accelerometers, gyroscopes, compasses, and cameras [100]. Early uses of these sensors have been largely user-centric, providing a benefit directly to the owner of the phone, such as for driving navigation. One example using many sensors simultaneously is Ubifit [44], a system to track physical activity using sensors in the phone. The system has been successful at getting participants to increase their physical activity [100].

Increasingly, though, these projects have begun to look outward. GarbageWatch from UCLA is a great example of a location-based crowdsourcing project aimed at bettering a community. Users are encouraged to photograph the inside of trash cans to highlight the need for more recycling bins in the community. The project has successfully brought about a change in the waste management policies of the UCLA campus [100].

This type of community activism through location-based crowdsourcing is, unsurprisingly, most popular in urban areas, where the number of mobile smart phones is high. This has given rise to a new form of crowdsourcing, dubbed urban sensing.

2.3 Urban Sensing

Urban sensing—-which Eric Paulos, in his chapter on urban informatics, has also called participatory urbanism [119]—is taking hold in a myriad of situations, to address such prominent issues as noise and air pollution in urban areas. A noise pollution and monitoring system called NoiseTube invites mobile phone users to record noise in their locations as they walk around urban areas [105]. Another system, aimed at residential noise, uses stationary mobile phones at fixed locations to provide daily or weekly summaries of noise in a particular neighborhood [177].

Air pollution has received even more attention. The Common Sense project in Oakland, California, used a network of hand-held air quality monitors to track air pollution and demonstrate the effects of trucks driving through residential areas [45]. The InAir project in Pittsburgh, Pennsylvania, outfitted the insides of homes with air quality sensors [93]. Poduri et al. approached the same problem in a different way, encouraging users to photograph the sky to capture images of air pollution [121]. The OpenSense project offers a vision of how to combine sensors from a variety of sources to create a community sensing network around air pollution, which would encourage crowdsourced data from many sources [1].

The Common Sense Community [170] takes this vision a step further, creating scaffolding for mobile sensing and analysis on any topic. Many people have observed the need for this kind of scaffolding, including Goldman et al.—as information is collected by participatory sensing systems, it becomes more and more difficult to make actionable sense of the data [71]. Cuff et al. describe this as the problem of "making urban sense" and stress the need for a data commons to both collect information and discuss the data. Pachube [115], a company self-styled as the solution to the "Internet of things," provides one means for data collectors to deal with a mass of data. Pachube enables real-time data collection of feeds from sensors, with a built-in method for sharing data with others who might be able to use it. One of the most widely touted uses of the system so far is in tracking temperature and other weather conditions in order to measure climate change [115].

The community aspects of urban sensing are critical. In all of these projects, participants have been noted to be motivated, at least in part, by the feeling that they were collaborating for the benefit of their communities. Benefiting communities is a common feature of participatory sensing [120], as it is of citizen science.

2.4 Collaboration and Social Networking

A sense of community and collaboration is a core element of many citizen science projects. Consider Pathfinder, a project whose goal is to create an online collaboration environment for citizen scientists [104]. Pathfinder has grown into an online community focused on education, in which teachers, students, and mentors collaborate on citizen science projects and project development. More than 20,000 users a day collaborate and discuss data protocols and submission, data retrieval from interactive databases, and background information on a variety of research topics, from stream monitoring to butterfly counts to measuring the ozone layer [117].

While many citizen science projects use Pathfinder as a community forum, others employ their own forums. eBird [51] is an example of a citizen science project with an active discussion forum fully integrated with the data submission forum. When participants submit sightings of birds in their area, other users can comment on or question the data directly. Analytical discussions of aggregated data are also common, for instance, analyzing the increasing range of the Eurasian collared dove in North America [50].

Other citizen science projects opt for more widespread forms of social networking. World Water Monitoring Challenge (WWMC) [159], for example, is a citizen science project for water monitoring with an active Facebook community [176]. While participants in WWMC contribute data on water quality from around the world using the data submission website, discussions, updates, and shared stories take place on Facebook.

While we will discuss how citizen science projects seek to engage participants using social networking in depth in Chapter 9, a few aspects bear mentioning. Citizen science projects that are fundamentally local in nature (e.g., local stream monitoring programs) often make use of in-person meetings, community gatherings, and town halls to encourage a sense of community [41]. For larger projects, particularly national or international citizen science initiatives, fostering a sense of community proves harder. Traditionally, larger organizations have created a sense of community by setting up local branch organizations, such as the local chapters of the Audubon Society, which enable a sense of community despite the great number of members. With the advent of the Internet and, in particular, of social networking technology, citizen scientists no longer need to look locally for a sense of community. Indeed, increasingly, we look farther afield to see ourselves as part of a larger, global community, whose goals nonetheless align with and affect our local lives.

2.5 Categorization of Current Citizen Science Projects

The following Table 2.1 shows a sampling of current citizen science projects. Many of these are collected from a National Science Foundation (NSF) workshop on citizen science held in May 2011 [41], or are drawn from Wiggin's taxonomy of citizen science [162].

Key to Categorizations of Citizen Science Projects:

year	year project was founded	c	collaborative participation
m	mobile submission	f	use of existing social networks, e.g,. Facebook
o	on-line/Internet submission	e	educational only (data not known to be used)
$	monetary incentives	p	repeat user community
r	ranking incentives	t	data categorization
g	explicit game aspects	l	data collection

Project	Description	year	
eBird ebird.org	Reporting bird observations	2002	mo - r - - - - p t l
Great Backyard Bird Count birdsource.org/gbbc	Annual 4-day bird counting event	2009	- o - - - - f - p t l
Australian Bird Count	Counting bird sightings in Australia	1989	- o - - - - - - p t l
Who's Whoo-ing mianus.org/owlcall	Reporting neighborhood owls	2009	- o - - - - - - p t l
The Lost Ladybug Project lostladybug.org	Counting species of ladybugs	2004	- o - - - - f - p t l
Bay Area Ant Survey calacademy.org/science/citizen_science	Surveying local ant populations	2009	- - - - - c - - - t l
Great Sunflower Project greatsunflower.org/	Counting species of bumble bee	2008	- o - - - - f - p t l
Monarch Larvae Monitoring Project mlmp.org	Tracking Monarch butterfly growth	1997	- o - - - - f - p t l
Firefly Watch mos.org/fireflywatch	Reporting firefly sightings	2008	- o - - - - - - p t l
Northeast Phenology Monitoring usanpn.org	Monitoring plant & animal lifecycles	1956	- o - - - c f - p t l
BudBurst budburst.org	Tracking seasonal changes in plants	2008	mo - - - - f - p t l
What's Invasive! whatsinvasive.com	Tracking invasive plants and animals	2010	mo - - - - f - p t l
Gravestone Project goearthtrek.com	Study of acid rain by measuring gravestone weathering	2009	- o - - - - - - p - l
SnowTweets snowtweets.org	Mapping snow depth	2010	mo - - - - f - p t l
Community Collaboratory for Rain, Hail, and Snow cocorahs.org	Backyard precipitation monitoring	1998	- o - r - c - - p - l
Creek Watch creekwatch.org	Waterway monitoring using iPhones	2010	m- - - - - f - p t l
World Water Monitoring Challenge wwmc.org	Water body quality testing	1983	- o - - - - f e p - l
Earth Watch earthwatch.org	Nonprofit that allows volunteers to aid scientists in conducting field work	1971	- - - - - - f - p t l
Alliance for Aquatic Resource Monitoring	Nonprofit that trains communities to monitor and restore waterways	1986	- - - - - - f - p t l
SETI-Live seti.org	Listening to space noise to find patterns	2012	- o - r g - f - p t -
FoldIt fold.it	Protein folding game	2008	- o - r g c f - p t -
GalaxyZoo galaxyzoo.org	Classifying galaxy images	2000	- o - r g - - - p t -
Stardust@home stardustathome.ssl.berkeley.edu	Finding interstellar dust particles	2006	- o - r g - - - p t -
Clickworkers	Classifying craters on Mars	1999	- o - r g - - - p t -
Open Dinosaur Project opendino.wordpress.com	Building a database of dinosaur bone measurements from publications	2009	- o - - - c - - p t -
CONE Welder	Bird observations by robotic camera	2007	- o - r g - - - p t l
GarbageWatch	Photographing trash-can contents to promote recycling	2009	mo - - - - f - p t l
See Click Fix seeclickfix.com	Reporting neighborhood problems	2010	mo - - - c f - p - l
Did You Feel It? earthquake.usgs.gov/earthquakes/dyfi	Reporting earthquake intensity data	1998	- o - - - - - - - - l
Twitter Earthquake Detection Program	Reporting earthquakes in real time	2009	mo - - - - f - - - l

Table 2.1: Some new citizen science projects that involve data collection and the technologies they employ for participation.

Chapter 3

Examples of Citizen Science

This chapter examines two successful citizen science projects that serve as best practice case studies. While numerous citizen science projects are started every year, many fail to reach the goals of their instigators, and few become ongoing projects that stand the test of time. The following two recent projects, eBird and World Water Monitoring Challenge, have succeeded in their goals and have reached widespread global participation for more than a decade.

3.1 Case Study: eBird

eBird is, by many measures, the most successful citizen science project today. With a dedicated group of more than 60,000 contributors, consistently high-quality data collected year round across the world, and numerous valuable scientific findings contributing to over 80 published research papers, eBird has been an overwhelming success [41].

The project's concept is simple: Cornell University, home of the premier ornithology department in the country, perhaps the world, wanted to make use of the skills and observations of the large existing community of birdwatchers to collect data on bird populations. Leveraging the existing birdwatching community has been crucial to the project's success. In the United States alone, there are more than 46 million birdwatchers who are 16 years of age and older—more than 20% of the U.S. population [154]. This population spans a spectrum from people who put out birdseed and casually observe birds at their backyard feeders, to dedicated "birders," as they call themselves in the United States. eBird's Steve Kelling draws an important distinction between these populations and describes how eBird targets birders [90]. Most birders are members of the Audubon Society, a distributed national organization for birdwatchers, and already participate in Audubon's annual Christmas Bird Count and other related bird-counting activities. In addition, most birders keep private lists of bird sightings for their own reference, in addition to these official bird counts. Most birders maintain a "life list" of all the bird species they have seen , and many also keep "trip checklists" of birds they sight on specific outings. Many birders post their trip check lists online for other birders to use as a reference, and compare their life lists with other birders'. This list mentality was crucial to the design of eBird. "Birders like lists, so we built eBird around that," said Kelling [90].

eBird is designed as an easy way for birders to maintain their bird lists on-line while sharing their observations with the ornithologists who need bird population data. The entire system is built around the checklist model and designed with common bird list formats in mind. Birders can record not only when and where they have seen what bird, but its plumage, age, gender, and activities, the number of each species, etc. It is even possible to list specific subspecies, or, if users are not sure what specific bird they have seen, they can report a genus or family, or even indicate they have seen one of two bird species that are difficult to tell apart. By providing a common format underneath the checklist interfaces, eBird makes it easier for birders to maintain aggregate lists, like their life list, across multiple trip checklists. All of these features appeal to birders and make them more likely to contribute data to eBird [90, 41].

Another smart move by eBird to attract users is to allow anyone to see all the data, in real time. This helps birders in a number of ways, each of which contributes to the website's appeal. First of all, the data helps birders find birds. Spring and fall migration are some of the most exciting times for birders; at these times birds pass through areas in which they cannot normally be observed.. Because migration is arduous, most birds, when they stop to rest on their journey, remain in the same spot for several days, feeding and building up strength for the continuing journey. It is during this time that birders have a chance to observe them. Local networks, particularly through Audubon Societies, exist to let birders notify one another of rare sightings, but these tend to be very local and in many cases poorly managed. eBird, however, provides visualization tools and alert mechanisms for birders to find out easily and immediately when anyone has seen a new or rare species in the area. This provides an important incentive for users to visit and contribute to eBird, as they can make direct and immediate use of the data [144, 90].

Most users access the data using the convenient data visualization tools provided on the eBird website, as shown in Figures 3.1, 3.2, and 3.3. A Google map with an overlay showing bird sightings is one of the most popular visualizations. The search interface allows filtering by species, or groups of species, by location, and by time frame, enabling birders to find specific species of interest to them. Two other visualizations allow users to explore longitudinal species data by exploring bird numbers by location over time. These visualizations are geared towards one of the research goals of the project, tracking bird population status. In addition to these visualizations, there is also an API that lets users query and download both the archive of more than 100 million records, and the real-time data, which includes more than 3 million bird observations made each month [41, 3, 51].

Another benefit of letting users see each other's data is that it enables community-based data quality checking. Birders can question reports by other users if they appear to be

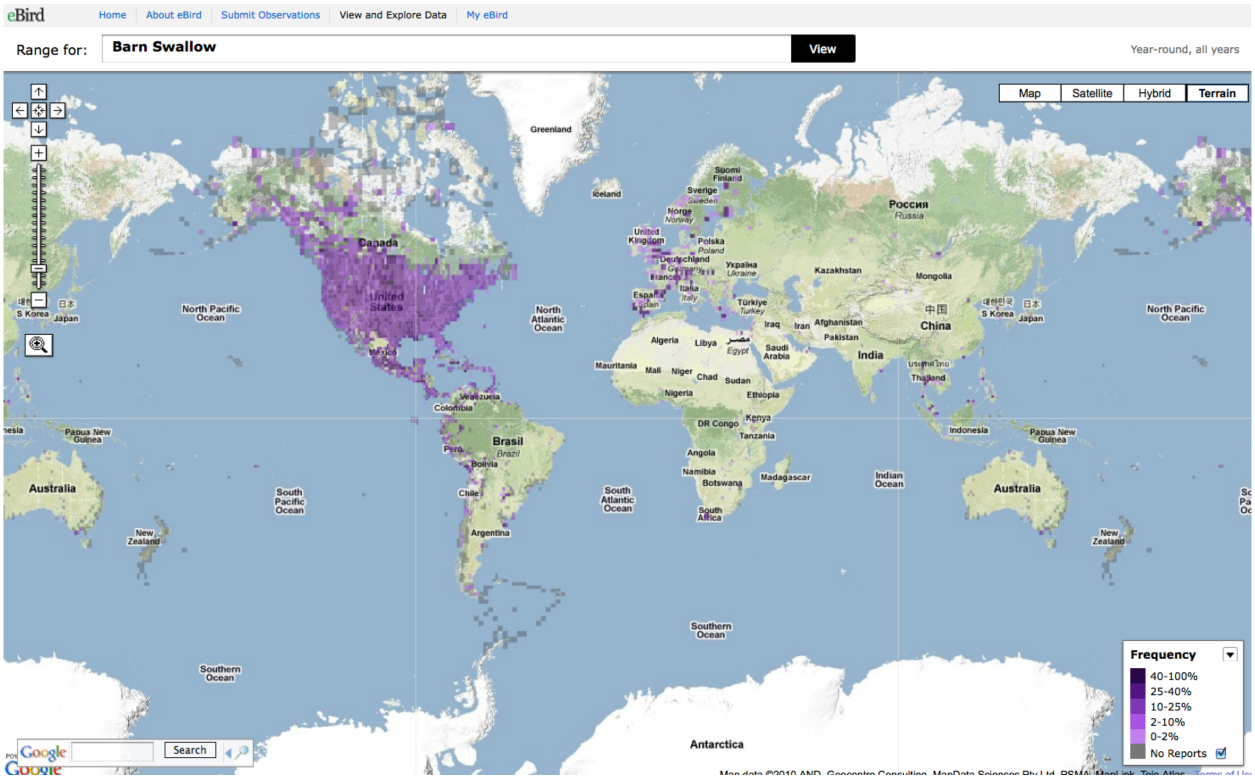


Figure 3.1: The eBird website shows the worldwide range map of a single species of bird, the barn swallow. The map is automatically constructed from reported observations of the barn swallow in the eBird database.

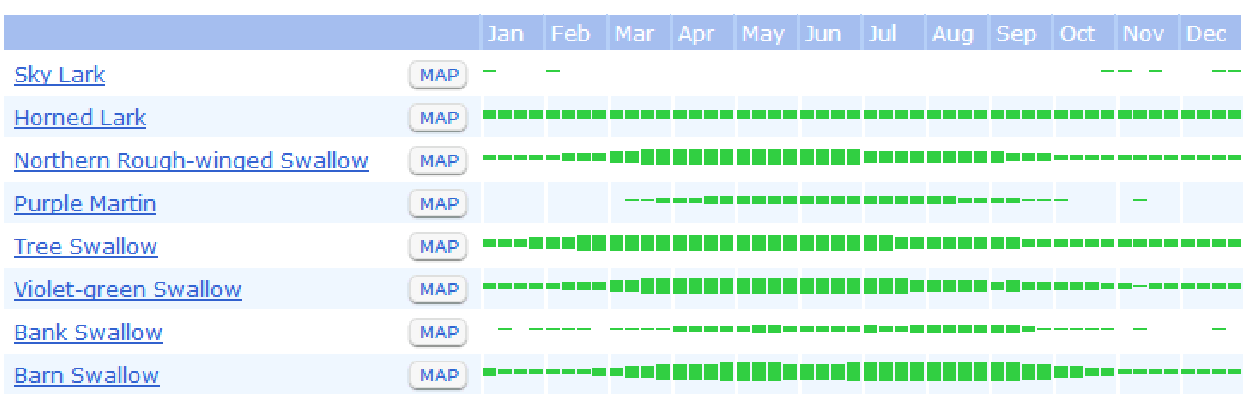


Figure 3.2: The eBird website shows yearly frequency of the barn swallow and related species in California. The visualization is automatically constructed from reported observations of these species in the eBird database.

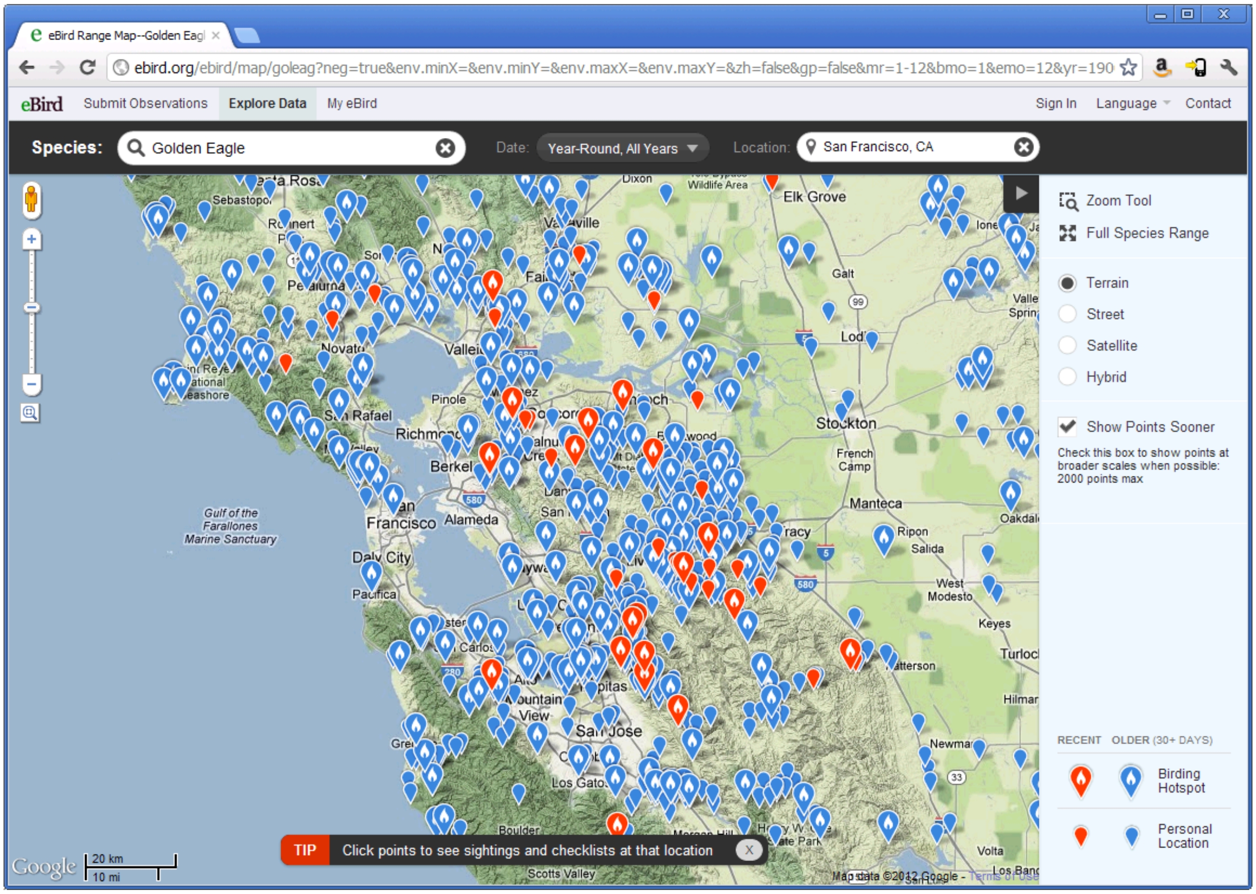


Figure 3.3: The eBird website shows individual sightings of the golden eagle in the San Francisco Bay Area. Users can drill down to see individual reports and can easily spot recent sightings (red pins) if they are searching for a particular type of bird in their area.

erroneous. eBird specifically recruits users for this purpose to act as "regional editors" [54].

eBird actually employs several quality-assurance mechanisms. The first and simplest is to look for outliers programmatically. An automated system notifies users of the following: "When you submit a checklist to eBird, we use automated filters that compare your observations with typical totals for that month and region. If a count on your checklist exceeds the expected daily total for a species, you will then be asked to confirm the entry" [54]. About 4% of eBird records are flagged for review [41].

Regional editors and scientists who are using the data can ask for further information on observations, including but not limited to those flagged by the automated system. A common way of establishing the observation is to provide photographic proof of a sighting for particularly unlikely species. Photos are commonly used across the birding community in this way, and eBird has adopted the practice [54].

Due to the well-known challenges in image recognition, eBird does not allow users to submit photos as observations, but rather requires users to identify the species themselves. From a data submission standpoint, photos are only used to back up the claim of an unusual observation [56].

eBird strives to make it as easy as possible for users to upload observations once they have identified the bird. Data can be submitted on the eBird website at any time, even if the birder is transcribing old observations from their personal records. For users who prefer to post observations even as they are looking at the bird, eBird provides a smartphone App for iPhone and Android, called the BirdLog App [84].

The BirdLog App was created in conjunction with Birdseye, an iPhone App originally created to provide on-the-go bird sightings reports for subscribers, using the eBird API. The company that authored the Apps, Birds in the Hand, charges $9.99 to download the App. This is an example of a non-standard funding method for developing a citizen science data submission platform [18, 19].

Another interesting aspect of eBird is that it uses competitions to encourage ongoing participation from existing users. Birders are regionally ranked by number of observations, in much the same way that traditional Audubon Society bird count competitions are run. The ranking establishes the top birders in each area [49]. Other competitions include selecting an international "eBirder of the month," who might be a top submitter, a student who has conducted important research using the eBird data, or someone who has contributed to the eBird community in another way [57]. eBird also supports "birdathons," such as International Migratory Bird Day, during which users have 24 hours to compete for the highest number of bird sightings in an area [143].

The winners of the "eBirder of the month" contest and other such awards, are announced via a variety of channels. eBird maintains a blog [142] with an RSS feed, where news and other announcements are posted, as well as a newsletter [53]. eBird also has a Twitter feed [51] and a Facebook page; however, these receive less content curation from eBird and less attention from users. For example, the eBird Facebook page has barely more than 6,000 likes and was posted to by eBird only 20 times in 2011 [55]. While this means the eBird

Facebook audience represents only a small portion of its user population, eBird still receives publicity (and thereby new users) from its presence on the Facebook network.

Having a dedicated team of people to provide content for community communications is important. In addition to the above services, for many of which content must be crafted, eBird puts out a weekly "BirdCast"—a forecast describing the state of the bird migration that week in the United States [91]. Supplementary news pieces keep birders aware of important developments in the ornithology community, such as the much-debated and finally located winter nesting grounds of the elusive black swift [17]. Many of these communications also address specific needs or requests of the community. For example, one podcast responds to the request of birders who want to know where data is most urgently needed so that they can prioritize those locations when birdwatching. In response, eBird provided interactive maps of where data is sparse [83]. Responding to another community request, eBird provided an easy guide to counting the number of birds of a single species sighted in a flock [52].

Perhaps the most important lesson from eBird's content-rich community experience is that it is important to engage users to maintain active interest.

3.2 Case Study: World Water Monitoring Challenge

The second citizen science project we will look at is very different from eBird in nearly every dimension. The World Water Monitoring Challenge (WWMC) is a project to "build public awareness and involvement in protecting water resources around the world by engaging citizens to conduct basic monitoring of their local water bodies" [159].

The primary goal of WWMC is education. While eBird targets users who are already experienced in data collection (bird identification), WWMC primarily targets users who have no experience collecting water quality data: grade school students. WWMC measures its success each year in number of participants, and not in scientific use of the data. And by this measure, WWMC is overwhelmingly successful. With 338,959 participants from 77 countries in 2011—a number that is growing every year—WWMC can truly be said to be educating people around the world about water quality and water stewardship [175].

As participation is its primary goal, the WWMC program has designed its data collection practices to make it as easy as possible to participate. Volunteers who participate in WWMC do so using a low-cost water quality testing kit designed by the WWMC team [174]. The kit is simple but cleverly designed to collect data on the five most important water quality measurements for freshwater bodies: water temperature, air temperature, turbidity, dissolved oxygen, and pH level. See Figure 3.4 for a diagram of the kit.

The kit items come in a plastic jar that is used to collect water. At the bottom of the jar is a secchi disk, a simple round sticker with white and black patches. When the cup is full,users can measure the turbidity, or cloudiness, of the water by assessing how easily this disk can be seen through the water and comparing what they see to an accompanying visual scale. The cup also has a flexible liquid crystal thermometer for measuring both air and water

Figure 3.4: World Water Monitoring Challenge test kit

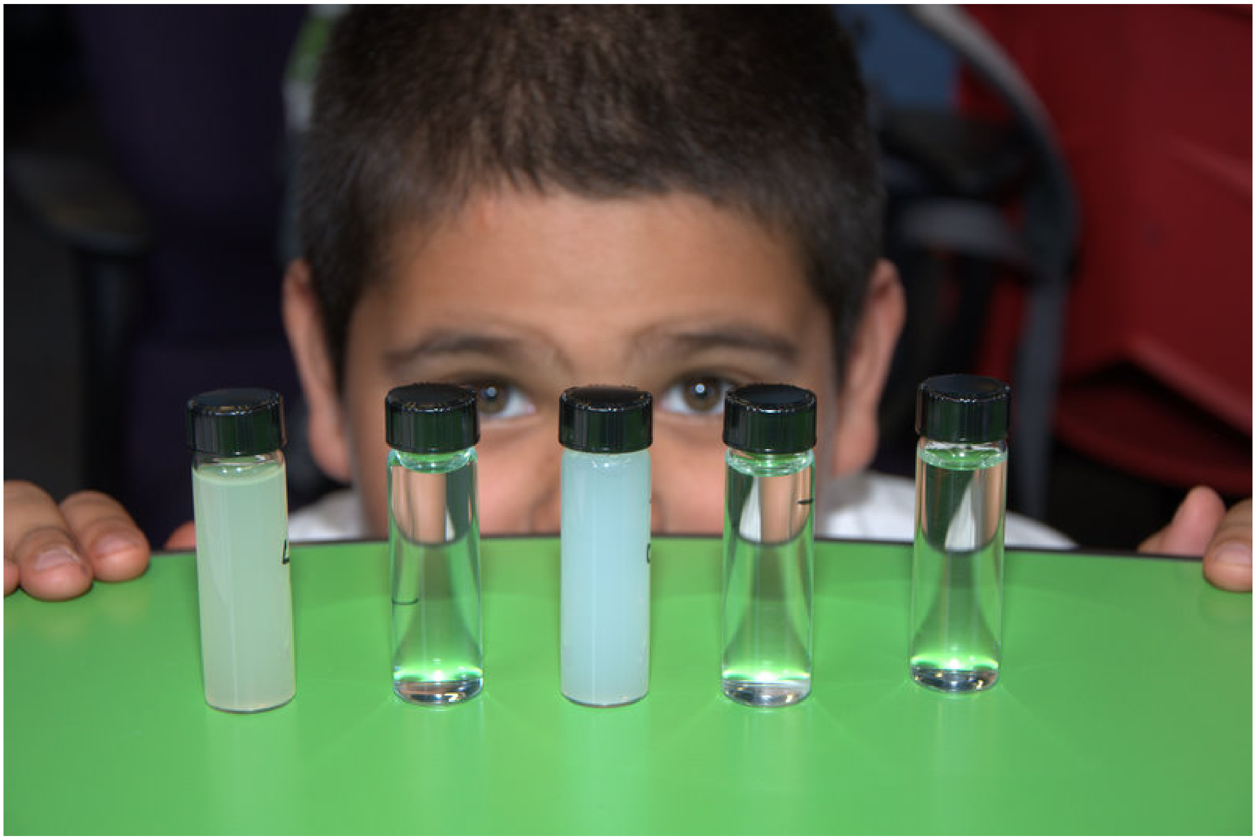


Figure 3.5: A World Water Monitoring Challenge participant tests water quality in San Jose, California.

temperature. Users can test pH and dissolved oxygen (DO) levels by pouring water into vials of premeasured volume and mixing in chemical reagent tablets. The color of the water after the reagent tables are dissolved determines pH and DO; users can get a measurement by comparing this color with an accompanying visual scale that shows the colors of pH values from 4 to 10 in single-unit increments, and shows the colors of DO values of 0 parts per million (ppm), 4 ppm, and 8 ppm. The kit also includes a simple, language-independent guide that uses comics to illustrate the test collection process.

