The Impact of Citizen Environmental Science in the United States

by George Wyeth, LeRoy C. Paddock, Alison Parker, Robert L. Glicksman, and Jecoliah Williams

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Summary

An increasingly sophisticated public, rapid changes in monitoring technology, the ability to process large volumes of data, and social media are increasing the capacity for members of the public and advocacy groups to gather, interpret, and exchange environmental data. This development has the potential to alter the government-centric approach to environmental governance; however, citizen science has had a mixed record in influencing government decisions and actions. This Article reviews the rapid changes that are going on in the field of citizen science and examines what makes citizen science initiatives impactful, as well as the barriers to greater impact. It reports on 10 case studies, and evaluates these to provide findings about the state of citizen science and recommendations on what might be done to increase its influence on environmental decisionmaking.

In April 2018, the Environmental Defense Fund announced that it would launch in late 2020 a satellite that can detect methane emanating from oil and gas operations, with the ability to monitor up to 80% of worldwide production.[1] This development comes at the same time that the Donald Trump Administration has sought to rescind regulations requiring companies to more closely monitor methane emissions from oil and gas operations and associated facilities, including pipelines and refineries.[2] The juxtaposition of these developments demonstrates that the game has changed in the relationship between government, regulated businesses, and members of the public, as science and technology leapfrog the limited ability or willingness of regulators to investigate, detect, and act on releases of this potent greenhouse gas.

This juxtaposition is an exceptional example of a divergence between government and nongovernmental environmental monitoring activity, but it is a striking illustration of the fact that government agencies no longer have a near-monopoly on gathering data and assembling information on the environment. An increasingly sophisticated public, rapid changes in monitoring technology, the ability to process large volumes of data, and social media are increasing the capacity for members of the public, advocacy groups, and community organizations to gather, interpret, and exchange environmental data.

This development has the potential to alter the historically government-centric approach to environmental governance. Data and information generated through "citizen science" can provide a richer understanding of environmental conditions and allow members of the public to play a more prominent role in environmental governance, both by prodding government action that puts pressure on polluting companies, and by helping companies to better understand their impact on the environment, perhaps leading to more self-initiated efforts to reduce environmental harms. While some concern has been expressed about the reliability of citizen science and citizen monitoring, this Article focuses on how citizen science and citizen monitoring that meet generally accepted data quality standards can enhance environmental governance.

However, citizen science has had a mixed record to date in influencing government decisions and actions, which is where its most concrete potential impact arguably lies.

1. Press Release, Envtl. Def. Fund, EDF Announces Satellite Mission to Locate and Measure Methane Emissions (Apr. 11, 2018), https://www.edf.org/media/edf-announces-satellite-mission-locate-and-measure-methane-emissions.
2. *See* Waste Prevention, Production Subject to Royalties, and Resource Conservation; Rescission or Revision of Certain Requirements, 83 Fed. Reg. 49184 (Sept. 28, 2018); Oil and Natural Gas Sector: Emission Standards for New, Reconstructed, and Modified Sources Reconsideration, 83 Fed. Reg. 52056 (proposed Oct. 15, 2018).

Citizen-generated data can inform government action in ways that include:

- increasing agency knowledge of environmental conditions,
- supporting rulemaking,
- providing additional data for environmental impact analysis,
- better informing permitting decisions,
- identifying potential violations,
- prodding agencies to act on violations, and
- helping to monitor how well states are performing delegated responsibilities.

This Article reviews the rapid changes that are going on in the field of citizen science and examines what makes citizen science initiatives impactful, as well as the barriers to greater impact. It then reports on 10 case studies that shed light on what is working, and what is not, in the field. Based on evaluation of these case studies, we provide a series of findings about the state of citizen science and recommendations on what might be done to increase its influence on government agencies.

In brief, we recommend:

1. The U.S. Environmental Protection Agency (EPA) and other environmental agencies should take specific steps to encourage and support the use of citizen science in their decisions and actions. Specifically, EPA should adopt a citizen science strategy aimed at creating a culture that is receptive to the use of citizen-generated data, and all agencies should take steps to "meet citizen scientists halfway" to maximize the use of their efforts.

2. Citizen scientists can and should learn from the successes of others. The case studies described below illustrate a variety of practices that can be used more widely.

3. Air programs in particular should seek to use citizen-generated data to better understand and address air pollution problems at the neighborhood level—especially in environmental justice communities.

4. Unnecessary legal barriers should be removed—especially laws adopted to protect specific business sectors from public oversight.

5. A system should be established for the validation of emerging sensor technologies that are commonly used by citizen scientists.

I. Introduction to Citizen Science

A. *The Citizen Science Explosion*

Citizen science is the involvement of the public in scientific research.[3] This activity includes gathering, analyzing, and sharing environmentally related scientific information, often obtained through advanced monitoring (increasingly through the use of new, lower-cost technologies that are deployed by organizations or individuals other than governments or regulated companies). It can take many forms, ranging from projects led by professional scientists in institutions (*contributory* citizen science),[4] to community-led efforts that orient toward community goals (*community science*, *community citizen science*, or *collegial* programs),[5] and many variations in between.

Citizen science is flourishing as a tool for scientific advancement and as a movement engaging the public. SciStarter.com, the most comprehensive inventory of citizen science projects, includes more than 1,700 projects and 50,000 active members.[6] There are at least 1,676 projects

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3. *See* Rick Bonney et al., *Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy*, 59 BioScience 977 (2009) (defining citizen science). Other terms and expressions are sometimes used to describe approaches with similar principles and goals, such as public participation in scientific research (PPSR), community science, community-based monitoring, and community-based management. *See* Melissa V. Eitzel et al., *Citizen Science Terminology Matters: Exploring Key Terms*, 2 Citizen Sci.: Theory & Prac. 5-11 (2017); Cathy C. Conrad & Krista G. Hilchey, *A Review of Citizen Science and Community-Based Environmental Monitoring: Issues and Opportunities*, 176 Envtl. Monitoring & Assessment 274, 274 (2011) (citing Graham Whitelaw et al., *Establishing the Canadian Community Monitoring Network*, 88 Envtl. Monitoring & Assessment 409 (2003)) (defining community-based monitoring); Heather L. Keough & Dale J. Blahna, *Achieving Integrative, Collaborative Ecosystem Management*, 20 Conservation Biology 1373 (2006) (defining community-based management). In the legal literature, terms such as volunteer monitoring, participatory action research, civil society research, and community policing are sometimes used to describe related practices. *See* Annie E. Brett, *Putting the Public on Trial: Can Citizen Science Data Be Used in Litigation and Regulation?*, 28 Vill. Envtl. L.J. 162 (2017); *see also* Abby J. Kinchy & Simona L. Perry, *Can Volunteers Pick Up the Slack? Efforts to Remedy Knowledge Gaps About the Watershed Impact of Marcellus Shale Gas Development*, 22 Duke Envtl. L. & Pol'y F. 303, 304 (2012) (discussing civil society research); Dara O'Rourke & Gregg P. Macey, *Community Environmental Policing: Assessing New Strategies of Public Participation*, 22 J. Pol'y Analysis & Mgmt. 383 (2003) (discussing community policing).
4. Jennifer L. Shirk et al., *Public Participation in Scientific Research: A Framework for Deliberate Design*, 17 Ecology & Soc'y 29, 32 (2012).
5. In *community science*, collaboratively led scientific investigation and exploration addresses community-defined questions, allowing for engagement in the entirety of the scientific process. Unique in comparison to traditional citizen science driven by researchers or institutions, community science may or may not include partnerships with professional scientists, emphasizes the community's ownership of research and access to resulting data, and orients toward community goals and working together in scalable networks to encourage collaborative learning and civic engagement. *See* Shannon Dosemagen & Gretchen Gehrke, *Civic Technology and Community Science: A New Model for Public Participation in Environmental Decisions*, *in* Confronting the Challenges of Public Participation: Issues in Environmental, Planning, and Health Decision-Making (Proceedings of the Iowa State University Summer Symposia on Science Communication) 143 (Jean Goodwin ed., Science Communication Project 2016). Community science is similar to "collegial" citizen science. *See* Shirk et al., *supra* note 4, at 32.
6. Lea Schell, *SciStarter's Top 10 Projects Are Here!*, SciStarter (Jan. 18, 2018), https://blog.scistarter.com/featured-projects/2018/01/scistarters-top-10-projects-2017/.

across the country that engage volunteers in data collection on water quality monitoring, with many thousands of participants.[7] The term "citizen science" in scientific publications is growing exponentially.[8]

Half of what we know about the effect of climate change on bird migrations comes from citizen science, though it may not be named as such.[9] Across the world, the professionalization of citizen science is reflected in established and emerging professional organizations.[10] In short, there has been a dramatic expansion both in the amount of activity that may be described as citizen science and in the recognition of its power as a tool for environmental protection.[11]

The potential for citizen science to inform action by government has been recognized at the highest levels.[12] In 2013, President Barack Obama's Open Government Access Plan encouraged agencies to use citizen science and crowdsourcing for agency operations.[13] This was followed in 2015 by a memorandum from Presidential Science Advisor John Holdren, calling on science agencies to institute policies in support of crowdsourcing and citizen science, and to advance the use of these tools.[14] Along with that mandate, the Office of Science Technology and Policy (OSTP) launched the Federal Crowdsourcing and Citizen Science Toolkit to guide the integration of citizen science into agency processes by supplying basic project models, process steps, and informational resources to federal employees.[15] Similarly, numerous states now maintain programs to facilitate citizen science and improve the utility of volunteer data.[16]

These steps led in 2016 to the enactment, with bipartisan support, of the Crowdsourcing and Citizen Science Act, which takes steps toward sanctioning the use of citizen science and crowdsourcing by federal agencies.[17] In general, it encourages, but does not require, the use of citizen science. Finding that such projects have the potential to accelerate the pace and increase the cost-effectiveness of scientific research and address societal needs, the Act codified the 2015 OSTP memo by explicitly granting agencies permission to carry out citizen science and crowdsourcing projects,[18] and provides that federal agencies may fund and utilize volunteer citizen science data to advance their missions.[19] It also encourages agencies to make data collected through crowdsourcing or citizen science projects available to the public, obligates agencies to notify participants as to expected modes of use and dissemination of the data,[20] and directs agencies to publicly promote citizen science initiatives to encourage broad participation.[21]

EPA has launched initiatives that indicate growing acceptance of citizen science data and initiatives, including soliciting a pair of reports from the National Advisory Council for Environmental Policy and Technology (NACEPT); those reports were completed in 2016 and 2018, recommending that the Agency embrace citizen science initiatives and citizen science data, communicate standards and data quality needs for different data uses, and consider the potential uses of citizen science data for all data uses, including regulation and enforcement.[22] Also

7. *See* Kristine F. Stepenuck, Improving Understanding of Outcomes and Credibility of Volunteer Environmental Monitoring Programs 18, 74 (2013) (Ph.D. dissertation, University of Wisconsin-Madison).
8. Duncan C. McKinley et al., *Investing in Citizen Science Can Improve Natural Resource Management and Environmental Protection*, 19 Issues Ecology 5 (2015).
9. Caren B. Cooper et al., *The Invisible Prevalence of Citizen Science in Global Research: Migratory Birds and Climate Change*, 9 PLoS ONE e106508, at 1-5 (2014), *available at* https://doi.org/10.1371/journal.pone.0106508.
10. These professional organizations include the Citizen Science Association, the European Citizen Science Association, and the Australian Citizen Science Association, with three additional associations emerging in Africa, Asia, and South America. In addition, in December 2017, the Citizen Science Global Partnership was launched to support and network these organizations for worldwide environmental progress. Martin Storksdieck et al., *Associations for Citizen Science: Regional Knowledge, Global Collaboration*, 1 Citizen Sci.: Theory & Prac. 10 (2016).
11. Brett, *supra* note 3, at 19 ("It could well be argued that this shift is the beginning of a new age of citizen science, as it becomes a mainstream and accepted method of data collection.").
12. Citizen science, of course, is not limited to the United States. International organizations such as the United Nations Environment Programme, the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the European Commission, and the European Environment Agency have highlighted the importance of citizen science. *See* UNESCO, WSIS+10 Working Papers (2013); Scottish Environment Protection Agency (SEPA), Corporate Plan 2012-2017 (updated 2014), *available at* https://www.sepa.org.uk/media/299696/2012-2017-corporate-plan-update-2014.pdf; European Environment Agency, Biodiversity Monitoring in Europe—The Value of Citizen Science (2013).
13. The White House, The Open Government Partnership: Second Open Government National Action Plan for the United States of America 12 (2013).
14. Memorandum From John Holdren, Assistant to the President for Science and Technology and Director of the Office of Science and Technology Policy, to Heads of Executive Departments and Agencies (Sept. 30, 2015) (Addressing Societal and Scientific Challenges Through Citizen Science and Crowdsourcing), https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/holdren_citizen_science_memo_092915_0.pdf. Among other things, the memo called on agencies to identify an agency coordinator and generate a catalogue of agency-supported citizen science and crowdsourcing projects. It also highlighted key principles of data quality, openness, and public participation.
15. *See* CitizenScience.gov, *Federal Crowdsourcing and Citizen Science Toolkit*, https://www.citizenscience.gov/toolkit/ (last visited Jan. 2, 2019).
16. *See* U.S. EPA, *Examples of State and Local Wetland Volunteer Monitoring Programs*, https://www.epa.gov/wetlands/examples-state-and-local-wetland-volunteer-monitoring-programs (last updated July 20, 2018); Minnesota Pollution Control Agency, *Citizen Water Monitoring*, https://www.pca.state.mn.us/water/citizen-water-monitoring (last visited Jan. 2, 2019); Jason Toft et al., *A Framework to Analyze Citizen Science Data for Volunteers, Managers, and Scientists*, Citizen Sci. Today, May 1, 2018, http://www.citizenscience-today.org/2018/05/a-framework-to-analyze-citizen-science-data-for-volunteers-managers-and-scientists/.
17. 15 U.S.C. §3724.
18. *Id.* §3724(d)(1).
19. *Id.* §3724(b), (d)(1)-(2).
20. *Id.* §3724(d)(6)(A)-(B). The statute states that agencies shall make such data available to the public "where appropriate and to the extent practicable . . . unless prohibited by law." *Id.* §3724(d)(6)(A). Accordingly, this language is largely hortatory and does not establish a legal requirement of public access or override other laws that restrict the use of data by federal agencies.
21. *Id.* §3724(d)(3), (6)(B). To assist these efforts, the U.S. General Services Administration and the Woodrow Wilson International Center for Scholars launched CitizenScience.gov. The website provides a catalog of federally supported citizen science projects, a community gateway to hundreds of citizen science practitioners and coordinators across government, and access to the Federal Crowdsourcing and Citizen Science Toolkit. *See* CitizenScience.gov, *Home Page*, https://www.citizenscience.gov/ (last visited Jan. 2, 2019).
22. NACEPT, Environmental Protection Belongs to the Public: A Vision for Citizen Science at EPA (2016) [hereinafter NACEPT I], *available at* https://www.epa.gov/sites/production/files/2018-04/documents/nacept_citizen_science_publication_eng_022318_rf508_508.pdf; NACEPT, Information to Action (2018) [hereinafter NACEPT II], *avail-*

