CITIZEN SCIENCE:
THEORY AND PRACTICE

Integrating Citizen Science into the Work of United States Environmental Agencies

SPECIAL COLLECTION:
LAW

CASE STUDIES

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ubiquity press

ABSTRACT

Citizen scientists in the United States (US) gather data on a wide range of environmental conditions. Environmental agencies, however, have a mixed record when it comes to capitalizing on the resource that this information represents. In 2020, the Environmental Law Institute (ELI), on behalf of the US Environmental Protection Agency, examined how citizen science was being used or supported by environmental agencies in states, tribes, and local governments in the US. This article summarizes and builds on that research to assess progress to date. It concludes that there is significant use by agencies of citizen-generated data on water quality, but much more limited use in other fields. This is particularly true for air quality data, where the technology for private data collection is much more recent. ELI called on agencies to be more proactive in exploring the value of citizen science data, and in providing leadership to help agencies build on each other's experiences. It is of interest that these recommendations are similar to recommendations also made in 2020 by the staff of the European Commission. Another important conclusion in ELI's recommendations is that agencies should see citizen science as an important tool in addressing environmental justice concerns.

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KEYWORDS:

citizen science and government; citizen science and policy; environmental justice; air monitoring technology

TO CITE THIS ARTICLE:

Wyeth, G. 2023. Integrating Citizen Science into the Work of United States Environmental Agencies. *Citizen Science: Theory and Practice,* 8(1): 11, pp. 1–12. DOI: https://doi.org/10.5334/cstp.490

INTRODUCTION

Government agencies have been aware of the emergence of citizen science from its beginning and have used the contributions of members of the public extensively in areas such as water quality monitoring and wildlife management. However, in many respects citizen science still has only limited or sporadic impact on government decisions and actions.

This article seeks to illustrate for a wider audience how citizen science is being integrated into government agency programs in the United States (US), and how agencies are supporting independent citizen science efforts for mutual benefit. It summarizes and builds on research conducted in 2020 by the Environmental Law Institute (ELI) at the request of the US Environmental Protection Agency (EPA). That research illustrates how US state, tribal and local agencies are working with citizen scientists. ELI's research is contained in three reports:

1. A set of case studies (ELI 2020a)
2. A summary of best practices (ELI 2020b)
3. Recommendations (ELI 2020c)

The article draws highlights from these reports, and builds on them to show potential ways of accelerating the pace at which citizen science can have an impact on environmental policy and programs. It also compares those conclusions with recommendations that were made at almost the same time by the staff of the European Commission (EC) (European Commission 2020), finding some striking parallels that suggest a common path forward. Finally, it reports on recent developments at the US EPA toward greater adoption of citizen science as a strategy for environmental protection.

The article uses the term "citizen science" throughout as a broadly applicable descriptive term. In some contexts, particularly where projects are initiated by members of environmental justice communities, the term "community science" is more appropriate and will be used instead. The US EPA now uses the term "participatory science," so that term appears when discussing some EPA documents.

BACKGROUND

The research summarized here was not EPA's (or ELI's) first involvement with citizen science. The public has played a role in monitoring water quality in some states since the 1990s, (Overdevest et al. 2004; ELI 2020a) and EPA's Office of Research and Development has studied emerging technology such as sensors for assessing air pollution to help the public understand and take advantage of those devices (US EPA [undated]).

Other developments have occurred on a government-wide basis in the US, most notably the enactment of the Crowdsourcing and Citizen Science Act of 2016, the formation of an interagency community of practice (Citizenscience.gov undated), and the adoption of agency policies such as the Citizen Science Strategy issued by the National Oceanic and Atmospheric Administration (NOAA) (NOAA 2021).

EPA first began looking at citizen science in a strategic way in 2016, when a report was issued by its National Advisory Committee on Environmental Policy and Technology (NACEPT). The report concluded that it was time for EPA to actively "embrace citizen science as a core tenet of environmental protection," integrating it into the full range of its work (US EPA 2016). However, NACEPT is an advisory group made up of a diverse and balanced set of stakeholders, and its recommendations are not binding on the agency. Thus, the report informed the Agency's thinking but did not itself make policy.

EPA's Inspector General also looked into the possible role of citizen science in the work of the agency, concluding that "EPA needs a comprehensive vision and strategy for citizen science that aligns with its strategic objectives on public participation." (US EPA 2018). In response to this recommendation, in 2022 EPA, released its official statement of "vision and principles" for participatory science (US EPA 2022). That document provides a high-level strategy, framed by three core principles: good science, community involvement, and informed decisions.