While the kit can collect only limited data consisting of coarse values (e.g., single-unit increments of pH value), it is extremely easy to use. Furthermore, in order to reach as many people as possible, WWMC keeps the price of the kit low ($13.00 [174]), and thousands of kits are offered free to groups in low- or middle-income countries. This reflects the primary purpose of the kits, which is not data collection, but education about water quality through participation in monitoring.

Since the purpose of the kits necessitates that they be cheap and easy to use, high-quality data is not expected. This is demonstrable in a number of ways. As part of an extracurricular outreach program at IBM, 18 students, ranging between 6 and 12 years old, made use of the WWMC kits to test the quality of local tap water.[1] This exercise was both educational for the students and an opportunity to observe the kits in action. On identical samples, the students reported pH readings with wildly different values—a standard deviation of over 1 pH. To put this in perspective for the water quality monitoring, the pH range in which freshwater fish successfully breed is only $6.0 - 7.2$ [92].

While this single experiment is not conclusive, the data published annually by WWMC tells a similar story. When multiple samples are taken at the same place and time (e.g., on a school outing with multiple students testing the water), the results reported to WWMC vary wildly. In fact, in the 2011 WWMC data set, on occasions when multiple students gathered data together at the same site and the same time, less than 6% of the values were consistent.[2] These data quality concerns are of little relevance, however, since to the knowledge of the WWMC team, the data is not used for any scientific analysis of water quality [128].

WWMC has acheived widespread participation without placing a heavy emphasis on creating a community of users. There are no message boards and no chat groups, and while WWMC has both Twitter and Facebook presences, they are sparsely followed, with only a little over a 1,000 likes on Facebook [176]. Compared to WWMC's nearly 340,000 participants in 2011 alone, the on-line WWMC community is tiny [175].

While many citizen science projects encourage user community building to recruit and engage participants, WWMC focuses on more direct recruitment. By working with partners, teacher groups, and other outreach communities, WWMC reaches out to potential participants around the world.

These simple approaches—recruiting outreach coordinators and educators directly and providing inexpensive, easy-to-use data collection kits—have helped make WWMC a worldwide citizen science success story.

[1] Conducted April 21, 2010, at IBM Almaden Research Center, San Jose, California. Results unpublished.
[2] Analysis conducted on 2011 WWMC report [175]. Results unpublished.

Chapter 4

Challenges and Opportunities in Citizen Science

Citizen science projects, like all new initiatives, face numerous challenges. In this chapter, we examine some of the challenges and opportunities faced by modern citizen science projects. Many of the example challenges facing citizen science projects are drawn from an NSF-sponsored workshop with citizen science practitioners to identify challenges in the field [41]. These challenges are paired with possible solutions and applications of technology to help engage citizen scientists in the digital age.

4.1 Collecting Data

Many citizen science projects begin with a group of people who are in need of data and are looking for a means to recruit volunteers to help them collect that data. Typically, this group pursues the initial design process—defining research questions, hypotheses, and study designs—on its own [164].

While it is typical for citizen science initiatives to begin by designing and defining the project and only later recruit public participation, an increasing number of projects are pursuing a more co-created method of design. Indeed, some citizen science projects can be considered co-created in their entirety, as members of the public conceive the question or concern and then recruit scientists to help them. This is often the case for issues of public concern, such as point sources of pollution [20]. Leaving aside the challenge of getting scientists interested in using the data, which we will discuss in Section 4.4, there are a lot of opportunities with this sort of "grass-roots" or "community science" approach.

Forexample, consider the project ReClam the Bay (RCTB), a nonprofit organization of 50 volunteers in New Jersey who pursue stewardship of Barnegat Bay [126]. Since 2006, community members living near the bay have organized a water cleaning and shellfish restoration project that includes condition monitoring. In 2009, to investigate variability in growth rates of larval shellfish, participants collected data on shellfish rearing from their own restoration, and then recruited scientists to help them analyze and understand the data. Community members recruited, trained, and engaged volunteers through local networks, and have partnered with local schools so that students can help gather data [20].

RCTB is an example of truly “participatory research,” as it is sometimes called by groups studying public participation in scientific research (PPSR) [20, 164]. As is typical for a PPSF project, RCTB is extremely localized, with participants engaged in a specific problem relating to their home communities. The availability of local organizations and on-the-ground community activists makes it possible to do most recruitment in person [20].

For larger projects, particularly nationwide projects, local recruitment is less viable. Stepping back from the participatory model of co-creation, consider a more common situation: a group of people with a problem want the public to collect data for them. In the traditional citizen science model, the group would define and design a study, and then they would move on to the the next challenge is of recruiting and training participants [21].

Most projects begin their recruitment by contacting communities of potential users [41]. If a project has been designed with particular users in mind (e.g., students), then recruitment usually begins with those communities (e.g., schools). However, it can often be difficult to get traction with a potential user community by simply presenting a plan. Youth groups in particular often have set agendas and objectives, and if a project is not tailored to fit them, their participation is unlikely [21].

One solution is to strategically partner with organizations that have potential users, in order to co-develop a project plan that fits with existing programs and objectives. It is often possible to reach out to a local chapter of a large organization, such as the Boys and Girls Club, and develop a project curriculum that fits them. With the support of the local chapter, it becomes possible to reach a much larger national audience [21].

Key to such project plans is education—how potential users will be trained to participate in the project. In many cases, the training must be two-fold—not only must volunteers be trained to collect the data, but they must also be educated on the problem the citizen science project is tackling. Training can be conducted in a variety of ways, so it is important to tailor the education to the community [21]. For example, young students respond best to in-person training with hands-on, interactive activities to help maintain their focus [97].

For participants in projects like eBird, it is a good idea to use not one but several types of training. eBird provides online tutorials and tips to help birders learn difficult tasks like bird counting, but also relies on the training in bird identification techniques that birders get from outings, typically with their local Audubon Society chapters [52]. This two-pronged approach in which local hands-on training is made available along with extensive online tutorials or materials, is common in successful citizen science programs [20].

4.2 Data Quality

Even with the best training, citizen scientists will collect some bad data. Indeed, this is true even for professional scientists, which is one reason why checks, protocols, and quality-assurance techniques are so widely employed in field science. For volunteer citizen scientists, the data collection protocols and quality-assurance methods are typically not as rigorous as for professional scientists, since this would significantly discourage participation. As such, data quality issues are a constant concern for citizen science projects that make use of their data [68].

Consider the earlier case study of World Water Monitoring Challenge (WWMC). When students were asked to try out the WWMC water quality test kits, their measurements of an identical sample were wildly variable. The variation in data was large enough that some measurements indicated a health environment for fish, while others suggested the water would kill off fish almost immediately. This variation occurred even though children were given a very clear instructional session and hands-on assistance by teachers during the activity. As we have observed, however, data quality is not of much concern in the WWMC project, whose goal is education, not data collection (see Section 3.2).

A more rigorous study evaluated the effectiveness of trained volunteers collecting marine ecological data through the Earthwatch Institute. Volunteers had training in identifying species, recording occurrences, and making measurements of some species to determine age. Despite this training, volunteers' assessments for the abundance of different species were inconsistent and inaccurate. Counting the number of each species was found to be the primary difficulty, and the study concluded that the volunteers needed significantly more field experience, training, and guidelines. Identification errors were also a problem, as many species are difficult to distinguish, even for experts. The study concluded that the citizen scientists were helpful to the project, but that their contributions were in taxonomy and computation, not the more challenging field work [68].

Citizen science projects are plagued with data quality issues stemming from identification errors. For example, consider the Monarch Larvae Monitoring Project, which asks volunteers to count the eggs and larvae of monarch butterflies on milkweed plants [153]. The participants are given a complicated task: they must recognize and report the different stages of monarch development. Potential participants must be trained in butterfly larva life cycles, but there is no good way to check that the training has succeeded. Indeed, chances are high that some users are not merely reporting the wrong life-cycle stage of the monarch, but the wrong caterpillar altogether. In response, the project is experimenting with a photo-based validation system, similar to the method employed by eBird [41].

In-person training can help address data quality issues and is particularly effective for somewhat complicated but not overly difficult collection procedures [41]. The Community Collaboratory for Rain, Hail, and Snow (CoCoRaHS) takes this approach, offering training sessions through local state chapters. More than 15,000 participants in CoCoRaHS take daily precipitation measurements at their homes each morning, and submit the data to be used in a national grassroots precipitation monitoring program. When they first join, participants are encouraged (though not required) to participate in a local training session, where they can also purchase an inexpensive ($25) rain gauge to use for the project [36].

Sampling bias is another major problem faced by citizen science projects. In the Monarch Larvae Monitoring Project, interviews with users have revealed that participants often fail to make an observation report when there are few or no monarchs. Users perceive that the reporting of the absence of eggs and caterpillars is of no value to the study. Volunteers also tend to abandon monitoring locations with few monarchs. This produces a non-random sampling, wherein volunteers only report on the most abundant monarch breeding locations. Nonetheless, despite these challenges in data quality, the project has continued to produce valuable data, which, after taking these quality concerns into account, researchers have used for a number of academic papers [41, 20].

The Monarch Larvae Monitoring Project also demonstrates another problem with using volunteers to collect scientific data. Participants, upon seeing monarch caterpillars at risk from natural factors such as predation and food scarcity, often try to save them. This introduces inherent bias in the data set and impacts the data's utility for population trending. The Monarch Larvae Monitoring Project team has settled on a partial solution, asking volunteers if they have brought the eggs or caterpillars indoors to raise, and discounting such data for some studies [41].

Human nature can interfere with accurate data collection for another, less altruistic reason: data can often be biased by users' own self-perception. For example, when self-reporting data from their own backyards, participants in citizen science projects are likely to inaccurately report whether the location is urban, suburban, or rural. Users may have a difficult time accurately describing their home or local environments because they wish to portray themselves and their communities in a positive way [41].

4.3 Using Technology Wisely

Sampling bias and misidentification introduce data quality errors in citizen science, but these are not the only sources of mistakes. Citizen scientist volunteers are known to make errors in data collection and entry, as are professional scientists [68].

This problem is often addressed—and indeed often first identified—through data cleaning.. Research into the area of computational data cleaning has yielded some useful approaches. Hellerstein's white paper on data cleaning [78] provides an overview of data cleaning methods for quantitative data in large databases, some of which can readily be applied to citizen science projects. Many tools employ statistical methods like outlier detection and categorization of data [78].

Outlier detection is the basis of the automated eBird data checking described in Section 3.1. As users submit bird checklists to eBird, their submissions are compared with current and historical data to determine whether any bird observations are statistical outliers. If so, then the data entry is immediately flagged for review [54].

One option that eBird has discussed (though it does not currently provide this feature) might be to alert users as soon as they enter the name of an unlikely species into their checklist [41]. This notion of data cleaning during data entry, is a relatively common idea, and has inspired the work by Chen et al. on dynamic surveys [30, 31, 32, 33]. Usher, a promising system developed by this UC Berkeley team, improves the accuracy of data entered into forms.

Usher learns a probabilistic model over data as it is entered and then adapts the entry system in several ways. Before data entry, the system orders the form's data entry fields to prioritize important data values. During data entry, the form is dynamically reordered and adapted, removing questions that are no longer relevant based on previous answers. Also during data entry, real-time feedback is given to users if data is outside of likely bounds, according to Usher's probabilistic model. After entry, questions with unlikely answers are asked a second time. Each of these approaches, and the system as a whole, has been shown to improve data quality [30, 31, 32, 33].

This technology has obvious application to citizen science, particularly in cases where a large volume of data is collected. Designing citizen science projects that make use of such error-checking systems from the outset can improve data quality. Still other existing technologies can improve data quality in cases where data is collected first on paper and then later digitized. This is a common practice in many citizen science projects, including WWMC [159] and MLMP [153], and indeed in any citizen science project for which field work is conducted [41]. The Shreddr project, again by Chen et al., applies computer vision, machine learning, and crowdsourcing to improve data quality during form digitization [34]. This technology is available to citizen scientists and others through a new startup, Captricity [35].

Platforms that enable sensing have also proven useful to citizen science. As described in Section 2.3, platforms like the OpenSense project [1], the Common Sense Community [170], and Pachube [115] create a scaffolding for mobile sensing and analysis on any topic. Pachube provides the means for collecting data in a cloud interface, as well as visualization and comparison tools. Another project more directly aimed at citizen science is the Open Data Kit (ODK) [6]. ODK is an open source toolset for noncomputer scientists, designed to help collect and aggregate data easily and quickly. The project has been used for a variety of outreach programs related to community health [76], as well as an urban trash reporting system [130]. However, these digital data collection systems cannot always apply directly to citizen science projects, because many projects require the collection of non-numeric data objects such as photos, audio recordings, and narratives [99].

However this is increasingly possible since many data collection platforms now have mobile data submission systems that can capture this rich data, including ODK and Pachube [6, 115]. Almost all mobile data submission is done using electronic forms on smart phones. Alternate mobile data entry systems using SMS messaging have repeatedly been shown to be more difficult to use and more prone to errors [118].

As an example of mobile data collection, consider Project BudBurst, a citizen science project that asks users to monitor plant life as the seasons change [111]. When it was started in 2007, the project was limited to web-based submissions. As part of a partnership with UCLA's Center for Embedded Network Sensing [28], Project BudBurst now has a dedicated mobile app with which users can easily capture pictures of plants and upload data [112]. Partnering with an engineering department focused on participatory sensing was an excellent means of building a mobile application. Because it was built by subject matter experts in the area of mobile design and interaction, the BudBurst App is well designed and easy to use, and it has beenwidely adopted.

That said, citizen science projects should be aware that developing technology through a partnership necessitates letting go of control of the project. If another group is implementing and disseminating a technology to enable citizen science, that group will ultimately have the control of its design [41].

4.4 Being Heard

A less common but nonetheless problematic challenge in citizen science arises when a group begins to collect data but has trouble sparking interest in it. This happens commonly in projects that begin locally to address some community concern like a polluted waterway. In the case of the ReClam the Bay (RCTB) project [126], concerned citizens were able to take action immediately by farming clams to repopulate the bay. Other projects have had a more difficult time drawing interest and action based on their observations.

The Alliance of Aquatic Resource Monitoring (ALLARM) is an organization chartered to help provide assistance to local communities for water monitoring, protection, and restoration [42]. One of the groups they have worked with is the Shermans Creek Conservation Association (SCCA), a group of residents of the Shermans Creek Watershed in Pennsylvania [136]. The group was formed in 1998 when concerned citizens opposed the construction of a gas-fired electrical plant in the watershed area. The community launched an aggressive data collecting project to demonstrate the effect this would have on the environment. ALLARM helped the group organize, publicize their project, and gain the attention of authorities. As a result of the efforts of SCCA, the land where the power plant had been proposed was re-zoned and the facility was never completed [136, 20].

By partnering with larger organizations such as ALLARM, smaller groups that want to get the word out about local issues can often reach a wider audience and gain the attention of authorities. Partnering can also provide the valuable opportunity to work from the outset with scientists who can help analyze and understand the data that will be collected.

Project BudBurst learned this firsthand [111]. The project was developed by the National Ecological Observatory Network (NEON), an ecological observation platform funded by the National Science Foundation. When selecting projects to pursue, the team needed to closely pair developers with scientists. They learned that communication between developers and scientists is essential to adopting methods and approaches that support the scientific protocols of the scientists who need the data [41].

4.5 Growth and Maintenance

A successful citizen science project's first major challenge is usually dealing with the sudden influx of users and data. This was the case, for example, with the launch of The Great Sunflower Project, which tracks bee populations by counting bees visiting sunflowers in participants' backyards [147]. The project met with immediate success, bolstered in part by increasing press coverage of colony collapse disorder, which is decimating bee populations worldwide [166].

Though Gretchen LeBuhn, the coordinator of the Great Sunflower Project, was excited by such immediate adoption, she quickly became inundated with questions from users. Two immediate responses helped improve the situation. The first was to move the entire project and all communication online. The second was to establish an online forum to encourage users to answer each others' questions. Now, rather than overwhelming administrators, those same questions are promoting a sense of community and fostering involvement of new members [41].

Rapid growth can also present budget problems for citizen science projects, many of which have very small operating budgets. Rather than hiring additional people or buying servers to deal with the deluge, many groups opt for partnerships with larger organizations. While partnering with an established data collection network can have advantages, it can be a challenge for some users to adapt to a new data submission method using the partner's tools [41]. Other projects look to cloud-based services such as Pachube [115] and Open Data Kit [6] to inexpensively manage their data while allowing for quick expansion. This can be an inexpensive way to bootstrap a citizen science project, but often requires a somewhat tech-savvy project coordinator [41].

The Community Collaboratory for Rain, Hail, and Snow (CoCoRaHS) provides a great example of controlled growth from a local to a national project [36]. Founded in 1998 by a small group of volunteers, the project has since expanded into a nationwide data collection program that constitutes the largest source of precipitation data in the United States, used in forecasting by the National Weather Service. Project leaders controlled the spread of the project by establishing a state coordinator, and often additional local coordinators, before they would accept volunteers in that region [41].

Retaining a measure of control over where growth takes place can also help reduce sampling bias. When choosing what areas to recruit future participants from, the Monarch Larvae Monitoring Project leaders deliberately select areas where data is sparse.

For some projects, however, the problem with growth is the challenge of continuing to engage users. A citizen science initiative might launch with a great deal of fanfare, but as soon as the buzz has died down, users may drop out rapidly. This is a problem faced by the

Open Dinosaur Project, an interesting citizen science project that asks volunteers who are interested in paleontology to review research literature in the field and help build a public database of the measurements of dinosaur bones [64]. While many so-called paleo-junkies join and make a contribution to the project, maintaining participation is the project's biggest challenge. One approach which has worked well is to get professional paleontologists to join the project, or to endorse the work as useful. Hobbyists exhibit increased interest in projects in which professional scientists are publicly involved, particularly if scientists are using the data for research publications [41].

Another common way to encourage users is to use a competition or game. Project Budburst is experimenting with this idea, working on a new game involving spotting plants, dubbed Floracatching. The purpose is two-fold: first, to encourage people to report on the life cycle of specific plants whose GPS location is known, and second, to identify plants of importance [41, 111]. To achieve the first of these goals, Floracatcher employs game aspects of geocaching, a popular outdoor activity wherein people hide and find containers, called "geocaches," which are identified only by GPS coordinate, and contain a logbook in which the finders can leave a note or mark indicating their successful acquisition of the geocache [167]. To achieve the second purpose, Floracatcher has similarities to a scavenger hunt, a technique employed by many citizen science projects, including bird counts, as described in Section 2.1.

Competition incentives can be introduced without explicitly gamifying the data collection. As we have seen, eBird makes use of regional and global rankings to encourage competition among birders [49, 57]. The Great Sunflower Project is also experimenting with this, motivating users by showing how they rank against other participants in terms of the number of bees spotted. The hope is that this will turn bee-spotting into more of a game [41, 147].

These techniques and tricks aside, the most universally effective way to encourage participation is simply to build a sense of community. As we will discuss in Chapter 8, citizens' reasons for participating and continuing to participate in volunteer projects are myriad. The social aspects of feeling part of a community almost always apply, however [16].

One seemingly easy way for a citizen science project to build community is to use existing social networking tools, such as Facebook [61]. However, establishing a presence on Facebook is not always easy, and while many citizen science projects try, they often have limited success. As discussed earlier in Chapter 3, eBird's Facebook presence has just over 6,000 likes—even if every one of those was a member of eBird, that would account for only 10% of the user population [41, 55]. eBird is actually relatively successful on Facebook. Project Budburst has accumulated only 260 likes on Facebook in the past year since launching [24], and the Monarch Larvae Monitoring Project (MLMP) has only 88 [108]. This probably has to do with page content. Budburst makes an average of only four posts a month, so there is little content to attract reposting [24].

Dedicated community tools are another means of building community. These are often home-grown, or based on packaged software commonly offered alongside website development tools, such as message boards, forums, or mailing lists. Citizen science practitioners interviewed at the NSF Workshop indicated that such tools are used often. While they are sometimes successful, as with the case of the eBird online user community or the MLMP website forum, developing dedicated social networks can place a heavy burden on project organizers. The need to maintain, curate, and troubleshoot the community tools can often be a challenging time sink, particularly for new or smaller projects that have limited staff and support [41].

Chapter 5

Designing for Science

Designing a citizen science project requires taking into account many challenges and avoiding the many pitfalls discussed in previous chapters. Here, we examine one particular citizen science project, Creek Watch [129], developed in the course of this dissertation research, to demonstrate how to (and how not to) build a citizen science project.

5.1 Identifying a Challenge

Creek Watch began as a discussion between IBM Research and the State of California Environmental Protection Agency. IBM, as part of a corporate "Smarter Planet" initiative, organized an open house and brainstorming session with the California EPA. One of the goals of this discussion was to find a way in which IBM's technology and expertise could be used to engage the general population to aid the EPA in areas of critical concern. Our research team wanted to develop a system for Citizen Scientists to collect environmental data of scientific value. The EPA assured us that water stewardship remains one of the biggest challenges in the state.

Indeed, water resource management is a huge challenge around the world, and the simplest way to describe the problem is that we do not have enough clean fresh water—not in the state, not in the country, and certainly not in the world. Rainfall cannot keep up with the rate at which we drain fresh water supplies, and despite efforts at management, lakes and water tables worldwide are dwindling. Global warming is causing a reduction in fresh water stored in glaciers, as well as raising sea levels and causing fresh water supplies to go brackish. At this rate, increased freshwater stress is expected to affect 1.7 billion people by 2020 [2].

At the same time that our freshwater supplies are dwindling, waterways are becoming increasingly polluted. The U.S. Environmental Protection Agency requires states to maintain a list of waters that are too polluted to meet state water quality standards, known as the "303[d] list" [59]. Water bodies are considered "impaired" if they are too polluted to be used for swimming, fishing, drinking, or other beneficial uses [161]. In California, trash is the second most common impairment pollutant (Diazinon, an insecticide, is the most common) [60]. In addition to being ugly, trash in waterways is harmful. Floating trash inhibits the growth of aquatic vegetation and is transported to the marine environment, where it can harm fish and wildlife. Diapers, medical waste, and broken glass pose health risks to humans [109].

To identify impaired waters, a state water board must collect and assess water quality data and determine if the water meets standards. The process is initiated by stakeholders who alert the water board of locations where water quality standards may not be met. Stakeholders include government entities, environmental groups, businesses, and citizens. Photographs tagged by location and time provide tangible evidence of trash in waterways. Photos can help identify the type of trash (e.g., bottles, paper, car parts, and medical waste) and source (e.g., individual littering, illegal dumping of landscape and construction debris). Items of particular concern are small buoyant plastic objects that flow into marine habitats and waste that affects human health, such as diapers, fecal matter, and medical needles [109].

Tracking the occurrence of trash over time and under different hydrologic conditions provides a more accurate assessment of trash deposition; trash accumulates during dry weather due to littering and dumping and gathers downstream in wet weather. Visual examination of photographed trash can reveal sources: trash above the water line is locally deposited, faded trash wrapped around roots indicates downstream transport from drainage systems upstream [109].

A three-year survey of 93 urban waterway sites in the San Francisco Bay Area found that more than half of the trash collected consisted of plastic items; that dumping and littering occur most frequently in sites with high public access; and that bottom-of-the-watershed locations have the most trash, due to downstream accumulation [109].

Because of this difficult situation in water quality and awareness, the EPA suggested that we should focus on water monitoring. The California EPA felt that if we could engage the public on this issue, by both making them more aware and asking for their help collecting data that their scientists need, then we could have a huge impact. A partnership was agreed upon whereby IBM would develop a Smarter Planet project with consultation and support from the state water board, a branch of the California EPA. Thus, we began a citizen science project about water.

5.1.1 Contextual Inquiries

One of the first challenges in developing a citizen science program is to narrow a general problem to a specific problem that can be tackled by citizen scientists. To narrow the problem from "California needs help with water," we first conducted a series of contextual inquiries with stakeholders in the areas of water resource management, water quality, and volunteer water monitoring.

We conducted in-depth interviews, with eleven scientists, environmental workers, and water monitoring volunteers from across seven organizations. Whenever it was possible, we conducted interviews in the field so as to elicit rich, *in situ* reflections; for interviewees who were too far away to meet in person, however, we conducted telephone interviews. From the government sector, we interviewed four ecologists in the California State Water Resources Control Board and the city of San Jose's water department. From the private sector, we interviewed three ecologists from San Francisco Estuaries Institute (SFEI) and the Southern California Coastal Water Research Project (SCCWRP). From the volunteer sector, we interviewed three volunteers from two local groups, the Stevens & Permanente Creeks Watershed Council (SPCWC) and the Alameda Creek Alliance. We also interviewed the volunteer outreach organizers of the Water Environment Federation, an international group of water quality experts whose more than 80,000 members included most of the environmental scientists we interviewed. These organizers are responsible for the World Water Monitoring Challenge (WWMC) project described in Section 3.2.

The primary goal of these interviews was to identify (1) what data was most needed by environmental organizations and could be gathered by citizen scientists; (2) how it would be used; and (3) how to best ensure that the data would actually be useful, including understanding the protocol and format required to make the data acceptable to the scientists. The challenge of getting useful data from citizen scientists was confirmed by the first interview subject:

> "In the early days it was an activity to engage understanding in water quality. It didn't matter what they did as long as they did something. Then we realized no one uses the data and they aren't monitoring for things we care about."
> —Interview #1, State Water Control Board

5.1.2 Education

Educating the public about conservation issues is an important goal of citizen science—for some projects, the most important. Scientists who work on water quality in California revealed in interviews that lack of awareness of water quality issues was a huge problem. Specifically, people are often unaware of the extent to which their activities are damaging the environment:

> "It used to be that industry was the problem. But the average resident (collectively) is now the problem. People's pesticides, car washing, dog poop, garbage that we drop—it's a really big problem."
> —Interview #7, an ecologist with the City of San Jose Environmental Services

By educating the public about water quality, officials believe they can cut down on residential dumping, the major contributor to water pollution in California. Any citizen science project to help improve water quality in California must therefore also educate the public about water.

5.1.3 Access and Human Resources

Perhaps the biggest opportunity for citizen science comes from the simple fact that there are more people who care about the environment than who work in environmental management full-time. The ecologists who monitor the local environment cannot be everywhere at once, and they are limited in their data-gathering abilities by small staffs and the lack of legal access to locations.

In San Jose, for example, there are 700 miles of creeks—far too much ground for any one agency to cover. Furthermore, much of the watershed runs through private property, and while the government's ecologists can legally access the water, they cannot trespass on the banks of creeks in private land. In practice, this means a lot of areas never get visited by officials and are not monitored.

Given the challenge of such a large area to cover, scientists wanted to engage as many participants as possible. More people participating in the program means more ground can be covered, more streams can be accessed, and more data can be collected. In addition, more people participating will mean more people will be aware of the issues surrounding water quality and will be able to take corrective action, such as refraining from littering.

5.1.4 Designing for Useful Data

One of the biggest challenges faced by organizations is sharing data. Environmental data is particularly tricky, because if two groups do not gather data in precisely the same fashion, their results may not be usable for comparison. How a test was performed is as important a part of the data as the results. Quality assurance (QA) techniques differ between organizations. Standardization is everything, but unfortunately, with so many different programs performing so many different measures for different reasons, this is easier said than done.

Even for programs in which the QA has been standardized, the problem of data sharing is not solved. Historically, each government organization has maintained its own databases, with poor interoperability. Data has most typically been exchanged as completed reports or spreadsheets. Recent legislation in California has mandated a statewide system to share this data, but the system is still being developed.