Figure 1. Spectrum of Citizen Science Data Use

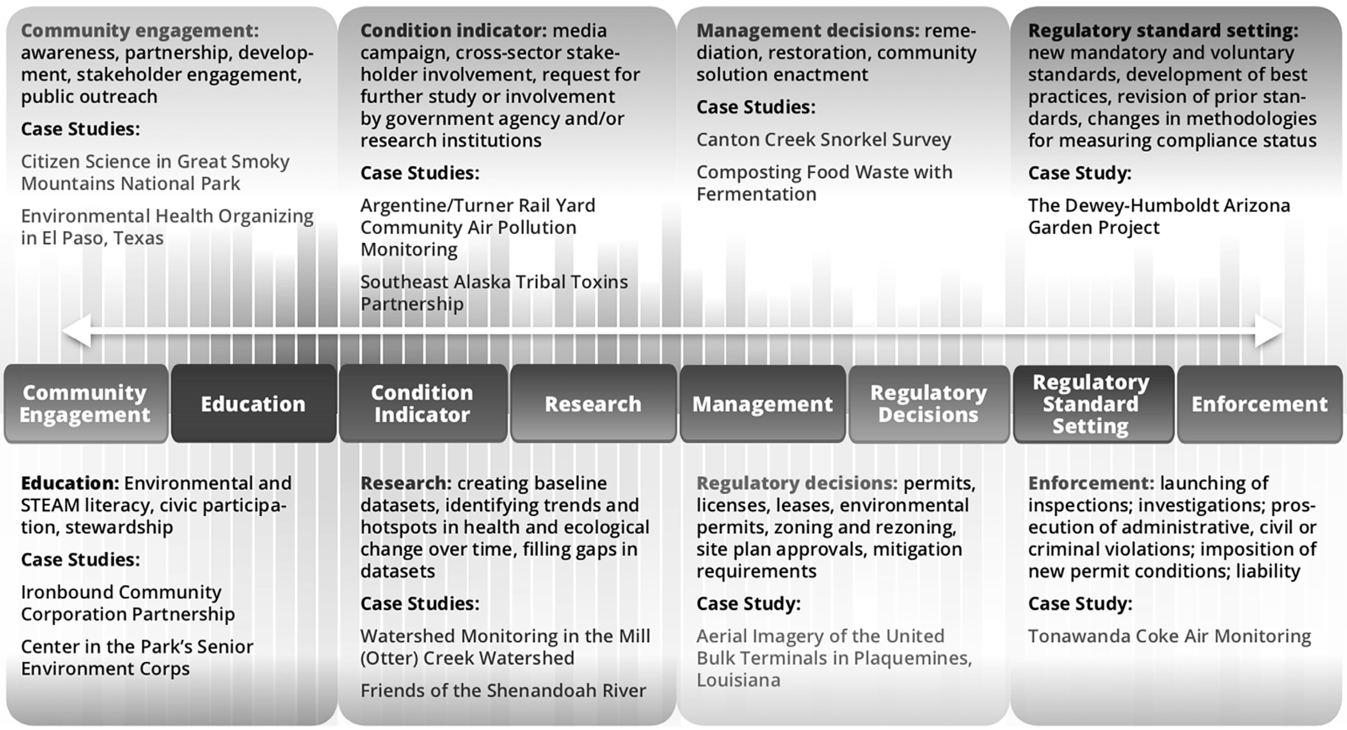

Figure 1. The spectrum of citizen science data use.

Case studies illustrate the range of ways that EPA can integrate citizen science into EPA's work, from engaging communities in environmental protection to using citizen science data for enforcement action. These examples address community engagement, education, condition indicators, research, management, regulatory decisions, regulatory standard setting and enforcement across the spectrum of data uses.

in 2018, EPA's inspector general issued a report calling on the Agency to create an overall citizen science strategy and build a culture of receptivity to citizen science.[23]

To date, there have been few signals from the current Administration of either support for or disapproval of citizen science. EPA's strategic plan strongly supports public engagement as a key agency goal, the EPA citizen science website remains unchanged, and the Administration has allowed the NACEPT to continue work on advice and recommendations for EPA on the use of citizen science.

B. *Citizen Science and Government Action*

The rapid growth in citizen science has wide-ranging, important implications. Citizen science can support a vast array of functions, from basic research to public education to informing public policy. Within the field of pollution policy,[24] the 2016 NACEPT report outlines a range of ways that citizen science can contribute to the mission of EPA and other governmental agencies, from community engagement to enforcement. That range is captured in Figure 1.

As the NACEPT spectrum shows, influencing government decisions and actions—issuing regulations, for example, or bringing enforcement cases—is one role that citizen science can play. The potential impact of citizen scientists may be greatest in these areas.[25]

able at https://www.epa.gov/sites/production/files/2018-04/documents/nacept_2018_citizen_science_publication_eng_final_v2_508_0.pdf. Within EPA, the Office of Research and Development has hosted a series of air monitoring workshops for citizen scientists, and the New England region hosted an Open Space meeting to promote collaboration and coordination on citizen science. EPA also has established a website with information on new monitoring devices; *see* U.S. EPA, *Air Sensor Toolbox for Citizen Scientists, Researchers, and Developers*, https://www.epa.gov/air-sensor-toolbox (last updated Nov. 19, 2018).

23. U.S. EPA, Office of Inspector General, EPA Needs a Comprehensive Vision and Strategy for Citizen Science That Aligns With Its Strategic Objectives on Public Participation (2018), *available at* https://www.epa.gov/sites/production/files/2018-09/documents/_epaoig_20180905-18-p-0240.pdf.

24. Citizen science also plays an increasingly significant role in the field of natural resource protection, which is outside the scope of this Article. States use data from citizen science for purposes such as monitoring trends in species of concern and identifying the presence and spread of invasive species. We did not attempt to catalog natural resource programs. For an example of such a program, see Wisconsin Department of Natural Resources, *Citizen-Based Monitoring*, https://dnr.wi.gov/volunteer/CitizenBasedMonitoring.html (last revised Mar. 21, 2018).

25. Historically, many considered that it was the responsibility of government to protect the environment; however, there seems to be a growing sense that other sectors and citizens themselves must now play a bigger role to achieve environmental goals. *See generally* Christine Overdevest & Brian

Many citizen science organizations say that the desire to impact government motivates their work,[26] and many citizen science project volunteers are motivated by the impact and relevance—or potential impact and relevance—of their efforts.[27] A recent emphasis in citizen science on the impact, relevance, and use of data for policymaking and action in government tracks closely the recent swelling interest in relevant and impactful science.[28]

Community citizen science projects are often initiated as a response to the perception that government entities are not taking needed action to deal with local environmental concerns.[29] In this role, citizen and community science groups often perceive themselves, and are perceived by others, as adversarial to government rather than cooperative (as is usually the case with watershed groups). With recent action by government agencies that demonstrate potential openness to and consideration of citizen science data, this perception may change.[30]

However, the experience of citizen scientists in seeking to impact policy has not been closely studied.[31] In particular, it has not been clear whether citizen scientists are successful in influencing government or what factors may make them most successful. The limited information available suggests that where researchers have attempted to do so, success has been mixed. A survey by EPA's inspector general found that while staff reported using citizen science frequently for purposes such as citizen engagement (27%) or research (23%), very few reported using such data in making regulatory decisions or for enforcement purposes (1% each).[32] In another survey of 345 volunteer water quality monitoring program coordinators, only a minority thought that decisionmakers were receptive to using their data for natural resource management decisions (31%) and policy decisions (21%).[33]

II. The Influence of Citizen Science: Drivers and Barriers

What explains the "explosion" in efforts by citizen scientists to impact policy, and what impedes those efforts? This section explores these critical issues.

A. *Drivers*

1. Advances in Technology

Advances in technology for measuring pollution levels and other environmental conditions have provided vast new opportunities and increased the potential for citizen science generally, as well as for increasing the impact of citizen science on government decisions and actions. Tools for data collection are more widely available and less expensive.[34] In addition, information and communication technologies, including social media, are making it possible to gather, document, view, share, and analyze data and information in expansive and innovative ways.[35]

Recently, low-cost sensors, including those available on mobile phones, have become widely available at a more reasonable cost for volunteer groups and citizen scientists, spurring innovation[36] in the use of these sensors for citizen science, especially in air quality monitoring. The use of smartphones for citizen science allows data to be collected in photographs and video, and through built-in and add-on sensors[37] (such as accelerometers) easily tracked through

Mayer, *Harnessing the Power of Information Through Community Monitoring: Insights From Social Science*, 86 Tex. L. Rev. 1493 (2008) (discussing government meta-regulation and the role of the public and other organizations in achieving environmental goals and ensuring compliance); Kristine F. Stepenuck & Kenneth D. Genskow, *Characterizing the Breadth and Depth of Volunteer Water Monitoring Programs in the United States*, 61 Envtl. Mgmt. 47 (2018) ("Rather than traditional top-down command and control structures, citizen participation was encouraged or even required at certain levels of government.").

26. Stepenuck & Genskow, *supra* note 25, at 54; Kristine F. Stepenuck & Linda T. Green, *Individual- and Community-Level Impacts of Volunteer Environmental Monitoring: A Synthesis of Peer-Reviewed Literature*, 20 Ecology & Soc'y 19 (2015).
27. Stepenuck & Genskow, *supra* note 25, at 55 (discussing motivational factors for participating in citizen science) (citing Josie Biedermann & Jake Blasczyk, Citizen Water Monitoring Survey—Streams. Final Report 20 (2006), *available at* http://watermonitoring.uwex.edu/pdf/level1/news/2006WAVSurveyResults.pdf (survey results indicated that the first reason why environmental monitoring volunteers continue to participate is to contribute to environmental/conservation/water concerns)).
28. Research funders and practitioners are more motivated to invest in research that is oriented toward results and translational research (i.e., the translation of research into practice). *See* Ramya Chari et al., RAND Corp., The Promise of Community Citizen Science (2017), https://www.rand.org/pubs/perspectives/PE256.html (citing National Center for Advancing Translational Sciences, https://ncats.nih.gov/ (last visited Jan. 2, 2019); National Institute for Occupational Safety and Health, *Research to Practice (r2p)*, https://www.cdc.gov/niosh/r2p/default.html (last reviewed Mar. 28, 2018); National Institute of Environmental Health Sciences, *Translational Science, Outreach, and Education*, https://www.niehs.nih.gov/research/supported/translational/ (last reviewed Nov. 23, 2018); Who Will Keep the Public Healthy? Educating Public Health Professionals for the 21st Century (Kristine Gebbie et al. eds., 2003)).
29. Alison J. Parker & Shannon Dosemagen, *Citizen Science Across a Spectrum: Broadening the Impact of Citizen and Community Science*, Sci. & Tech. Stud. (2018) (manuscript at 4); *see also* The White House, *supra* note 13, at 4 (citing Overdevest & Mayer, *supra* note 25, at 1510-11 (discussing citizen science with the goal of forcing EPA enforcement actions)).
30. *See* Parker & Dosemagen, *supra* note 29, at 4.
31. A number of prior studies have compared the results from volunteer water monitoring with those obtained by professional scientists. *See* Brett, *supra* note 3. Other sources have analyzed the legal and other contexts for citizen science, but have not looked at the actual experience of those in the field. *See, e.g.*, James McElfish et al., Envtl. Law Inst. & Wilson Ctr., Clearing the Path: Citizen Science and Public Decision Making in the United States 40 (2016).
32. U.S. EPA, Office of Inspector General, *supra* note 23, at 9.
33. Stepenuck & Genskow, *supra* note 25, at 54.
34. *See* Emily G. Snyder et al., *The Changing Paradigm of Air Pollution Monitoring*, 47 Envtl. Sci. & Tech. 11369-77 (2013). Examples of new monitoring devices are discussed in U.S. EPA, *Air Sensor Toolbox for Citizen Scientists, Researchers, and Developers*, *supra* note 22.
35. The evolution of monitoring technology is discussed in greater detail, *supra* Part I.
36. *See* Intelligent River, *Home Page*, https://www.intelligentriver.org/data (last visited Jan. 2, 2019).
37. Chari et al., *supra* note 28, at 7 (citing Greg Newman et al., *The Future of Citizen Science: Emerging Technologies and Shifting Paradigms*, 10 Frontiers Ecology & Env't 298-304 (2012); Steven Bishop, *Citizen Science Is Stimulating a Wealth of Innovative Projects*, Sci. Am., Oct. 1, 2014, https://www.scientificamerican.com/article/citizen-science-is-stimulating-a-wealth-of-innovative-projects/).

global positioning systems that are automatically included in most smartphones.

Examples of the emergence of new monitoring capabilities include infrared cameras that can detect the release of volatile organic compounds that are not otherwise visible[38]; the PhyloChip that can use DNA fingerprinting to detect the source of bacteria contamination in water[39]; Clemson University's MoteStack sensor connection and data transmission "Intelligent River" systems that can report data in real time on water pollution parameters[40]; the s::can spectrolyser, a multiparameter probe that uses ultraviolet-visible spectrometry to monitor water in real time[41]; handheld fine particulate matter ($PM_{2.5}$) monitors[42]; wearable devices to detect air pollution[43]; and information systems such as the Real Time Geospatial Data Viewer[44] and similar information systems being developed by IBM.[45]

2. An Increasingly Sophisticated Public

The rise of citizen science may also reflect the growing understanding of and comfort with technology among non-scientists.[46] This may be especially true in the context of climate change, where the U.S. government has dramatically reduced its focus. One recent example of low-cost monitoring technologies is the Berkeley Atmospheric CO_2 Observation Network (BEACO$_2$N). BEACO$_2$N is a web of about 30 low-cost carbon dioxide (CO_2)-sensing monitors that are installed at two-kilometer (1.24-mile) intervals across the city of Oakland, California, and that allows communities to identify hot spots and facilitate reductions in CO_2 emissions.[47] Local environmental organizations across the country have developed significant technical capacity that they did not have a decade ago.

3. Limited Agency Capacity and Data Gaps

At the same time that the capacity of citizen scientists is growing, several of the agencies that have traditionally provided most environmental data are under tight resource constraints.[48] This is not a new problem. Governmental science has always faced limits on the ability to generate the data needed to understand environmental issues.[49] Necessary initiatives and data sets are often nonexistent, incomplete, or inadequate.[50] For example, as of 2000, only 19% of water bodies were monitored to comply with the Clean Water Act (CWA).[51] In recent years, agency resources for data gathering have not kept pace with needs, and in some cases are declining.[52] Declining budgets have also led to more widespread concern about the adequacy of governmental environmental monitoring and the ability of governments to maintain the appropriate expertise.[53]

Citizen science can fill data gaps and provide information useful for effective decisionmaking, as well as provide data over spatial and temporal scales that would otherwise not be possible.[54] Although citizen science does often require a substantial investment, it can leverage government resources effectively, which is especially attractive as budgets of government agencies continue to decline.