As a way of finding more specific, tangible models that might be adopted, EPA's Office of Research and Development contracted with ELI in 2020 to study how citizen science is already being used, or supported, by environmental agencies in the states, tribes, and local governments.

To understand why EPA focused on states, it is important to describe the role of states in the US system of environmental protection. That system is built largely around a set of national environmental statutes, governing discrete environmental concerns, such as the Clean Air Act, the Clean Water Act, and other laws such as those regulating chemicals, pesticides, and hazardous waste. In this structure, much regulatory authority is delegated to the states. The laws ensure a substantial degree of uniformity, but states do not report to EPA, do not have to adopt the same rules or policies, and have a great deal of discretion in implementation (Rabe 2010).

As a result, states are often a source of innovation in environmental policy. With more limited resources, and closer to the people and problems in the field, states have incentives to experiment with new ways of achieving their goals. Not all do—some explicitly adopt a policy of doing the minimum required by federal law and no more—but some actively pursue new approaches.

The potential for members of the general public to gather environmental data presents states with many opportunities for innovation. Over time, states found that publicly generated data could be a resource to draw on. The purpose of ELI's research was to find out what they did with this opportunity, and what lessons that experience might have for EPA and for other states.

ELI's research involved, first, online research to survey as many citizen science initiatives as possible, from which to select those in which agencies had a significant role. After the most relevant projects were selected, case studies were carried out in which program participants were interviewed (including both agency officials and non-agency participants) and materials were reviewed. When initial drafts of the case studies were complete, three 90-minute online conversations were conducted with a variety of project participants as well as with other experts in the field, to help in drawing the most important findings from the research.

This article summarizes the findings of that research and builds on it to highlight findings and actions that could enhance the role of citizen science.

Four parts follow:

1. A summary of the case studies, broken down by policy topics
2. Overarching patterns
3. Recommendations to EPA and other agencies
4. The path forward

CASE STUDIES BY POLICY TOPIC

ELI carried out a total of fifteen case studies, across the following policy arenas:

1. Water quality
   a. Surface water monitoring
   b. Wetlands assessment
   c. Harmful algal blooms
2. Air quality
3. Enforcement

It is important to note that because the research was commissioned by the US EPA, it did not study the use of citizen science as a tool for management of wildlife and other natural resources (which does not fall under EPA's purview). EPA primarily focuses on reducing pollution; other agencies such as the Department of the Interior and its state equivalents address issues such as biodiversity and endangered species.

WATER QUALITY MONITORING

Environmental data gathering by private citizens has its longest history, and is most advanced, in monitoring water quality in surface waters such as rivers, lakes, and streams. Some state environmental agencies have worked with members of the public for up to two decades to monitor surface water quality (ELI 2020a).

Under the US Clean Water Act, states are required to assess and report on the level of pollution in their water bodies. However, monitoring is resource intensive and exceeds what most states are able to do themselves. Therefore, EPA's regulations permit—indeed, require—states to consider all readily available data when developing these reports, including data from outside sources (ELI 2020a).

The case studies illustrate how many states have gone further and actively recruit private citizens and local environmental groups to help with water monitoring. (ELI 2020a). These groups can take samples, and have them analyzed in certified laboratories, in the same way as agency monitoring staff do. If the proper technical protocols are followed, data obtained through volunteer monitors can be considered equivalent to agency-gathered data in determining whether rivers, lakes, and streams meet standards.

Volunteer water monitoring programs date to the 1990s and have spread to many states. Although a precise count is not available, at least half of the states appear to use the work of citizen scientists to a significant extent. States provide support for volunteer monitors in a variety of ways, such as:

- training for volunteers;
- technical assistance, such as protocols for data collection;
- providing sampling equipment;
- field audits to ensure good practices are being followed;
- access to accredited laboratories for data analysis;
- tools to facilitate data submission; and
- funding through small grants.

These state programs vary considerably in their design and approach. The best established have large networks of volunteers, either overseen directly by agency staff, or working through independent nongovernmental watershed groups. For example, Virginia's Citizen Water

Quality Monitoring Program reported in 2018 that almost 1,300 volunteers from 140 organizations provided data on over 3,600 stream miles and 29,800 acres of lakes. The state estimates the monetary value of this effort, in terms of what it would have cost the state to do the same monitoring, at $ 3.25 million annually. Over 20% of the data in the state's official water quality report under the Clean Water Act comes from non-agency volunteers (Virginia Department of Environmental Quality, 2018).