Getting information from private and volunteer groups can be an even harder problem. In the area of watershed health, for example, volunteer groups typically aggregate any data they've collected into a yearly report that is made available to government organizations as a summary document. Some more sophisticated groups may also include a spreadsheet of the original data in this once-a-year report. Because these groups typically have a driving mission (e.g., searching for mercury or other toxins local to their area, or tracking water flow rates that affect fish spawning), the data they collect is focused on a specific problem, and may not include information that other organizations may need to make further use of the data.

Discussions with the California EPA presented a somewhat bleak picture. There are more than 250 organized and recognized groups in California working on watershed health [59], yet their data collection, QA, and sharing practices mean that few will have their data used by others. Indeed, we discovered that three different types of organizations use data, and that consistency in data practices vary wildly within groups:

1. Government organizations: These organizations are responsible for the enforcement of regulations pertaining to water use, wastewater discharge, and pollution, at state, regional, county, and city levels.

2. Private groups: These are typically consulting companies that work closely with government organizations. Most are funded by grants, for example, by private parties to conduct evaluations for environmental permits.

3. Volunteer groups: These are typically organized on a city or county level and meet anywhere from twice a year to pick up trash, to monthly to monitor water quality with professional equipment.

5.2 Focusing on a Problem

5.2.1 What Data to Collect

There are many problems in watershed management for which more data could help. While much of this data requires specialized equipment to measure water quality, some of the most helpful data requires only simple observation. We identified water flow rate as a critically needed piece of data early on in the interviews:

> "Wherever people go, if there's a creek, if would be great to get info on flow. Qualitative and quantitative: Take a picture and send to a database, GPS-tagged. This would be tremendous—we need data on flow."
> —Interview #1, State Water Control Board

Water flow rate in creeks is critical to understanding the health of a watershed. Vast networks of tributaries carry runoff from all across the watershed into major waterways, and eventually into drinking water and farm fields. In California, many streams are seasonal, drying out during the long, hot summer and flowing again once the winter rains begin.

These small waterways, taken in the aggregate, provide most of the water in California. An estimate of how much water there is, particularly if collected over multiple years for comparison, would enable better water management in the state.

These waterways can also be a pathway for pollution. Without an accurate picture of when water is flowing where in the watershed, it is very difficult to track pollution to its source. Unfortunately, flow data available to environmentalists is spotty at best.

> "We're not getting a lot of [flow] data. Most is generated by discharge permits—when someone has a permit to discharge [waste water] into a stream, they are required to monitor flow, so we get that information. But for the ambient [measurements], there are many more places we can look than we have people or resources for. Flow is kind of hidden, but it's really important. What happens is when we have to get it it's too late to go back in time."
> —Interview #4, State Water Control Board

A second critical area we identified that citizen science could help was information about trash.

> "Many of the most serious water quality problems in California are associated with non-point source pollution. Trash is a severe non-point source problem. Trash clogs our waterways, blocking fish migration paths, impairs aquatic life, and poses a threat to many beneficial uses of our creeks and streams."
> —Interview #1, State Water Control Board

While trash surveys and cleanups are conducted regularly by many groups, there is simply too much ground for professional scientists to cover without help from citizen scientists.

The problem of getting data on such simple measures as flow rate and trash is compounded by the fact that citizens often assume good news is not worth reporting.

> "We have a citizen stream keeper program—people go out at least once a month to a creek to observe it, but if they don't see anything bad, they don't report, so we don't know."
> —Interview #6, Local Water Monitoring Volunteer Coordinator

We concluded that, to be successful, the App must equally support and encourage the reporting of problems and situations where nothing seems amiss. We concluded from these contextual inquiries that a citizen science application for monitoring water quality would provide the most benefit to the environmentalists who need the data if it enabled people to report on water flow and trash.

5.2.2 What Data Not to Collect

The contextual inquiries also revealed many requests for data which we decided not to try to collect. In particular, most organizations doing water quality monitoring conduct chemistry tests on water samples to evaluate the health of the waterway. Some of these tests are relatively simple to conduct, others much more complicated, and all require a range of equipment.

The most widely adopted water monitoring project is the World Water Monitoring Challenge (WWMC), and therefore their chemical water test kits are some of the most widely used. However, as previously described in Section 3.2, the accuracy of the data collected by these kits is questionable. Indeed, the local Stevens & Permanente Creeks Watershed Council (SPCWC) revealed in interviews that they do not trust these or any other chemical testing kits for their data collection. Instead, they rely on expensive (approximately $2,000 per unit) water testing equipment to collect water data. (see Figure 5.2.2).

Figure 5.1: Expensive (approximately $2,000 per unit) but accurate water testing equipment used by a local watershed group to test water quality. The probe is being placed into its protective casing after calibration by the volunteer. The error-prone reel of wiring which connects this probe to the monitoring unit is visible in the background.

These expensive water testing probes are not without their challenges. In order to be used, the equipment must be calibrated on a known sample of water immediately before use. Issues with the equipment plague field scientists. On a field trip with SPCWC members, we observed data failure modes including a faulty connection and a kinked wire preventing data transmission. In addition, the equipment cannot be used on samples of water, but must be dropped directly into the water body being tested. This presents a particular challenge for public organizations like SPCWC, who by law can monitor water only from public access locations. Many creeks and streams are only publicly accessible where they pass under roads. Dropping a $2,000 piece of equipment 30 feet off a bridge while standing on the curb of a busy road is not for the timid. The private individuals who own land along the river can legally access the banks to conduct monitoring more easily.

The scientists we interviewed were mostly skeptical about accepting chemistry data from other groups—partly because of the data standards and quality assurance issues described in

Section 5.1.4, and partly because they were hesitant to trust anybody else's test equipment. In interviews with the city of San Jose Watershed Protection Team, we discovered that they can take action only on chemistry data collected by stationary chemical test units that are installed in major waterways throughout the county. These equipment units are so prohibitively expensive (approximately $8,000 each) that the city can purchase only a few them, largely in partnership with other organizations.

The problem with accepting chemical data that others have collected is so huge in fact, that most groups are advised against trying to start their own data collection procedures unless they have a specific purpose in mind for the data:

> "What I tell all the new groups is, only collect data which you yourselves are going to use."
> —Interview #9, State Water Control Board

The exception, of course, is collecting data according to the pre-established protocols of an established group, such as the California EPA. This can be done, and indeed is how SPCWC is able to share data with other water quality groups in California. However, if they want to share their data, groups must complete time-intensive quality assurance evaluations that can be burdensomely restrictive to new groups.

Other water quality data requested by field scientists included invertebrate counts, algae and bacteria tests, and invasive plant and animal reports. All of this data is difficult to collect. Volunteers require training to identify invertebrates and invasive plants and animals, and even then they frequently do a poor job of counting organisms [68]. Algae and bacteria tests can only be conducted by professional labs. None of these data requests were conducive to a large-scale, low-barrier citizen science project.

5.3 Designing the Solution

Based on these contextual interviews, we designed Creek Watch, a participatory creek monitoring system for water flow and trash. Creek Watch has two design objectives: to enable people to report on water flow and trash, and to reach as many people as possible—so that we could not only collect more data but also educate the public about water issues.

Given these design goals, Creek Watch employs a free smartphone application with a simple interface for uploading data. The project enables volunteers to report on water flow and trash, as well as to share photographs of creeks. Water researchers and any member of the public can view and analyze the collected data. To make the project as widely accessible as possible, Creek Watch can be used anywhere, and it is anonymous, to deter concerns about privacy.

Water Level	Flow Rate	Trash
Dry: No water present	Still: Water is present but is not visibly flowing	None: No trash in the water and surrounding area
Some: Water fills less than 75% of the channel	Slow: Water is present but is barely moving	Some: A few items of trash, such as cans, bottles
Full: Water reaches up almost to the top of the banks	Fast: Water is present and flow is easily detected	A lot: Ten or more items of trash

Table 5.1: Water observation definitions used in Creek Watch, from the California EPA's Surface Water Ambient Monitoring Program, reproduced from [94]

5.3.1 Data Format

To ensure that the data collected would be useful to existing programs, we drew on the California Environmental Protection Agency's Surface Water Ambient Monitoring Program Bioassessment Standard Operating Procedures [26], and Rapid Trash Assessment Protocol [109]. These manuals define procedures for reporting on water flow (composed of water level and flow rate) and trash levels.

In consultation with the California State Water Resources Control Board, we adopted the definitions in Table 5.1 for Creek Watch.

These observations, combined with a photo of the creek, provide the data that water monitoring organizations most requested. In addition, these observations are simple and verifiable enough (by photo) that scientists stated they would trust the data from anonymous untrained users (i.e., anyone with the iPhone App).

5.3.2 Rejected Approaches

Engineers are always tempted to add features and functionality, and such was the case with Creek Watch. However, since one of the primary goals of the project was to make an App that was easy for citizen scientists to use, the interface had to be as simple as possible.

Several "bells and whistles" were considered and rejected during the course of the design. We seriously considered adding competitive aspects to Creek Watch or turning it into a game. The success of Luis von Ahn and others in building games with a purpose makes an appealing case for encouraging users with game mechanics [158] and eBird's ranking competition demonstrates that game aspects can also work in citizen science applications [57]. However, in discussions with the state water board, scientists expressed concerns about data integrity. They worried users might try to "game the system" and submit erroneous data reports. Because Creek Watch submissions are anonymous and the data was simple, it would be extremely difficult to distinguish falsified reports from genuine ones. While falsified reports remain a risk regardless of gaming aspects, it was felt that competition would encourage this behavior.

Another rejected feature was image recognition on photos of creeks to automatically determine flow rate and count trash. Despite the great advances in image recognition technology and the earnest desire of several of the scientists and volunteer organizations, it was determined that simply asking users to estimate water flow, volume, and trash was the most accurate way to sample data.

Finally, a much-desired feature was regretfully rejected due to implementation challenges. Given the GPS capabilities of smartphones, it was hoped that Creek Watch could inform users of the name of the creek they were surveying. While this is readily possible for roadways, landmarks, and businesses through geocoding APIs such as the Google Maps API [73], at the time we were developing Creek Watch, there was no API for waterways. Despite repeated conversations and brainstorming sessions with both California EPA officials and the United States Geographical Society, we could not find a way to include this feature. However, as the GPS coordinates of waterways are recorded as part of Creek Watch reports, this could, in the long term, kick-start geocoding.

5.4 Building the Solution

Creek Watch was built using a classic iterative design process. The system has two parts: an iPhone application for collecting data, and a website, creekwatch.org, where data can be shared and viewed.

The data collection tool is a mobile application for the iPhone (see Figure 5.2). Central to the application is the data reporting feature, where users can report on a creek they are looking at. Each data definition is supplemented with a photographic example (see Figure 5.3). Using the GPS in the phone, the application appends location and time-stamp information to each report, which it then sends to a central server.

If users do not have cell phone reception when they capture data (as is often the case for creeks alongside hiking trails), the application stores data locally on the phone for later uploading. Users can browse through data they have uploaded as well as data that still needs to be uploaded. A map visualization enables users to see recent data points collected by others in their area, including photos.

When data is submitted in the iPhone application, it is packaged as a JSON object and sent to a the Creek Watch server. The Creek Watch server is a simple cloud installation, with a LAMP stack (Linux, Apache, MySQL, PHP). Data is stored in the MySQL database and photographs are stored on the file system. The project's website, creekwatch.org, gives the public access to the data.

The creekwatch.org website contains a map interface (Figure 5.4) and a table view of the data (Figure 5.5). The map interface was built in Javascript, HTML, and CSS using the Google Maps API. The table view was built in PHP.

A map of all collected data points is the central visualization on creekwatch.org. The map enables contributors to browse the data if they wish to "poke through" their own and

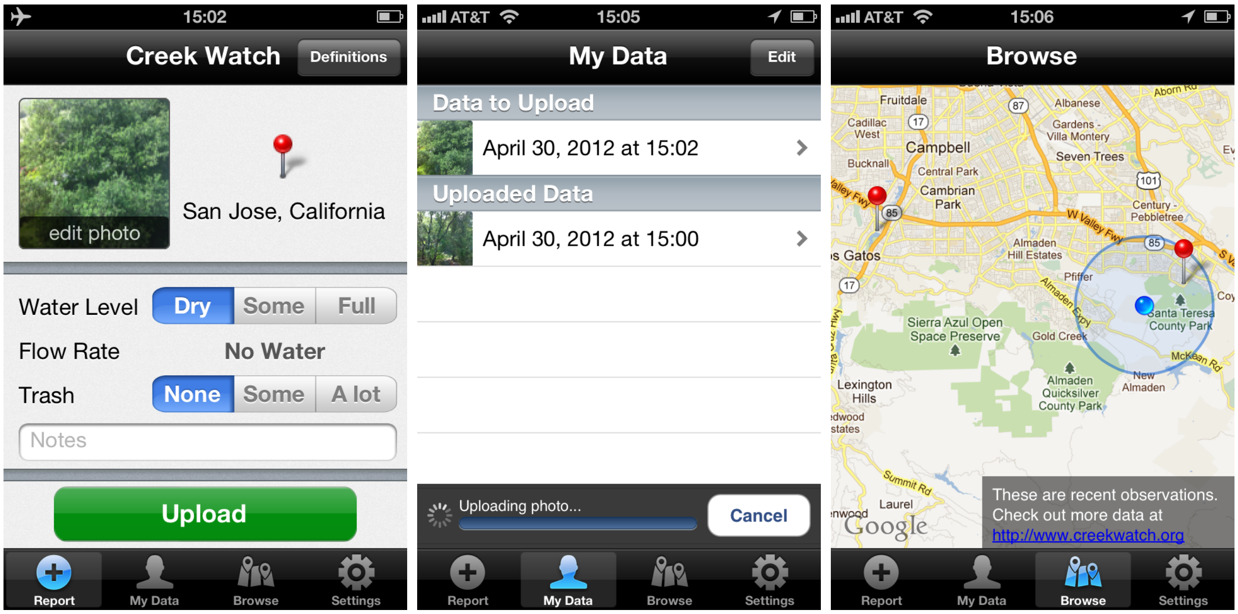


Figure 5.2: Screenshots of the Creek Watch iPhone App.

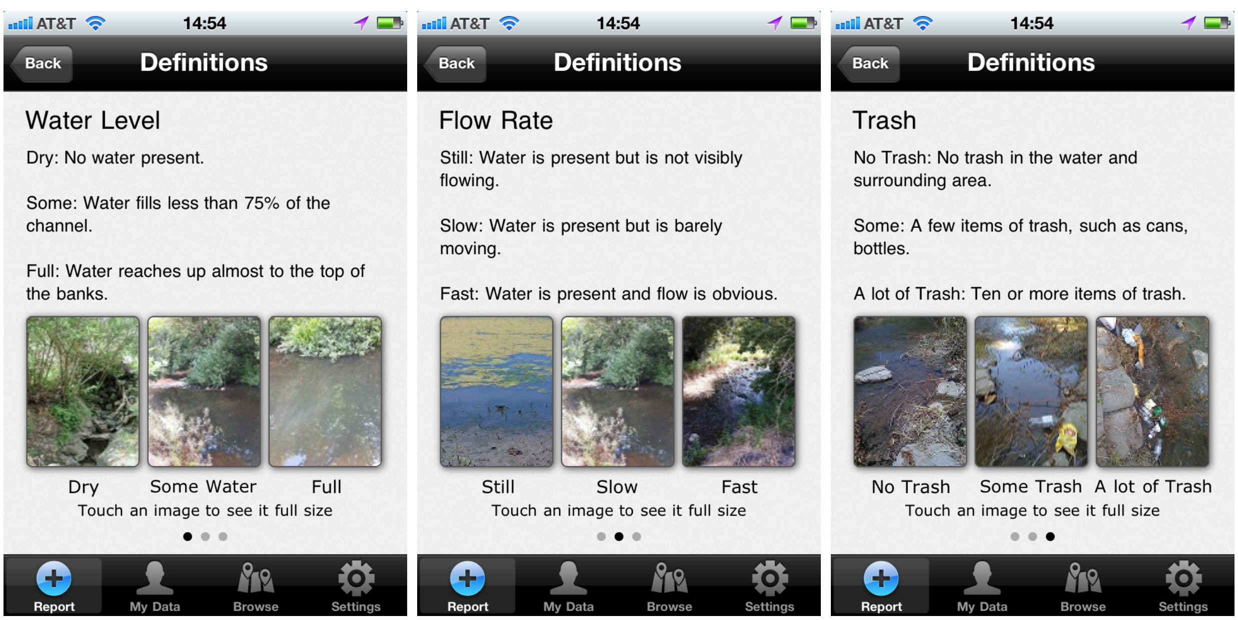


Figure 5.3: Definitions used in the Creek Watch iPhone App.

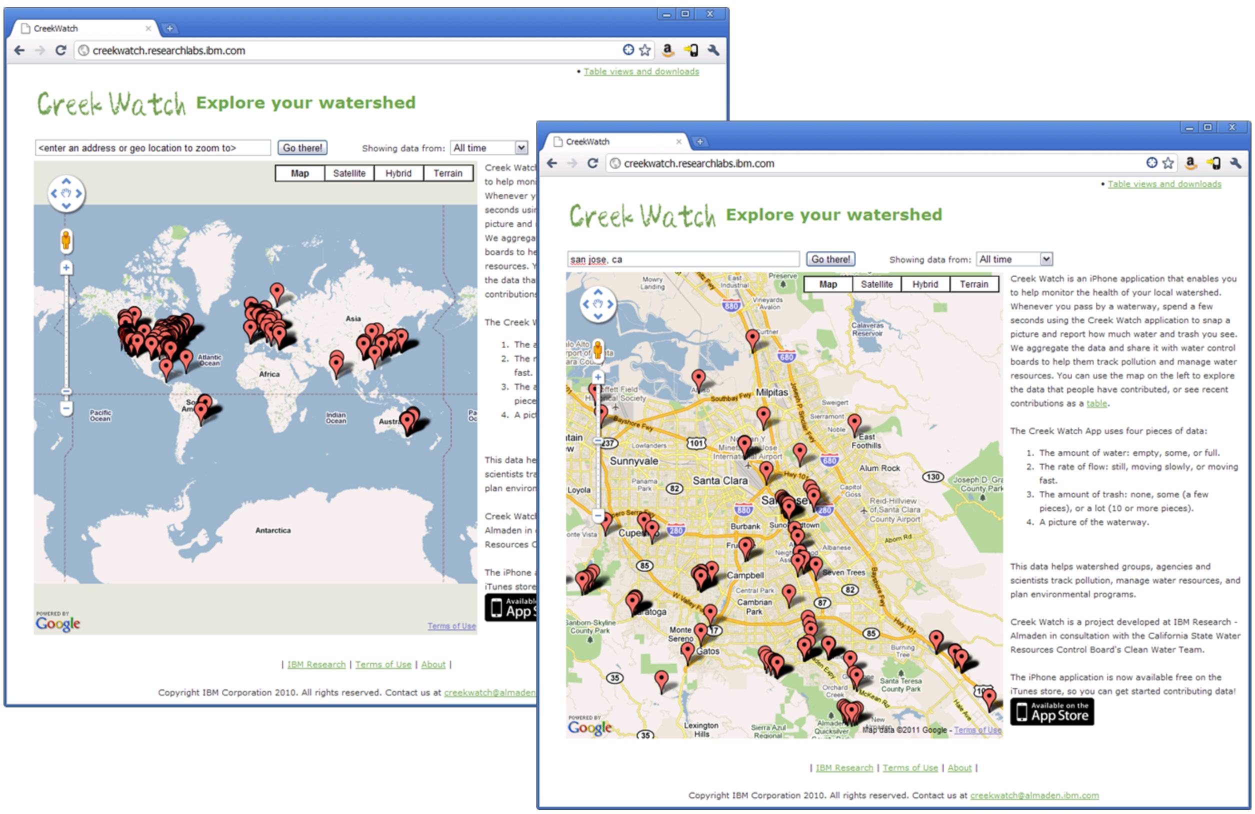
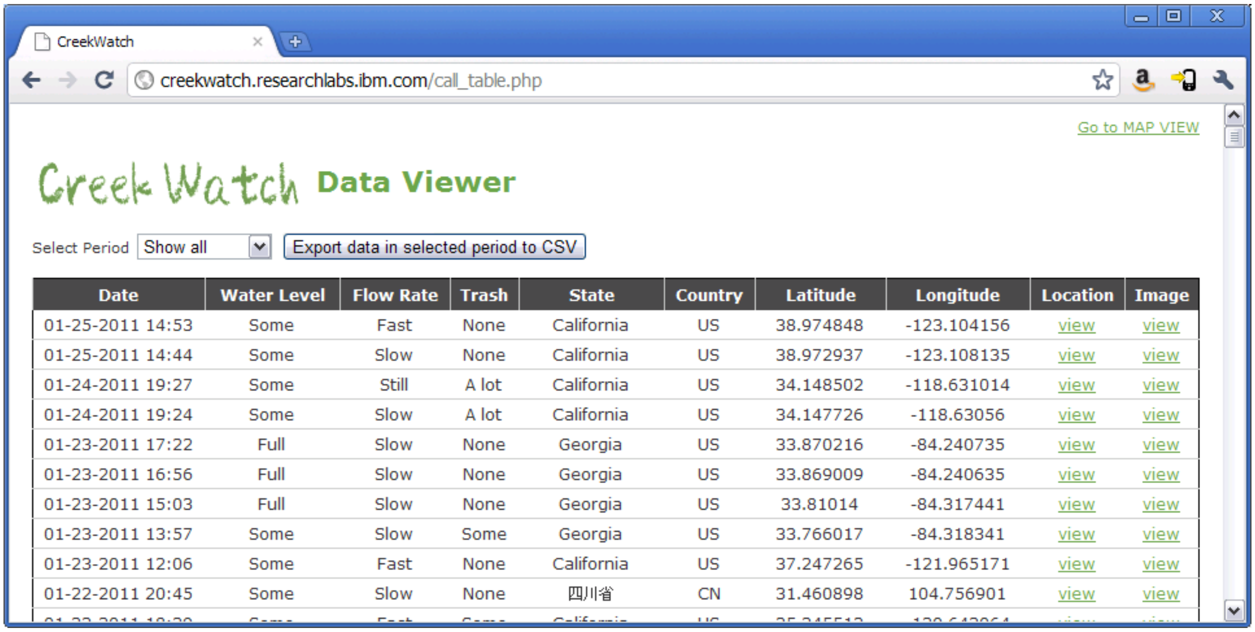


Figure 5.4: Screenshots of the Creek Watch website [129] showing the map view of all data Worldwide and locally in San Jose, California.



Date	Water Level	Flow Rate	Trash	State	Country	Latitude	Longitude	Location	Image
01-25-2011 14:53	Some	Fast	None	California	US	38.974848	-123.104156	view	view
01-25-2011 14:44	Some	Slow	None	California	US	38.972937	-123.108135	view	view
01-24-2011 19:27	Some	Still	A lot	California	US	34.148502	-118.631014	view	view
01-24-2011 19:24	Some	Slow	A lot	California	US	34.147726	-118.63056	view	view
01-23-2011 17:22	Full	Slow	None	Georgia	US	33.870216	-84.240735	view	view
01-23-2011 16:56	Full	Slow	None	Georgia	US	33.869009	-84.240635	view	view
01-23-2011 15:03	Full	Slow	None	Georgia	US	33.81014	-84.317441	view	view
01-23-2011 13:57	Some	Slow	Some	Georgia	US	33.766017	-84.318341	view	view
01-23-2011 12:06	Some	Fast	None	California	US	37.247265	-121.965171	view	view
01-22-2011 20:45	Some	Slow	None	四川省	CN	31.460898	104.756901	view	view

Figure 5.5: Screenshots of the Creek Watch website [129] showing the table and download view of all data.

others' submissions. A Google Maps mash-up with the Creek Watch database displays the location of every data point as a map pin, centered on the user's current location. The data collected at each location is available as a pop-up window with a photo of the creek, or as hover text over each pin (see Figure 5.6). As a security and privacy precaution, users can report inappropriate images from this view.

The table view makes it easy for scientists to work with the collected data. Each column is enabled with filters (time, location, data values), and the filtered data can be exported to a CSV file for inclusion and integration with existing projects. The table view is publicly available, so that anyone can manipulate and download the data in this fashion. However, the intended audience is the data consumers in environmental management positions.

Further details on the development of Creek Watch can be found in Appendix A, which includes code architecture and development of both the iPhone App and the server/website.

5.5 Validating the Design

Creek Watch was developed in consultation with the State Water Resources Control Board. Successive versions received evaluation and comment and were iteratively improved. Once a first working version of the iPhone App was complete, it was put immediately to community testing to get feedback.

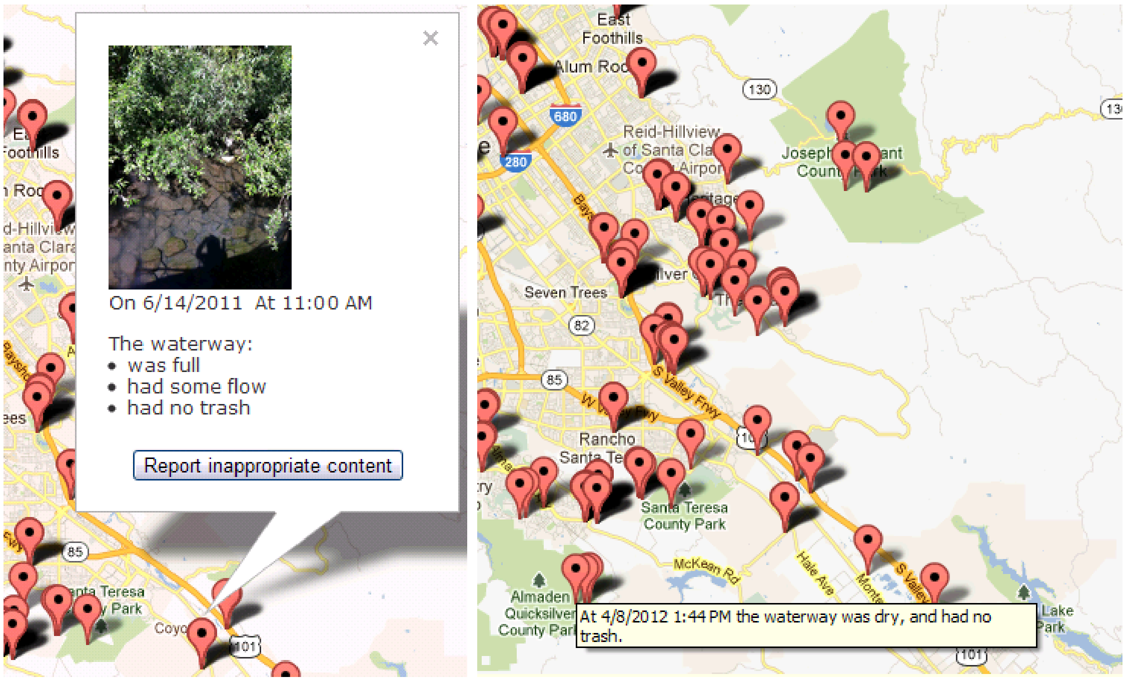


Figure 5.6: Pop-up and hover text of data point details on the Creek Watch website [129]

5.5.1 Community Open House

Working with the city of San Jose watershed protection group, we organized a public meeting at a local community center to demonstrate the App to the public and get feedback. The meeting was attended by 65 individuals who responded to citywide advertisements for a meeting on water quality. A few of the attendees were members of the water organizations we had interviewed during the contextual inquiries. Most, however, were new faces to us, and were not already members of a watershed organization, according to a voluntary survey. The majority of attendees were over the age of 50 and well educated—all survey respondents stated they had post-secondary education.

The early version of Creek Watch was well received by the audience. In the open suggestion and brainstorming session afterwards, many spoke up with positive comments and expressed an interest in participating once the app was available. In addition, we received suggestions for additional features. Some features that were requested, such as the ability to submit chemical test data, had already been considered and rejected, as described in Section 5.3.2. The audience also requested features that would help individuals keep track of their participation, including a way for users to track how long it had been since they last made a report, and an automated reminder system to visit their local stream. Some audience members also wanted a way to report immediate problems they witnessed, like someone dumping waste into a river, for immediate action by the authorities.

5.5.2 Survey

To help decide if we should include some of the features requested at the community meeting and to get further ideas, we conducted a subsequent online survey. We offered the survey by email both to people at the meeting who had signed up and to members of a 2000-person California-wide mailing list on water issues managed by the State Water Resources Control Board. Respondents were entered into a draw to win one of several $20 Amazon gift certificates.

The survey had 30 respondents, of whom 73% were already members of some kind of watershed alliance. Most were already participating in some kind of volunteer activity related to water quality, with various levels of involvement. The survey found that 47% of respondents participated in an organized water monitoring activity in addition to other volunteer activities related to water, 40% participated in restoration projects such as trash cleanups and creek restoration work. However, answering a separate question, only 60% of respondents indicated that they were currently participating in activities. Only 2 respondents (7%) reported that they observe creeks and report to authorities if something is wrong.