4. Growing Attention to Community-Level Conditions and Environmental Justice

In addition to resource limitations, there is a mismatch between "the knowledge science generates and the knowl-

38. *FLIR Receives Innovation Award for Methane Detecting Cameras*, FLIR (Apr. 17, 2018), https://www.flir.com/news-center/industrial/flir-receives-innovation-award-for-methane-detecting-cameras/.
39. *See PhyloChip: DNA Microarray for Rapid Profiling of Microbial Populations IB-2229*, Berkeley Lab (Aug. 29, 2014), https://ipo.lbl.gov/lbnl2229/.
40. *See* Intelligent River, *supra* note 36.
41. *See* s::can Messtechnik GmbH, spectro::lyser™, http://www.s-can.at/medialibrary/datasheets/spectrolyser_ww_EN.pdf.
42. *See* Aeroqual, *PM_{10}/$PM_{2.5}$ Portable Particulate Monitor*, https://www.aeroqual.com/product/portable-particulate-monitor (last visited Jan. 2, 2019).
43. *See* Brian Handwerk, *With Wearable Devices That Monitor Air Quality, Scientists Can Crowdsource Pollution Maps*, Smithsonian, Mar. 12, 2015, https://www.smithsonianmag.com/innovation/with-wearable-devices-that-monitor-air-quality-scientists-can-crowdsource-pollution-maps-180954556/.
44. *See* U.S. EPA, *Real Time Geospatial Data Viewer (RETIGO)*, https://www.epa.gov/hesc/real-time-geospatial-data-viewer-retigo (last updated Sept. 8, 2016).
45. *See* Jay Hardikar, *Environmental Analysis in the Era of Cloud and Big Data Platforms*, IBM, Jan. 30, 2017, https://www.ibm.com/blogs/bluemix/2017/01/environmental-analysis-era-cloud-big-data-platforms/.
46. Conrad & Hilchey, *supra* note 3, at 274 (citing Whitelaw et al., *supra* note 3; Catherine Conrad, *Towards Meaningful Community-Based Ecological Monitoring in Nova Scotia: Where We Are Versus Where We Would Like to Be*, 34 Environments 25-36 (2006)).
47. *See* Alexis Shusterman, *Low-Cost Sensors Track CO_2 Where It Counts*, Conversation, July 21, 2016, https://theconversation.com/low-cost-sensors-track-co2-where-it-counts-43828.
48. Conrad & Hilchey, *supra* note 3, at 273.
49. *See*, *e.g.*, David L. Markell & Robert L. Glicksman, *Dynamic Governance in Theory and Application, Part I*, 58 Ariz. L. Rev. 563, 586-90, 594-600 (2016).
50. Conrad & Hilchey, *supra* note 3, at 273.
51. Brett, *supra* note 3, at 19 ("The most recent biennial National Water Quality Inventory Report to Congress found that, out of the total 3,692,830 miles of rivers and streams in the Nation, only 699,946, or 19%, had been assessed during the prior two years for their water quality and their ability to support designated uses."); *see also* William V. Luneburg, *Where the Three Rivers Converge: Unassessed Waters and the Future of EPA's TMDL Program: A Case Study*, 24 J.L. & Com. 25 (2004); 33 U.S.C. §§1251-1387, ELR Stat. FWPCA §§101-607.
52. Stepenuck & Genskow, *supra* note 25, at 47 (discussing decreasing agency budgets and resulting monitoring programs in some states) (citing Jeffrey P. Cohn, *Citizen Science: Can Volunteers Do Real Research?*, 58 BioScience 192 (2008)); Claudia Copeland, Cong. Research Serv., RL30030, Clean Water Act: A Summary of the Law (2016). EPA's budget has been flat at best for more than five years, and many states are under similar constraints. Further, Trump Administration budget proposals over the past two years would have significantly constrained agency resources at both the federal and state levels, likely further restricting government ability to gather, analyze, and disseminate information. Although such deep cuts were not ultimately adopted by the U.S. Congress, they reflect ongoing political pressure to shrink EPA.
53. Conrad & Hilchey, *supra* note 3, at 274 ("Concern about the effectiveness of government monitoring has been attributed to government cutbacks in funding and staffing for ecological monitoring as well as questions about government staff expertise when dealing with complex environmental challenges.").
54. Brett, *supra* note 3, at 165; Conrad & Hilchey, *supra* note 3, at 280; *see also* Barton H. Thompson Jr., *The Continuing Innovation of Citizen Enforcement*, 2000 U. Ill. L. Rev. 185, 223 (2000), *available at* https://illinoislawreview.org/print/volume-2000-issue-1/the-continuing-innovation-of-citizen-enforcement/.

edge society needs."[55] Particularly with regard to air pollution, agencies primarily monitor either on a very broad scale (perhaps a handful of monitors across a large city) or at individual sources to ensure compliance. This leaves a gap with regard to environmental conditions on a neighborhood scale, which is where citizen concern is often the greatest. Projects driven by members of the public can provide information at a local scale to help identify local problems that might otherwise be ignored.[56]

Neighborhood-scale environmental data are especially important in addressing concerns about environmental justice. Many citizen science efforts are driven by underserved communities concerned about the impacts of pollution from multiple sources. Studies such as the Los Angeles Multiple Air Toxics Exposure Studies (MATES)[57] have documented the adverse impact of toxic air pollutants along transportation corridors that frequently run through low-income communities and communities of color. Similarly, states and community organizations have begun to focus more on environmental justice issues associated with exposure to toxics in these communities.[58]

5. Laws That Invite the Use of Citizen-Generated Data

Some environmental programs explicitly anticipate and sometimes facilitate the use of citizen-generated data.

❑ *Clean Water Act*. The clearest opportunity for the use of citizen-generated data exists in water quality protection programs. The CWA requires each state to determine the quality of its waters, identify waters that do not meet state-established ambient quality standards, and undertake regulatory actions to bring those waters into compliance.[59] Waters falling below quality standards due to the presence of a pollutant must be designated as "impaired" and listed as such.[60]

EPA regulations specifically provide for citizen-submitted information throughout this process. Each state must "assemble and evaluate all existing and readily available water quality-related data and information" in maintaining its list of impaired waters, including information about "waters for which water quality problems have been reported by local, state, or federal agencies; members of the public; or academic institutions."[61] These regulations not only require each state to actively solicit public commentary on impaired water listings as well as total maximum daily load (TMDL) proposals and adjustments, but also require states to provide a written rationale for any decision *not* to use relevant and readily available data.[62]

EPA's integrated reporting guidance recommends further steps that facilitate the use of citizen-generated data, including transparency regarding state assessment methodology and the quality assurance and quality control criteria used to evaluate data submitted by third parties.[63] The guidance explicitly identifies "conservation/environmental organizations" and "citizen monitoring groups" as entities that the state should encourage to develop quality assurance project plans (QAPPs).[64] States are authorized to review and comment on proposed QAPPs, and may even issue formal approvals creating a presumption in favor of the quality of data collected in conformity with such plans.[65]

A growing number of states have put programs in place that support the collection and submission of water quality data by citizen science groups. These programs provide a variety of assistance ranging from funding, help in development of QAPPs, and field audits.

❑ *Clean Air Act*. Other statutes allow the use of citizen science data, but do not actively encourage doing so. Many statutes provide opportunities for public input on decisions, such as the designation of areas as in attainment with Clean Air Act (CAA)[66] standards or environmental review under the National Environmental Policy Act.[67] However, these opportunities do not ensure that agencies will consider data submitted by citizen scientists. For example, some courts have specifically found that EPA does not need to take citizen science information into account under the CAA.

The CAA requires that, within one year of issuance or revision of a national ambient air quality standard (NAAQS), each state submit to EPA a list of air quality control regions within the state divided into three categories: nonattainment, attainment, and unclassifiable.[68] An area is unclassifiable if existing data do not permit a determination as to its compliance status. The U.S. Court of Appeals for the D.C. Circuit has found that EPA can ignore private monitoring data it has been unable to verify

55. Brett, *supra* note 3, at 3 (citing Scott Frickel et al., *Mapping Knowledge Investments in the Aftermath of Hurricane Katrina: A New Approach for Assessing Regulatory Responses to Environmental Disaster*, 12 Envtl. Sci. & Pol'y 119, 119 (2009)); *see also* Kinchy & Perry, *supra* note 3, at 306.
56. Overdevest & Mayer, *supra* note 25, at 1521.
57. South Coast Air Quality Management District, *Health Studies*, https://www.aqmd.gov/home/air-quality/air-quality-studies/health-studies (last visited Jan. 2, 2019).
58. *See* Minnesota Pollution Control Agency, *Community Air Monitoring Project*, https://www.pca.state.mn.us/air/community-air-monitoring-project (last visited Jan. 2, 2019); Texas Environmental Justice Advocacy Services, *Community Air Monitoring*, http://tejasbarrios.org/air-monitoring/ (last visited Jan. 2, 2019).
59. 33 U.S.C. §1313(c).
60. *Id.* §1313(d). For each impaired water body, the state must develop a total maximum daily load (TMDL) that sets a maximum permissible amount of the pollutant stemming from both point and nonpoint sources.
61. 40 C.F.R. §130.7 (2018).
62. *Id. See* McElfish et al., *supra* note 31, at 30-31.
63. *See* U.S. EPA, Guidance for 2006 Assessment, Listing, and Reporting Requirements Pursuant to Sections 303(d), 305(b), and 314 of the Clean Water Act (2005), *available at* https://www.epa.gov/sites/production/files/2015-10/documents/2006irg-report.pdf.
64. *Id.*
65. *Id.* The guidance states, however, that the absence of a state-approved QAPP should not be used as the basis for summary rejection of project data submitted by citizen groups.
66. 42 U.S.C. §§7401-7671q, ELR Stat. CAA §§101-618.
67. 42 U.S.C. §§4321-4370h, ELR Stat. NEPA §§2-209.
68. 42 U.S.C. §7407(d)(1)(A).

in making classification decisions.[69] The Eleventh Circuit has also found that EPA's CAA "credible evidence" rule,[70] which allows EPA and the states to use an expanded range of evidence to assess compliance status and respond to noncompliance, does not extend to citizen suits.[71]

B. Barriers

At the same time, a number of factors limit the ability of citizen scientists to impact government decisions.

1. Professional Skepticism

First, citizen science faces skepticism regarding the quality of data produced[72] and a general failure of institutions to embrace nontraditional sources and emergent information.[73] Despite the encouragement for the use of citizen science discussed earlier, citizen science can face strong skepticism from both scientific and regulatory communities, including decisionmakers at all levels of government. EPA's inspector general in a recent report on citizen science noted a lack of "buy in" for citizen science as a key barrier.[74]

The vast majority of volunteer water quality managers reported that their programs lack credibility with decisionmakers.[75] Many officials are concerned that the studies citizen scientists conduct will not meet scientific standards. This skepticism is prevalent within agencies. For example, a 2014 survey of federal agency staff identified data quality as a significant barrier to the use of citizen science data.[76] Although citizen science projects often have multiple goals, it is generally understood that the primary purpose of most citizen science work is usable science.[77]

The challenge that citizen science faces in terms of understanding and receptivity among agency staff is similar in some respects to the response when environmental justice was first identified as an agency priority in the William Clinton Administration. It took many years of repeated efforts to build a culture across EPA programs and functions that recognized the importance of environmental justice and the ways in which it could be considered in agency decisions and actions.[78] Integration of environmental justice into regular EPA functions such as rulemaking, permitting, and enforcement occurred only after EPA Administrator Lisa Jackson made the issue a priority and directed that the Agency develop guidance on incorporating environmental justice into its strategic plan and its routine activities. Similar leadership may be needed to fully incorporate citizen science into EPA's work.

2. Uncertainty About Rapidly Changing Technology

Second, concerns remain that low-cost sensors and other technologies used by citizen scientists do not yet meet high accuracy standards and are not adequate for data collection for the scientific and legal communities.[79] As discussed above, technology innovation has been a primary factor behind the growing role of citizen scientists, especially as it has dramatically reduced the cost of monitoring devices, at least for certain types of air pollution. Rigorous testing has demonstrated the value of some new devices.[80] However, many of the new devices have not reached the level of accuracy achieved by agency monitors or monitors deployed by regulated sources.

Still, as our case studies demonstrate, some citizen science projects are able to meet quality assurance/quality control requirements, especially projects that involve university experts in the program design. It is also important to keep in mind that data quality needs vary depending on the intended use.[81] "Understanding that there is a place for

69. *See* Mississippi Comm'n on Envtl. Quality v. Environmental Prot. Agency, 790 F.3d 138, 154-55, 45 ELR 20104 (D.C. Cir. 2015).
70. 40 C.F.R. §52.12(c) (2018).
71. *See* Sierra Club v. Tennessee Valley Auth., 430 F.3d 1337, 1351-53, 35 ELR 20237 (11th Cir. 2005).
72. *See* Conrad & Hilchey, *supra* note 3, at 281 (discussing skepticism of citizen science data); *see generally* Robert Gellman, Wilson Ctr., Crowdsourcing, Citizen Science, and the Law: Legal Issues Affecting Federal Agencies 59-60 (2015) (giving overview of legal issues with citizen science); Margaret Kosmala et al., *Assessing Data Quality in Citizen Science*, 14 Frontiers Ecology & Env't 551 (2016). Brett, *supra* note 3, articulates this skepticism at length and discusses a number of studies comparing results from professional and volunteer water monitoring (generally finding close correlation in some cases but differing results in others).
73. Lynn E. Blais & Wendy E. Wagner, *Emerging Science, Adaptive Regulation, and the Problem of Rulemaking Ruts*, 86 Tex. L. Rev. 1701 (2007) ("In theory it is hard to deny the power of information revolutions to enhance environmental policy making, but in practice it remains to be seen whether government institutions are up to the task of making good use of information as it arises.").
74. U.S. EPA, Office of Inspector General, *supra* note 23, at 8.
75. Stepenuck & Genskow, *supra* note 25, at 56.
76. Melissa Gedney, *An Exploratory Study on Barriers*, Commons Lab, Sept. 7, 2014 (describing agency views of citizen science), https://stipcommunia.wordpress.com/2014/09/07/an-exploratory-study-on-barriers/.
77. Bonney et al., *supra* note 3, at 978.
78. After President Clinton issued an Executive Order requiring federal agencies to take environmental justice into account in their daily work, studies conducted by the National Academy of Public Administration found that more work was needed to embed environmental justice considerations into the work of the Agency. *See* Philip Rutledge et al., Nat'l Acad. of Pub. Admin., Environmental Justice in EPA Permitting: Reducing Pollution in High-Risk Communities Is Integral to the Agency's Mission (2001). These steps included consistent leadership from the top officials at EPA emphasizing the importance of environmental justice and integrating environmental justice into the routine activities of the Agency such as rulemaking, permitting, and enforcement. It was not until Administrator Lisa Jackson took these steps that environmental justice became fully integrated into the work of EPA. It is likely that a similar effort is needed starting at EPA's senior leadership level and integrated into the Agency's day-to-day work to fully integrate citizen science in the ways recommended by the NACEPT reports.
79. Eric Biber, *The Problem of Environmental Monitoring*, 83 U. Colo. L. Rev. 1, 59 (2011) (discussing the lack of information on ambient environmental conditions and the lack of accessibility and feasibility for use by volunteer groups); David Hindin et al., *Advanced Monitoring Technology: Opportunities and Challenges*, Envtl. Mgmt., Nov. 2016, *available at* https://www.epa.gov/sites/production/files/2016-11/documents/article-adv-mon-technology.pdf.
80. South Coast Air Quality Management District, *Air Quality Sensor Performance Evaluation Center*, http://www.aqmd.gov/aq-spec (last visited Jan. 2, 2019).
81. Brett, *supra* note 3, at 33 ("recognizing that perfect data accuracy, or complete confidence in data quality, may be impossible in environmental monitoring is a crucial component of citizen science data collection").

less than perfect data is effectively a prerequisite for including citizen science in regulatory contexts."[82]

3. Restrictions on the Use of Citizen Science Data by Agencies

Citizen scientists also confront impediments in the statutory design of the programs they seek to influence, and in a variety of other legal requirements that may come into play when the government acts on, or simply publishes, citizen-generated data.