Arizona's Water Watch Program provides a different model. It is newer, having been launched in 2017, and relies heavily on apps and other technology to help volunteers collect and report data. Its apps vary in sophistication from very simple tools for untrained volunteers to advanced versions for experienced teams. Even tourists can submit information using these tools. More sophisticated apps provide volunteers with detailed information, as well as a platform for submitting water quality data (ELI 2020a).

While the primary use of data from these programs is to help the state assess water quality, the data can be used for other purposes as well. Michigan, for example, makes its data available to the public online, which is of interest to local residents, tourists, and even potential buyers of lakefront property. The data can also be used by other state agencies (ELI 2020a).

Some states without organized volunteer programs still solicit or facilitate the use of citizen-generated data. Some issue annual or biennial data calls. Another approach is to create a portal for data submission by independently operating citizen organizations (Indiana Department of Environmental Management undated).

Enforcement is generally not a focus of citizen scientists gathering water quality data, but when watershed groups do discover evidence of violations (e.g., evidence of a sewage spill), they may refer the matter to an environmental agency. For their part, agencies generally prefer to gather their own evidence and not rely on information from others (ELI 2020a).

A critical issue in volunteer water monitoring programs is ensuring that data is valid enough to support regulatory and other agency decisions. To achieve this, some agencies provide detailed guidance to volunteers about data quality; they typically use a 3-tier structure that distinguishes between high-quality, mid-level, and low-level data, and they make it clear how data at each level can be used. The highest quality data is considered usable for regulatory assessments. Data at the second tier may be used by the state in highlighting areas that appear to warrant further investigation or enforcement action, or to prioritize its own monitoring work. Third tier data can still be useful, primarily to make the general public more aware of environmental concerns in a local water body, or for school groups; in those cases, noting the presence of a concern is sufficient even if the data are not precisely quantified (ELI 2020a).

Providing clear and explicit guidance on these data quality requirements is important for the citizen scientists because it helps them understand how their work may have an impact, and what they must do if they want their data to be used. It makes it more likely that volunteer time and effort is well spent, and that data collected through hard work is not discarded for lack of quality. States also prepare standard monitoring protocols called Quality Assurance Project Plans (QAPPs). Following these protocols is required for volunteer data to be considered acceptable by agencies.

OTHER USES OF CITIZEN SCIENCE FOR WATER RESOURCES

Citizen scientists also play a role on other important water-related issues.

Cyanobacteria blooms

Cyanobacteria are a widespread problem in the US. These bacteria can "bloom" in vast quantities, creating an unsightly surface scum and, more importantly, releasing toxins into the water. (These are often referred to as "algal blooms," although algae are not actually involved.) The toxins can kill fish, contaminate water supplies and make a lake or stream unsuitable for recreation (ELI 2020a).

Detecting cyanobacteria is difficult because the blooms occur locally across large areas and intermittently. Agency staff cannot routinely check every water body, so some agencies increasingly rely on reports from the public. Some states simply provide phone numbers, email addresses, or other channels for reporting, and publicize the need to the public. Around Lake Champlain, which lies between New York and Vermont, an organized monitoring program has been established using volunteers who check designated locations on a regular basis and send in their findings. Agencies review photos and other data to assess whether a cyanobacteria bloom appears to be present, and when it's appropriate, they post the finding on the web. Because Lake Champlain is a major hub for tourism, having current information available to the public is extremely valuable—regarding both where blooms are occurring and where the water quality is acceptable for recreation (ELI 2020a).

Wetland assessment

Volunteer data collection is also done to assess the health of wetlands. There is no federal mandate to submit data on wetlands; rather, the need for this information is driven by local concerns.

ELI's study focused on a well-established wetland health assessment program in Minnesota. Run at the county level, it operates much like a water monitoring program, with a small staff recruiting and training volunteers using professional quality protocols. The type of data gathered is different from water quality monitoring: rather than analyzing samples for pollutants, the researchers look for macroinvertebrates (such as insects and small crustaceans), and count the types of plant species that are present. Agency staff do not do sampling, but are available to address questions about species identification.

In contrast to water quality monitoring efforts, in which data is primarily used by the state agency for regulatory purposes, wetland data is used by a variety of parties, for differing reasons. Local governments are major users. Local residents also have a strong interest in the wetlands that are an amenity for them. Watershed associations use the data to measure progress on their own goals (ELI 2020a).

AIR QUALITY MONITORING

The case studies show that the role of citizen science is less developed with regard to monitoring air pollution. The primary reason is technology: whereas water quality sampling requires relatively simple technology that is within the capacity of non-governmental groups, air quality is monitored by agencies using extremely expensive and advanced equipment. Such devices are far beyond the financial capacity of most citizen organizations (ELI 2020a).