Of the survey respondents, 30% reported that they have smartphones, 44% of which were iPhones. This result was higher than expected based on market penetration of the iPhone at the time the survey was conducted (June 2010).

We asked the survey respondents about features they thought would make them more likely to contribute information about their local watershed (see Table 5.5.2). Existing design goals and features of the system that had already been implemented were highly ranked. For example, roughly three-quarters of respondents said it would be "very helpful" to have an easy way to make reports about the watershed, with a map showing the reports. Two of the features requested in the community meeting, a way for users to track how long it had been since they last reported and a way to remind users to visit streams, were less popular, with only about one-third of respondents feeling that these features would be "very helpful."

The survey was biased by the fact that most respondents were already members of watershed organizations and involved in watershed conservation or monitoring. However, since the purpose of the survey was to get feedback and ideas on features, requesting advice from an interested sample set of the population was appropriate.

The survey also asked respondents how often they saw a problem by a creek, how often they saw a problem by a stream they pass by (e.g., trash, pollution, sick wildlife, crime), how often they felt they should report the problem, and how often they actually did. The results, given in Table 5.5.2, reveal some interesting trends. Perhaps not surprisingly, far fewer people actually report problems by creeks than see problems, even when they feel they should make a report a to someone. In fact, 57% of respondents reported seeing problems more frequently than they reported them. The most commonly reported problem was trash. This suggests there is a great need for an easy-to-use trash-reporting mechanism like Creek Watch.

Interestingly, only 47% of respondents indicated they pass a stream or creek on a daily

Which of the following would make you more likely to contribute information about your local watershed?	% of respondents who indicated 'very helpful'	% of respondents who indicated 'very helpful' or 'somewhat helpful'
An easy way to report what I see	73%	97%
Confirmation that my report has been received by someone in authority	73%	97%
A website with a map of places where more information is needed (e.g., streams at risk)	73%	93%
A website with a map showing all reports for your area	77%	93%
A way to track how long it's been since you last made a report	30%	63%
Reminders to visit a place you regularly observe	37%	67%
A way to report from the field, e.g., by submitting photos and reports from a mobile phone	53% (67% of users with smartphones)	73% (83% of users with smartphones)

Table 5.2: Results of a survey on what would encourage the public to report on waterways.

How often do you...	> daily	> weekly	> monthly	> a few times per year	not often
go past an open body of water (creek, stream, lake, reservoir)	53%	87%	93%	100%	0%
notice something wrong by the water (trash, pollution, sick wildlife, crime)	30%	57%	80%	97%	3%
feel that you should report something	13%	27%	37%	80%	20%
actually report something	0%	0%	7%	37%	63%

Table 5.3: Results of a survey on frequency of involvement with streams.

basis, even though the State Water Resources Control Board estimates that every Californian passes multiple streams a day during their regular commute or activities. This suggests that even people who participate regularly in watershed activities are unaware of the extent of the watershed.

The survey results also suggest that there is a need for a reporting mechanism for immediately actionable problems like crime or sick wildlife, a request which was echoed from the community meeting. However, in discussions with the partners at the water authority, we were advised not to interfere with this area of their jurisdiction in this project.

5.6 Informal Usability Testing

In parallel with the iterative design, community meeting, and feature survey, we conducted usability testing of the iPhone application and website. The primary purposes of the usability testing were to ensure the App was easy to use and to find any bugs. Usability testing was primarily conducted with colleagues at the IBM Almaden Research Center who were asked to try out the App or website. Coffee was sometimes used as an incentive.

Early testing revealed some critical usability challenges. Most notably, we discovered that the iPhone interface needed to have very high contrast to be visible outdoors in sunlight, which is where it is intended to be used. Furthermore, even with a high-contrast interface, it is difficult to see small buttons or text in bright sunlight, so the interface needed to be redesigned with larger buttons and text.

Other usability problems uncovered during this phase of testing included awkward placement of buttons, flow issues with the interface, and poor icons. One major change we made during this phase was to reorder the activities in the App. While we originally designed the App to open to a screen showing all of the user's reports to date, users found it more natural to begin at the screen where a report is made.

As a final prelude to launching the beta version of the iPhone App, we conducted a more formal usability evaluation. From the non-technical staff at IBM, we recruited four people who had some experience with iPhones but had never seen the App before. Users were compensated with a coupon for the cafeteria. Testing took place off-site by a local creek near the office, and users were asked to try out the App in both on line and off line modes.

In response to this usability evaluation, we made two changes to the application: (1) users had trouble finding the definition pages, so we added text to a the button that reveals these pages, and (2) users wanted to be able to navigate directly to a view of more data points, so we placed a link to the Creek Watch website on the App's map view page.

Having garnered input via iterative design with initial users, we compiled a beta version of Creek Watch that could be distributed remotely, so that we could conduct formal user testing on the efficacy of the system.

Chapter 6

Testing for Usefulness and Usability

Gauging the success of a citizen science project is difficult because there are so many different measures of success. Consider the differences between the two successful citizen science projects in the case studies in Chapter 3. To the eBird organizers, their project is a success in large part because of the excellent research that has come out of the data collected by participants. For World Water Monitoring Day, success is measured in terms of participation, with no concern for data quality or usefulness. Both seek to educate the public, but the goals of each are different.

Creek Watch was designed primarily to help the California EPA and other water organizations with water monitoring. As such, it was critical that the data collected should be useful. In order to evaluate Creek Watch, we needed to see if the system could collect scientifically valuable data. Therefore, we turned to environmental scientists to evaluate the system.

6.1 Study Design

To design and conduct a field deployment study to evaluate the effectiveness of Creek Watch, we recruited 10 environmental scientists who own iPhones from the city of San Jose Environmental water division. The study participants included four environmental agents, three environmental outreach or volunteer coordinators, two managers, and one environmental analyst. Six participants were male, four female, with an average age of 45 (standard deviation 9.7). All participants had academic degrees related to environmental management or ecology.

None of the user study participants were involved in the brainstorming, early interviews, or design of Creek Watch. While we did work with other scientists from their department to develop the application, for the user study we wanted to see how unbiased scientists would react.

The user study consisted of three steps: a pre-study interview, a deployment study, and a post-study interview. The study lasted for three weeks.

6.1.1 Pre-study Interview

The purpose of the pre-study interview was to understand the users' data needs and collection practices. Pre-study interview questions included:

1. When you need data/information, how do you collect/access it?
2. Do you share data you collect? If so, how, and how is it used?
3. How often do you participate in field work?
4. What are the difficulties you perceive in water monitoring?

Each interview lasted about thirty minutes, followed by an introduction to the Creek Watch application and website. At the end of the interview, demographic and occupational information was collected.

6.1.2 Deployment Study

Participants were asked to use both the Creek Watch application and the website whenever they felt was convenient over a three-week period. During this time they logged a total of 65 data points in the Greater San Jose area.

6.1.3 Post-study Interview

The purpose of post-study interviews was to understand both how useful the users felt this data would be to them and what their reactions were to using the App as a data collector. Post-study interview questions included:

1. Did you visit the Creek Watch website? How often, when, and why did you visit this website?
2. What were good or convenient factors in the website?
3. What are possible improvements for the website?
4. How often and under what circumstances did you use the application?
5. What were good or convenient factors in the application?
6. What are possible improvements for the application?

Each interview lasted from thirty minutes to an hour. At the end of the interview, participants were given a $10 Amazon gift coupon.

6.2 System Evaluation

In the pre-study interviews, participants reaffirmed the conclusions of the contextual inquiries. Getting data on water quality is a serious problem. While we were conducting the study, several of the participants were in the process of deploying a river monitoring system in Coyote Creek, one of the largest waterways in San Jose. The system consists of nine autonomous units, costing approximately $72,000 total. The units continuously measure five basic characteristics of the water, and store the data for later retrieval. With this level of expense, widespread deployment is not an option, and most of the creeks in San Jose will remain unmonitored.

While autonomous units are not the only way to measure creek health, site visits by field agents do not provide complete coverage of the watershed. When describing the most important difficulty he faces in his job, one of the field agents stated:

> "Access is a problem. The big thing is we can only measure in places we can get to, resulting in data gaps."

Three out of the four field agents also identified this as their top problem.

Users were in the unique position of being both the collectors and the consumers of the data. This enabled us to get a true end-to end view of the system through their eyes. We divide the findings from the user study into those relating to consumption of data and those relating to collection of data.

6.2.1 Data Consumption

The users overwhelmingly agreed that Creek Watch provided very useful data while also presenting a low barrier to entry for users.

Trash data was of particular interest to the user group. Some users immediately wanted to use the trash data for existing programs in tracking watershed health:

> "We would use this data… That's our big focus right now—trash."

Several users commented on the use of the data for local trash cleanup events. One of the project managers observed that it was:

> "A great tool to monitor creeks and help us identify problem areas— one of my coworkers is on creek cleanup and trash keeps coming up."

One of the volunteer coordinators who manages cleanup events found it useful to have the clusters of data points contributed by other users:

> "When you get a lot of data points, you can see where most of the trash is in the creeks. When groups have cleanup events, now we can find these trash areas."

The field agents also saw benefits to the trash data. One commented:

> "For our work in particular [enforcement of dumping regulations], I would be interested in the trash information—to see where folks are finding trash along the creeks."

These findings were particularly interesting because the contextual inquiries suggested that flow data was in greater demand than trash data. That these users emphasized trash data may be a reflection on the responsibilities of this user group in particular. While the scientists we interviewed during the contextual inquiry discussed longer-term plans to use the data in environmental planning, the city scientists in the user study seemed more concerned with immediate action items.

Flow data was nonetheless considered useful. One user commented that Creek Watch was "a good way to inventory streams and maybe even keep track of the ephemeral nature of some streams and creeks." The general consensus was that flow data is useful in the long run for planning, trending, and mapping.

All of the users emphasized their belief that Creek Watch would promote public engagement, increase awareness of watershed health, and provide informal science education for volunteers. One of their main goals is to make city residents think more about their water and where it comes from. Creek Watch gives them a way to engage with their constituents over watershed management.

From a system perspective, the users were very pleased with their ability to access the data they were collecting. They made several suggestions—for example, that we should add filters to the data table to show data by city or state to the data table, which we implemented.

As discussed, the table view was the interface designed for the users to access as data consumers, and in the pre-study interviews, most users agreed that this was how they would like to access the data for use in existing programs. However, in the subsequent interviews with users, we found that users preferred the map view for data consumption. Users described "getting a sense of the area" by browsing photographs, as well as "finding trash" using the map view.

Several users requested that the filters available for the table view (by data value) be added to the map view, so that they could use the map more effectively for their work.

Though users will sometimes need to download the data in CSV format and work with it using their own tools, the map view is undeniably useful for data consumption.

6.2.2 Data Collection

All of the users were impressed by how simple and easy to use the app was. The consensus was that making data submission simple was the most important goal. One user summed it up as:

> "Very easy, very quick. I pull up at the creek next to the business I am inspecting and use it."

Five out of ten users had friends and family members try out the application with similar results. They reported that the other party found the application "simple to use" and "easy." This suggests that, in general, volunteers without a scientific background will be able to use the application without difficulty.

Furthermore, the user study revealed that the application is considered "fun," a sentiment echoed by all of the users. This is how one user described the experience:

> "We played find the creek: Pull over at a creek, jump out of the car, find a good vantage point, enter the data."

Both of the users with school-age children took their kids out to a creek to use the application and found it useful as a teaching tool. One user recalled:

> "We talked about recording only what you see and not what you think—a nice teaching moment."

This user was responding to an interesting phenomenon in data collection:

> "When we went to a place that I could not see any trash, [my son] said 'some trash' because of what he knew from other times he'd seen in the area."

The problem of preconceptions resulting in faulty data is an interesting area worth exploring in future research.

One notable finding was that several users requested a comment field to write down a description of what they were seeing. This was particularly interesting because none of these users could think of a way that, as data consumers, they would have a use for this data. They simply "wanted to be able to add a little more data." We implemented this feature based on their feedback, as shown in Figure 6.1.

We implemented several small changes based on user observations, including making it clear that there can be only one photo per data point, and making it easier to add location information after the fact, for data taken outside GPS range.

Five of the users reported using the website to compare the data they had collected with other data points in the system. One reported:

> "I would occasionally browse data [on the map view]—looking where other people were making observations and checking out their photography."

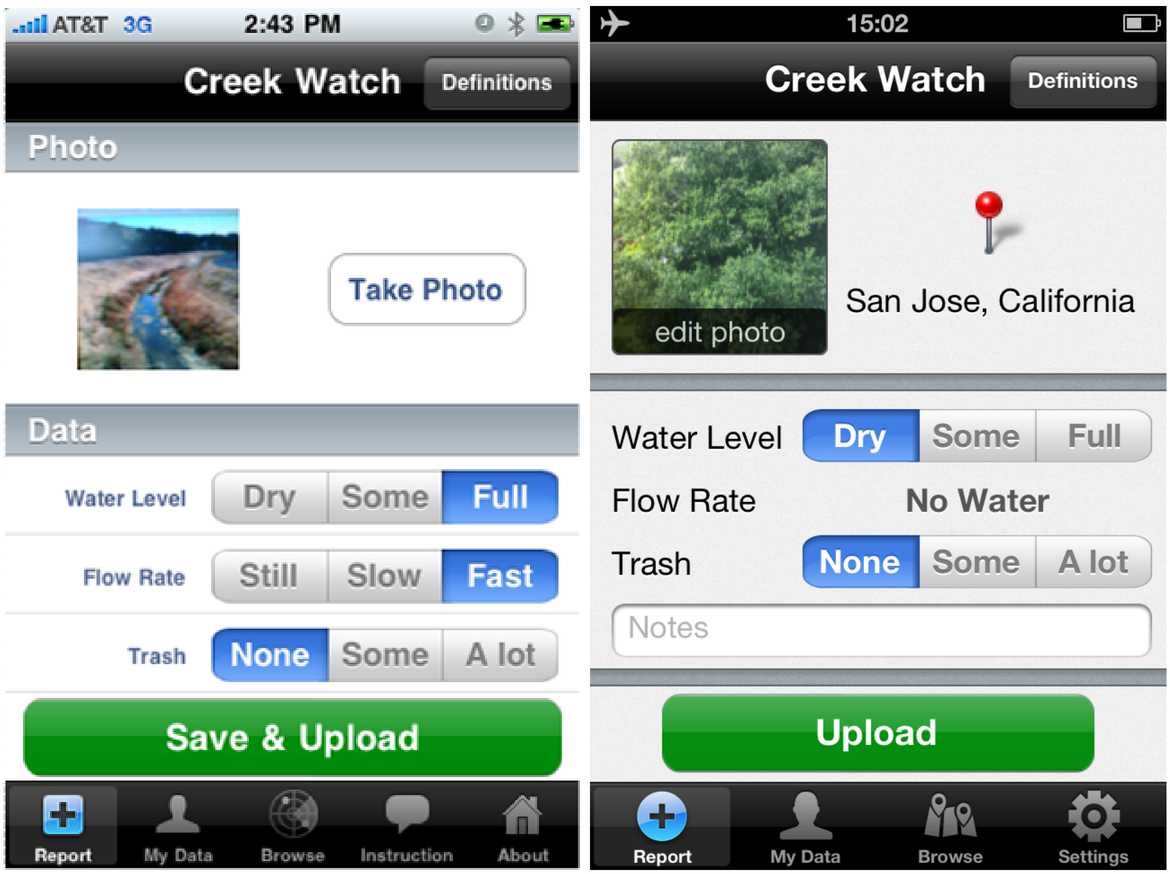


Figure 6.1: Creek Watch before and after the study, with changes implemented. Users requested a comment field, even though they did not have a clear idea of what they would write or how they would use the notations. They wanted to "be able to add a little more data."

Although the map was designed for sharing data, we found that users frequently used it as a tool for self-checking. Many users reported checking the data on the map “as a reference” to make sure their data was at least as good as their peers’. We note that this behavior presents an opportunity to seed expected use by ensuring a site has an initial set of “ideal” data points for early adopters to refer to. Previous work in this area has not highlighted this as important, perhaps because most citizen science projects started by HCI researchers focus on widespread and/or rapid adoption by users.

Overall, the users were very pleased with the system, both as data collectors and as data consumers. Even after the study has formally concluded, they have continued to use the application. Subsequent conversations revealed that two of the field agent users plan to incorporate the application into their regular data-collecting practices, replacing their current pen-and-paper data collection. They plan to use the App to log water flow and to use the photos to log general states of areas.

We intended Creek Watch to be used by citizen scientists, not by experts in support of their data collection. Thus it was surprising to see the system used in partial support of the practices of professionals. This is further proof that the data collected is useful for existing programs.

6.3 Lessons

The above user study validated the design of Creek Watch as a citizen science project, and suggested we were ready to launch. Our usage data, which is discussed in the following chapters, confirmed this.

The goal was to design a citizen science application that would collect useful data for scientists but would be easy for volunteers to use. A key part of that process was using HCI methods to investigate the needs of data consumers. We can generalize the following lessons from the results of this user study, with application to other citizen science projects:

Lesson: When HCI methods are applied to the data as well as the interface, the resulting system can collect more useful data.

Lesson: Providing reliable and standardized data enables organizations beyond initial stakeholders to benefit from the data in unanticipated ways.

For example, field agents used the data to identify trash cleanup sites and adopted the App as a data collection tool.

Lesson: Plant “seed” data as an example to users.

New users make use of sample data to validate their collection practices.

Lesson: Combine captured data that organizations can use immediately with data that provides long-term, aggregate value.

Furthermore, Creek Watch, once launched, provided an additional benefit of citizen science: the project serves as a platform and focus point for education and awareness around watershed issues.

Chapter 7

Deployment Results

Creek Watch launched publicly in October 2010 on the Apple iTunes store (see Figure 7.1). The project was sponsored by IBM in partnership with the California Environmental Protection Agency's Clean Water Team. Both organizations publicized the partnership and the project, and there was a great deal of press accompanying the launch.

7.1 Preparing for Launch

Three main avenues of recruitment for Creek Watch participants were prepared in advance of the launch: (1) traditional press releases, (2) targeted recruitment through existing water organizations, and (3) a Facebook page.

Both IBM and the California EPA put out press releases about the launch. Undoubtedly due in part to the prominence and connections of these organizations, the press releases received significant attention. Within the first month of launching, Creek Watch was featured in two local TV news interviews, two local radio interviews, the front page of the San Jose Mercury News, and 48 original national and international news articles, leading to over 400 news articles (including re-publications) in the search results for "Creek Watch" on news.google.com.

In addition to the press releases, Creek Watch was advertised on mailing lists for individuals and organizations interested in water. The California EPA maintains lists of over 2,000 groups that organize water-related activities, and each of these groups was contacted via email with an announcement of the launch, to be forwarded to their participants.

Creek Watch was also advertised on Facebook. In advance of the launch, a Facebook page for Creek Watch was created through the IBM People for a Smarter Planet initiative. The page was stocked with preview images of the iPhone App and website, descriptions of both the App and the design process employed in partnership with the Clean Water Team, and a "coming soon" button for iTunes downloads. Posts on Facebook about Creek Watch development and testing status were made weekly, and content was sometimes added by

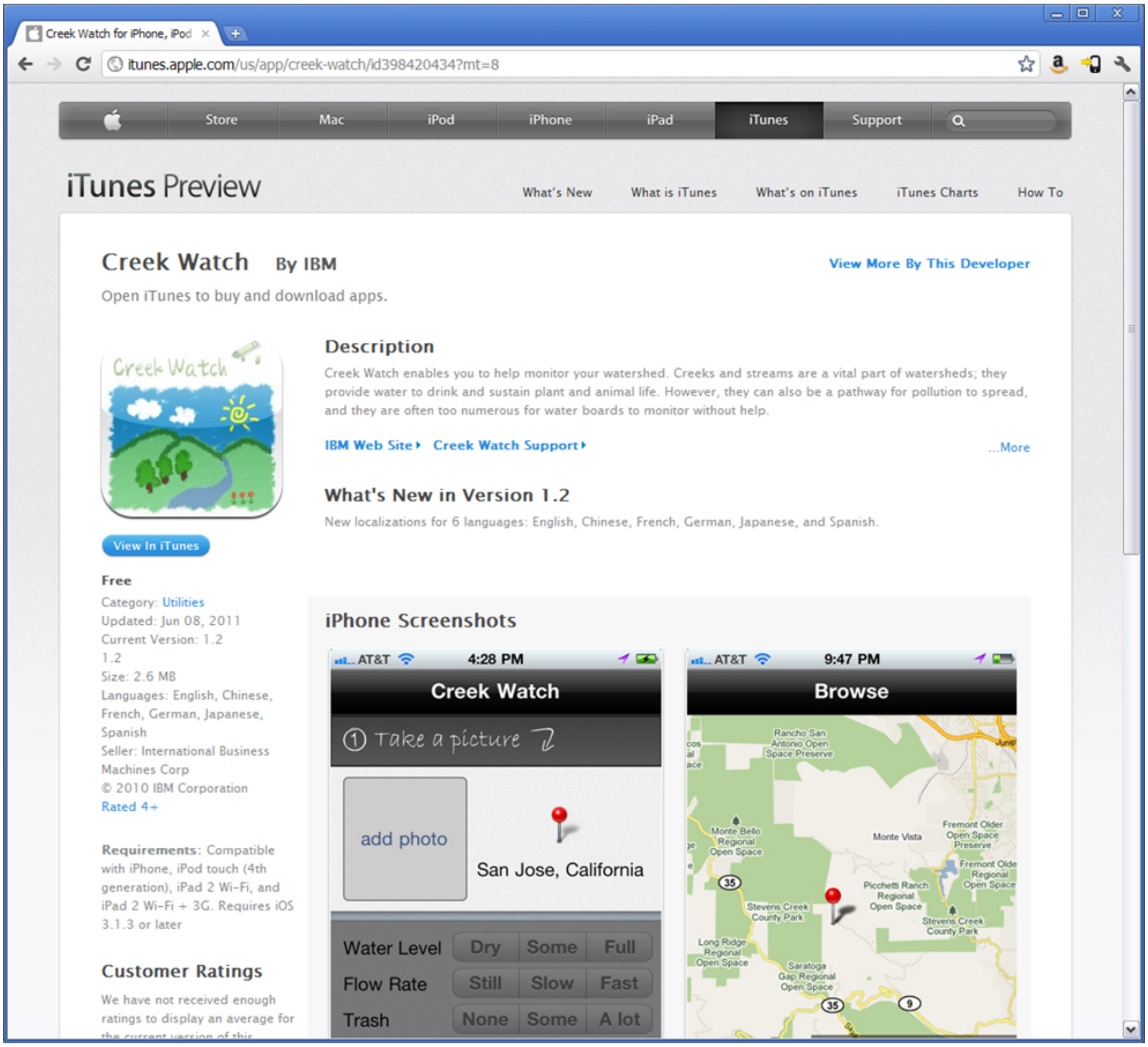


Figure 7.1: Creek Watch is available for free in the iTunes App Store.

partners, including members of the City of San Jose Stormwater Team and the California EPA Clean Water Team. The pre-launch campaign lasted two months, and by the time of launch, Creek Watch had over 30,000 friends on Facebook.

7.2 Participation

Creek Watch launched in October 2010. At the time of the launch, announcements were made on Facebook and on several mailing lists of potential users from water organizations, including a 2,000-person mailing list maintained by the California water board. IBM and the California EPA both put out press releases at the time of launch, but it was a few weeks before the news story was picked up, first locally and then internationally. As seen in Figures 7.2 and 7.3, a spike in both App downloads and report submissions accompanied both the launch and news reports.

7.3 Some Observations

As can be seen in Figures 7.2 and 7.3, there are more App downloads than data submissions. This is consistent with expectations from other citizen science projects; more people will sign up for a project than participate in it. To date, more than 4,000 people have downloaded the application; however, only 2,000 reports have been submitted.

Interestingly, we can see from Figure 7.3 that users are more likely to use the App when they are reminded to do so by news stories. A spike in data submissions has accompanied every major news article on Creek Watch.

7.3.1 Desks and Faucets

Almost as soon as Creek Watched launched, the system began receiving some bad data. Indeed, with the first version of Creek Watch, about 15% of first-time users of the first version of the App submitted photos of things other then creeks,; most of these were photos of desktops or of water which was not in a creek (see Figure 7.4). Faucets, toilets, and glasses full of water were common bad data submissions. A snapshot of a user's home or office, or in some cases, of their children, was also common. A second version of Creek Watch helped address these mistakes, as described in Section 7.5.

Despite concerns over the possibility of malicious data submissions, Creek Watch has not become a vector for explicit content publication. The "bad data" has been limited to seemingly accidental posts and misunderstandings.

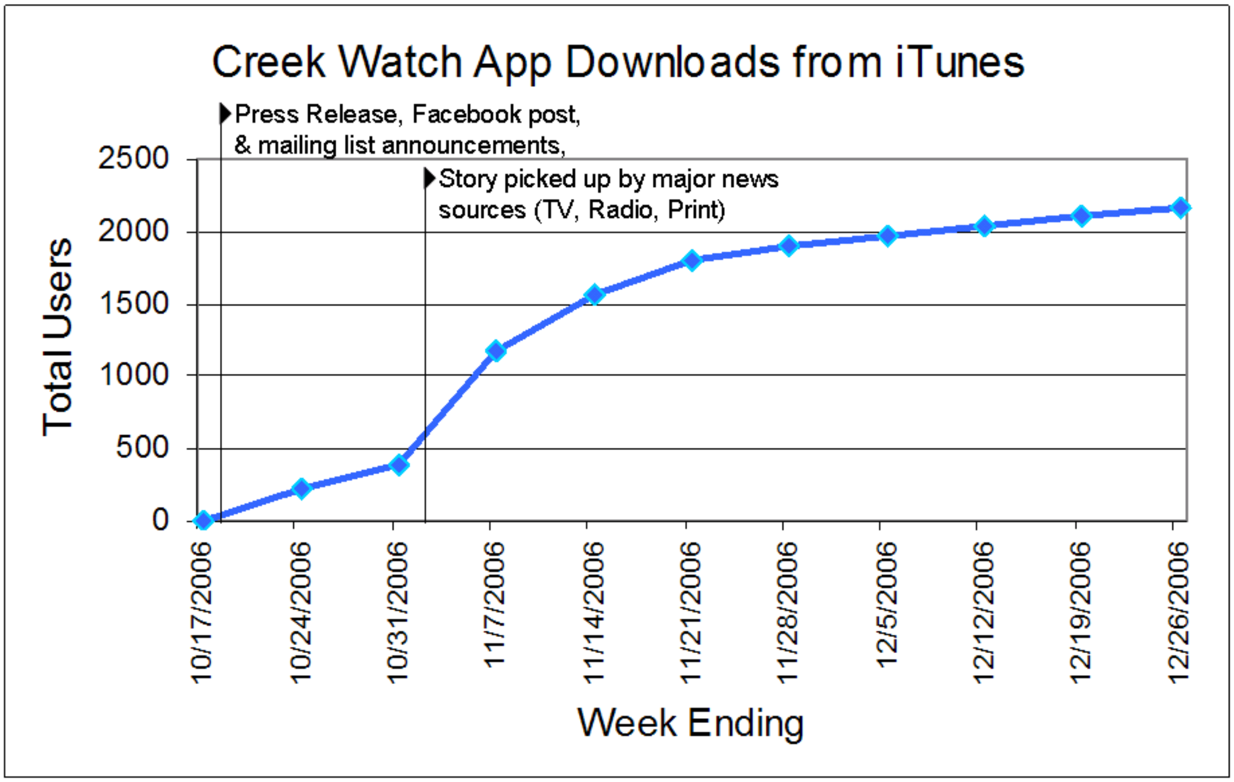


Figure 7.2: iTunes downloads of the Creek Watch App after launch. Recruitment included a press release, targeted recruitment through existing water organizations mailing lists, and a Facebook campaign. A large increase in downloads coincided with Creek Watch's being featured on the evening news in San Jose, with subsequent stories by local radio and print news sources.