The rules that govern the use of data by federal agencies may limit the impact of citizen science, either as the basis for a regulatory action or simply for incorporation into a public report. These rules do not directly limit what citizen scientists can do, but they may limit the ability of agencies to use or publish citizen science data.[83] For example, the Information Quality Act[84] may limit the ability of federal agencies to make citizen-generated data available to the public, and the Paperwork Reduction Act[85] may limit the ability of citizen groups to work with federal agencies to develop questions that may be used to gather information.

In addition, courts may limit the use of citizen science-gathered information to establish violations absent expert testimony that can establish both the reliability of the monitoring technology and the conclusions drawn from the data gathered using the technology. If data gathered by citizen scientists is offered as evidence in federal court (e.g., in a citizen suit or agency enforcement case), it will be required to meet the requirements for admissibility of expert testimony established in Federal Rule of Evidence 702[86] and *Daubert v. Merrell Dow Pharmaceuticals*.[87]

Daubert concerns both the method of data collection and the methods applied to synthesize and interpret the results.[88] Some commentators have suggested that the rigors of this standard present a significant hurdle to the admissibility of citizen science evidence in the absence of corroborating data collected by professional scientists.[89] However, there is nothing inherently disqualifying about citizen science under the *Daubert* test, so long as the evidence and the methodology behind it are adequately supported by a duly qualified expert.

If a project has been conducted appropriately, such an expert should be able to establish that the data or results were the "product of reliable principles and methods."[90] If a project observes known, tested, and approved scientific protocols in performing data collection, the results are likely to comport with this standard.[91] It would also be necessary to show that the "principles and methods" have been "reliably applied," considering the data quality standards governing research methodologies.[92] This inquiry is sensitive to both the type of project and the planned uses for the data.[93] The quality of the instruments used to carry out these protocols would have to be demonstrated through expert testimony.[94]

Citizen science projects that are structured in accordance with formal QAPPs[95] or that can otherwise establish adherence with standardized quality assurance and control guidelines (such as those required by a federal agency) are likely to satisfactorily demonstrate reliable application.[96] Demonstration that a project provided rigorous methodological training to volunteers would also help meet this part of the test.[97]

82. *Id.* at 31.
83. *See* McElfish et al., *supra* note 31, at 40. These laws do not directly affect the use of data by states, although some states may have their own equivalent requirements. The collection of certain information may also raise concerns under various privacy laws that require basic safeguards for personal information contained within systems of records maintained by agencies. These federal laws do not apply to agency grantees, state or local governments, recipients of federal funds, or the private sector; as such, they are of little relevance to most citizen science projects. Moreover, compliance with privacy laws does not present a significant hurdle to implementing citizen science at the federal level: satisfying relevant requirements is easily within the control of the agency (i.e., records systems can be modeled in compliance with statutory guidance), and almost no use of such data would necessitate the dissemination of personal information about members of the public, the research team, or the agency. *See* Gellman, *supra* note 72, at 72-74.
84. 44 U.S.C. §3516 note.
85. *Id.* §§3501-3520.
86. Fed. R. Evid. 702.
87. Daubert v. Merrell Dow Pharms., 509 U.S. 579, 23 ELR 20979 (1993). According to this standard, a witness who is qualified as an expert may testify in the form of an opinion or otherwise if (1) the expert's scientific, technical, or other specialized knowledge will help the trier of fact to understand the evidence or to determine a fact in issue; (2) the testimony is based on sufficient facts or data; (3) the testimony is the product of reliable principles and methods; and (4) the expert has reliably applied the principles and methods to the facts of the case. *Id.* Many states have also adopted the *Daubert* standard, although some use alternative standards (such as a "general acceptance" standard) or allow a more lenient standard that may present a lower barrier to admissibility of citizen science data. *See* Goeb v. Tharaldson, 615 N.W.2d 800, 31 ELR 20101 (Minn. 2000); Donaldson v. Central Ill. Pub. Serv., 767 N.E.2d 314 (Ill. 2002); McElfish et al., *supra* note 31, at 48.
88. Where citizen science data are to be considered, methodology reviewable by the courts may include specific scientific techniques employed during data collection, as well as (more generally) the use of volunteers to collect the data in the first place. *See* Brett, *supra* note 3, at 200.
89. *See id.* at 197, 201 (noting that validation typically requires comparison between the finding of professional and volunteer researchers).
90. Fed. R. Evid. 702(c).
91. *See* Brett, *supra* note 3, at 200-01.
92. *Id.* at 203.
93. *Id.*
94. *Id.* at 201; *see also* Jennifer Lu, *Cheap, Portable Air Sensors Tell Communities What They Breathe*, Bloomberg Env't & Energy Rep., Jan. 29, 2018 (noting that data that cannot be validated nevertheless support "actionable" data collection by efficiently targeting and refining investigation efforts by entities resourced with expertly graded equipment), *available at* https://bnanews.bna.com/environment-and-energy/cheap-portable-air-sensors-tell-communities-what-they-breathe-corrected.
95. *See* U.S. EPA, Guidance for Quality Assurance Project Plans (2002) (EPA/240/R-02/009), *available at* https://www.epa.gov/sites/production/files/2015-06/documents/g5-final.pdf; U.S. EPA, The Volunteer Monitor's Guide to Quality Assurance Project Plans (1996) (EPA 841-B-96-003), *available at* https://www.epa.gov/sites/production/files/2015-06/documents/vol_qapp.pdf.
96. Brett, *supra* note 3, at 203-04. It has been argued that data from citizen scientist projects will face difficulty under the *Daubert* test because of general skepticism of citizen science within the scientific community as a whole. *Id.* at 204-05. However, if a duly qualified expert scientist testifies in support of a specific data collection project, and if the relevant project conforms with a formal QAPP or other verified methodology, it seems unlikely that such data would be excluded out of hand for simply bearing the label "citizen science."
97. *See id.* (discussing EPA's strict requirements for citizen participants in local monitoring initiatives under the CWA).

Other requirements may apply in selected cases. For example, EPA regulations provide that federal enforcement under the CAA may be based on "any credible evidence or information."[98] It seems likely, however, that data meeting the *Daubert* test would be considered credible under that rule.

4. Legal Barriers to the Gathering of Data by Citizen Scientists

Beyond these hurdles that citizen scientists must meet if their data are to be used in official decisionmaking, some laws actually discourage the private collection of data for purposes of seeking action by the government.

❑ *Limiting collection of environmental data*. The most prominent example of limitations on citizen data gathering is a law adopted in 2015 by the Wyoming Legislature in response to water sampling by the Western Watersheds Project (WWP), which studied the water quality impact of grazing on public lands.[99] Ranchers unhappy about this effort filed suit alleging that WWP had trespassed on private property in the process of taking samples. When this approach proved ineffective as a deterrent,[100] the livestock industry turned to the legislature for relief.

The state legislature adopted a pair of laws creating civil and criminal liability for trespass to collect "resource data"—a new category of trespass with more severe sanctions than were available for other forms of trespassing.[101] The new laws imposed heightened penalties[102] upon individuals gaining unauthorized access to private property for the purpose of collecting resource data, regardless of whether the actual collection of data took place on private or public land.[103] They also prohibited the use in court of data obtained where a trespass occurred, and required state agencies to expunge any such data from their records.

Although the statutes' sponsors justified them as a protection for private landowners from acts of trespass committed by groups such as WWP in the course of monitoring,[104] they were seen by many as a bald attempt by the Wyoming Legislature to shield the livestock industry from liability for violations of the CWA and other environmental laws.[105] WWP and other groups challenged the law's constitutionality.[106] The statute was initially upheld on the ground that the First Amendment does not create a right to trespass,[107] but the U.S. Court of Appeals for the Tenth Circuit overturned that decision on appeal, holding that the act of collecting resource data is entitled to First Amendment protection.[108]

The statute specifically targeted data collection.[109] On remand, the district court struck down a key part of the law, which penalized trespass even where data were only gathered on public land.[110] Other parts of the law, which

98. 40 C.F.R. §52.12 (2018).
99. The WWP project is discussed in further detail *infra* Section III.B.5.
100. *See* Press Release, Falen Law Offices, L.L.C., Landowners File Trespass Lawsuit Against Western Watersheds Project (June 11, 2014), https://buddfalen.com/wp-content/uploads/2014/08/Press-Release.pdf; *Sparring Begins in Civil Lawsuit Alleging Trespassing by Western Watershed Project; Defendants Seek Dismissal*, County 10, Dec. 15, 2014. The suit was dropped after the trial court found that even if trespassing had occurred, punitive damages would not be available, reducing the value of the litigation as a threat to WWP. *See Wyoming Trespass Lawsuit Dropped!*, WWP, Aug. 19, 2016, https://www.westernwatersheds.org/2016/08/om-337/.
101. Wyo. Stat. Ann. §§6-3-414 (criminal liability), 40-27-101 (civil liability). The statute defined the term "collect" as taking a "sample of material" or a "photograph," or "otherwise preserv[ing] information in any form." *Id.* §6-3-414(d)(i). It defined "resource data" as "data relating to land or land use," including that related to "air, water, soil, conservation, habitat, vegetation or animal species." *Id.* §6-3-414(e)(iv).
102. *Compare id.* §6-3-414(d)(i) (2015) (establishing the maximum penalty for a first-time violation to include a possible one-year prison sentence and a fine of $1,000), *with id.* §6-3-303(b) (2016) (maximum six-month jail sentence and a fine of $750). In addition, the new law removed the general requirement of knowledge that one was on private land to be guilty of trespass. *Compare id.* §6-3-303(a) (requiring actual knowledge or notice), *with id.* §6-3-414(a) (lacking such a requirement). The civil section authorized recovery of litigation costs, which are not generally recoverable. *Id.* §40-27-101(d).
103. This somewhat odd wording was tailored to fit the original allegation that WWP had trespassed on private land in order to reach the public land where it took samples. *See* Justin Pidot, *Forbidden Data: Wyoming Just Criminalized Citizen Science*, Slate, May 11, 2015, https://slate.com/technology/2015/05/wyoming-law-against-data-collection-protecting-ranchers-by-ignoring-the-environment.html.
104. *See* Emma Gannon, *Wyoming Criminalizes Citizen Science*, Courthouse News Service, May 18, 2015 (quoting Rep. Marti Halverson: "When a person trespasses to collect resource data, that person is not only trespassing—he is stealing data that is the property of the landowner."), https://www.courthousenews.com/wyoming-criminalizes-citizen-science/.
105. Pidot, *supra* note 103; Gregory Nickerson, *Data Trespassing Bill Is Aimed at Public Lands Grazing Battle*, WyoFile, May 19, 2015, https://www.wyofile.com/data-trespassing-bill-is-aimed-at-public-lands-grazing-battle/. Indeed, Wyoming legislators referred to WWP and the other groups involved in the trespass controversy as "activists," "extremists," "nefarious," and "evil," and one senator described the incident that prompted the legislation as an "attack on property rights" by "a group of people that don't necessarily see [things] the same way." Complaint for Declaratory and Injunctive Relief at 4, Western Watersheds Project v. Attorney Gen., No. 15-CV-169-S (D. Wyo. Sept. 29, 2015).
106. The law was amended in an attempt to defeat the legal challenge; *see* Wyo. Stat. §§6-3-414, 40-27-101 (2016). The changes narrowed the scope of the law by eliminating a reference to "open lands" and removing the phrase "submitted or intended to be submitted to any agency of the state or federal government" from the definition of "resource data." This did not, however, succeed in avoiding the constitutional issue.
107. *See* Western Watersheds Project v. Michael, 196 F. Supp. 3d 1231 (D. Wyo. 2016), *rev'd*, 869 F.3d 1189 (10th Cir. 2017).
108. Western Watersheds Project v. Michael, 869 F.3d 1189 (10th Cir. 2017). Finding that the statutes at issue targeted the "creation" of speech by imposing heightened penalties on those who collect resource data, the court reasoned that the laws' concern with private property did not defeat the need for First Amendment inquiry. *See id.* at 1194-98 (citing Sorrell v. IMS Health Inc., 564 U.S. 552, 570 (2011) ("[T]he creation and dissemination of information are speech within the meaning of the First Amendment."); Watchtower Bible & Tract Soc'y of N.Y., Inc. v. Village of Stratton, 536 U.S. 150, 166 (2002) ("[That] a citizen must first inform the government of her desire to speak to her neighbors and then obtain a permit to do so [is] a dramatic departure from our national heritage and constitutional tradition.")). The court also noted that a challenge characterizing Wyoming's general trespass statute as impairing the advocacy groups' right to gather information likely would have been unsuccessful; rather, it is the fact of differential treatment under the contested statutes that poses constitutional "creation of speech" concerns. *See* Zemel v. Rusk, 381 U.S. 1, 17 (1965) ("[T]he right to speak and publish does not carry with it the unrestrained right to gather information.").
109. *Western Watersheds Project*, 869 F.3d at 1192.
110. Western Watersheds Project v. Michael, 2018 WL 5318261, 48 ELR 20186 (D. Wyo. Oct. 29, 2018).

were not raised in the appeal from the original district court ruling, remain in effect, however.[111]

Although the Wyoming law is unique to date, it builds upon so-called ag-gag statutes that criminalize the undercover filming or photography of activity on industrial farms.[112] Although such laws have similarly been struck down on constitutional grounds in Idaho[113] and Utah,[114] they remain on the books in six other states.[115] In a January 2019 summary judgment order, a federal district court in Iowa struck down on First Amendment grounds an Iowa statute that made it a serious misdemeanor to gain access to agricultural property by false pretenses or to provide false information on an employment application at an agricultural production facility.[116] This decision indicates that conducting monitoring activities from public property is likely well within the scope of First Amendment protection.

These examples suggest that courts will look skeptically on laws that explicitly seek to punish the gathering of data by members of the public. Nevertheless, such laws continue to emerge, and even portions of the Wyoming statute remain in effect.