This changed when lower-cost air sensors became available, making it possible for citizens to test the quality of air in their own neighborhoods. This provided a new body of data that offers measurement on a much smaller and more granular scale than has been possible in the past.

However, the data from air sensors are not comparable to those from agency monitors. Readings are less precise and less reliable; similar devices may show wide variations in results (AAPCA 2020). As a result, agencies are generally not willing to accept such data or to use it in making major decisions, and are less certain about how publicly generated data can be used (Wyeth et al. 2019).

Therefore, air monitoring by the public generally takes place independently of government agencies and is not integrated into agency data collection efforts; ELI found no examples of air monitoring programs similar to the volunteer water programs described earlier. Air agencies are still at the early stages of learning how to take advantage of the information being brought to them by private citizens.

Moreover, in contrast to water quality, air quality issues often arise in the context of concerns by residents who are unhappy about their immediate conditions and are advocating for agencies to do more about those problems. The cases tend to involve conflict, rather than cooperation, between the residents gathering data and the agencies (Wyeth et al. 2019).

As a result, in contrast to water monitoring, where a fairly uniform model is used across many states, air quality citizen science projects were highly varied, and each represents a different approach.

The examples ELI found included the following:

Community air monitoring network

Imperial County, at the southern tip of California, is home to low-income, primarily Hispanic residents who are concerned about the generally high levels of air pollution in the area. Beginning in 2013, the community, working with academic advisors and a state agency, built a network of 40 local air monitors to supplement the state's relatively limited number of official monitoring stations. The community monitors were calibrated relative to official monitors, and data was displayed on a website operated by an advocacy organization (ELI 2020a).

In 2017, the Imperial Valley model was incorporated into state legislation on environmental justice, which required similar networks to be established in disadvantaged communities around the state (California Legislative Information 2017).

Air quality in an environmental justice community

One community in which that legislation was carried out is West Oakland. The West Oakland Environmental Indicators Project (WOEIP) is one of the best-established community air monitoring programs in the country. Founded in 1999, it has advocated for improving the environment of a low-income community impacted by a major port, highways, and other pollution sources. A major part of its work has been gathering data on air quality, on a local scale that agency monitoring networks can't reach. These decades of scientific work have built working relationships with government agencies and other key actors, which led to WOEIP co-leading the 2019 development of a comprehensive community emissions reduction plan (Bay Area Air Quality Management District 2019).

Support for community air toxics screening

A different approach was found in the State of New York, which provides monitoring equipment to local groups through a competitive grant program. Unlike most air monitoring projects, it focuses on toxic air pollutants (e.g., benzene), rather than particulates, and is designed to feed results to the agency. The program does not run continuously, but when resources are available, it selects community groups who are given tools for taking air samples, which are analyzed in a state laboratory. The results are not used directly in regulatory or environmental enforcement actions, but the agency uses them to identify possible areas of concern and to assess the effectiveness of its regulatory system.

Publicizing data from personal air sensors

Yet another approach is to create a platform through which the data being generated independently by air sensor owners can be made public. For example, the Puget Sound Clean Air Agency has created an online map that reports air monitoring data both from agency monitors and privately owned air sensors. The site pulls in data from every approved sensor in a four-county region, calibrating the data to improve its accuracy, and reporting both agency and private data together. The Community Science Station in Mecklenburg County, North Carolina, allows air sensor users to calibrate their devices with an agency-quality air monitor, and **then to** use their devices to gather data pursuant to an approved research plan. Resulting data must be shared with the state agency (Mecklenburg County undated).

Documenting offensive odors

A very different model does not involve the use of air sensors, but uses an app to facilitate reporting of direct personal observations of odors that might indicate an environmental problem. ELI's study highlighted a program in Pittsburgh, Pennsylvania, but other cities have similar systems. Odors can be fleeting, and unlikely to be captured by agency monitoring, so public reporting is extremely valuable.

ENFORCEMENT

A third set of case studies involved environmental enforcement. Law enforcement agencies have always relied to some extent on citizen complaints to identify potential violations. In the environmental arena, the emergence of new tools and the active engagement of the public in monitoring programs creates the potential for this practice to become more reliable and more institutionalized. In this context, reporting by members of the public fills gaps left by the difficulty of agencies in detecting violations, especially those involving short-lived events or remote locations.