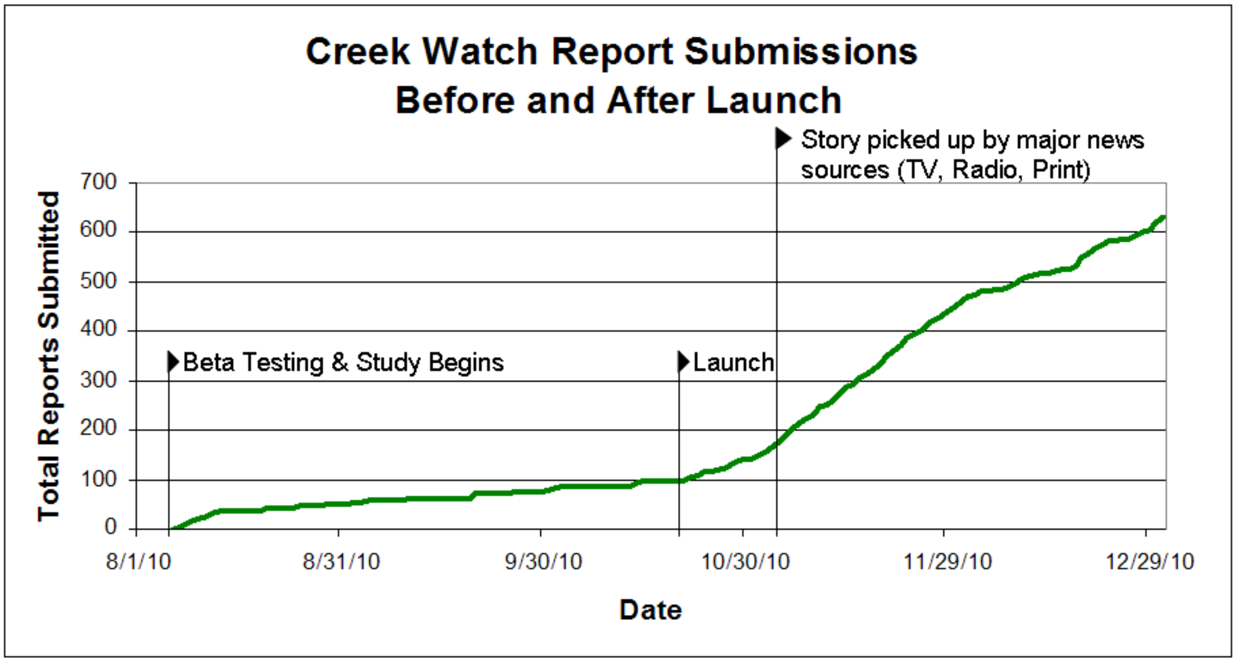


Figure 7.3: Report submissions from the Creek Watch App began during the beta testing / study with City of San Jose scientists. Similar to the spike in downloads, a large increase in report submissions coincided with Creek Watch's being featured on the evening news in San Jose, with subsequent stories by local radio and print news sources.

Figure 7.4: Example photos from Creek Watch showing bad data. About 15% of first time users of the first version of the App submitted photos of things other than creeks; most of these photos were of desktops or of water not in a creek.

7.3.2 Useful and Interesting Data

Creek Watch has already proven useful for immediate action on polluted waterways. San Jose officials use the data to pinpoint areas of greatest urgency for community trash cleanups. It is particularly useful for them to have photos to see exactly how bad the trash buildup in an area is. Figure 7.5 shows photos of trash submitted by Creek Watch users. These areas were flagged for cleanup.

In San Jose, waterways flow year round, and so a report of blocked water flow indicates a problem. However, in some climates, waterways experience an annual freeze that prevents flow for a portion of the year. While this was not an anticipated use of the "no flow" reporting system, showing the time-frame of seasonal freeze is also valuable (see the example in Figure 7.6).

Another unintended use of the system is to explicitly report on water levels in reservoirs. Some users have been photographing water markers, as in Figure 7.6, to indicate the precise water level.

Flooding is another condition which Creek Watch was not designed to monitor, but which the public is interested in reporting. Figure 7.7 shows the flooding in Sao Paulo, Brazil, from January 7 to 9, 2011. These photos show a town center undergoing severe flooding in which a bridge is washed out. While Creek Watch is not intended as a means to report flooding, it is interesting to note that users still submit this type of data.

Figure 7.5: Example photos from Creek Watch show trash.

Figure 7.6: Example photos from Creek Watch show unintended uses of the system.

Figure 7.7: Example photos from Creek Watch show flooding.

7.4 Use of the Data

The California EPA and our other local partners have been excited by both the public response to Creek Watch, and by the data collected. In addition to the aforementioned trash programs, scientists in California are using the data from Creek Watch to build a model of water availability in the state.

Since the Creek Watch launched, organizations beyond California have begun to make use of the data. We have been contacted by watershed monitoring groups in other states including New York, New Jersey, Colorado, and Florida, who are using Creek Watch as part of their volunteer programs. The data is being used in New York to identify pollution hotspots for creek cleanups. In New Jersey, the app was used for a series of surveys in 2011. In Colorado, the data is being used to track seasonal water changes. In Florida, the app is being used as a part of an educational program around watershed health. In Michigan, Creek Watch is part of the Great Lakes Region water monitoring challenge called waterpressures, and the app is used to collect data on water level and stream bank erosion.

Internationally, Creek Watch has also been widely adopted. Users from over 25 countries have submitted data, with more then 50 data points in 12 countries. We are aware of three countries besides the United States where data is actively being used by local organizations. In Canada data is collected as part of an educational program and used by the province of Quebec. In the Netherlands, data is used by a private organization tracking flood risks. In Korea, the data is used by the City of Seoul to find pollution hot spots, and identify impaired waterways for community cleanup events. We have also been contacted by agencies in Ireland, Brazil, Japan, and Australia about using Creek Watch for local water monitoring, however we are unaware of any specific use of Creek Watch data in those countries.

Organizations using Creek Watch have, for the most part, contacted us only after they have been using the system and the data for some time. In fact, most organizations have only contacted us to let us know they are using the system when they have a problem. For example, we were contacted by many organizations in March 2011, when the Creek Watch server went down for several days due to an outage on the cloud server farm. Due to Creek Watch's anonymous data submission process, we have no way of knowing who is collecting and using the data unless we are contacted directly. We speculate that other organizations are probably making use of Creek Watch data, but have not contacted us because service has been uninterrupted.

7.5 Updated Version

A second version of Creek Watch was released in April 2012. One of the primary goals of the updated version was to reduce the number of bad data points submitted to the system. Studying the bad data points suggested that the majority of "desk" photos came from first-time users. We theorized that users were simply trying the App out and accidentally submitted a report. To combat this, we introduced a confirmation screen for first-time users' data submissions, as shown in Figure 7.8.

In addition to accidental first-time submissions, we noticed that a greater percentage of errors came from international locations. This was particularly the case for the photos of water not in a creek. We theorized that international users may have been confused by the English-language instructions. To address this, we internationalized Creek Watch into six languages, based on the most frequent user populations. Localized versions were authored in French, Spanish, German, Chinese, Japanese, and English, as shown in Figure 7.9. Translation was done by volunteers fluent in each language.

With a goal of reducing bad data by further clarifying the report submission process, we added, in all six languages, a new instructional walk-through for first-time users. The instructions take the user through each step of the report submission process, as illustrated in Figure 7.10.

These new features were successful in reducing bad data submissions from 15% to 5%, as shown in Figure 7.11. Upon further examination of the images, it was found that a large number of bad data points were submitted by a single user in one session. The GPS location and photos suggest that this user was a young child in Korea who was playing with the App. Discounting this single user's submissions results in a bad data total of only 3% of reports.

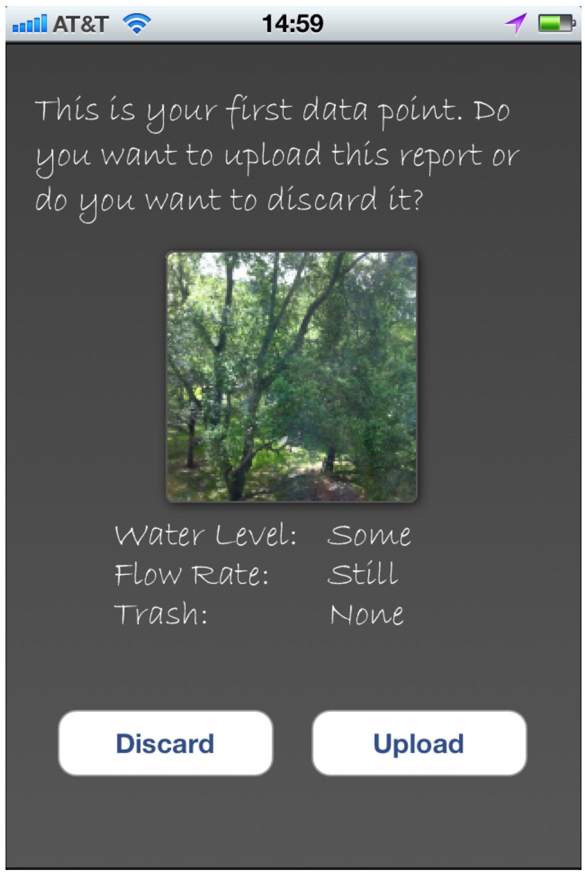


Figure 7.8: Since the second release, the Creek Watch App includes a confirmation screen for first-time data submissions.

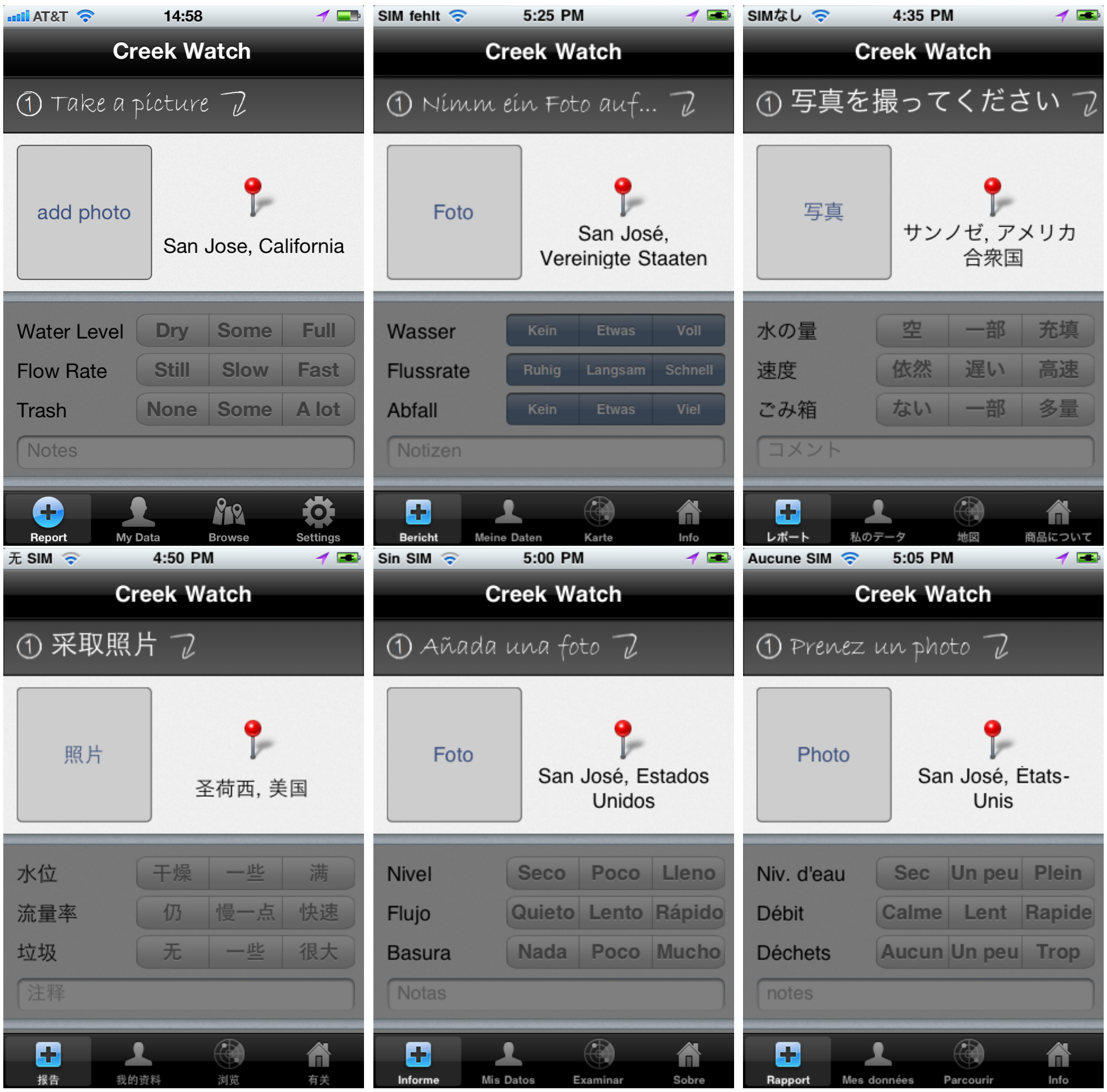


Figure 7.9: Since the second release, Creek Watch is now available in six languages.

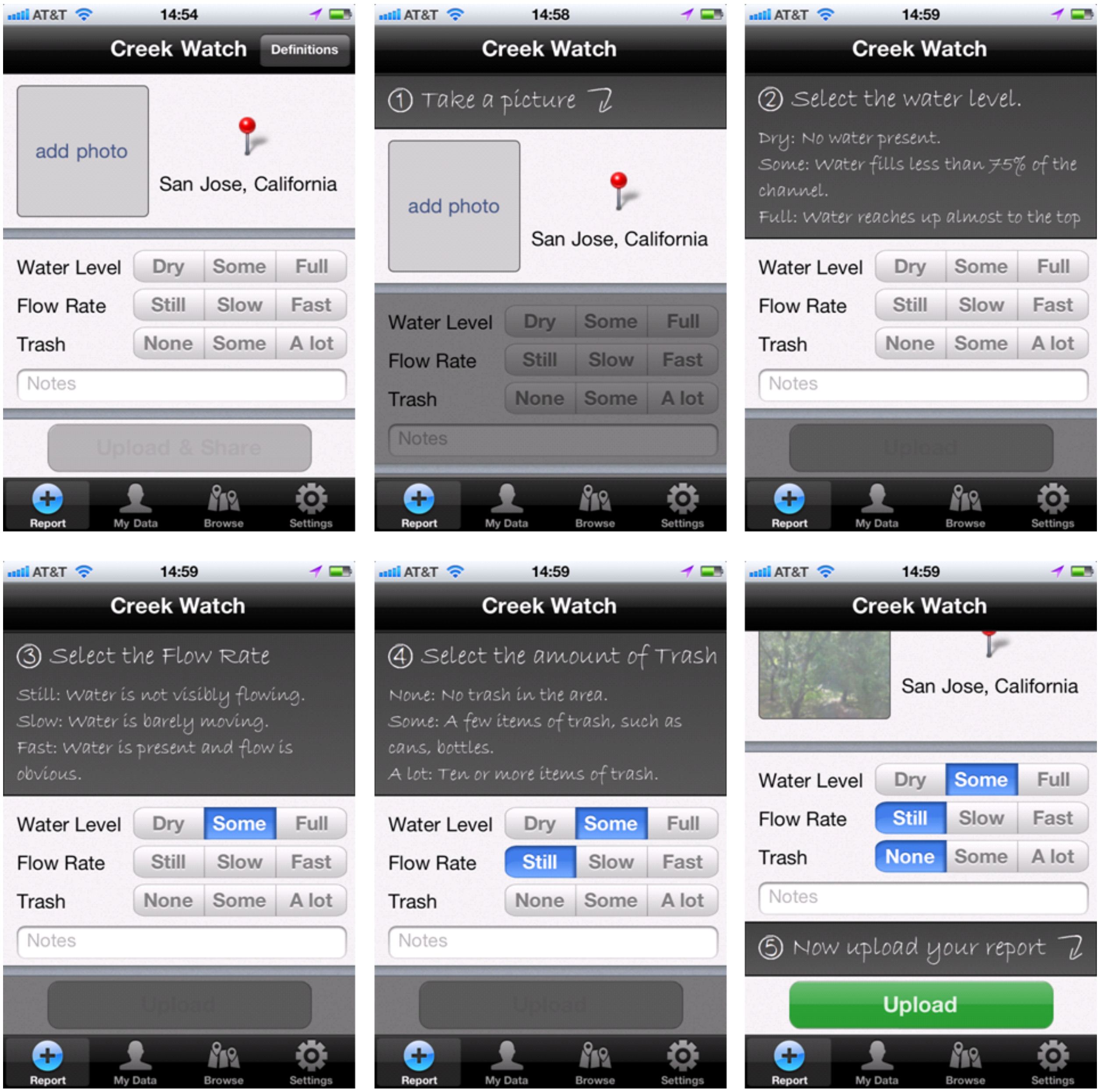


Figure 7.10: Since the second release, the Creek Watch App has included step-by-step instructions for first-time data submissions.

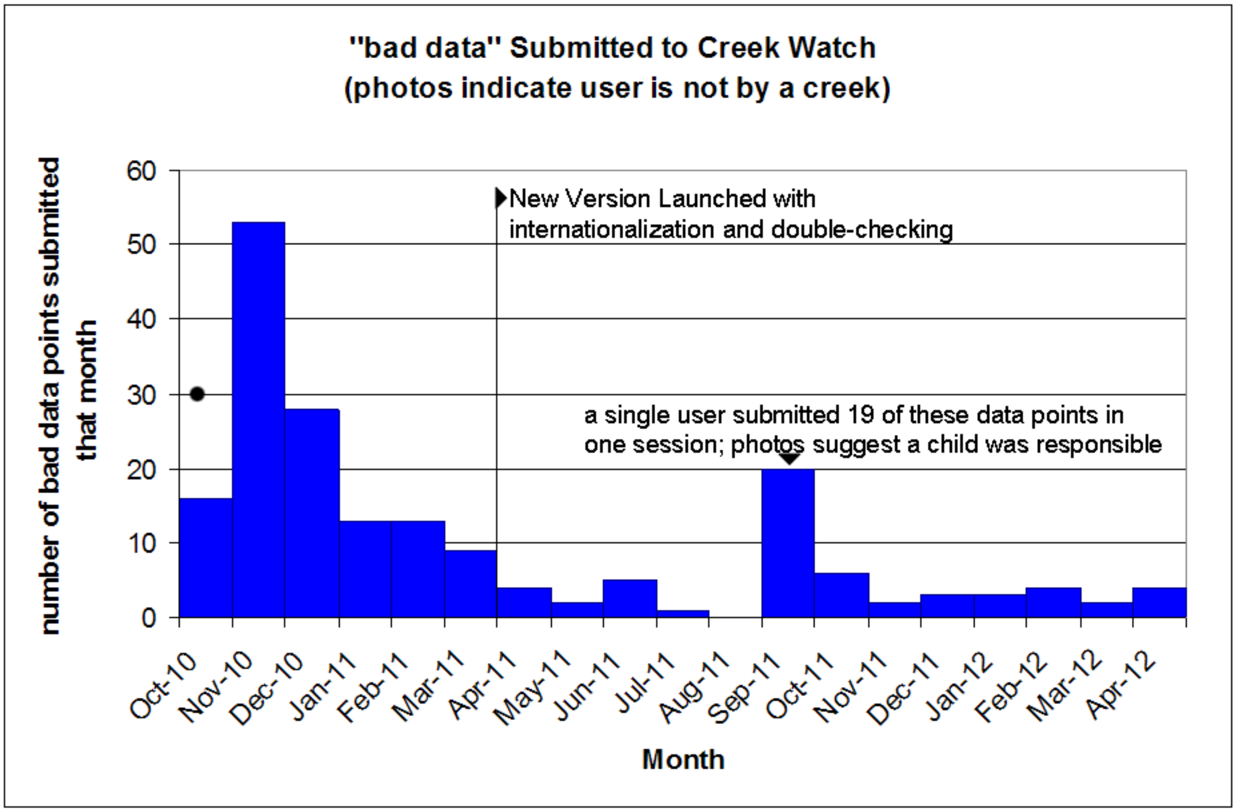


Figure 7.11: The amount of bad data submitted to Creek Watch was reduced after the launch of the second version of the App.

Chapter 8

Motivating Citizen Scientists

The community open house and Creek Watch showcase organized through the city of San Jose (Section 5.5.2) was an example of engaging local users to be active in their community. A sense of community is repeatedly reported as a key motivation for volunteers in citizen science [37, 132, 146, 113]. The suggestion that building community leads to increased participation and involvement is one reason so many citizen science projects have created on-line communities. As we saw in Section 2.4, many projects have created Facebook pages where community members can indicate their support for a project by "liking" it and can then discuss or share information related to the project.

Using Facebook to connect with a community of users has been particularly successful for Creek Watch. As mentioned in Section 7.1, Creek Watch had more than 30,000 friends on Facebook by the time of launch. This number grew to more than 220,000 by the release of the third version of the iPhone App, as can be seen in Figure 8.1.

Based on the popularity of the Creek Watch Facebook page, the use of social networking to promote and engage users is worth serious consideration. At the NSF-sponsored workshop on citizen science in May 2011, the case of Creek Watch on Facebook, and of the use of social networking features in general, was discussed with a team of 27 practitioners. Participants believed there would be benefit in terms of recruitment and engagement from creating and maintaining a Facebook page, but that this is unsubstantiated by any hard evidence. However, the discussion of the motivations of participants suggested that the use of Facebook or other social networks should be beneficial to a citizen science project. Participants in all projects were observed to be motivated by a sense of community. It was also observed that motivations for participation can change over time. For example, people may start volunteering at an outreach facility out of altruistic motives, but often stay and continue to participate because of the sense of community and social engagement [41].

During these discussions, we also identified some key changing trends in citizen science [41]:

Figure 8.1: Creek Watch has more than 220,000 "likes" on Facebook.

1. A shift in focus from contribution to participation, wherein volunteers increasingly want to get involved and engaged with all levels of the project
2. An increase in the number of available technologies to promote and aid citizen science, including social networking technologies.
3. Increasingly skilled hobbyists and subject matter enthusiasts forming the core workforce of volunteers.

Not only does social networking allow for the development of community, but it allows engagement with existing communities. This is important because of the common trend that people participating in citizen science are often already passionate hobbyists in the area [41]. For example, Community Collaboratory for Rain, Hail and Snow (CoCoRaHS) participants are mostly weather enthusiasts. The organizers believe this is partly due to the dedication necessary to collect the data; data collection is easy and quick, but must be done every morning. As such, only people with an interest in meteorology remain active, but this hobbyist population is large enough that more than 15,000 people actively participate in CoCoRaHS [41, 36]. In several cases of water quality monitoring (e.g., RCTB, SCWRP), the project is driven largely by concerned members of a community [41]. This suggests that connecting with existing communities, for example via Facebook, may be a worthwhile means of recruiting participants.

Andrea Wiggins' research on engaging a community and building a citizen science project out of existing amateur activities confirms that this is an important and successful way to develop a program [163]. Hobbyists and the communities that support them also provide important means for recruiting participants, as is the case with the eBird project [51], which leverages existing communities of bird watchers who are often members of local birdwatching societies (e.g., Audubon in the U.S.) [41]. If the participants of a project are largely recruited from existing hobbyist communities, they may have a different set of motivations.. In particular, these participants often place a high value on learning new things or developing skills [113].

8.1 Learning and Personal Development

Personal development is a motivation for continuing involvement in a number of citizen science projects. Participants who have long-term engagement with a project typically participate in a number of different activities, often with increasing complexity as they become more skilled and more involved. Projects that offer a scaffolding of activities can encourage this behavior in users, helping build a user community which includes mentors and leaders in addition to new volunteers [41].

Porter's Funnel Model of Participation supports this notion of levels of involvement connected to personal development. As participants become more skilled and more involved, they are able to advance to higher levels of participation [122]. This is also consistent with Preece and Shneiderman's Reader-to-Leader framework for participation in group activities using the web, such as Wikipedia authorship [123]. It is important to note, however, that involvement in a project is not a one-way street from new recruit to community leader; participants need to be able to vary their participation and responsibilities to suit their lifestyle and interests at any point [41].

Learning new things is often cited as a motivation for citizen scientists [87, 114, 107]. Participants feel motivated by the opportunity to learn, even though in many cases they gain few or no new skills or knowledge from their participation [39]. Projects seeking specifically to train or educate the public are best advised to set out to do so directly, rather than as a by product of data collection practices [21].

The opportunity to learn new things and gain experience with a new aspect of scientific interest is particularly motivating for projects with field work [87]. However, learning is also an important motivator for scientific computation projects where the participants do no field work and in many cases very little work at all. For instance, consider projects where participants use idle time on their computers, (e.g., SETI@home to search for signals in space [152], or Folding@home to solve biochemistry problems [116]). Nov et. al. have termed these new Internet-based citizen science projects "SciSourcing." In their work they have discovered that participants in SciSourcing have different motives from participants in crowdsourcing for non-scientific purposes. Specifically, SciSourcing participants were motivated foremost by the opportunity to learn, and not at all by building a reputation or being identified for their work [114]. Participants in these projects have also been shown to be motivated by knowing that their work contributes to a worthy goal, suggesting that they have overlapping motivations with citizen scientists who do fieldwork [113].

8.2 Demographics

The incentive to learn new things and develop skills has been observed to motivate younger participants significantly more than older participants [133]. Older volunteers, who often make up a larger portion of participants in citizen science projects [160], report that they volunteer because they want to use their leisure time constructively [133]. Whether or not participants are learning new skills, practitioners have observed that building and maintaining participant confidence is critical to the success of long-term projects [41].

The demographics of citizen scientists suggest other possible means of motivating participation, based on established theories of political participation. In particular, the demographics of several studied citizen science groups (e.g., [160], [22]) match the highest level of participation in the political system, as described in the socioeconomic status model of structured political participation established by Verba in 1972 [155]. This model, which continues to hold true today, demonstrates that people whose socioeconomic background makes them most likely to participate in politics (e.g., to vote), are motivated by "soft incentives," such as a desire to be part of collective action [101]. The body of research on motives for political participation dwarfs that of research on motives for citizen science participation. These parallels suggest that much can be learned about motivating citizen scientists from lessons on how to motivate voters.

Community building is a key motivator for both political participation and citizen science. Indeed, the clearest difference between the motives of citizen scientists and those of professional scientists is just this: citizen scientists are much more motivated by collectivism [132]. This is consistent with established patterns of volunteerism. In Wilson and Musick's work on understanding volunteering, which involved a comprehensive survey of 3,617 individuals, they found that people are more likely to volunteer if they are more social (i.e., report more frequent conversations and meetings in their daily lives) [171]. Younger volunteers are also significantly more likely than older volunteers to be motivated by social or collaborative activities, such as meetings or other opportunities to interact with others [133]. These findings suggest that targeting younger, more social individuals may increase participation in citizen science projects.

8.3 Enjoyment of the Outdoors

Citizen scientists for some projects are often motivated by a desire to spend time outdoors [58]. In particular, birdwatchers have been frequently shown to be motivated to participate in bird count activities in order to spend time enjoying nature, to be alone, and to learn about the environment [107, 22]. In a survey of 756 bird watchers, motivations to "experience the sights, sounds, and smells of the outdoors" and "be alone" were ranked the highest, beating out the more common motivations of volunteers, most notably building friendships or other relationships [107].

As in all populations, there are spectrum of motivations, however. While most bird watchers are strongly motivated by spending time outdoors, more advanced participants (often termed "birders"), also have a strong achievement orientation: they are strongly motivated by their interest in competing over bird counts, building life lists, and expanding their personal knowledge of birds [107]. By focusing on lists and achievements, the eBird project targets this groupin other words, the project its target community are a good match [51].

Surveys show that citizen scientists are predominantly well educated and earn above-average incomes (e.g., [160], [22]). A large percentage of citizen scientists are either older individuals (particularly retirees) or parents with who have children living in their household [160]. This is consistent with established patterns of volunteerism—the presence of children still at home increases volunteerism [139, 171]. Families with children are also known to be interested in enjoyment of the outdoors as an activity for its own sake [172].

8.4 Achievements and Competition

While Creek Watch is not designed to explicitly encourage advanced users, the kinds of achievement and competition incentives that attract advanced participants in birdwatching citizen science may still be good options for motivating participation. At the NSF workshop on citizen science, several practitioners discussed their experiences using achievements to motivate users. Leader boards and other ranking or reputation systems are common. One of the reasons they are theorized to work is that participants feel a sense of accomplishment when they advance to a higher participation level [41].

It was also observed that users can be just as motivated by intangible rewards like badges and points than by prizes or other physical rewards. Being recognized for an accomplishment alone is a strong motivator for citizen scientists [41]. This phenomenon has been seen in several other contexts. In Von Ahn's work on games with a purpose, users have completed a myriad of menial tasks as part of competitions for intangible awards [158, 157, 156].

It is even possible to motivate people to travel to collect data using intangible rewards such as badges. The recently popularized location-based sharing service, Foursquare [40], has demonstrated how badges and awards can encourage people to actively travel across their neighborhoods, cities, and countries to collect awards with no tangible value [102]. In a recent crowdsourcing study with the goal of acquiring images of a large area to build a comprehensive 3D model, users were successfully motivated by a competition to collect images [149]. Participants were rewarded both for collecting images from diverse locations and for collecting a large number of images, suggesting that rewards can encourage a variety of data collection practices.