❑ *Limiting use of invasive technology*. New technologies now enable a range of monitoring activities that allow for data collection even without physical entry onto target lands. In particular, drones and other aerial sensor devices are increasingly efficient and affordable for civilian use, and facilitate both intentional and unintentional discovery of environmental violations.[117] In 2011, for example, a drone hobbyist accidentally documented massive unfiltered discharges of animal blood from a Dallas, Texas, meat packing plant into a nearby river.[118] After uncovering the incriminating images among his personal photographs, the individual submitted the evidence to state and federal authorities triggering a compliance investigation resulting in multiple charges.[119]

Some states (including Texas) have now enacted legislation providing enhanced legal protection of property containing critical infrastructure such as petroleum refineries, nuclear facilities, and chemical and rubber manufacturing facilities.[120] While such laws reflect in part legitimate concerns about public safety and security, they have implications for environmental groups using such technology.[121] Companies have also successfully petitioned the courts for injunctions preventing environmental groups from disrupting operation of critical infrastructure facilities.[122]

As the widespread use and technological capability of devices such as drones and high-definition and infrared cameras increases, issues of privacy and trespass will continue to shape the legal landscape of citizen science data collection.[123]

❑ *Strategic lawsuits against public participation*. Finally, citizen scientists may be faced with lawsuits brought by parties who feel threatened by their activities, asserting claims such as defamation or libel, interference with a business interest, nuisance, or intentional infliction of emotional distress.[124] Some of these suits are commonly referred to as "strategic lawsuits against public participation" (SLAPPs).[125] The aim of such suits is not to prevent the gathering of data directly, but to intimidate advocates by subjecting them to the expense and stress of litigation.[126]

Even where these suits are unsuccessful on the merits, they can drain the limited resources of citizen and advocacy groups.[127] Thirty-two states have enacted anti-SLAPP

111. Portions of the law remaining in effect include those providing enhanced penalties for trespass where data are gathered on private land, prohibiting the use of such data in court, and requiring state agencies to expunge such data from their records. Wyo. Stat. Ann. §6-3-414(a), (f), (g). The holdings in these cases would seem to cast doubt on the constitutionality of those provisions as well.
112. *See* Mark Bittman, *Who Protects the Animals?*, N.Y. Times: Opinionator, Apr. 26, 2011 (coining the phrase "ag-gag" in reference to the effect of such laws upon whistleblowers of animal rights abuses at farming facilities), https://opinionator.blogs.nytimes.com/2011/04/26/who-protects-the-animals.
113. *See* Animal Legal Def. Fund v. Wasden, 878 F.3d 1184, 48 ELR 20005 (9th Cir. 2018) (holding that Idaho statute criminalizing entry into agricultural production facility by misrepresentation violated the First Amendment, but that criminalizing obtaining records of such a facility by misrepresentation did not).
114. *See* Animal Legal Def. Fund v. Herbert, 263 F. Supp. 3d 1193 (D. Utah 2017) (finding the statute unconstitutionally overbroad).
115. These include Alabama, Arkansas, Iowa, Kansas, Missouri, and North Carolina. *See* The Humane Society, Does My State Have Big-Ag Laws? (2018), http://www.humanesociety.org/sites/default/files/docs/does-my-state-have-big-ag-laws.pdf.
116. Animal Legal Def. Fund v. Reynolds, 2019 WL 140069, 49 ELR 20007 (S.D. Iowa, Jan. 9, 2019).
117. *See* Lucas Satterlee, *Climate Drones: A New Tool for Oil and Gas Air Emission Monitoring*, 46 ELR 11069, 11079 (Dec. 2016).
118. *See* John Villasenor, *Observations From Above: Unmanned Aircraft Systems and Privacy*, 36 Harv. J.L. & Pub. Pol'y 457, 506 (2013).
119. *Id*. The charges were later dropped after a county Health and Human Services investigator trespassed on company property while collecting samples. *See* Eric Nicholson, *Craig Watkins Reportedly Dropped Trinity Pig Blood Case Over Trespassing Investigator*, Dallas Observer, May 15, 2014, http://www.dallasobserver.com/news/craig-watkins-reportedly-dropped-trinity-pig-blood-case-over-trespassing-investigator-7134409.
120. *See* Harvard Law Sch. Emmett Envtl. Law and Policy Clinic, A Manual for Citizen Scientists Starting or Participating in Data Collection and Environmental Monitoring Projects 36 (2017) [hereinafter Citizen Science Manual].
121. *Id. See generally* Dow Chem. Co. v. United States, 476 U.S. 227, 16 ELR 20679 (1986).
122. *See* Shell Offshore, Inc. v. Greenpeace, Inc., 2015 WL 2185111, 45 ELR 20071 (D. Alaska May 8, 2015), *appeal dismissed as moot*, 815 F.3d 623, 46 ELR 20053 (9th Cir. 2016) (prohibiting Greenpeace from using drones to protest over Shell's planned offshore drilling site in the Arctic).
123. Other legal doctrines likewise impose relevant limits on an individual's ability to gather data, such as laws prohibiting stalking, loitering, and destruction of property. *See* Citizen Science Manual, *supra* note 120, at 30.
124. *See* Robert T. Sherwin, *Ambiguity in Anti-SLAPP Law and Frivolous Litigation*, 40 Colum. J.L. & Arts 431, 436 (2017).
125. George W. Pring, *SLAPPs: Strategic Lawsuits Against Public Participation*, 7 Pace Envtl. L. Rev. 3, 4 (1989).
126. *Id*. at 6.
127. *See* James M. Redwine, *Does It Hurt to Get Slapped: A Study of the Perils of Citizen Involvement*, 32 Nat. Resources & Env't 15, 17 (2017). In 2000, for example, a hog producer in Nebraska sued two local individuals for defamation after they filed written comments concerning the operation's environmental record with state regulators. Sand Livestock Sys., Inc. v. Svoboda, 756 N.W.2d 299 (Neb. Ct. App. 2008). In a 2006 case, after environmental organizations campaigned in the Michigan Legislature to restrict the use of a pharmaceutical chemical, a pharmaceutical company sued, alleging defamation, tortious interference with business, trade disparagement, and decep-

statutes that seek to curtail abusive and baseless actions.[128] However, many analysts question the efficacy of such laws and predict that the threat of frivolous litigation will continue to deter political participation by advocacy groups.[129]

III. What Does Citizen Science Look Like? Ten Case Studies

Relatively little has been done to assess the experience of citizen scientists in the field, and in particular to evaluate what seems to be working (or not working) in their efforts to influence government agencies. As a first step toward filling this gap, we conducted interviews with a variety of organizations engaged in citizen science, completing a total of 10 case studies.[130] These case studies are not a random sample of citizen science initiatives. Rather, they represent examples from the NACEPT report and from other examples that have come to the authors' attention, selected to reflect the diversity of citizen science activities. They include a balance of air and water examples, as well as one involving a toxic substance.[131]

The groups we studied varied widely

- in focus, including projects focusing on air and water pollution, and one focused on toxic chemical exposures,
- in size, from large statewide or regional efforts to small projects targeting local problems,
- in approach, from projects working closely with agencies to those acting independently and even adversarially, and
- in the role of professional scientists, from projects designed and led by professionals to those led by citizen scientists with assistance from scientists.

A. *Citizen Science and Air Pollution*

Four of the case studies involve monitoring of air pollution.

1. Air Alliance Houston: Tracking Air Quality in a Low-Income Neighborhood

Air Alliance Houston (AAH) was formed in 1988 to combat the city's smog problem. In 2011, AAH purchased monitors to assess air quality in areas where government monitors were not present. It wanted to find out whether it could detect variations in air quality that the regulatory monitors (which are fewer in number) might miss. Although the regulatory monitors are highly sophisticated in the low-income neighborhood of Galena Park that was the focus of AAH's study, there is only one agency-maintained monitor compared to the five sampling sites used by AAH. AAH found significant levels of particulate pollution in Galena Park, such as in areas adjacent to highways.[132]

To enhance the credibility of its study, AAH worked with the monitor's manufacturer and with experts at Rice University to select its monitors, and design and carry out the study. The results were analyzed in a certified laboratory.

An opportunity to use this data presented itself in 2014 when EPA invited public comment on whether particulate pollution in Houston exceeded the recently revised NAAQS for $PM_{2.5}$.[133] EPA proposed finding Houston in attainment with the new standards, based on data from the official network of regulatory monitors.

AAH, together with the Sierra Club, submitted a comment to EPA containing the results of its research in Galena Park, arguing that the results from the state's single monitor in the vicinity of Galena Park were not representative of that community, and that its results from five other locations showed the standard was often being exceeded in that community.[134] Based on that data, AAH and the Sierra Club urged EPA to conduct further monitoring in Galena Park.

However, EPA stood by its original finding and designated Houston as in attainment with the $PM_{2.5}$ standard. It acknowledged the data submitted by AAH, but noted that the monitors were not federal reference methods, and that the sampling by AAH did not occur over the full three-year period that EPA uses to make attainment designations.[135] EPA did not conduct further monitoring before making a final attainment designation.

Understandably, the staff at AAH found this response frustrating. They had invested many months in gathering data, working with academic experts to make it as reliable as possible. They felt that the monitors provided reliable information on a much more detailed scale than was possible with the Agency monitors, and that they were of good

tive trade practices. *See* Morton Grove Pharms., Inc. v. National Pediculosis Ass'n, No. 08-C-1384 (N.D. Ill. 2008). After two years of active litigation, the case settled without any reassignment of legal fees.

128. *See*, *e.g.*, Public Participation Project, *State Anti-SLAPP Laws*, https://anti-slapp.org/your-states-free-speech-protection (last visited Jan. 2, 2019).

129. *See* Redwine, *supra* note 127, at 17-19; Sherwin, *supra* note 124, at 467-68.

130. The full case studies are on file with the authors. Interviews were conducted by phone between August 2017 and May 2018.

131. Our examples did not include wildlife and biodiversity studies, which are also an important focus of work by citizen scientists. *See* Stepenuck & Genskow, *supra* note 25.

132. *See* AAH & Global Community Monitor, Air Pollution and Public Health in Galena Park, Texas (2014).

133. This proposal followed on the promulgation of a revised (lower) standard for $PM_{2.5}$ that EPA had issued in 2013. 78 Fed. Reg. 3086 (Jan. 15, 2013). When EPA issues a new standard, it then reviews available data nationwide to determine which areas have pollution exceeding that standard.

134. Letter From Al Armendariz, Senior Campaign Representative, Sierra Club, and Adrian Shelley, Director, AAH, to Mary Henigin, Acting Director, Office of Air Quality Planning and Standards (Sept. 29, 2014), https://www.regulations.gov/document?D=EPA-HQ-OAR-2012-0918-0295. AAH argued that the results from the single monitor in the area were not representative because steps had been taken to reduce pollution in the vicinity of that monitor (which is near, but not in, Galena Park), and that those steps did not benefit Galena Park itself. AAH and the Sierra Club also argued that EPA's method of calculating pollution levels was inappropriate because it excluded data from exceptional events.

135. U.S. EPA, Responses to Significant Comments on the State and Tribal Designation Recommendations for the 2012 Annual $PM_{2.5}$ National Ambient Air Quality Standard (NAAQS) 57 (2014).

enough quality to raise questions that at least warranted a closer look before a determination was made.

2. Clean Air Carolina: Enhancing State Monitoring

Another citizen science effort focusing on air quality attainment is being carried out by Clean Air Carolina (CAC), based in Charlotte, North Carolina. Since 2016, CAC has been running a citizen science initiative called AirKeepers to monitor local levels of $PM_{2.5}$ pollution, using low-cost, mobile air monitors. This effort was launched to supplement the state's monitoring network, which had been reduced in size by the state legislature as a cost-cutting measure. Concerned about this reduction in the state's monitoring capacity, CAC worked with experts at EPA, University of North Carolina at Charlotte, and elsewhere to identify and validate reliable, low-cost monitors and design a reliable study.

CAC is able to use multiple low-cost monitors in areas where the state has been determining air quality through the use of a single, high-quality monitor. In this way, CAC can measure conditions in many locations throughout a city or county (although with less precision than the reference monitor), allowing it to measure air quality on a smaller geographic scale than the state agency.

CAC's first monitors were put in place in 2017; by mid-2018, it had 85 monitors in place across 35 counties. Hurricane Florence slowed progress, but CAC hopes to have at least one monitor in place in each of the state's 100 counties by Earth Day 2019. Data from the sensors are uploaded to websites allowing public viewing of the results.[136]

In addition to enhancing the state's official monitoring network, the project is improving the information available to the state and other public entities, and making additional data available for use in research. CAC also hopes that providing quality data will help mobilize members of the public with regard to specific local issues such as facility permitting. It hopes that, ultimately, data from its sensors might persuade the state to increase the number of official monitors.

3. Redeemer Community Partnership (Los Angeles): Monitoring a Local Nuisance

The AAH and CAC groups focused on ambient air quality. In contrast, the Redeemer Community Partnership (RCP), a faith-based group that works on social and community issues in a low-income south Los Angeles neighborhood, is focused on the potential health impacts of a specific pollution source: an operating oil and gas production site.[137] Under a project manager with a public health degree, RCP has partnered with academic institutions to design studies that measure the health impacts of the facility.

To select monitors and design its research, RCP worked with academic experts at the University of Southern California, Occidental College, and the University of Colorado (CU). In 2015, RCP worked with the CU researchers to deploy a small number of monitors in the community for six weeks while also surveying local residents for reports of adverse health events. The monitoring data found a correlation between heavy activity observed at the site and higher levels of pollutants compared to the ambient environment.[138]

Later that same year, RCP deployed more than a dozen monitors throughout the neighborhood. The data analysis is nearly complete, and RCP expects to publish another paper on the effectiveness of low-cost monitors to detect local-level pollution impacts of the extraction facility. Currently, RCP is working on setting up another study to compare air quality readings with community reporting of health complaints. It is also planning to equip local residents to use an app referred to as a FracTracker to make similar comparisons.

RCP's ultimate aim is to pressure the city to restrict or terminate the facility using its land use control and public health authorities, which are broader and more open-ended than CAA regulations.[139] Its ongoing research seeks to demonstrate health impacts that would provide a basis for such action.

4. Citizens for Clean Air (Alaska): Showing the Need for Regulatory Scrutiny

Fairbanks, Alaska, has one of the highest levels of particulate pollution in the country[140]—well above national standards—primarily because 17,000 homes in the area rely on wood stoves for heating.[141] Citizens for Clean Air (CCA) is seeking to make environmental agencies and the local government recognize the extent of the problem. Its primary achievement to date has been to persuade EPA to accept data from a monitor that had been set up by the local borough and use that information for regulatory purposes. EPA had been skeptical of the readings at that monitor because they seemed too high.

136. CAC, *Airkeepers*, https://cleanaircarolina.org/airkeepers (last visited Jan. 2, 2019).

137. *See* RCP, *Make Jefferson Beautiful Campaign*, https://www.redeemercp.org/make-jefferson-beautiful (last visited Jan. 2, 2019).