Many citizen science initiatives may discover indications of violations by accident; for example, watershed groups carrying out routine water monitoring may discover sewage leaks or direct pollution discharges, and report these observations to the agency they work with (Kimura and Kinchy 2019). Occasionally, local groups concerned about air pollution from specific facilities have taken the step of gathering air quality data to show that pollution levels are unhealthy (Citizenscience.gov, undated)

.However, some agencies have begun using new technology to encourage public reporting in a more systematic way. These tools expand the reach of agencies to detect violations that would be extremely difficult to find otherwise.

ELI found two programs aimed at detecting excessive idling (e.g., by trucks and buses), in New York City and Washington, DC (US EPA 2020a). The cities maintain mobile apps that the public can use to report idling, including photos, video, and geolocation—sufficient to support action by the agency.

A similar online tool is available in California to identify potential misuses of pesticides. Such events are very hard for agencies to detect, so a reporting app allows the public (including farmworkers) to submit information when they believe pesticides are being used improperly or applied unsafely (e.g, where they can blow across property lines and affect people outside the intended area) (ELI 2020a).

Some may not consider the use of these apps to be citizen science, but simply technology that facilitates reporting of personal observations. They do, however, involve citizens and generally require some degree of precision in reporting such as photos, videos, or locational data.

PATTERNS ACROSS THE CASE STUDIES: APPROACHES AND ISSUES

From these case studies, ELI identified patterns in how agencies work with citizen scientists, as well as a variety of dimensions on which such efforts can vary. A number of other themes also emerged from the survey (ELI 2020a).

PATTERNS IN AGENCY APPROACH

Agency role

ELI found that agencies can work with scientists in a number of ways; there is no single model. Some programs are created and run by agencies, with volunteers assisting almost as additional agency staff. In other cases, agencies partner with independent groups on a co-equal basis Agencies may also be in a support role, largely providing technical assistance to members of the public who design and carry out their own projects.

How data is used

Second, projects vary widely in how data is used, from providing information to the public (e.g., on the location of harmful algal blooms) to informing agency regulatory decisions such as whether a water body is considered impaired under the Clean Water Act. It is very common for citizen-generated data to be used as a starting point—a signal of need for further investigation by the agency—even if the data is not sufficient to reach a firm conclusion.

Strategies for engagement

Agencies interact with citizen scientists in a variety of ways. As noted above, projects may vary in terms of who has the lead and who is in a support role. Another distinction is between structured programs, in which volunteers and community groups participate as identified members, and more arms-length arrangements in which agencies issue data calls or create a platform for submission of data gathered independently. Another strategy is for agencies to collaborate with each other and with citizen groups (as in the Lake Champlain algal bloom monitoring program.) Finally, agencies may be in an assistance or capacity-building mode.

FREQUENTLY RECURRING ISSUES

Certain issues arise frequently across the various efforts to use citizen science in agency programs.

The problem of data quality

The issue that arose most frequently across almost all of these examples is the question of data quality. For government agencies to use citizen-generated data, or data from community scientists, they need to be persuaded that it is valid—both for their own purposes and because they are concerned about challenges that might be brought in court or in administrative proceedings. A good deal of progress has been made in this regard in water programs, which have been using volunteer data for many years. The challenges are greater for data on air quality, largely because the devices used by citizen scientists are very different from and less sophisticated than those used by agencies. However, the experience in water suggests approaches that could be used to maximize the value gained from non-agency air quality data. Moreover, agency monitoring systems have limitations that citizen data can help overcome. There appears to be a common incentive, therefore, to find ways of overcoming data quality issues even in connection with air sensors (Wyeth et al. 2019).

Environmental justice and use by indigenous communities

ELI found a number of instances in which environmental justice communities are gathering data as part of their advocacy (ELI 2020a). Equity has become a high priority in US environmental policy, and strengthening the role of citizen science (often called "community science" in this context) into the overall equity agenda will be important.

Two of the case studies, the West Oakland Environmental Indicators Project and Imperial Valley Community Monitoring, involved environmental justice communities. Other examples, not cited in ELI's report, have also drawn attention (Kimura and Kinchy 2019).

Independent data gathering is attractive to communities in part because it makes new information available, but also because it changes the roles and relationships of community members and government agencies. Communities in which there is historic distrust of government and other institutions also value having ownership of their own data rather than depending on others (Kimura and Kinchy 2019).

The experience of community scientists to date has not been uniformly successful, however. Agencies sometimes—perhaps often—are reluctant to act on community-generated data in the way local residents had hoped. There can be many reasons for this—from purely technical, to legal and bureaucratic. The data may simply not fit the frameworks that agencies are operating in, or the data may be viewed as not reliable enough to use in making major decisions (US EPA 2014).