8.5 Rewards and Incentives

The line between rewarding someone for their help and paying them for their services is delicate. While we have seen that aspects of gaming or competition can motivate users to increase their participation, it is important not to take rewards too far. Consider the case of blood donation in the United States. There is a chronic shortage of donor blood available to hospitals, and there have been a variety of attempts to encourage more volunteers to participate in blood drives. Interestingly, volunteers have indicated less willingness to donate blood if compensated with a cash incentive [138]. Most people see blood donation as an altruistic act, so a direct pay structure is at odds with their reason for participation [70]. People are more likely to respond to calls to donate due to social pressure from friends or family. [70]. Interestingly, however, non-monetary compensations can sometimes encourage donation. For instance, a survey with 45,000 respondents from a pool of people who had donated blood suggested that while cash incentives would discourage some donors from returning, offering free blood screening for common concerns like cholesterol and prostate antigens were strong incentives to return and donate again [70].

It is important that incentives be perceived as commensurately valuable with the effort performed [124]. This may in part explain the disinterest among blood donors in receiving money for their life-saving contribution. Monetary incentives have also been shown to be unsuccessful in some cases of crowdsourcing. In particular, Mason and Watts demonstrated that Amazon Mechanical Turk workers who were paid more were no more motivated than others who were paid less for the same task. Their work suggests that it may not be possible to buy more participation or better work from a crowd of volunteers [106].

Of course, not all incentives will apply to all potential volunteers (e.g., a female blood donor will have little interest in prostate antigen screening). In their study of volunteers at United Way, a national volunteer association, Puffer and Meindl observed that incentives must be matched to the individual motives of participants in order to be effective. They divide motives into three classic cases—rational, normative, affiliative—and observe that if volunteers have motives of a particular class (e.g., a rational motive such as self-interest or career advancement), then incentives should also be of that class (e.g., rational incentives of material rewards, or skill acquisition). For the other cases, where volunteers are motivated by normative factors (e.g., altruism), they suggest normative incentives such as symbols and awards, and where volunteers are motivated by affiliative factors (e.g., a desire to form group bonds), they suggest affiliative incentives such as social activities and formal ceremonies [124].

Using rewards, structured incentives, and competition, however, raises concerns about data integrity. Amazon's Mechanical Turk [4] users have been shown to routinely game the system if left unchecked [43]. Citizen science projects that encourage competition often have to add measures to check for bad data (e.g., [51], [63]). Indeed, bad data problems appear to be present in nearly all on-line contribution or collaboration systems, from eBird to Wikipedia. Due to these concerns, our partners at the California Environmental Protection Agency requested that we not incorporate any explicit incentives, ranking, or competition aspects into the App.

8.6 Volunteerism

While often fraught with bad data problems or even malicious users, online projects in which volunteers donate time can provide good insight into how to incentivize citizen scientists. Wikipedia [168] is a particularly interesting example, as contributors receive little, if any, recognition for their work, yet the project's success can be seen in the millions of people who volunteer their time. The main motivation reported for contributing to Wikipedia is a desire to contribute to the project's goal of identifying and publishing true facts about the world. Users are motivated directly by contributing to this cause, and also by seeing their contributions as a small but valuable part of the whole [67].

Other on-line communities exhibit similar motivations. For instance, participants in the Galaxy Zoo project [178], in which users classify images of galaxies from the Hubble space telescope, rank contributing to astronomy as their highest motivator for joining the project [125]. This exactly parallels the observations of practitioners at the NSF workshop on citizen science, who observed that many participants are motivated by "simply wanting to help" [41].

While it is tempting to hope that people participate in citizen science simply because they wish to help, and while participants themselves often report this, such self-reported altruism should not be taken at face value. In an interesting study of the motivations of contributors to an online mathematics community, volunteers who participated were both surveyed and had their behavior on the site tracked. While users reported in the survey that their desire to help others is their prime motivator, their behavior patterns on the site suggested that reputation building may be a more important incentive [146].

Indeed, the difficulty in understanding why we do what we do, and, in particular, why volunteers spend their time and energy where they do, is an old problem. Classical understandings of the motives for donating time or money are fraught with problems. As Baston and Ahmad point out in their evaluation of community involvement motives, none of the classical notions of egoism, altruism, collectivism, or principalism are sufficient to explain what motivates volunteers [16]. It is more practical, perhaps, to consider what approaches have been shown to motivate people than to consider the more philosophical question of what causes motivation.

To that end, we can observe a few motivations which have been shown to encourage participation in citizen science. Enabling community building, both by targeting existing communities and by encouraging participants to share and collaborate, is almost universally recognized as a good idea [98]. Enabling participants to learn and develop skills is also valuable [87, 114, 41, 107]. Encouraging users to get outside and enjoy nature is often successful at motivating participation [58, 107, 22, 172]. While games, competition, and reward structures can be successful, they can sometimes lead to data problems (e.g., [43, 63]). For this reason, and at the request of our partners who use the Creek Watch data, we have not pursued this avenue. Rather, we will focus on engaging users as a community and explore the use of social networks to this end.

Chapter 9

Using Social Networking for Promotion

As we have seen in Chapter 8, social aspects such as a sense of community and peer pressure play a large role in motivating users to participate in citizen science projects. Social networks provide an opportunity to engage communities of users in citizen science. Early experiments with Creek Watch on Facebook indicated that this might be a successful means of recruiting and engaging participants. Discussions with other citizen science practitioners suggested that this was an area of interest, and that while many projects were experimenting with social networking, there were no concrete results to demonstrate the success of social networking tools for citizen science [41].

9.1 Integration with Facebook and Twitter

As an experiment in social networking, a new version of Creek Watch released in March 2012 includes integration with Facebook and Twitter (see Figure 9.1). Users who submit reports can choose to automatically post their observations to their Facebook wall or Twitter stream. Visitors to the Creek Watch website who have clicked on a link from one of these Facebook or Twitter posts are tracked anonymously to measure the effectiveness of this feature at recruiting new users and increasing web traffic. This feature is consistent with the observed uses of microblogging tools such as Twitter and the Facebook wall, since microblogging is commonly used to announce casual or daily activities [86].

As can be seen in Figure 9.2, Creek Watch users more commonly (70%) post observations to Facebook than to Twitter; however, Twitter posts generate more visits. While individual Twitter posts are clicked on by more people than Facebook posts, the audiences appear different. Click-throughs from Facebook posts are 2.5 times more likely to result in a download of the iPhone App than click-throughs from Twitter posts (see Figure 9.3). Indeed, visitors

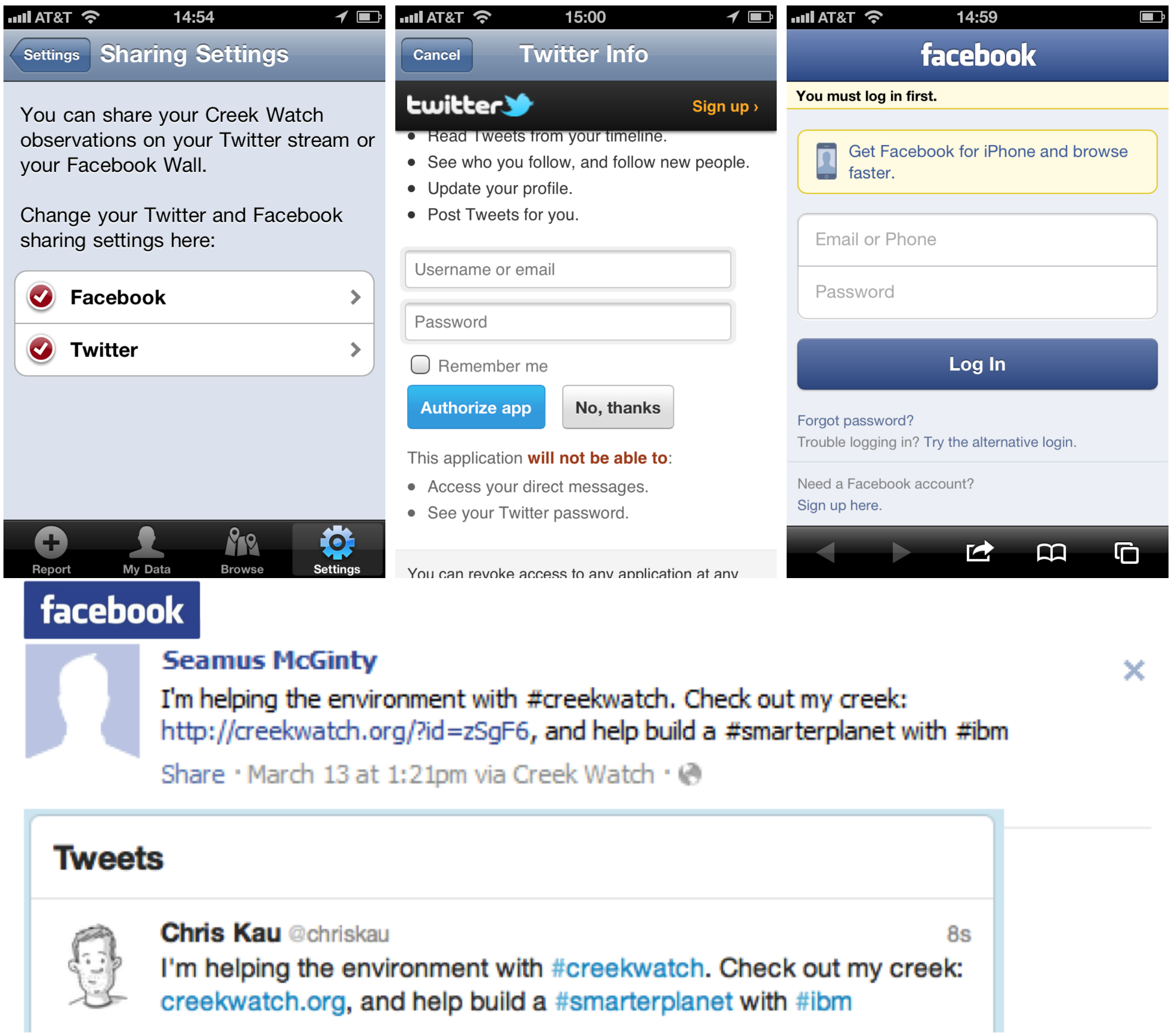


Figure 9.1: Screenshots of the Creek Watch feature for posting to Facebook and Twitter, and corresponding posts.

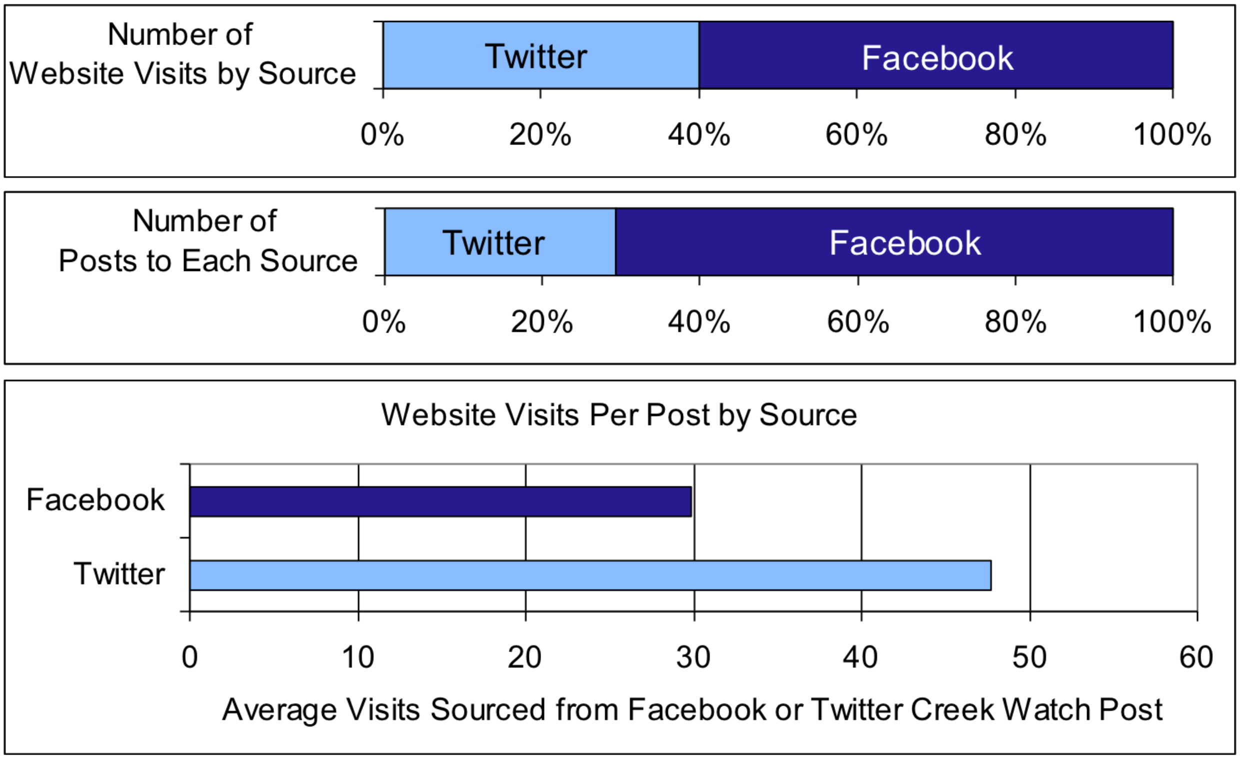


Figure 9.2: The frequency with which visitors to creekwatch.org clicked on a Creek Watch observation posted to Facebook or Twitter.

who clicked on a Twitter post are no more likely to download the App than any other web visitor, with a conversion rate of about 3%. The Twitter results are unsurprising in light of Bansky et al.'s work on the influence and diffusion of tweets, which suggests that it is difficult to predict what content will generate re-tweeting or which users will be the largest influencers, indicating that Twitter may not be a reliable means for promotion [15].

The effect of a Facebook or Twitter post is relatively local and highly transient. Each Facebook or Twitter post generates between 0 and 152 website hits, with an average of 29.52 hits per post (median 21). As shown in Figure 9.4, the increase in web traffic resulting from the post is concentrated in the first 2 to 5 hours, with small peaks centered about 9 hours and 20 hours after posts. These smaller peaks coincide with the evening of the day the post is made, and the morning of the following day, as most Creek Watch reports are made between 8 a.m. and 1 p.m.

These results illustrate that integration with Facebook and Twitter resulted in an increase in web traffic (project awareness), but that only integration with Facebook resulted in an increase in downloads (recruitment).

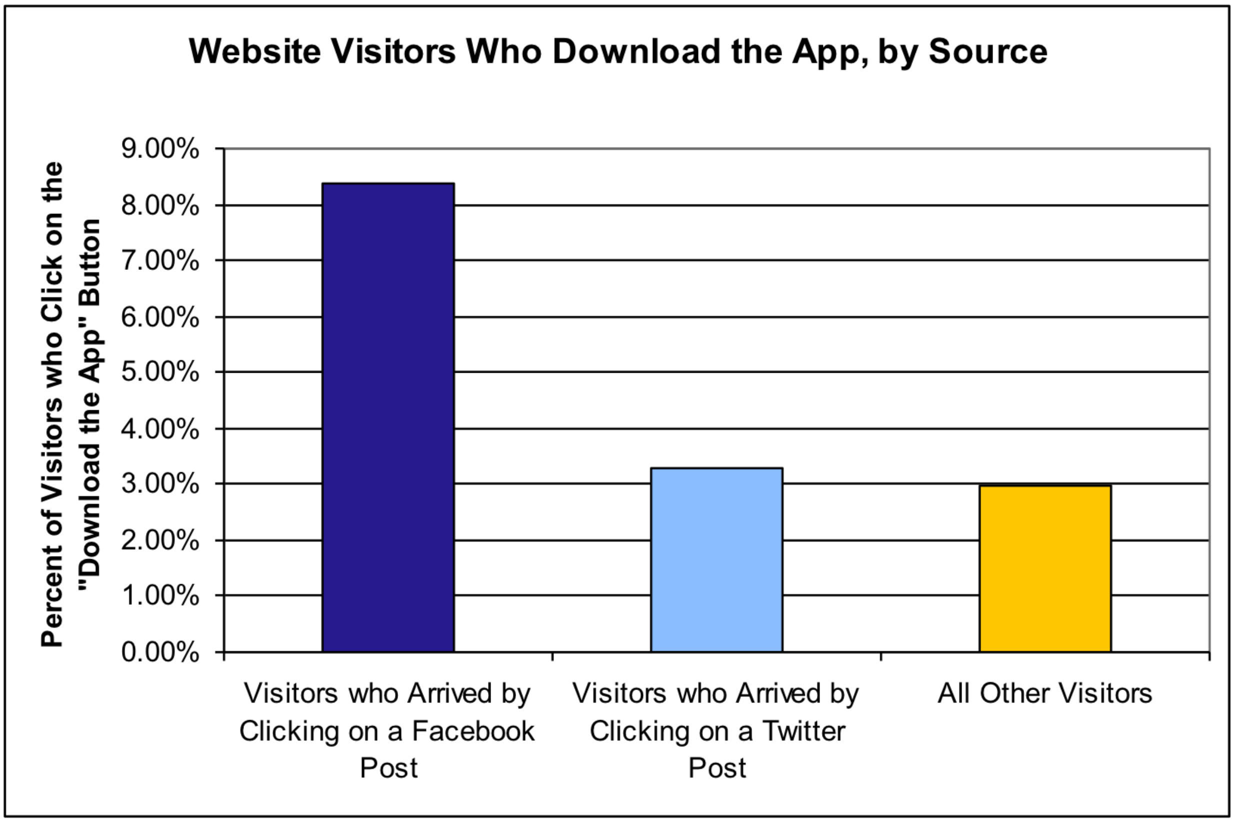


Figure 9.3: The percentage of users who click on the download button on creekwatch.org is different for each referring website. Data plotted represents 52 App downloads from Facebook click-throughs and 22 App downloads from Twitter click-throughs.

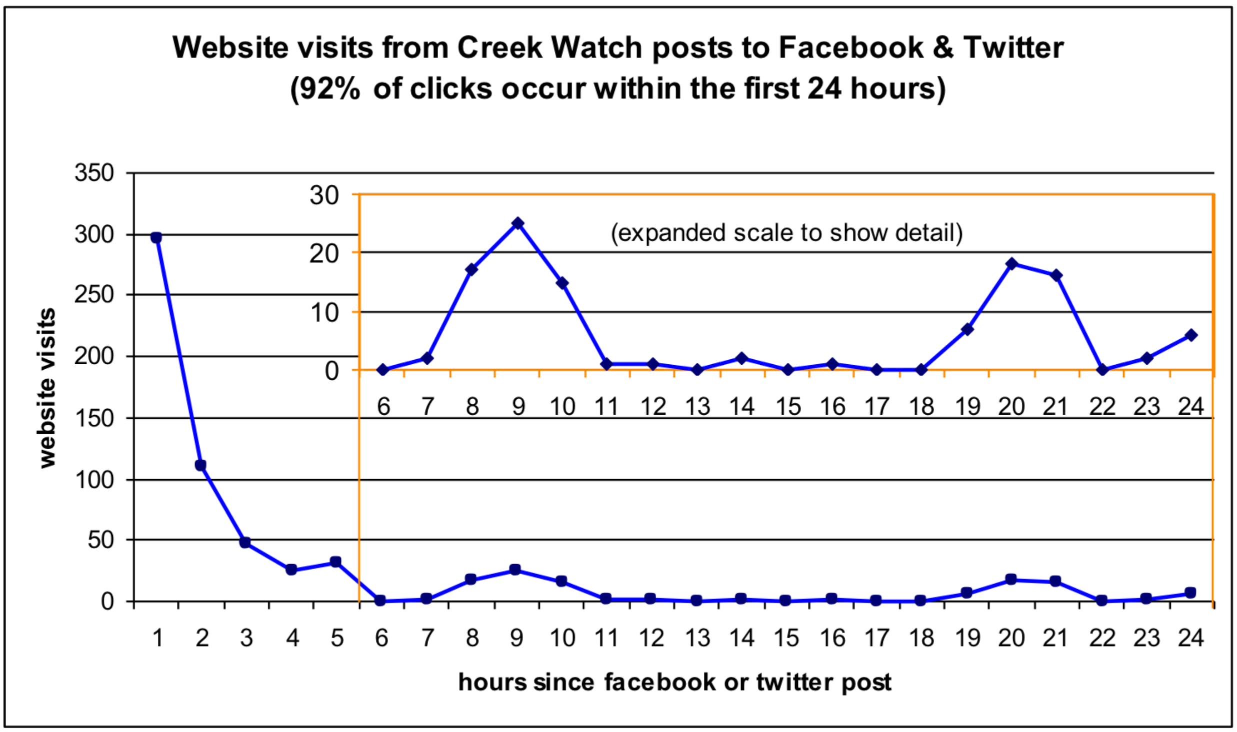


Figure 9.4: Visits to creekwatch.org from clicks on a Facebook or Twitter post, shown by time since post.

Source	**Total Respondents**	**Percentage Female**	**Age**	**Percentage with College Degree**	**Percentage with Graduate Degree**
Facebook	28	48%	39 $\pm$11	92%	59%
Direct Email	14	23%	48 $\pm$13	100%	46%
Mailing List	97	49%	50 $\pm$14	94%	51%
Total	139	47%	47 $\pm$14	94%	52%

Table 9.1: Demographics of Survey Respondents by Source

9.2 Impressions of Facebook and Twitter Integration

While the social networking feature shows promise, it was used less then we expected. In the first eight weeks of use, 21% of reports submitted to Creek Watch were also posted to Facebook or Twitter.

To try to understand the reasons behind the low adoption rate of this feature and to investigate Creek Watch use patterns in general, we conducted a survey (N=139). Due to the anonymous nature of Creek Watch and of iTunes App downloads, we could not target Creek Watch users directly. Instead we sent the survey through three channels: (1) posting on the Creek Watch Facebook page and the pages of Creek Watch's sponsors (28 respondents), (2) emailing a government mailing list for people who are interested in water conservation (97 respondents), and (3) emailing a list of 121 people who had contacted the Creek Watch team directly at some point (14 respondents). There were 139 total survey respondents, with an average age of 47 (standard deviation 14) and a 47% to 53% female-male breakdown. The survey showed 94% of respondents have a college degree, of whom 52% also have a graduate-level degree.

About two-thirds (65%) of respondents had heard of Creek Watch, of whom 22% had downloaded the Creek Watch App. Of respondents who had downloaded the App, 55% indicated they had used it to submit at least one report, but only 15% indicated they submit frequent, regular reports. Interestingly, none of the survey respondents had used the Facebook or Twitter feature. Indeed, 41% of users were unaware of the feature, and 9% do not have a Facebook or Twitter account, and 51% of users were aware of the feature but chose not to use it. Of those who chose not to use it, 46% indicated their reason was “I'm not interested in [this feature]”, 46% indicated “I don't want to clutter my Facebook page or Twitter stream,” and 8% cited privacy concerns. There were no write-ins.

We also asked survey respondents if they had “liked” Creek Watch on Facebook, or planned to. Of respondents with a Facebook account, only 10% had already done so; a further 45% stated they planned to do so, and 45% stated they did not plan to “like” Creek Watch. Of the subset of users who were aware of the Twitter and Facebook posting feature but chose not to use it, 56% indicated that they had "liked" Creek Watch on Facebook or planned to.

Respondents indicated they had heard of Creek Watch through several channels: 12% indicated they had heard of it through a social network, 15% from a news article, 21% through word of mouth, and 44% from a group or mailing list. As Creek Watch's launch was advertised on the same mailing list from which 70% of respondents came, there is unavoidable bias in these numbers.

This survey is limited by several sources of bias, including the demographics of the respondents, an unusually high percentage of whom have college degrees (94%). While 54% of respondents were over the age of 45, most Creek Watch users (84%) are under the age of 45. While 32% of users over the age of 45 do not have a Facebook account, those that do were no more or less likely than users under the age of 45 to "like" Creek Watch on Facebook. Another source of bias is the method of recruiting respondents. While only 30% of respondents were reached through Facebook or the targeted mailing list, 55% of Creek Watch users came from these sources.

9.3 Conclusions about Social Networks

We conclude that integrating Facebook and Twitter into the App did help get the word out about the project, but that only Facebook posts (and not Twitter posts) led to more people signing up for Creek Watch. However, the low adoption rate of this feature, combined with the fact that many users stated their unwillingness to use this feature but were willing to "like" Creek Watch on Facebook, suggests that developing a Facebook community may be more useful than adding a feature to post to Facebook and Twitter automatically. As a result of this work, we plan to focus our efforts at recruitment on social networking platforms, but to focus our efforts for data collection on existing communities through local channels.

Chapter 10

Recruiting Participants

How best to recruit users to a citizen science project remains an open question. In an NSF-sponsored workshop bringing together citizen science practitioners and computer science researchers [41], we explored several recruitment strategies used by practitioners. It became clear that there was no consensus or understanding of which recruitment methods work best, nor how to evaluate such methods. For some projects, (e.g., eBird), data collection is the priority, and all efforts are focused on increasing the number of data reports so that more data is available for scientific research. Other projects (e.g., Word Water Monitoring Challenge) place more emphasis on awareness and education, focusing on engaging a large number of people about an issue [41].

The initial launch of Creek Watch in October 2010 resulted in a lot of news stories and buzz, and also gained us 2,000 users within the first month. However, as discussed in Section 7.1, we pursued a number of different recruitment strategies simultaneously for the launch. These included an international press release, announcements locally to existing water management communities and other interested parties, and announcements to the Creek Watch Facebook page with more than 30,000 followers. Given these many simultaneous methods of recruitment, it is unclear which played the largest role in raising awareness and drawing participants.

10.1 Recruitment Experiments

To explore the question of how best to recruit participants, we conducted three separate campaigns several months apart to recruit volunteers: (1) a press release with international web news coverage; (2) a participation campaign that targeted groups in two cities five months later; and (3) a social networking campaign promoting a new version of the App on Facebook and Twitter nine months after that. The results of these campaigns in terms of website visitors, iPhone App downloads, and report submissions are described here.

Recruiting via Press Release and News Coverage

In January 2011, three months after the launch of Creek Watch, an international press release highlighted the project. The announcement was included in 23 web news articles and resulted in a spike in downloads of the Creek Watch App, as well as a spike in the number of report submissions (See Figures 10.2 and 10.3).

Centennial Campaign

In June 2011, in collaboration with two city water boards, we launched a participation campaign dubbed "Creek Watch Snapshot Day." Participants were recruited through a community service outreach program to make coordinated observations of the waterways of greatest concern in their local areas. More than 100 people signed up to participate. This campaign, and the resulting press, resulted in an increase in downloads and report submissions, as seen in Figure 10.1.

Social Networking Campaign

In March 2012, we launched a new version of Creek Watch with social networking features. Instead of putting out press releases, we announced this feature through a social networking campaign, including a six-hour Q&A with 512,496 Facebook and Twitter followers. The Q&A resulted in 1,511 people "talking about this," (i.e., the number of people who interacted directly with the campaign by posting questions or re-posting/tweeting content) and a "viral reach" of 26,973 people (i.e., of the people "talking about this," the "viral reach" is the total number of their friends and followers who saw their activity). A YouTube video embedded in the Facebook conversation received 920 views.

10.2 Comparing Recruitment Strategies

Comparing these three methods of recruitment, we can see that the international press release and the social networking campaign resulted in similarly sized download spikes (see Figure 10.2). This suggests that the Facebook campaign was just as effective at recruiting new users as the traditional press campaign.

The participation day, which was aimed primarily at encouraging data collection, not new user recruitment, did not result in a download spike. However, as can be seen in Figure 10.3, the participation day was very successful in increasing report submissions from users. By comparison, the social networking campaign resulted in very little increase in report submissions. This suggests that if data collection is the goal, focusing on new users may be less useful than encouraging existing users.