138. The study results were published in Bhavna Shamasunder et al., *Community-Based Health and Exposure Study Around Urban Oil Developments in South Los Angeles*, 15 Int'l J. Envtl. Res. & Pub. Health 138 (2018).

139. In October 2017, the city made a zoning determination that imposed more stringent rules on the operation of the facility. RCP's data were not ready at the time of that decision, which was based on community testimony and other grounds. However, RCP continues to gather data in the hope of achieving further restrictions. (Interview with Niki Wong, Director of Policy & Organizing, RCP (Jan. 23, 2018)).

140. *See U.S. Cities With the Worst Air Pollution*, CBS News (listing Fairbanks as the U.S. city with the worst annual particulate pollution), https://www.cbsnews.com/pictures/air-pollution-worst-us-cities-2018/18/ (last visited Jan. 2, 2019).

141. Particulates are also emitted by burning tires and garbage, but wood stoves and wood boilers are the primary sources.

To persuade EPA, CCA carried out its own air quality study, using lower-cost monitors. It worked with the University of Alaska and MetOne, a manufacturer of monitoring devices, to select appropriate devices and locate them at a variety of locations in the Fairbanks area. To address concerns that these devices might not function properly under Arctic conditions, the group placed one of its monitors next to an official regulatory monitor. The results of the study showed that the very high particulate matter levels that had been reported earlier by the borough's monitor were accurate.

This demonstration satisfied EPA that the readings in the original monitor were reliable, and EPA agreed to consider future readings from that monitor for official air quality assessment purposes. An additional benefit of CCA's study was to persuade the local government to take action against an individual polluter, based on the data from its sensors.

B. *Citizen Science and Clean Water*

A second set of case studies involved efforts to monitor water quality.

1. Monitoring the Chesapeake Bay: A Multiparty Effort

The potential role of citizen scientists in informing critical regulatory decisions on clean water is well illustrated by the complex efforts under way to restore the Chesapeake Bay. Many federal, state, and local agencies are involved, as well as a plethora of nonprofit and public interest groups.

Because the problems of the Chesapeake are so complex, and the degree of public interest is so great, systems have been set up to support and capitalize on the work of citizen scientists. Organizations ranging in size from small bands of volunteers to nonprofits with a large paid staff gather data on water quality. To varying degrees, states have established programs to use the monitoring data from some of these groups in their statutory reports used in determining which water bodies are impaired. EPA's Chesapeake Bay Program also uses citizen science data for other less formal purposes, such as its report card on cleanup progress. Finally, two nongovernmental organizations help build capacity in citizen groups and assist states that do not have their own volunteer coordinators.

The primary way in which citizen-generated data can influence regulatory decisions relating to the Chesapeake is through its use in the integrated reports on water quality that are submitted by the states biennially under §§303(d), 305(b), and 314 of the CWA.[142] These reports are central to determining which water bodies are considered impaired and in establishing requirements for compliance with the Chesapeake TMDL.[143]

The states in the Chesapeake Bay Watershed use citizen-generated data in different ways. Some have established programs designed to facilitate the use of citizen-generated data and include the data in their integrated reports.[144] Others work with groups less formally, and accept data but generally use it for secondary purposes, such as identifying water bodies that will be monitored by the state. Data not used in the integrated reports can also be used by EPA's Chesapeake Bay Program as part of its report card on the Bay, which does not have legal effect but serves as an accountability measure under the interstate agreement that governs the cleanup effort.

One group of citizen scientists providing data for CWA reporting is the Nanticoke Watershed Alliance (NWA), based in Vienna, Maryland. The NWA's Creekwatchers Program was formed in 2008, at the encouragement of the Delaware Department of Natural Resources and Environmental Control (DNREC). DNREC provided a grant to start the program (and continues to provide financial support), and helped it write its first study design.

Today, the program has 40 volunteers who monitor at many locations in the Nanticoke River and its tributaries. The sampling is done pursuant to a quality assurance project plan that is approved annually by DNREC, the Maryland Department of the Environment, and EPA. Samples collected by volunteers are taken to laboratories that return the data to NWA. At the end of the year, NWA submits the data to the states of Delaware and Maryland, who may use it in their integrated reports.

Although NWA's work primarily relates to monitoring ambient conditions, it sometimes identifies local compliance issues as well. On one occasion, it found data showing high bacterial counts near a poultry rendering plant. Concerned about this, it submitted that information to the state as an indicator of a problem that might require closer investigation. Because NWA does not consider itself an advocacy group, it did not act on the data itself; rather, it forwarded the data to other groups who might be more likely to take action.

Another group whose data are regularly used for regulatory purposes is the Friends of the Shenandoah River (FOSR), based in Winchester, Virginia.[145] Founded in 1989, FOSR has 80 volunteers who collect water samples at 150 sites throughout the Shenandoah Watershed. FOSR has its own accredited laboratory to test samples, the only

142. 33 U.S.C. §§1313(d), 1314, 1315(b).

143. *See* American Farm Bureau Fed'n v. Environmental Prot. Agency, 792 F.3d 281, 45 ELR 20129 (3d Cir. 2015) (upholding the Chesapeake Bay TMDL).

144. *See*, *e.g.*, Virginia Department of Environmental Quality, *Citizen Water Quality Monitoring*, http://deq.state.va.us/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/CitizenMonitoring.aspx (last visited Jan. 2, 2019); Maryland Dep't of the Env't, Maryland's 2016 Integrated Report of Surface Water Quality (2017), *available at* https://mde.maryland.gov/programs/Water/TMDL/Integrated303dReports/Pages/2016IR.aspx.

145. *See* NACEPT I, *supra* note 22, at 34.

one in the Chesapeake region that is run by a citizen scientist organization. The data generated by the FOSR meet Virginia's data quality requirements and are included in the state's integrated reports under the CWA.

States play a critical role in facilitating the use of citizen-generated data. Virginia has the most robust volunteer monitoring program in the Chesapeake Watershed. In 2016, more than 20% of the data in the state's integrated report came from citizen scientists.[146] Maryland actively solicits data from external sources, including citizen groups, and uses data in its integrated report if the data quality is found to be adequate. However, it does not work with groups throughout the process to the extent that Virginia does. Until 2009, Pennsylvania had a volunteer monitoring program that provided assistance to citizen groups, but it ended due to budget cuts. Some assistance is still provided to groups such as the Senior Environmental Corps (SEC) (see below), but the state does not use such data in its integrated report.[147] It does use data for screening and trend analysis to identify areas in which there have been significant changes in water quality.

Other systems help to build capacity for citizen science in the Chesapeake region. In 2017, EPA's Chesapeake Bay Program established a certification system for citizen groups gathering water quality data in the Chesapeake region. Data from groups certified at the highest level qualify for inclusion in the integrated reports. This program is still in its early stages and at the end of 2017, only a small number of groups had achieved such certification.[148]

In addition, two nongovernmental groups assist smaller local organizations in developing the expertise to provide high-quality data. The Chesapeake Monitoring Cooperative (CMC) trains local groups and certifies them against the Chesapeake Bay Program's standards in the District of Columbia, Maryland, and West Virginia.[149] The Alliance for Aquatic Resource Monitoring (ALLARM), at Dickinson College, provides training and technical support for local groups where the state does not do so.[150] Originally formed as a home for projects designed and led by professional scientists, ALLARM has placed increasing emphasis on mentoring grassroots efforts. For example, it reviews local groups' study designs and provides protocols to use in studying issues such as fracking. It certifies groups for the Chesapeake Bay Program in New York and Pennsylvania. Both CMC and ALLARM work with local governments as well to encourage consideration of citizen-generated data.

Thus, in contrast to the air pollution efforts described earlier, the work of citizen scientists is well integrated into the initiative to restore the Chesapeake Bay.

2. Senior Environmental Corps (Pennsylvania)

The SEC is a volunteer organization with local units in 24 counties across Pennsylvania.[151] It has been in existence for more than 10 years. SEC has been doing water quality monitoring under an agreement with the Pennsylvania Department of Environmental Quality (PDEQ) and the Pennsylvania Department on Aging. Although Pennsylvania's formal program was terminated, PDEQ still provides a grant to support the SEC and approves its quality assurance project plan every two years. SEC collects water samples once a month (and samples for macroinvertebrates twice a year). It does monitoring statewide.

SEC provides a contrast with the groups discussed above in that, in addition to informing water quality determinations, it has discovered and reported local water quality problems that may lead to enforcement or other agency action. Because SEC has established a long-standing record of measuring water quality, it can detect unusual departures from that baseline. When such departures are found, PDEQ can investigate to fully understand what is going on.

For example, in 2010, SEC was able to measure the impact of a blowout at a fracking well, on the basis of which the state brought an enforcement action against the owner of the well. In another case, SEC volunteers at the Philadelphia Center in the Park discovered high levels of *E. coli* in Monoshone Creek, indicating that raw sewage was being discharged from a wastewater treatment facility. When this information was reported to the Philadelphia Water Authority, the agency undertook a million-dollar program to repair leaking pipes.[152]

3. Nebraska Watershed Network: Large-Scale Campaigns

The Nebraska Watershed Network (NWN), based at the University of Nebraska-Omaha,[153] represents a different model. Between 2011 and 2017, NWN carried out more than 10 large-scale citizen science campaigns, involving hundreds of volunteers across multiple states, aimed at assessing water quality, primarily in the Mississippi

146. Virginia Dep't of Envtl. Quality, 2017 Citizen and Non-Agency Monitoring Activity Report (2018).

147. According to DEQ, this is because the sampling protocols used by volunteer groups are less sophisticated than those the state uses, involving kits that do not require laboratory analysis. Officials working with citizen groups expressed frustration at the reluctance of water quality staff to consider data that did not follow its usual protocols even though it was collected and analyzed under a rigorous QAPP.

148. Interview with Liz Chudoba, Water Quality Program Manager, Chesapeake Monitoring Cooperative (Jan. 18, 2018).

149. *See* Alliance for the Chesapeake Bay, *Chesapeake Monitoring Cooperative*, https://www.allianceforthebay.org/our-work/key-program-focuses/building-stewardship/chesapeake-monitoring-cooperative/ (last visited Jan. 2, 2019).

150. *See* Dickinson College, *Alliance for Aquatic Resource Monitoring (ALLARM)*, https://www.dickinson.edu/allarm (last visited Jan. 2, 2019).

151. *See* SEC, *Home Page*, https://www.secofusa.org/ (last visited Jan. 2, 2019). Information on SEC obtained in an interview with Melinda Hughes, of Nature Abounds, on December 29, 2017. SEC is a part of Nature Abounds.

152. *See* Marcia Siegal, *Senior Volunteers Prompted $1 Million-Plus Emergency Repair*, Phila. Corp. for Aging, Apr. 12, 2016, http://www.pcacares.org/blog/senior-environment-corps-discovery-prompted-1million-plus-emergency-repair/.

153. NWN ceased operation in 2017 after its director, Prof. Alan Kolok, relocated to another state. However, its model is unique enough to warrant a close examination here.

and Missouri Rivers. These efforts focused especially on atrazine, the second most heavily used herbicide in the United States and a significant pollutant of water bodies in agricultural regions. These efforts began when its director learned that it was possible to determine the level of atrazine in surface water at very low cost and with volunteer labor, by using paper strips rather than the traditional approach of taking samples and conducting laboratory analysis. Campaigns have ranged from local- or state-level efforts to testing across the entire Mississippi River, from Minnesota to Louisiana.

To ensure that strips were read consistently and accurately, NWN trained volunteers using videos and conducted focus groups. It also provided the option to submit photos of strips, if the volunteer was uncertain about the reading.

These campaigns have generated a large volume of data, maintained in a publicly available database. The data are used by researchers, and in science, technology, engineering, and mathematics (STEM) education. Data from the campaigns are also submitted to a national database maintained by the Consortium of Universities for the Advancement of Hydrologic Science (CUAHSI).[154]

Although it was NWN's ultimate expectation that its data would inform officials such as legislators, state agencies, and local water suppliers, it did not make a concerted effort to approach that audience. Rather, it focused first on establishing the scientific validity of its approach by presenting the results at scientific conferences and in scientific publications,[155] as well as carrying out educational and public information efforts.

4. The Potomac Riverkeeper: Using Data in Litigation

The Potomac Riverkeeper, a local branch of the national Waterkeeper Alliance,[156] regularly engages in litigation against polluters. Citizen science sometimes plays a role in these cases. In one instance, Riverkeeper staff investigated a coal ash storage pond at the Dominion Power facility in Possum Point, Virginia. After seeing what appeared to be leaks in the pond, the staff collected samples from nearby locations in the Potomac River, which revealed high levels of toxic metals. On the basis of that data, the Riverkeeper sent Dominion a notice of intent to file a citizen suit under the CWA.[157]

The threat of litigation (from a sophisticated and competent organization) was sufficient to persuade Dominion to negotiate new measures to control the runoff from the coal ash pond. In addition, the information provided by the Riverkeeper was sent to the state that was in the process of renewing Dominion's CWA permit. As a result, the new permit required steps to prevent future releases. Thus, the Riverkeeper organization was able to put pressure on the state to address concerns that would otherwise become the subject of litigation, and Dominion had an incentive to agree to the permit terms rather than face a lawsuit.

As noted earlier, data collected through citizen science would have to meet rigorous standards to be admissible in litigation.[158] The Riverkeeper anticipated that, if the Dominion case were litigated, more detailed sampling and analysis would be required. Such sampling might be done by technical experts. Since the case did not reach that point, the case study does not shed light on the admissibility issue.

5. Western Watersheds Project: Taking on the Livestock Industry

WWP, based in Idaho, focuses on the impact of livestock grazing on public lands. The work of its Wyoming office has become controversial and led to the legislation discussed above.[159]

WWP's monitoring in Wyoming focuses on measuring concentrations of *E. coli* in streams affected by livestock. WWP is the smallest of the groups described here; most of its sampling was conducted by a single staff member in the Wyoming office. However, WWP is not unsophisticated; it developed a research design or quality assurance project plan that was approved by the Wyoming Department of Environmental Quality (WDEQ).

Beginning in 2008, WWP began submitting its data to the state for consideration in listing streams as impaired. The state agency initially refused to accept the data, but the state used a later round of data in its integrated report for 2012. On the basis of that data, the state declared three water bodies to be impaired.

However, in 2014, the state reversed its impairment determination because after further investigation, it concluded that the sampling device being used by WWP was not acceptable because it was not a recognized commercial product but a homemade device.[160] Although the WDEQ did not consider WWP's data acceptable for use in the integrated report, it does use that information in planning and prioritizing its own monitoring. Therefore, the work of WWP, if continued, could impact future water quality findings.