Communities understand the importance of data quality and often make extensive efforts to ensure that their work meets high standards of scientific rigor. Moreover, community data can have value because agencies have significant data gaps, especially on local conditions (Wyeth et al. 2019).

Indigenous communities are also using scientific tools, for similar reasons. For example, the Yukon River Intertribal Watershed Commission, a body formed by tribal and indigenous groups in Alaska and Northern Canada, monitors water quality in the Yukon River across a vast stretch of Alaska and western Canada—a classic example of filling gaps that exceed the abilities of agencies. Its activities are similar to the state water monitoring programs described earlier, but the work is done by indigenous community members. YRITWC also gathers data on the effects of climate change on hydrology, water quality, and the landscape (ELI 2020a).

Impact of new technology

Another theme running through the case studies is the central role of innovative technology. This includes new tools for gathering data, such as air sensors, but also tools for obtaining reports from private citizens, tools for coordinating agency volunteers, and technology for analyzing and displaying data. These took many forms:

Mobile apps are being used to give individuals a channel for reporting events such as cyanotoxic blooms in lakes and streams, strange odors in the city, excessive engine idling, and improper application of pesticides. These disparate efforts all address limits that agencies face in monitoring highly dispersed environmental conditions (ELI 2020a).

Agencies are also using apps and other technology to make it easier for volunteers in the field to submit their results. These apps can also educate volunteers to improve the quality of reporting—for example, by providing information about what volunteers are being asked to provide and what to look for (ELI 2020a).

Online databases make it possible for the data collected by private citizens to be shared widely, not just used by the agency. Creative use of graphics makes the data more accessible—for example, results are mapped to show how environmental conditions differ across the region being studied. Publicly accessible databases also make the information available to other users. Michigan's water monitoring program found that its data was being used by people looking for the best lakes on which to buy property (ELI 2020a).

RECOMMENDATIONS

It is apparent from the case studies that the integration of citizen science into agency programs and decisions is still developmental in the US, and its impact on government policy is uneven. It varies across the type of environmental issue being studied, across agencies, and over time.

What more could be done—particularly by government—to accelerate the uptake of citizen- or community-generated data into policies and programs? ELI recommended a number of steps that could move agencies in that direction (ELI 2020c).

"RECOGNIZE AND HARNESS THE VALUE OF CITIZEN SCIENCE"

The first recommendation goes to the mindset of the agencies. In general, ELI encourages agencies to look for the ways in which data could be useful, rather than focusing just on its limitations. It suggests "meeting the citizen scientists halfway."

This can mean not only using data in existing programs, but rethinking those programs. For example, community-generated data provides information about air pollution on a neighborhood scale that has not generally been available in the past (Wyeth et al. 2019). It may be less precise than data from agency monitors, but its availability creates the possibility of redesigning air pollution control programs to operate not only on a broad regional basis, as is currently the case, but on a more focused, localized basis too. Taking advantage of this would require establishing a new structure not currently present in the US system of air pollution control (Wyeth 2020).

ELI's specific recommendations on how to better harness the value of citizen science include (this is a selective list):

- Programs should proactively survey the potential uses of citizen-generated data, across the full spectrum from community engagement and education to regulation and enforcement.
- Programs (especially at the federal level) should compile and share information about ways in which such data is currently being used, in a national project repository.
- Programs should recognize leading efforts, and leverage existing funding streams (grant programs) to support new ones.

"ESTABLISH LEADERSHIP HUBS FOR COORDINATION AND INFORMATION SHARING"

Second, ELI recommends that EPA, or possibly others, create centralized leadership hubs to "capture and share the collective knowledge of those in the field." It notes that most agency efforts operate independently of each other. In its research, ELI heard a desire from practitioners in the field to know more about what other similar programs are doing, what works, and what approaches are being used.

ELI suggests that even on a small scale, a central hub could take steps such as:

- assembling, sharing, and updating information on existing efforts across the states;
- highlighting successful strategies and quantified results;
- providing advice on best practices based on the experience of others; and
- carrying out evaluations to assess progress and to identify approaches that should be replicated.

While these hubs would not dictate policy, they could develop consensus guidance on recommended approaches based on state experience (ELI 2020c).

ELI did not point to any single entity as responsible for providing such leadership. It noted that EPA program offices are obvious candidates, but that hubs could also be formed in other organizations including the associations of state environmental programs (ELI 2020c).

ELI also suggested that agencies explore areas in which citizen science is not currently being used, but where it might be in the future. (For example, indoor air quality is not regulated in the US, but data collected by homeowners might be valuable.) It also recommended looking into whether legislation should be adopted, probably at the state level, to solidify the role of citizen science (ELI 2020c).