These experiences with promoting Creek Watch and with social network integration in the App indicate that these were successful ways to get the word out about the project, and they

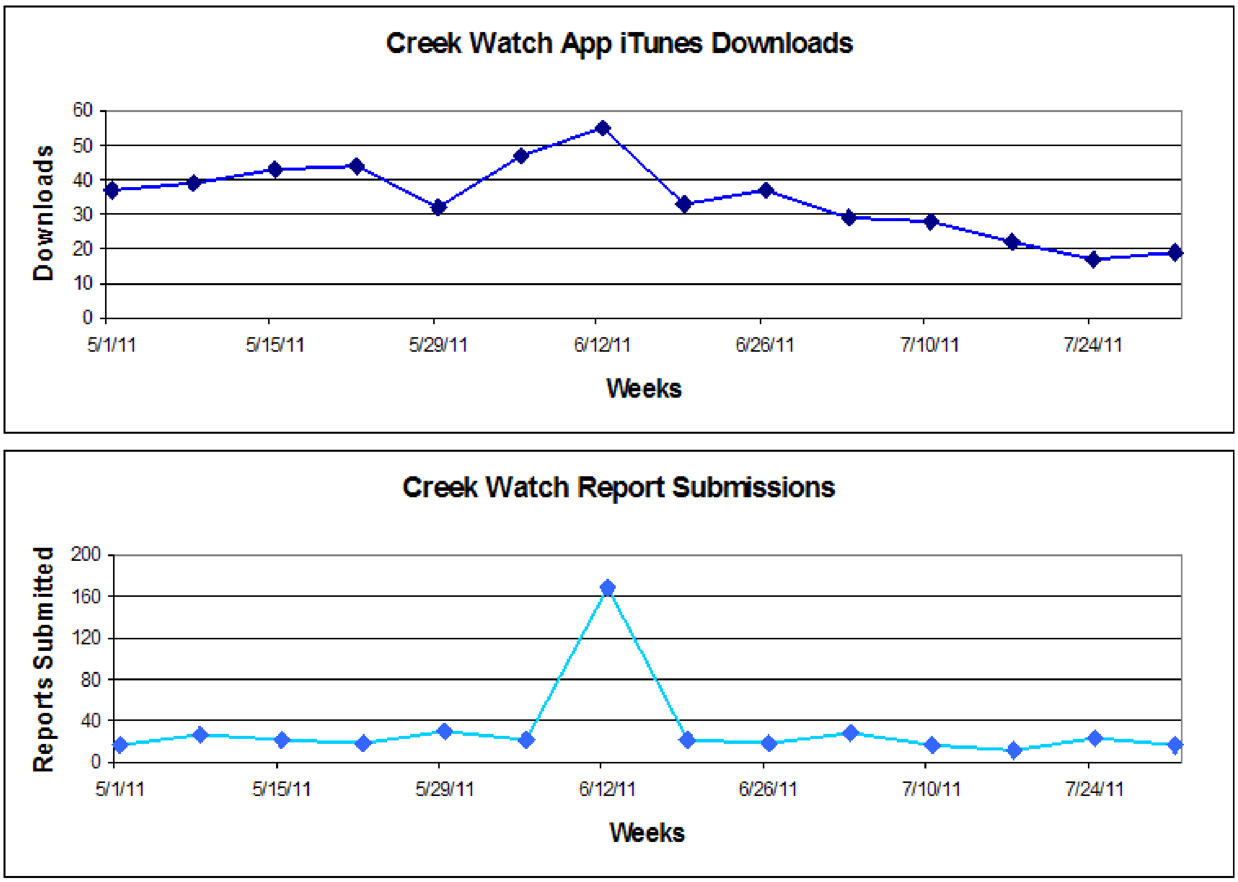


Figure 10.1: Downloads and report submissions during Creek Watch Snapshot Day on June 16, 2011.

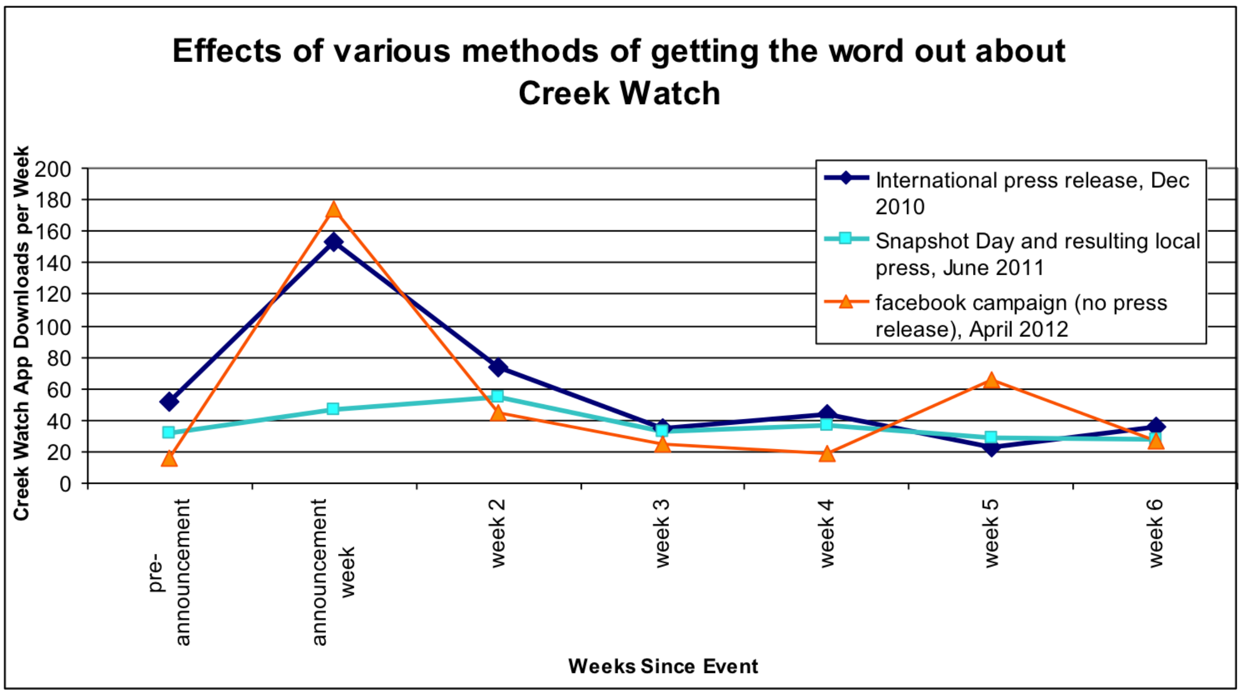


Figure 10.2: iTunes App downloads of Creek Watch during three different campaigns, each spaced months apart, are overlaid based on start date to show relative effects.

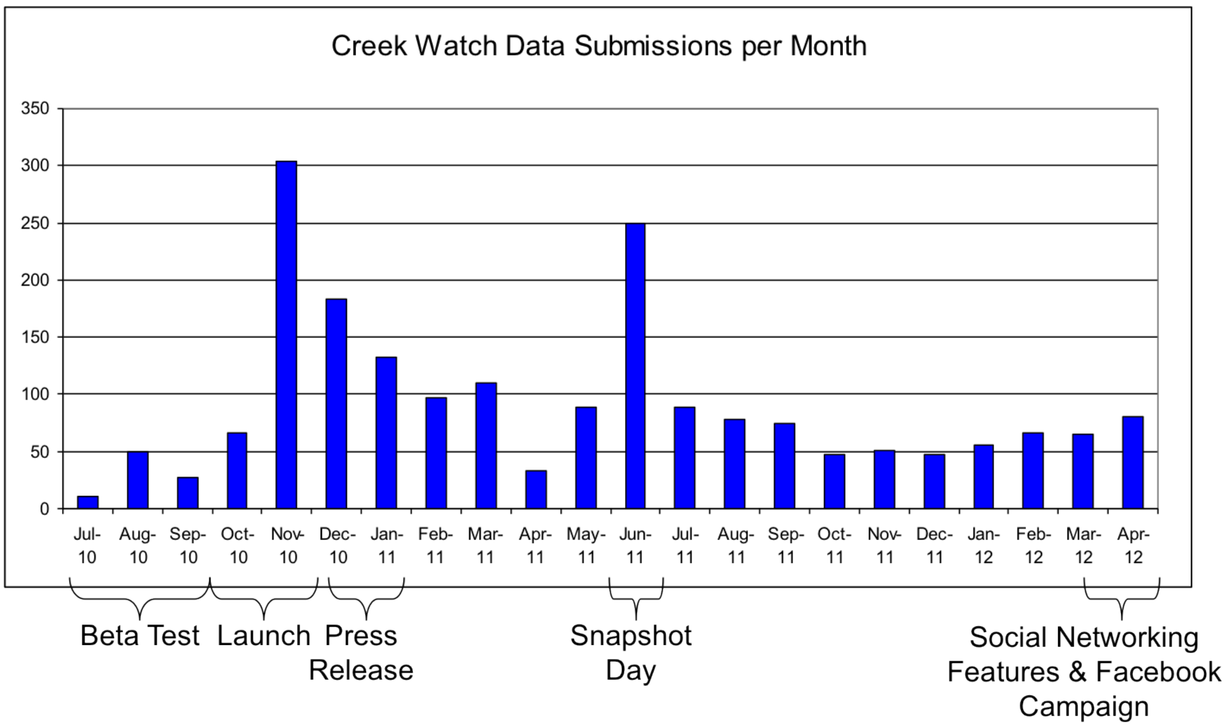


Figure 10.3: Creek Watch report submissions over time.

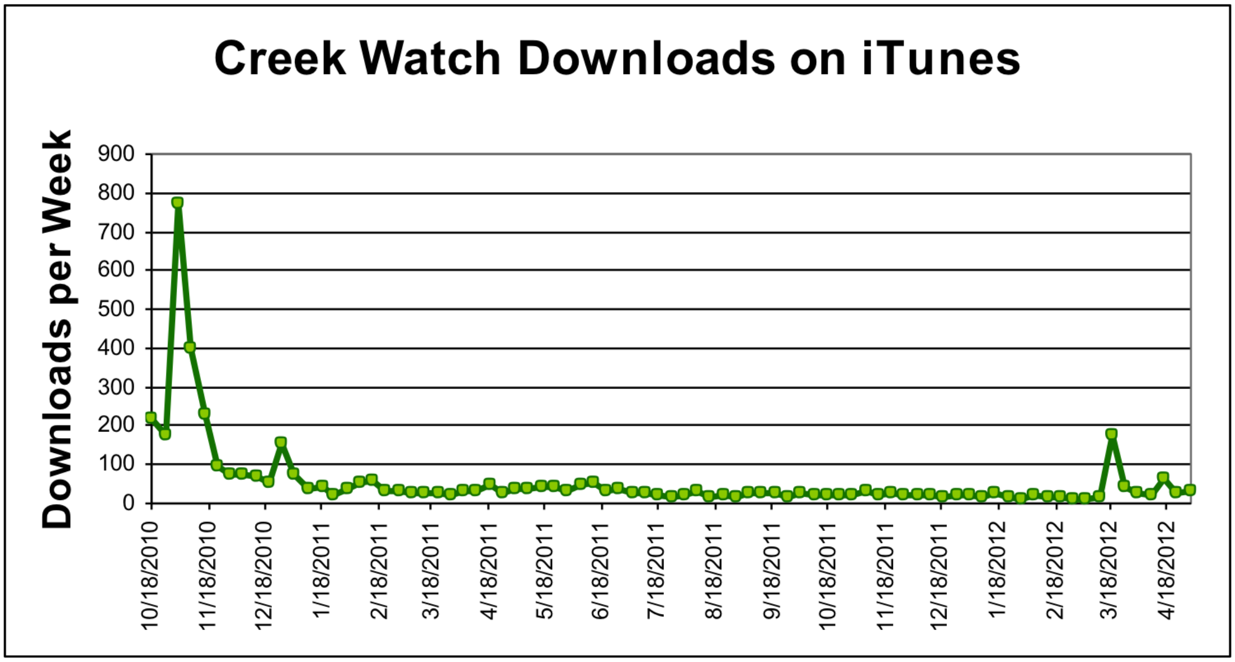


Figure 10.4: Creek Watch downloads over time.

show potential for increasing the number of participants. However, these results are limited by the fact that the work applies to only one crowdsourced citizen science project. These results are also limited by timing effects, in that these experiments were conducted over the course of 14 months—a very long time on the Internet. Changing interest in mobile apps and crowdsourcing during this time would have affected the results. Other news stories or events taking place during our campaigns would also have affected the results. Thus, while the data from campaigns, improvements, and surveys seems compelling, the possibility remains that the results are due to other factors beyond our control.

That said, we are able to conclude that, in the case of Creek Watch, a social networking campaign was just as successful at recruiting participants as an international press release, and more successful than a participation campaign through existing communities. However, the participation campaign resulted in more data being collected (presumably by existing users) than either of the other campaigns.

Chapter 11

Discussion

This dissertation has explored challenges and opportunities in citizen science, focusing on observations and experiences from the design, deployment, and testing of a citizen science project, Creek Watch. In addition, we have reviewed the past and present history of citizen science and identified some useful strategies and lessons from other projects:

- Partnerships between organizations that have established connections to scientists and authorities, and experienced technology groups, can be useful.

- Competitions, games, and other social incentives can encourage users, but be aware of data quality issues stemming from gaming the system.

- Consider human factors such as sampling bias and interference with the natural environment.

- User training improves data quality, particularly when conducted in person, but trained volunteers cannot replace experts for some difficult tasks.

- Provide open data tools to give everyone access to real-time data with interactive visualizations.

These realizations helped guide the evolution of Creek Watch. By employing user-centered iterative design in collaboration with scientists who need the data, we built Creek Watch to collect data that is useful to scientists and water authorities, while still being usable by untrained novices (Chapter 5). User studies with scientists and data collectors validated the design as both usable and useful (Chapter 6). Furthermore, this work has provided the following lessons:

- When HCI methods are applied to the data as well as the interface, the resulting system can collect more useful data.

- Providing reliable and standardized data enables organizations beyond initial stakeholders to benefit from the data in unanticipated ways; for example, field agents use the data to identify trash cleanup sites and have adopted the App as a data collection tool.
- Plant "seed" data as an example to users, as new users make use of sample data to validate their collection practices.
- Combine captured data that organizations can use immediately with data that provides long-term, aggregate value.

Our iterative design process and contextual inquiries with stakeholders also provided the following guidelines which were useful in the development of Creek Watch and which may apply directly to other projects:

- Design citizen science projects to appeal to existing communities.
- Discuss the design with as wide a variety of groups as possible and design for data sharing, using established standards whenever possible.
- Explicitly encourage the reporting of negative data.
- Collect only data that citizen scientists can reliably gather; avoiding anything requiring complicated measurements.

The deployment of Creek Watch provided several lessons in launching an international citizen science mobile App (Chapter 7). Subsequent versions of the iPhone App solved emergent problems with data quality by providing international translations, an instructional walk-through, and a confirmation screen for first-time submissions. Based on the deployment, we can suggest the following guidelines:

- Enabling users to test the data submission process reduces the amount of "bad" test data submitted by first-time users.
- If making a project available worldwide, provide international translations with clear instructions.

The trial of a feature which allows users to post Creek Watch observations automatically to Facebook or Twitter met with limited success. Use of this feature and a survey of its use suggest that posting to social networks can raise awareness, and that Facebook but not Twitter posts lead to more sign ups. However, the low adoption rate of this feature, combined with the fact that many users stated they were unwilling to use this feature but willing to "like" Creek Watch on Facebook, suggests that developing a Facebook community may be more useful than adding a feature to post to Facebook and Twitter automatically (Chapter 9).

This dissertation further examined how social networks can be used to recruit and promote a crowdsourced citizen science project. Recruiting through social networks was found to be just as successful at increasing user sign ups as recruiting through traditional media channels (press releases and news stories), and more successful than a participation campaign. However, a participation campaign through local organizations was more successful at increasing data submissions (Chapter 10). This suggests that if project awareness and sign-ups are a primary goal, a Facebook and Twitter campaign may be effective.

- Social networks can be useful for raising project awareness; however, developing a community page may be more useful than integrating data collection with users' microblogging streams.
- A Facebook and Twitter campaign can be just as effective at recruiting new users as press releases and news coverage.
- A participation campaign through local groups can be an effective means of increasing participation among existing users.

This dissertation work is limited in several ways. While these lessons are hopefully applicable to other citizen science projects, the work is based primarily on a single case study. The conclusions drawn from this work are necessarily situation dependent, and the lessons may not apply in other situations. In addition, many of the technologies explored in this work, particularly social networks and mobile technology, are in a state of rapid change. While these lessons apply today for this project, the changes to and the changing use of these technologies means that many of these lessons may soon be obsolete. Nonetheless, it is the author's hope that this dissertation contains lessons that are specific enough to be used presently, as well as lessons general enough to be relevant as technology changes.

11.1 Future Work

How best to build a Citizen Science project remains an open question. This dissertation suggests some directions for future research that may build upon this work.

As mentioned in Section 5.3.2, we seriously considered adding competitive aspects to Creek Watch or turning it into a game. The success of Luis von Ahn and others in building games with a purpose makes an appealing case for encouraging users with game mechanics [158] and eBird's ranking competition demonstrates that game aspects can also work in citizen science applications [57]. We were unable to pursue this avenue of research due to our partner's concerns about data integrity. However, this was based on an assumption that users might try to "game the system" and submit erroneous data reports, and that competition would encourage this behavior.

While there is ample evidence that gamers will “game the system” given the opportunity, gamification should not be completely discarded. There may be a way to add competition or game features to citizen science projects without introducing bad data. Or, there may be ways to identify and remove the type of bad data introduced by gamification. This is an interesting and useful avenue for future research.

Another feature which we would have liked to include in Creek Watch was informing users of the name of the creek they were surveying. While this is readily possible for roadways, landmarks, and businesses through geocoding APIs such as the Google Maps API [73], there is currently no API for most landmarks, including waterways. Discussions with the EPA and the United States Geographical Society suggested that there are serious technical barriers to this data becoming available. While cartographers have made some very detailed maps which are now available digitally as huge vector-based GIS databases, a reverse lookup by latitude and longitude location is difficult. Solving this challenge would worthwhile with applications far beyond Citizen Science.

Another area of research that would be helpful is in image recognition. Techniques for processing digital photographs are improving rapidly, however it is not possible today to take a photo of a creek and automatically determine flow rate and count trash. If this technology were available, every photo taken by a waterway could become a data point for water monitoring.

Looking beyond water monitoring, image recognition technology could be developed to identify trash, invasive species, and other things which citizen scientists expend effort finding and identifying. As the number of photos taken by phones around the world increases exponentially, there is great potential to use these images for citizen science, even if the photographer did not take the photo with a scientific purpose in mind.

11.2 Conclusion

There are a myriad of factors in the design of a citizen science project, and each situation necessitates a unique approach to the problem. While there is no single path to success, it is hoped that lessons from this dissertation work will inform decisions and provide guidance to the community of computer science researchers, scientists, and volunteer coordinators who are working to engage citizen scientists in mobile crowdsourcing projects.

Appendix A

Creek Watch Technical Details

Developing Creek Watch was done in two parallel parts, as it consists of two connected systems, an iPhone App and a server.

A.1 iPhone App Development

Apple iPhone development is a very restricted and regulated process. The Creek Watch iPhone App was therefore developed using the standard steps and tools, which are enumerated here as a guideline for other citizen science iPhone App developers:

1. Join the Apple iOS Developer Program, as either an individual ($99/year) [8], or a company ($299/year) [9].
2. Download Xcode, the Apple-authored development environment for iOS (must be done on a Mac) [14].
3. Download and install the latest version of the iOS SDK [7].
4. Write the App (see upcoming Section A.2 for further details).
5. Using the Provisioning Portal [12], create a unique App ID.
6. Create a Distribution Certificate in the Provisioning Portal [12] and use it to sign your App.
7. Using Xcode [14], create an Archive of the App (the final bundle of files to upload).
8. Create an App profile on iTunes Connect [11] with the following items:
    - The App Archive
    - A description of the App in 700 characters or less

- Screenshots of the App—at least one, with up to four secondary screen shots
- An icon for your App, in sizes 57 x 57 pixels, 72 x 72 pixels, and 114 x 114 pixels (the larger sizes are technically optional, but are used for retina displays)
- iTunes artwork, 512 x 512 pixels or 1024 x 1024 pixels (the larger size is technically optional, but is used for retina displays)
- Optionally, additional versions of the above materials for each language in which the App is available (for Creek Watch, this was six languages).

9. Submit the App to Apple for review using iTunes Connect [11].

10. When your App has been approved by Apple, it will appear in the iTunes store [10], available for download.

Developers are advised to expect little communication with the Apple iTunes review team. It is typical for an App to wait in queue for several days or weeks before being reviewed. In the case of Creek Watch, we waited over a week for the first release, only two days for the second update, and nearly two weeks for the third update. The only communications we received from Apple during the process were automated emails stating that the App had been received, was entering review, and (moments later) had been approved.

A.2 iPhone App Code Architecture

The Creek Watch iPhone App is a custom-built application in Objective-C [13], designed in Xcode [14]. The architecture is illustrated in Figures A.1 through A.4. As with many iPhone App's, the bulk of the code is used to control the UI. This is done through a View Controller, which creates and sets frames and UI objects (Figures A.2 and A.3).

The App uses the following open source SDKs: JSON [88], Facebook [62], and Twitter +OAuth [69]. JSON is used as the data interchange format between the App and the Creek Watch server. The Facebook and Twitter +OAuth packages are used to enable users to post Creek Watch observations to their personal Facebook page or Twitter feed.

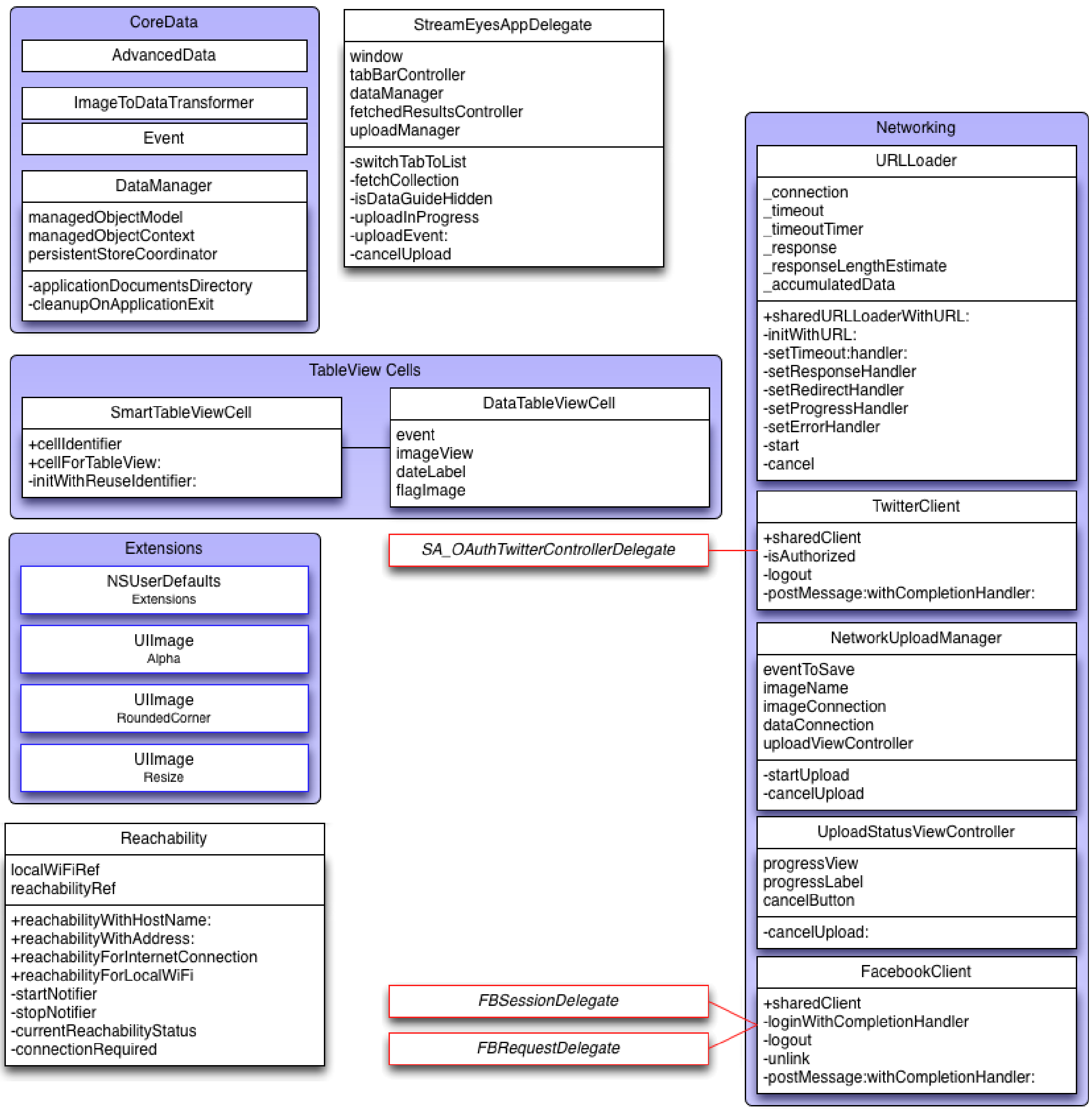


Figure A.1: Creek Watch iPhone App code architecture. Diagram continues in Figures A.2 and A.3, the view controllers, Figure A.4, the Twitter +OAuth API, Figure A.5, the JSON package, and Figure A.6, the Facebook API.

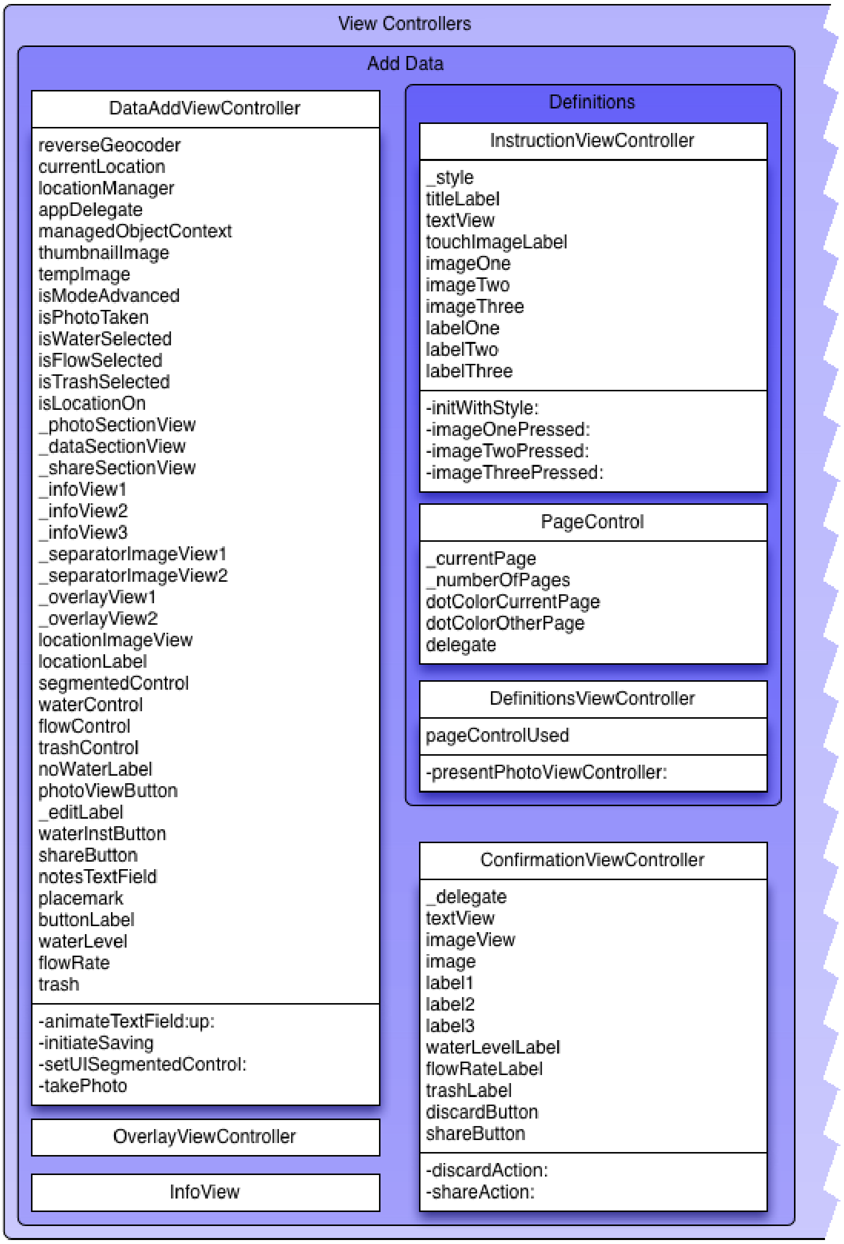


Figure A.2: Creek Watch iPhone App code architecture, continued from Figure A.1. This shows components of the View Controller, which makes the UI for the App. Continues in Figure A.3.