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154. *See* CUAHSI, *Home Page*, https://www.cuahsi.org/ (last visited Jan. 2, 2019).
155. Contributions to the scientific literature growing out of the work of NWN include Alan Kolok et al., *Empowering Citizen Scientists: The Strength of Many in Monitoring Biologically Active Environmental Contaminants*, 61 BioScience 626 (2011), and Jonathan Ali et al., *Citizen-Based Scientific Data Collection: Fact or Fiction?*, 12 Integrated Envtl. Assessment & Mgmt. 400 (2016).
156. *See* Waterkeeper Alliance, *Home Page*, https://waterkeeper.org (last visited Jan. 2, 2019).
157. Telephone Interview with Philip Musegaas, Vice President of Programs and Litigation, Potomac Riverkeeper (Jan. 12, 2018).
158. *See supra* Section II.B.3.
159. *See supra* Section II.B.4.
160. Telephone Interview with Wyoming DEQ Staff (Mar. 6, 2018). *See* Mike Koshmrl, *State Scraps E. Coli Data*, Jackson Hole News & Guide, Aug. 12, 2015, https://www.jhnewsandguide.com/news/environmental/article_90e8a50a-0f0e-51bb-aa81-d85b0cbccaa1.html.

C. Citizen Science and Exposure to Toxics

Most of the examples discussed here involve citizen research on air or water pollution. One exception is the Gardenroots project in Arizona, which studied the exposure of residents to harmful chemicals—in particular, arsenic—through several exposure pathways.

In 2008, EPA placed the Iron King Mine and Humboldt Smelter site, in Dewey-Humboldt, Arizona, on the Superfund national priorities list.[161] At a public meeting held by EPA, local residents expressed concern that they might be exposed to arsenic contamination from the site through the soil in their gardens.

One of those attending the meeting was Monica Ramirez-Andreotta, then a graduate student at the University of Arizona and a coordinator at the university's Superfund Research Center. After hearing the residents' concerns, she contacted them to organize and carry out a study to find out whether locally grown food was contaminated and, if so, how much was safe to eat. The resulting effort grew into what is now the Gardenroots project.[162]

More than 40 residents responded to a call for volunteers. Ms. Ramirez-Andreotta developed the sampling and analysis protocol, but the residents participated in the research design—selecting locations and the timing of data collection to match the growing season. Residents were also trained to collect soil, water, and vegetable samples. Those samples were delivered to the university's cooperative extension office, which sent them to a laboratory for analysis. Although the focus was on food safety, the study looked at other exposure pathways such as drinking water.

Funding for the project was provided by a grant from EPA, and EPA staff were kept informed of progress, but EPA did not direct the research or influence the research design.

The results showed that residents were exposed to arsenic in three ways: in drinking water, through incidental soil ingestion, and by eating vegetables from their gardens. Of the three exposure routes, arsenic exposure was greatest from drinking water, followed by incidental soil ingestion and vegetables. Many of the vegetables that participants were growing in their home gardens had higher arsenic concentrations than those reported in the 2010 U.S. Food and Drug Administration Total Diet Study.[163]

These findings shifted the focus of the effort. While information on locally grown vegetables was useful, Ms. Ramirez-Andreotta expanded her work to include educating residents on monitoring and treating local well water. In addition, the community took the data to EPA and the Arizona Department of Environmental Quality, which investigated the local drinking water supply system and concluded that arsenic levels exceeded Safe Drinking Water Act[164] standards. The drinking water supplier received a notice of violation and a fine for the violation.

In 2015, Dr. Ramirez-Andreotta, now an assistant professor at the University of Arizona, established the Gardenroots project that carries out similar research at multiple sites in three counties across Arizona, emphasizing Superfund and resource extraction sites. The number of people trained to do data gathering now exceeds 100 residents. Her work has also expanded to Pennsylvania, where she was asked by the Southeast Pennsylvania Environmental Health Working Group to study the impact of fracking, and northern California to study impacts of mining in the Sierra Nevadas. The research has also been published in academic publications.[165]

IV. What Do the Case Studies Tell Us About Citizen Science?

A. Citizen Science Takes Many Forms

Part I presented a spectrum of possible ways in which data generated by citizen scientists could be used, which was developed by an EPA advisory committee. As Table 1 shows, the work of the citizen scientists we studied touched on all parts of the spectrum but one.[166]

Thus, citizen science should not be regarded as monolithic. Rather, it is important in assessing the potential value or success of citizen science efforts to identify the purposes for which a citizen science effort is being or would be pursued.

B. Are Citizen Scientists Having an Impact?

The core question presented in this Article is whether citizen scientists are succeeding in having an impact on government decisions and actions, and why or why not. Given the diversity of the initiatives we studied, it is not surprising that the answers varied among the cases. However, important lessons can be taken from what we found.

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161. *See* 42 U.S.C. §9605(a)(8)(B) (requiring adoption and revision of that list).

162. *See* University of Arizona, *Gardenroots*, https://gardenroots.arizona.edu/ (last visited Jan. 2, 2019).

163. The Total Diet Study reports the levels of contaminants and nutrients in the average U.S. diet, from year to year. These reports do not represent a finding as to whether such exposures are harmful or safe. *See* U.S. Food and Drug Administration, *Total Diet Study*, https://www.fda.gov/food/foodscienceresearch/totaldietstudy/default.htm (last updated Feb. 23, 2018).

164. 42 U.S.C. §§300f to 300j-26, ELR Stat. SDWA §§1401-1465.

165. *See* Monica D. Ramirez-Andreotta et al., *Environmental Research Translation: Enhancing Interactions With Communities at Contaminated Sites*, 497 Sci. Total Env't 651-64 (2014), *available at* https://www.sciencedirect.com/science/article/pii/S0048969714011887?via%3Dihub; Monica D. Ramirez-Andreotta et al., *Building a Co-Created Citizen Science Program With Gardeners Neighboring a Superfund Site: The Gardenroots Case Study*, 7 Int'l Pub. Health J. 139-53 (2015); Monica D. Ramirez-Andreotta et al., *Analyzing Patterns of Community Interest at a Legacy Mining Waste Site to Assess and Inform Environmental Health Literacy Efforts*, 6 J. Envtl. Stud. & Sci. 1-13 (2015).

166. None of the cases we observed provided data for use in regulatory standard setting, one of the NACEPT categories. This may simply have been a result of examples that came to our attention. Furthermore, standard setting typically focuses on information about the health effects of exposure to pollution; citizen science efforts to measure ambient pollution would not address health impacts.

Table 1. Case Studies Mapped Across the NACEPT Spectrum

Uses of Citizen Science	Examples
Community Engagement	Most examples had elements of community engagement
Education	NWN; CAC; Chesapeake groups
Condition Indicator	AAH; CCA
Research	CAC; NWN; RCP
Management	CAC (placement of state monitors); CCA (placement of state monitors)
Regulatory Standard Setting	None
Regulatory Decisions	Chesapeake groups (impaired waters listing); SEC (prioritizing state monitoring for impaired waters); WWP (impaired waters listing); AAH (sought to influence attainment designation); RCP (land use controls and siting); Potomac Riverkeeper (influenced permit requirements)
Enforcement	Potomac Riverkeeper; Gardenroots

1. Management

Two of the cases illustrated the use of citizen science data in decisions about agency management and operations. In both cases, the result was to inform the placement of official monitors by state agencies, which then provide data for key regulatory decisions. For example, the Alaska-based group CCA considered obtaining official agency approval of a regulatory monitor in their community a major accomplishment. Similarly, one aim of CAC's statewide monitoring program is to demonstrate to the state of North Carolina the need to maintain additional regulatory air monitors.

2. Regulatory Decisions

Several examples showed the potential for citizen scientists to impact regulatory decisions. The most common example of regulatory use is in water quality programs, for purposes of the assessments that are used in determining which water bodies are considered impaired, and in developing TMDLs. Citizen-generated data can also inform agency actions that, while not regulatory in a legal sense, play a closely related role. For example, citizen science data that might not qualify for inclusion in an integrated report may still be used by EPA's Chesapeake Bay Program in rating progress against the goals and outcomes defined by states in the Chesapeake Bay Watershed Agreement, which drives future restoration efforts.

Where data are not used directly for regulatory purposes, they can be used to inform agency priorities and planning—for example, in decisions on where agencies will conduct their own monitoring. Even though data from WWP was determined by WDEQ not to be usable for an impairment finding, the state did report that it would consider that information in targeting watersheds for assessment. Similarly, Virginia's program states that data that do not qualify to be used in determining whether water bodies meet state standards can still be used to prioritize the state's own monitoring efforts.

3. Permitting

Since one of the strengths of citizen science is in providing more detail on local pollution levels, permitting is a likely application. Citizen science efforts are often driven by environmental justice concerns, and these frequently relate to siting and permitting. For example, the work of the RCP in Los Angeles is aimed at influencing local planning and zoning decisions relating to an industrial facility in a low-income neighborhood. The Potomac Riverkeeper's monitoring of coal ash storage at a power plant led to the inclusion of additional control requirements in the facility's CWA permit.

4. Enforcement

We also saw examples in which citizen science was used in enforcement. Although none of the cases involved use of citizen-generated data directly in court, there were examples in which citizen-generated data prompted agencies to conduct investigations of their own and, if necessary, take enforcement action. The SEC in Pennsylvania reported two such cases, one involving a fracking facility and one involving sewage discharges in Philadelphia. The Gardenroots project in Arizona discovered high arsenic levels in drinking water, which was reported to the state and led to a finding of a violation at the local water system. Interviews with states also confirmed that information from citizen monitoring efforts would sometimes lead to investigation and enforcement.[167] The NWA in Maryland, which primarily gathers data regarding impaired waters, reported a similar experience, although in this case it is not clear whether the state took action based on that data.

The Potomac Riverkeeper is unusual among the groups we studied in that it takes action against individual sources of pollution. In one instance, its staff did informal sampling that led to the discovery of leakage from a coal ash pond. Based on that data, it filed a notice of intent to bring a citizen suit. However, the issue was resolved without litigation.[168] Riverkeeper staff indicated that if it had been necessary to file suit, further sampling would most likely have been conducted by traditional experts.

5. Gap Filling

Finally, one role for citizen scientists is to fill gaps where the government is unable to act. For example, when North Carolina's Legislature reduced funding for air monitoring, CAC used lower-cost sensors to measure air quality statewide. The Gardenroots project received an EPA grant to carry out research that responded to concerns from members of the public, which the Agency did not have the ability to do itself.

C. Drivers

The examples we studied shed light on the drivers for the expansion of citizen science.

1. Advancements in Technology

Our case studies confirmed that the emergence of new technology has been tremendously empowering, sometimes in ways that were not anticipated. New monitoring technology was a critical factor in all of the case studies relating to air pollution. In all four cases, citizen scientists played a role that would not have been possible 10 years ago. Further, new technology makes it possible even for small organizations to generate credible data, enhancing their ability to interact with agencies.

Changing technology was less prominent in the case studies relating to water pollution. The nature of water sampling is such that even traditional technologies could be used by citizen scientists to generate data usable in regulatory decisions. While devices are changing (e.g., providing results without the need for laboratory analysis), the changes are more incremental.

Another product of new technology is the creation of online platforms to which data can be submitted and thus shared among researchers as well as made available to the public. NWN, for example, has an online database that collects information from the hundreds of individuals involved in its large-scale campaigns. This makes the data readily available not only to the researchers running the project, but also to the public at large. NWN also submits data to a central portal maintained by the CUAHSI.[169] Some states maintain websites where they publish data from volunteer water monitoring groups.[170]

Such platforms are not just of academic interest. They allow data to be analyzed by a wider pool of researchers and by a broader public that might not otherwise be familiar with a particular initiative. In a less obvious way, they can be empowering for small groups that would not otherwise have a way of making their information widely available. One group in Pennsylvania reported that it found users as far away as California were downloading data from the central database run by the Chesapeake Bay Program, and that this made their small local effort seem much more significant.[171]

One potentially empowering aspect of new technology that does not appear to have been fully capitalized on is crowdsourcing environmental data collection. Especially in air monitoring, there would seem to be great potential in the much larger numbers of data points that can be generated by small, low-cost sensors used by large groups of citizen scientists. Although the cheaper devices available to community groups may not be as precise as the monitors agencies use, they can be deployed in much larger numbers. If protocols can be developed to equate the quality of data from large numbers of low-cost sensors with that of

167. A well-known case in which data from citizen activists led to an important enforcement action occurred in Tonawanda, New York. *See* Video: Winning the Battle Against Tonawanda Coke (Clean Air Coalition 2011), https://www.youtube.com/watch?v=hfOtpqzxi8c (last visited Jan. 2, 2019).

168. These examples show the unpredictable and nonlinear nature of environmental problem solving. The data were also provided to the state and influenced a pending reissuance of the facility's permit. The issue then was brought up in the state legislature, where a resolution was negotiated under which the facility agreed to conduct further research on the impacts of the coal ash pond.

169. *See* CUAHSI, *supra* note 154.

170. *See*, *e.g.*, Michigan Clean Water Corps, *MiCorps Data Exchange*, https://micorps.net/about-data-exchange/ (last visited Jan. 2, 2019).

171. Telephone Interview with Julie Vastine, Executive Director, ALLARM (Mar. 2, 2018).

approved regulatory monitors, both the citizens and agencies might benefit.

2. An Increasingly Sophisticated Public

Another potential driver noted earlier was growing sophistication among the general public, especially increased familiarity with new technology. In fact, the case studies revealed that citizen scientists are more sophisticated than is often assumed by agency staff and other experts. All citizen scientists studied were very aware of the need for scientific rigor and made extensive efforts to ensure their work is credible.

In almost every example we studied, the citizen scientists reached out to and worked closely with professional scientists to select appropriate devices and design their studies; took steps to validate the devices they were using, such as by co-locating them with a federally approved reference monitor; and provided thorough training for volunteers. This was true of both large and small groups; even the smaller groups either had significant in-house expertise or partnered with others for such expertise.

A few illustrations show how citizen science groups addressed this challenge:

- AAH and CAC established partnerships with academic organizations, as well as consulted with technical experts in selecting the sensors for their projects. Similarly, CCA worked with experts at the University of Alaska, and the RCP relied heavily on advisors from CU to recommend the sensors that they should use.
- Co-locating sensors with reference monitors, in order to validate the accuracy of the devices citizens are using, is a common practice. CAC and CCA used this strategy.
- Groups also recruit in-house experts with scientific or public health expertise, as was the case in the RCP and CAC examples.
- In NWN and in the Gardenroots programs, academic scientists led the projects.
- Volunteers who collect data are extensively trained. NWA and NWN provided such training.
- It is not uncommon for the work of citizen scientists to be published in scientific journals, as was the case with NWN, RCP, and Gardenroots projects.

Citizen science initiatives also take advantage of the growing sophistication and technical awareness of nonexpert volunteers, who need to be able to carry out studies that will meet scientific standards. An example is the approach used by NWN, in which paper strips were used by very large numbers of volunteers to test for water contaminants over a wide geographic area. Although such strips have been available in the past, they have not been seen as sufficiently reliable to make formal water quality decisions. By carrying out extensive training and verification of its volunteers, NWN sought to show that its campaigns could be considered scientifically acceptable.