"EMBED CITIZEN SCIENCE IN COMMUNITY ENGAGEMENT PRACTICES"

Environmental justice is a top priority for EPA and other agencies in the US. As noted earlier, science is being used as a tool by environmental justice communities. ELI recommended that EPA, and other agencies, take a proactive approach in working with these communities so that their data gathering efforts are impactful and useful to the agencies (ELI 2020c).

Any such effort must be part of a larger collaboration between agencies and communities who do not necessarily view them with a high degree of trust. Therefore, ELI concluded, "agencies will need to learn how to integrate community science into their efforts at building successful community partnerships, and to work with communities who are engaged in gathering data." This will involve "building skill in communication on environmental risk," and educating community members on the nature of agency authorities (so they know what the agency can do with data), as well as on the technical aspects of data gathering.

Specific steps recommended by ELI included convening and facilitating discussions among state and local agencies (through the leadership hubs described above). Other recommended measures included steps such as:

- identifying and sharing successful practices, on effective risk communication;
- setting clear expectations on potential data use;
- providing guidance to communities on proper data gathering, data quality, and new technology, and technical tools to help them gather data useful to agencies;
- identifying experts who can advise and assist community scientists;
- engaging communities in the analysis and use of data gathered;
- providing training and opportunities for agencies to share and learn from each other's experiences and from established best practices; and
- establishing grant programs or, if possible, using existing grant programs to help communities acquire equipment, for technical advice, and to manage data gathering initiatives.

"STRENGTHEN THE QUALITY AND USE OF CITIZEN-GENERATED DATA"

The fourth set of recommendations involves a variety of measures that would help citizen scientists generate high-quality data that is likely to be useful to agencies. These steps include:

- providing clear guidance, information, and training to the public (and to agency staff) on potential ways agencies can use data, the types of data that are acceptable for each use, appropriate study design, and the technology most appropriate for each purpose;
- providing direct assistance to citizen scientists in development of study designs;
- engaging with technology developers to identify agency needs and to encourage improvements for agency purposes;
- expanding existing work to evaluate new sensors and using the results to identify sensors that are appropriate for agency use;
- commissioning an analysis on the relative quality of crowdsourced sensor data and refining our understanding of the value of such data; and
- creating public-private partnerships that can utilize the ability of technology firms and other nongovernmental entities to fund and carry out activities that are beyond the capability of agencies.

"COORDINATE THE SHARING OF DATA MANAGEMENT SYSTEMS AND PRACTICES"

The final set of recommendations addresses the technical aspects of utilizing citizen-generated data and building on the collective knowledge of agencies and communities. Agencies have developed increasingly sophisticated technical tools for collecting data, reporting it, and making it available to the public. However, these tools and practices may not be shared due to proprietary rights. "Data sharing can also be impeded by lack of uniform data standards or adequate metadata." (US EPA 2020c).

ELI recommended that EPA, states or others take steps such as:

- issuing common guidelines for data management practices and the development of data management tools;
- promoting the principles of FAIR (Findable, Accessible, Interoperable, Reusable) and CARE (Collective Benefit, Authority to Control, Responsibility, Ethics);
- agreeing on proper metadata to avoid the potential misuse or misinterpretation of data; and

- evaluating and sharing information on new and existing data management tools and platforms to guide agencies on their possible uses.

Around the same time that ELI did the research described here, the staff of the European Commission (EC) prepared a paper on "Best Practices in Citizen Science for Environmental Monitoring," which paralleled ELI's work to some extent (European Commission 2020). A comparison of the two is interesting and instructive.

The use of citizen science tools has made great progress in the EU, in some respects surpassing progress in the US. EU member states have greater independence in this regard than US states, allowing for more rapid adoption in some countries. An extended discussion of how citizen science is addressed by EU member states is beyond the scope of this article. However, comparing the two analyses suggests that agencies in the EU face issues similar to those in the US.

The EC staff report makes recommendations in four major areas: matchmaking between knowledge needs for environmental policy and citizen science activities; promoting awareness, recognition and trust; promoting data quality and interoperability standards and sharing tools; and supporting coordination and cooperation for policy impact.

These recommendations parallel to a remarkable degree those from ELI's look at environmental programs in the US—even though the analyses were not coordinated in any way.

These similarities suggest that citizen science is at the same stage of development globally in its potential to inform and be used in policymaking. In particular, issues of basic confidence in the approach, and quality of data, are widespread barriers. Agencies are still unsure what to make of data from nontraditional sources.