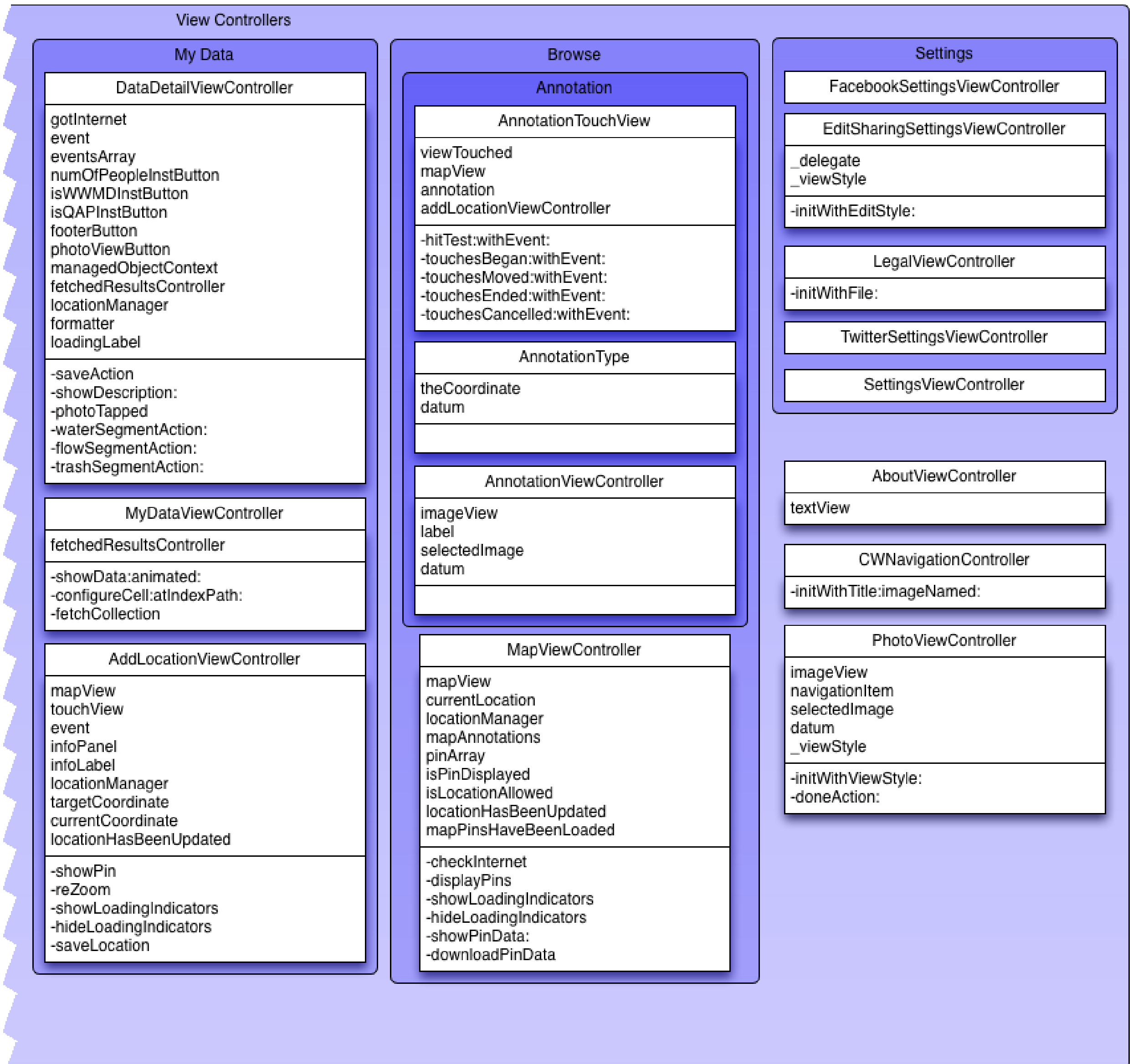


Figure A.3: Creek Watch iPhone App code architecture, continued from Figure A.1. This shows remaining components of the View Controller, which makes the UI for the App (continuation of Figure A.3).

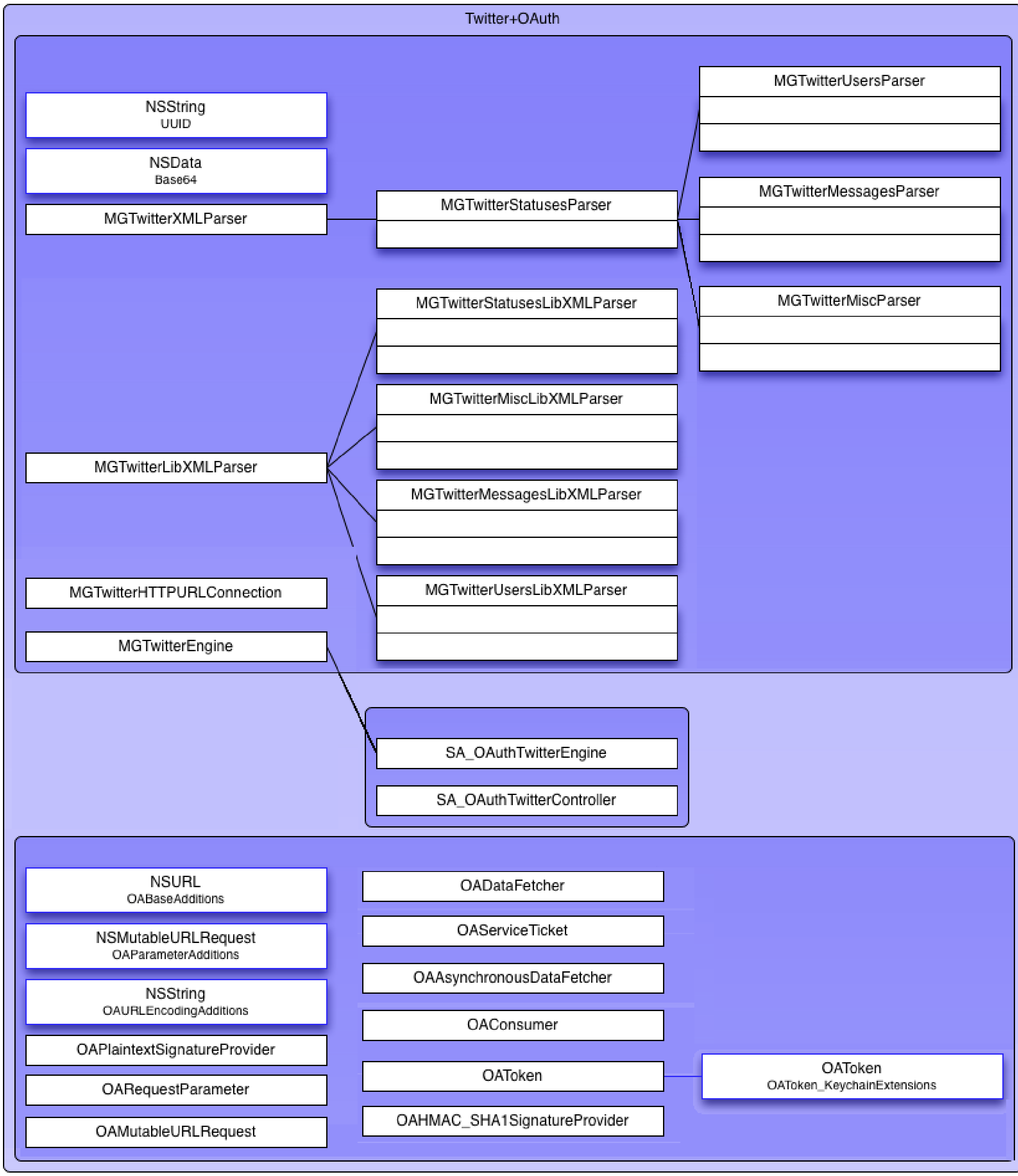


Figure A.4: Creek Watch iPhone App code architecture, continued from Figure A.1. This shows the Twitter +OAuth API used for enabling users to post Creek Watch observations to Twitter.

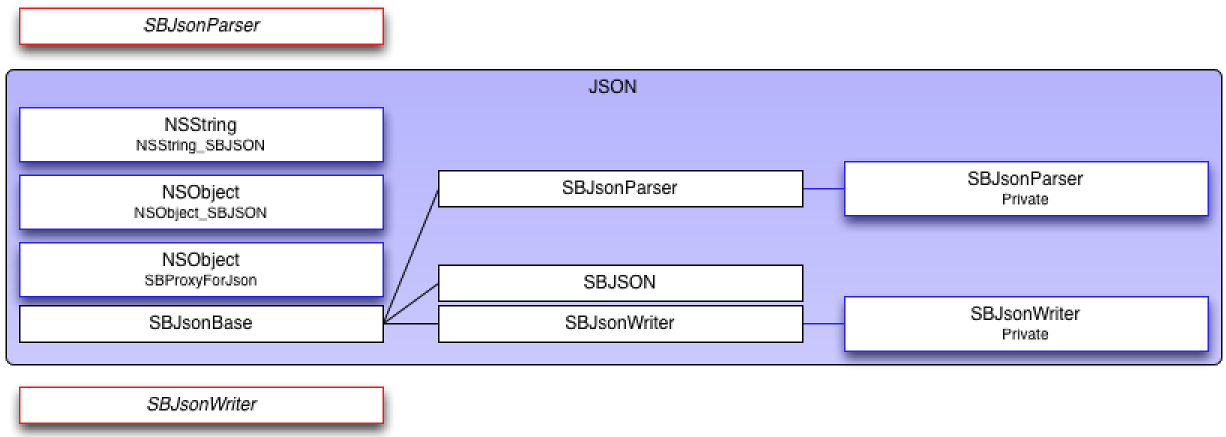


Figure A.5: Creek Watch iPhone App code architecture, continued from Figure A.1. This shows the JSON API used for communicating with the Creek Watch server.

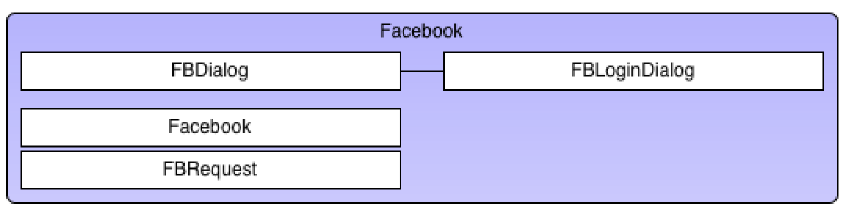


Figure A.6: Creek Watch iPhone App code architecture, continued from Figure A.1. This shows the Facebook API used for enabling users to post Creek Watch observations to Facebook.

A.3 iPhone App Operation

The core functionality of the Creek Watch App is report submission. Therefore, the first screen users see when opening the App is the report submission screen. If a user has not yet submitted a report (first-time users), the user is taken on a guided walk-through of the report submission process. Screenshots from this walk-through can be seen in Figure A.7. Subsequent report submissions skip this walk-through, but the explanation of how to submit a report, with definitions for each of the terms, remains available. Screenshots of report submission and the definitions screens are shown in Figure A.8. Users can also look at recently submitted data points by them and others, as shown in Figure A.9. Figure A.9 also contains screenshots of the settings pages, where users can update Twitter and Facebook sharing settings, view the legal document to which they agreed when downloading the App, and learn about the project.

Figure A.7: Creek Watch walk-through.

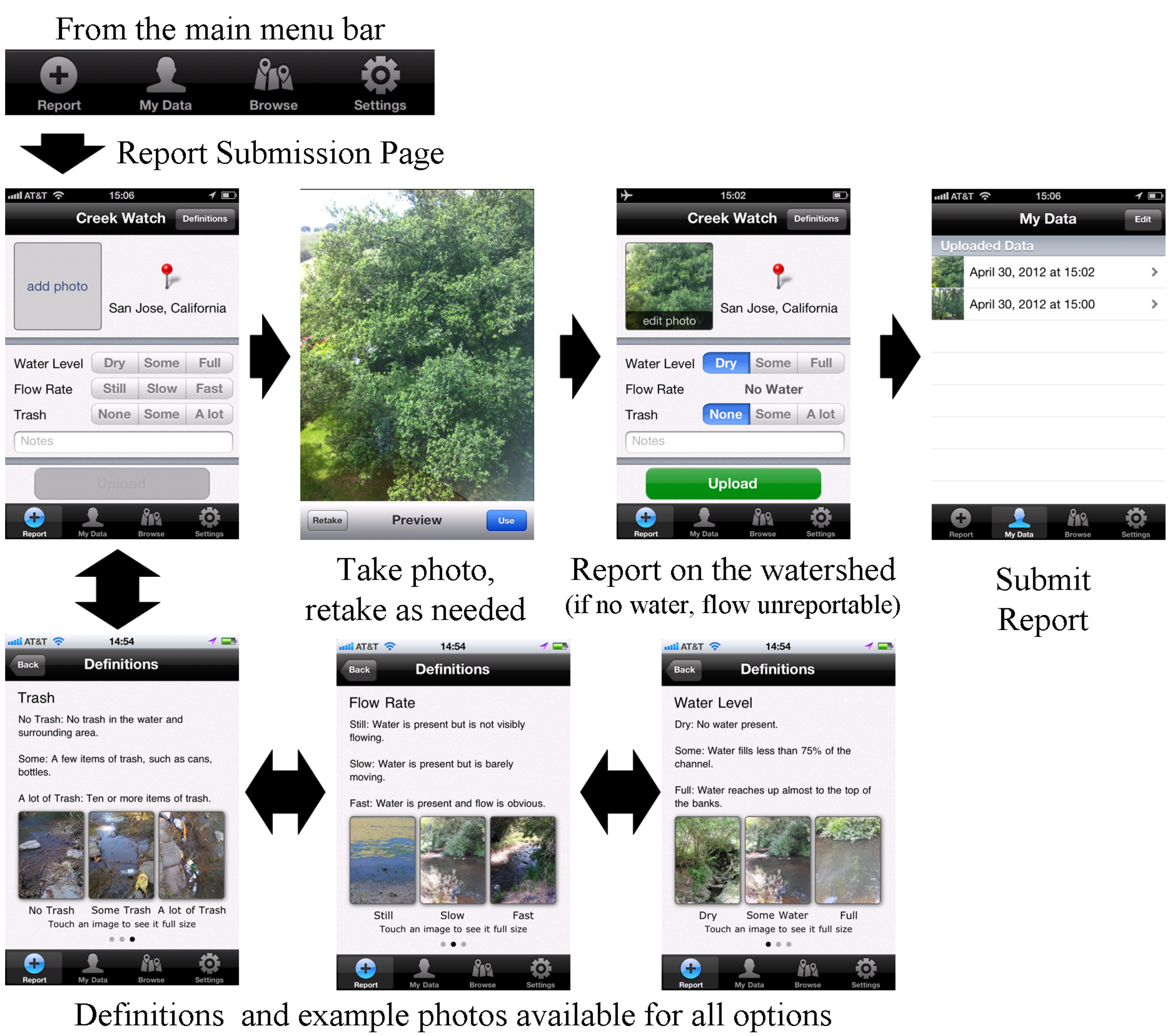


Figure A.8: Creek Watch walk-through.

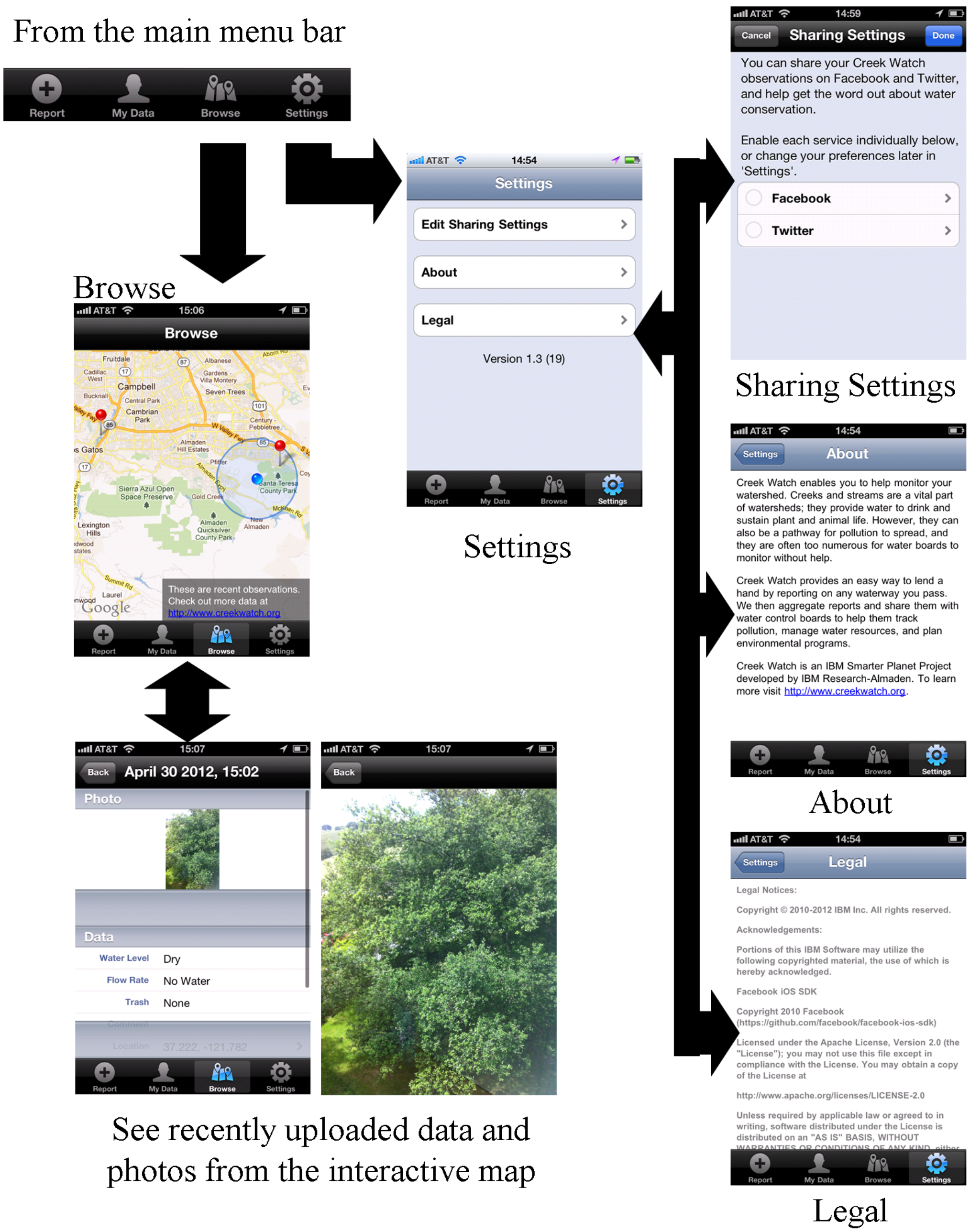


Figure A.9: Creek Watch walk-through.

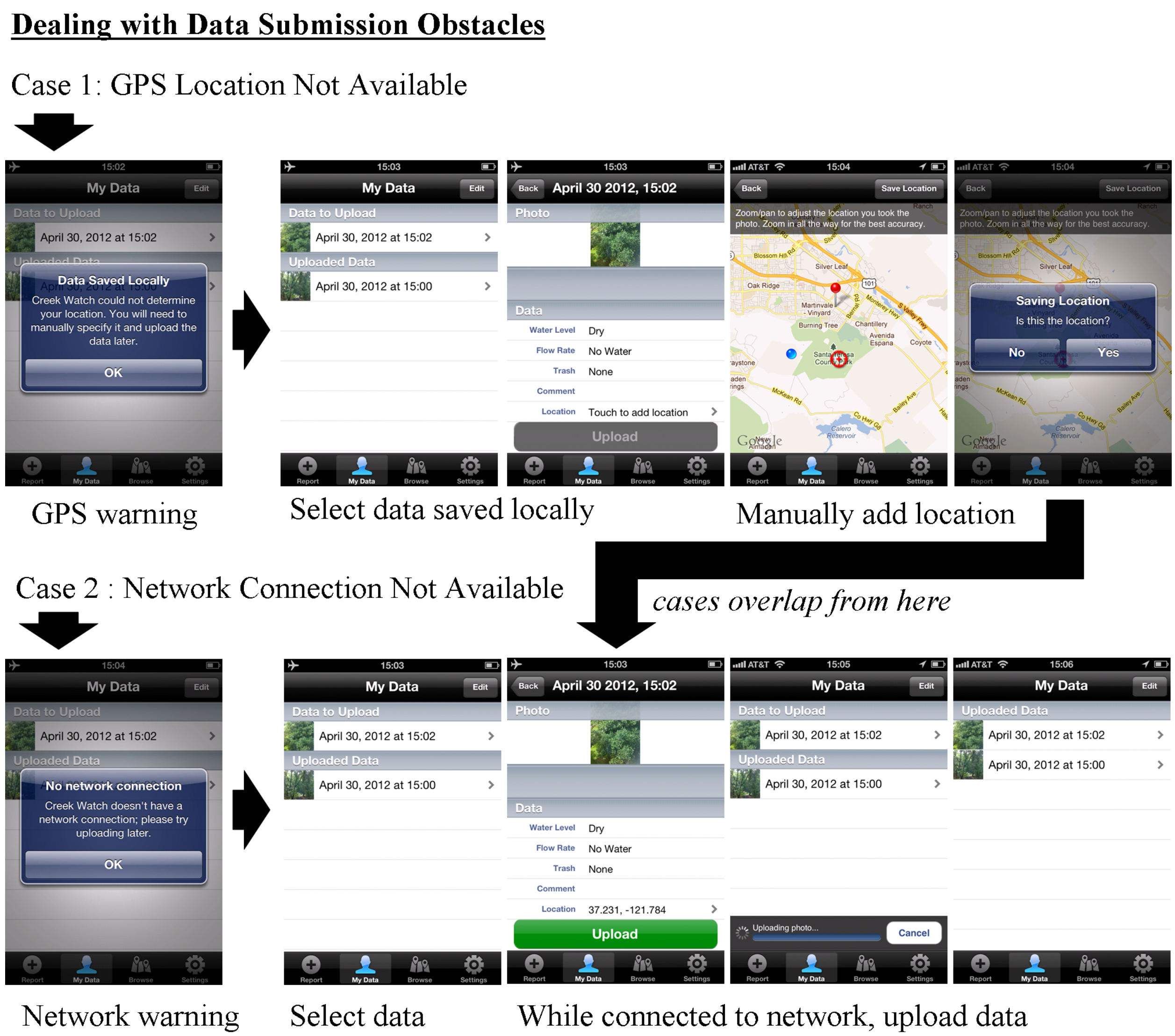


Figure A.10: Creek Watch walk-through.

A.4 Communication Protocols

Creek Watch uses JSON [88] as a data-interchange format for the App to communicate with the server, and for passing serverside objects between the website and the back end.

A.4.1 Sending Data from App to Server

The following data in Table A.4.1 is sent to the server by the Creek Watch App, as JSON object.

sent parameter	description
report ID	a random hash unique[1] to this data point
userid	a random, not personally identifiable hash unique[2] to instance
creation date	time stamp from moment photo was taken
latitude	observation location
longitude	observation location
image	a url to the image on the filesystem
water level	value {0,1,2} for {none, some, full}
flow rate	value {-1,0,1,2} for {no water, no flow, slow, fast}
trash volume	value {0,1,2} for {none, some, a lot}
Facebook key	used to to link to the data point from Facebook
Twitter key	used to to link to the data point from Twitter

Table A.1: JSON parameters returned sent to the server by the Creek Watch App (names of actual parameters obscured for security).

The report ID on the iPhone App side is checked for uniqueness locally only. A new key is generated on the server as the database entry ID for each report submitted.

The userid is a 12 character ID which is probabilistically unique but not actually checked against a list of user ID's on the server, as that would require a data connection at the time the App is first run—an assumption we do not make.

A.4.2 Requesting Data Points from Server

The following JSON object is requested by both the App, for use in the map of nearby data points, and also by the web page for plotting data on the interactive map (see Table A.2 for query and Table A.3 for response).

request parameter	description
latitude	of center of where data is being requested
longitude	of center of where data is being requested
radius	within this distance in miles from the location specified
max data age	optional; limits the number of days to retrieve data from (recent first)
max data points	optional; limits to a set number of data points (recent first)

Table A.2: JSON parameters of the data request function (names of actual parameters obscured for security).

response parameter	description
latitude	observation location
longitude	observation location
image	a URL to the image on the file system
creation date	date of observation
insert date	date of entry into Creek Watch server
water level	value {0,1,2} for {none, some, full}
flow rate	value {-1,0,1,2} for {no water, no flow, slow, fast}
trash volume	value {0,1,2} for {none, some, a lot}

Table A.3: JSON parameters returned by the server in response to the data request function (names of actual parameters obscured for security).

A.5 Cloud Server Architecture and API's Used

The Creek Watch server receives and stores data from the Creek Watch App, and hosts creekwatch.org, where the data is publicly accessible. The server is a cloud machine with a LAMP stack, that is, a virtual machine running Linux, Apache, MySQL, and PHP. It is located on the IBM Research Labs cloud.

Most of the server code is written in PHP [148], including the above data submission and requesting services. The index page of creekwatch.org, which features an interactive map of all the Creek Watch data points, was developed in Javascript, and uses the Google maps API [72]. A code diagram of the server can be seen in Figure A.11, including the back-end PHP files and the front-end HTML files.

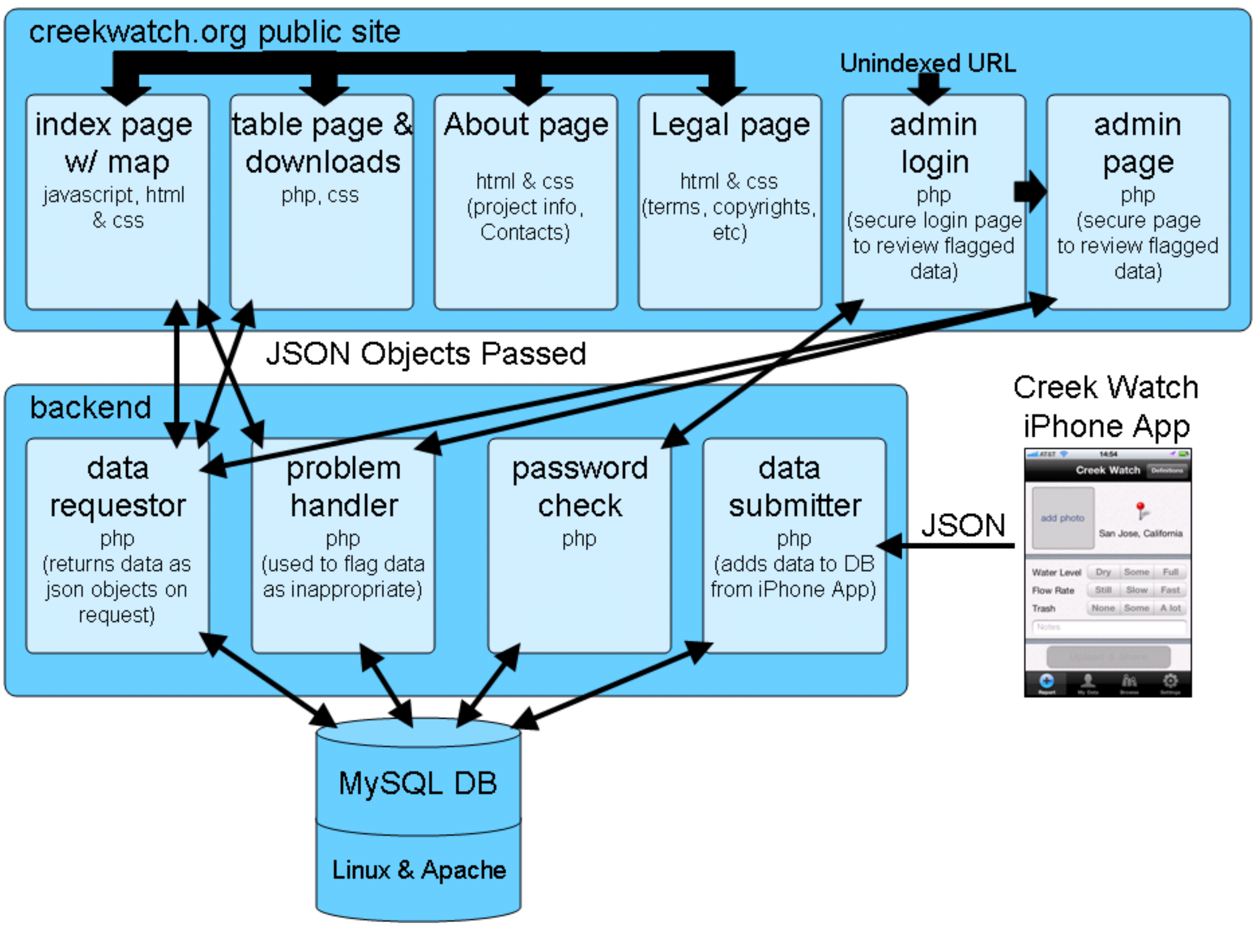


Figure A.11: Creek Watch server diagram (names of actual files obscured for security)

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