The idea of "matchmaking," or as ELI put it, "meeting the citizen scientists halfway," is a response to those concerns. This involves identifying the questions and decisions that citizen-generated data can be relevant to, and setting out guidelines and protocols for what needs to be done to make the data acceptable for those uses. This step requires action by agencies, whose guidance will be critical, although others can help connect the dots as well.

Increased coordination and cooperation, on the other hand, can be initiated by the citizen scientists themselves. They can create channels and platforms for sharing experiences, building common practices and continuously improving the state of the art.

THE PATH FORWARD

The research summarized here is limited in scope; it is focused on states, tribes, and local governments. Nevertheless, it reveals patterns and trends, which in turn point to actions that could be taken to enhance the policy impact of citizen science. The fact that a parallel analysis in the EU points to similar steps suggests that there is a shared path forward, based on a few broad themes:

1. *Finding the value in citizen-generated data*
   This means examining what kind of data can be generated, and how that data might be usable by government agencies even if it is different in nature from traditional data. Data that is less than perfect can still have value if agencies think creatively about its potential uses.
2. *Creating shared guidelines on data use*
   Once there is an understanding of how data can be used, and what needs to be done to make sure data is appropriate for that use, agencies can issue public guidelines accordingly. This will benefit both the citizen scientists, who will be better able to make sure their time and effort is spent effectively, and agency staff who will know to assess the data submitted to them. If citizens and agency staff are on the same page, the impact of citizen science should be greatly enhanced.
3. *Providing central leadership*
   A great deal of expertise already exists. However, it is not shared in any organized way. Central leadership can coordinate and share that knowledge, and facilitate consensus on recommended approaches without dictating or imposing decisions.

ELI did not specify who should take the steps it recommended. In many cases the most likely actor would be the US EPA (which commissioned this research). State, tribal, and local agencies themselves could also take action, either individually or through their associations. Some topics call for joint federal-state action. And some measures could be undertaken by non-governmental actors, such as those involved in developing sensor technology.

Some steps are already being taken at the US EPA that are consistent with these themes. In 2022, EPA released a vision document on the role of participatory science at the agency (US EPA 2022). A companion data management roadmap, still under development, will define specific actions needed to improve data infrastructure that supports the flow of citizen science data from collection to ultimate use.

EPA has also taken steps with regard to use of data from air sensors. In 2022, it announced a new $20 million grant program for community air monitoring, inviting applications from states, local governments, tribes and community organizations (with a minimum of $2 million set aside for the latter). The solicitation does not specifically refer to low-cost air sensors, but a sensor-based data gathering initiative would fit its criteria.

Also, in June 2020, its Office of Air and Radiation issued a new policy stating that EPA will study the effective use of data from air sensors, which could ultimately benefit private citizens using those devices (US EPA Office of Air and Radiation 2020). The policy first reasserts that data from air sensors cannot be used in a formal regulatory fashion, but goes on to state that "certain data streams … could still be useful in non-regulatory applications." As examples of possible uses of such data, the policy lists providing a better understanding of local air quality, helping in the siting of regulatory monitors, and identifying hot spots. The policy also states that many questions remain about data quality, data interpretation, and data management that need to be addressed, and that EPA will work with states, tribes, and local air agencies on these issues.

CONCLUSION

ELI's analysis of the integration of citizen science data into government programs and policies, along with the very similar analysis of developments in the EU and UK, point to a field that is in flux but on a path to progress. While some of the remaining challenges are technical—especially the need for better technology and agreed upon protocols to address problems of data quality—the larger challenge is institutional and lies, in particular, with the need for centralized leadership simply to collect and share the existing expertise, and to help emerging programs learn from or build on those that already exist. This, then, is where efforts at further progress will need to focus.

ACKNOWLEDGEMENTS

The original research summarized in this article was carried out by the author with Kasantha Moodley of the Environmental Law Institute. Valuable guidance in that effort was provided by Jay Benforado and Demi Gary of the US Environmental Protection Agency. Essential research support was provided at ELI by Ananya Bhattacharya, Siena Fouse, and Jessica Oo.

COMPETING INTERESTS

The author has no competing interests to declare.

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TO CITE THIS ARTICLE:
Wyeth, G. 2023. Integrating Citizen Science into the Work of United States Environmental Agencies. *Citizen Science: Theory and Practice,* 8(1): 11, pp. 1–12. DOI: https://doi.org/10.5334/cstp.490

Submitted: 31 December 2021 **Accepted:** 25 November 2022 **Published:** 20 March 2023