Government agencies sometimes provide technical assistance as well. Water quality efforts, such as those in the Chesapeake Bay area, involved close working relationships between the citizen groups and experts at federal and state agencies. Groups such as NWA and FOSR had their research designs approved in advance by EPA and the state, and the states also did periodic field audits. In some cases, facilitating organizations such as CMC and ALLARM provided technical assistance where the state did not have that capacity. These provided a strong basis for allowing the resulting data to be treated as equivalent to government data and used in the integrated reports required under the CWA.

3. Limited Agency Capacity and Data Gaps

A third driver identified above was the limited, and even shrinking, resources available to agencies to conduct monitoring, which creates a need that citizen scientists can fill. This did indeed turn out to be a factor in a number of the examples we studied.

The use of volunteers to help assess water quality has a long history; water programs have never had the resources to assess all water bodies. Over time, this has evolved to a robust partnership between state agencies and independent citizen groups such as those described in the Chesapeake Bay case study. Some states, such as Virginia, have an active program to support citizen groups, which they see as a cost-effective way to supplement state monitoring efforts. Other states are less proactive but still solicit and accept citizen-generated water quality data. (At the other end of the spectrum is the example of the WWP, whose work to test the impact of livestock grazing turned out to be politically controversial, and whose data was ultimately not accepted.)

Another twist on the role of nongovernmental groups in filling gaps where agencies lack resources is the emergence of organizations that help smaller citizen groups build their capacity to carry out credible citizen science in states that cannot offer such assistance. One of these is the CMC, which helps local groups in Maryland improve their skills and, if possible, become certified by EPA's Chesapeake Bay Program to submit data for inclusion in official water quality reports. A similar function is carried out in Pennsylvania by ALLARM, based at Dickinson College.

CAC also illustrates how limits on agency resources were a motivating factor. CAC launched its AirKeepers project after the state legislature reduced the size of the agency's air monitoring network as a budget-cutting measure. By mid-2018, it had 85 air sensors in place across 35 counties, and it plans to have at least one in every county in the state by Earth Day 2019. Although its devices are not approved for making regulatory determinations, they are a valuable complement to the state's more limited network and can measure trends or spot potential problems.

4. Growing Attention to Neighborhood-Level Conditions and Environmental Justice

Several of the examples we studied confirmed the importance of community and environmental justice concerns as a driver for citizen science, especially with regard to air quality. Air pollution has long been a source of environmental justice concern[172]; changing technology means that residents now have the technical capability to do their own air quality assessment rather than relying solely on government agencies.

For example, neighborhood concerns, especially in low-income communities, drive the work of AAH. AAH developed the capacity to assess air quality in an area affected by emissions from the Houston Ship Canal (and traffic to the port facilities). It acquired five medium-cost monitors that provided more detailed information than was available from the single government monitor in the vicinity. Similarly, the RCP is using citizen science to measure the impact of an operating oil and gas well in a low-income, underserved neighborhood with the aim of persuading city officials to restrict or even terminate the facility's operation.

These examples illustrate the ways in which new technology empowers communities, and also the challenges that they still face.

5. Laws That Invite the Use of Citizen-Generated Data

As noted earlier, the existence of "entry points" in the statutes, regulations, and programs carried out by an environmental agency is an important factor in the ability of citizen scientists to influence government decisions and actions. This conclusion was borne out in the examples we saw. Most notably, pursuant to the explicit requirement in CWA regulations that agencies consider data from non-agency sources, many states have established programs that, to varying degrees, assist or at least allow citizen groups to submit data for official use. This is less true under the CAA, however, as the discussion below demonstrates.[173]

D. Barriers

1. Professional Skepticism

We identified skepticism about the scientific rigor and credibility of projects carried out by citizen scientists earlier as a significant barrier. Both professional scientists and agency personnel are reported to be reluctant to rely on citizen-generated data for this reason.

Our case studies suggest that these concerns may be overstated. As indicated above, in all the examples we reviewed, citizen science groups anticipated the need for scientific rigor and built it into their work. In some cases, scientists and other experts were closely involved in the project, while in others, scientists led the effort.[174]

There were some indications that skepticism nevertheless exists. For example, EPA rejected AAH's data, even though it had been carefully gathered with expert assistance, because it was done with devices other than approved federal reference methods.[175] We also found that while some state agencies actively partnered with citizens on water quality assessments to ensure that the data gathering was well-designed, states that lack that capacity tend to view non-agency data with caution.

These experiences comport with the EPA inspector general's finding that EPA officials do not yet perceive citizen science as reliable or useful for regulatory or enforcement decisionmaking.[176]

2. Uncertainty About Rapidly Changing Technology

As anticipated, uncertainty about the new technologies used by citizen scientists presented challenges in winning acceptance from regulators, although it was not a universal problem. The clearest example was the experience of AAH, which tested air quality in a low-income neighborhood near the Houston Ship Canal. Although it did not use the formally approved regulatory monitors that agencies use (which are prohibitively expensive for a local group), it used devices that cost roughly $4,000 each—not low-cost sensors.

With these devices, AAH was able to sample more intensively—in five locations compared to only one agency monitor. It found pollution levels that at times significantly exceeded national standards. It submitted that data to EPA for consideration in determining whether Houston as a whole should be considered in attainment with those standards. However, EPA did not use the AAH data, for reasons that included the nature of the monitoring devices and the length of the study (which did not match EPA's standard time frame for monitoring to make attainment designations).

172. *See, e.g.*, Christopher D. Ahlers, *Race, Ethnicity, and Air Pollution: New Directions in Environmental Justice*, 46 Envtl. L. 713, 715 (2016).

173. *See infra* Section IV.E.

174. Brett, *supra* note 3, argues that the only way to effectively verify the results of citizen data gathering would be to duplicate them with studies by professional scientists. It is not clear, however, why data gathering subject to rigorous research plans, and conducted by well-trained volunteers, would be unreliable. The emergence of new monitoring devices, especially for air, can also address many data quality concerns.

175. U.S.EPA, *supra* note 135, at 57.

176. U.S. EPA, Office of Inspector General, *supra* note 23, at 8.

3. Restrictions on the Use of Citizen Science Data by Agencies

A third potential barrier noted above was the body of requirements restricting the collection and publication of data of any kind by federal agencies. These requirements did not appear to be a factor in any of the examples we studied. In some cases, the citizen scientists were not seeking to influence a federal agency, so these laws did not come into play. In others, the way in which citizens asked for their data to be considered did not trigger such laws. For example, offering data to inform agency decisions on where to place their own monitors, or offering it as suggesting a need for further investigation by the agency, does not have legal implications. And purely voluntary citizen science efforts do not trigger the Paperwork Reduction Act.[177]

The one area in which citizen data are clearly used for federal regulatory purposes is where they are included in state water quality assessments. However, we heard no concerns regarding such use; presumably the strict screening done by states before citizen science data are accepted meets federal data quality requirements.

This is not to say that the restrictions on use of data by federal agencies are never a concern; the absence of any examples of this barrier in our case studies may reflect the specifics of our small sample. However, it also indicates that those restrictions are not a fundamental hurdle in many cases.

4. Legal Barriers to the Gathering of Data by Citizens

Outright legal prohibitions on data gathering, as discussed in Section II.B., are relatively rare and did not play a major role in most of the examples we studied. However, one example, WWP, confronted what is perhaps the single most egregious example of such laws to date. The law adopted by the Wyoming Legislature was a very concerted effort to silence citizen scientists whose findings were inconvenient to the livestock industry.

WWP also found itself stymied because the state agency, which initially accepted its data on grazing impacts, later reversed itself on the basis that the device WWP used was not technically acceptable. WWP argued that its device is effectively indistinguishable from commercially available and widely accepted devices and that the state's criteria were unfounded. We are not in a position to judge the merits of this debate, but it shows that regulatory interpretation can become an insuperable obstacle where a collaborative relationship does not exist between citizen scientists and government. This is an example where a more proactive approach on the part of the agency might allow it to obtain useful data that would not otherwise be available.

5. Other Barriers

We also found barriers other than those originally hypothesized. In particular, even where there are formal entry points for the use of citizen science data, many practical impediments remain. One important challenge is the lack of clear guidance from agencies regarding the nature of data they will consider. As a result, citizen scientists find themselves guessing about what they have to do.

Some state water programs have tried to address this problem by creating transparent data quality tiers that establish criteria that citizen science groups can use to design their research. Similarly, some state water programs work with local groups on their study designs or QAPPs. A group working with an approved QAPP can have a high degree of confidence that its data will be accepted.

Another barrier is limited funding for citizen science. It is hardly surprising that citizen groups tend to be short on resources. Although changing technology has dramatically increased access to lower-cost devices that can generate reliable and useful data, resource limitations will always set bounds on what smaller groups can accomplish. For example, most of the projects we studied were time-limited, especially for air quality monitoring.

E. Citizen Science and the Challenge of Local Air Quality Issues

A pattern that we observed in some of our cases was a mismatch between the local concerns of many citizen science groups, and the broader, more regional emphasis of air monitoring by agencies. This reflects in part a historic lack of highly granular, neighborhood-level data, and in part the effect when agency monitors are located in areas where they are unlikely to pick up the pollution of greatest concern to low-income communities. The emergence of citizen science creates the potential to fill some of the existing gaps in air quality information.

One example of this mismatch was the work of AAH, which used five monitors to measure particulate levels in an area where only one agency monitor was located. That work showed variations within the community and exceedances of air quality standards that had not been detected by the official monitor. The RCP, focused on measuring the air quality impact of an oil and gas facility in Los Angeles, provided another example. CCA, in Alaska, used low-cost sensors to demonstrate the need for an official regulatory monitor in a neighborhood impacted by particulates from wood-burning stoves.

The value of monitoring by citizen scientists at the local level became apparent in the aftermath of Hurricane Harvey in Houston. Based on readings from its network of air monitors, EPA advised the public that air quality had not

177. None of our case studies involved attempts to introduce citizen-generated data in court. The Potomac Riverkeeper collected data to form the basis of a citizen suit, but anticipated that if the case went to trial, it would have additional sampling done by an expert. Telephone Interview with Philip Musegaas, Vice President of Programs and Litigation, Potomac Riverkeeper (Jan. 12, 2018).

been adversely affected. However, more targeted sampling conducted by the Environmental Defense Fund using mobile sensors found local hot spots with high pollution levels that were not detected by the Agency.[178]

The need for more neighborhood-level monitoring has been recognized for some time,[179] but there are relatively few examples of neighborhood-scale monitoring. One notable exception is the series of MATES in Los Angeles, which have included microscale studies of 14 local communities, using mobile platforms, to complement monitoring at 10 fixed sites across the entire Los Angeles area.[180] The studies found that diesel emissions along major transportation routes was the most significant health threat by an order of magnitude over the second-highest toxic air emission, benzene.[181] Small-scale monitoring will be key to understanding the relative contributions of the various sources of air pollution.

The emergence of low-cost mobile monitors, and the growing number of citizen science organizations willing to place those devices in many locations, creates the potential for a much richer understanding of pollution at the local level, which can strengthen the ability of agencies to address the environmental problems of overburdened neighborhoods. Data from citizen scientists can also help to inform the placement of the agency monitors used in making official air quality determinations to ensure that impacted neighborhoods are not overlooked.

For this to happen, though, agencies will also need to think creatively about how citizen-generated data may be useful, even if the devices are not approved for regulatory use or the research design is not standard agency practice. This has not always been the case. For example, EPA chose not to consider the data submitted by AAH. Rigorously gathered data can still be informative and useful in responding to local concerns, even if it differs from standard agency practice.

178. *See* Frank Bajak & Lise Olsen, *Hurricane Harvey's Toxic Impact Deeper Than Public Told*, Associated Press, Mar. 23, 3018 (EPA official says that the Agency's general assessments did not necessarily reflect local hot spots), https://apnews.com/e0ceae76d5894734b0041210a902218d; Matt Tresaugue, *How a Tech Startup and Nimble Nonprofit Exposed Toxic Releases During the Houston Flood*, Envtl. Def. Fund (Sept. 21, 2017) (describing Environmental Defense Fund (EDF) local monitoring), https://www.edf.org/blog/2017/09/21/how-tech-startup-and-nimble-non-profit-exposed-toxic-releases-during-houston-flood; Rebecca Hersher, *Slow and Upbeat EPA Response to Hurricane Harvey Pollution Angers Residents*, Nat'l Pub. Radio, Nov. 13, 2017, https://www.npr.org/sections/health-shots/2017/11/13/560476366/slow-and-upbeat-epa-response-to-hurricane-harvey-pollution-angers-residents. EPA and the state also had to reduce the number of operating monitors for a period of time, delaying the official response. The state has noted that the levels detected by EDF, although high, did not represent a health hazard; it also noted some technical concerns with the EDF data. Texas Comm'n on Envtl. Quality, Citizen Collected Evidence: Environmental Defense Fund Post-Harvey Monitoring (2017), *available at* https://www.tceq.texas.gov/assets/public/response/hurricanes/Environmental-Defense-Fund-post-Harvey-monitoring.pdf.

179. *See* David E. Adelman, *The Collective Origin of Toxic Air Pollution: Implications for Greenhouse Gas Trading and Toxic Hotspots*, 88 Ind. L.J. 273, 300-03 (2013); *id.* at 300 (stating that EPA data lack the resolution necessary to detect neighborhood-scale hot spots).

180. *See* South Coast Air Quality Management District, *supra* note 57.

181. *Id.*

F. The Contrast Between Air and Water Programs

A second overarching finding from these case studies is the stark contrast between the use of citizen science in water and air programs. There has been a long history of volunteer assistance in water monitoring to supplement limited agency staffing. These efforts have evolved over time so that independent citizen groups are now conducting water quality data and providing that information for use by state agencies in making impairment determinations. In many cases, the working relationship between such groups and the states was close and collaborative, which made it possible for states to accept the data and use it for official purposes.

In contrast, this kind of relationship does not exist in air programs. Citizen science groups gathering air quality data tend to do so independently of the agencies, with little or no advance collaboration. As a result, the likelihood that the data will be accepted is less, and the potential for friction between citizen scientists and agencies is greater. At a minimum, citizen scientists face significant hurdles persuading agencies to consider their information. Even where there has not been friction, the citizen science groups tend to operate in parallel with the agencies, not in partnership.

There are historic, technical, and policy reasons for this difference, which may not be easily overcome. Most notably, citizen scientists gathering water data can use the same devices as agencies, making their information interchangeable. In the air pollution context, citizen scientists cannot afford the high-quality regulatory monitors and are using lower-cost devices, which are often not approved for regulatory purposes. There is also the difference in focus between local and regional problems discussed above.

Nevertheless, there may be opportunities for the air program to learn from experiences under the water program and make better use of citizen data. Again, agencies can think creatively about gaining value from citizen-generated data rather than rejecting it entirely. It may, for example, be possible to develop protocols for using data from nonregulatory monitors at least as a check on agency findings. Air programs may also be able to provide assistance to local groups with regard to study design and by providing data quality criteria in the same way that water programs do.

G. What Makes Citizen Science Impactful?

If there is one question that underlies the research here, it is: What makes citizen scientists effective in actually having an impact on decisions and actions of government agencies? Even within our limited set of case studies, we found a variety of outcomes. Some citizen scientists were very impactful. For example, their data fed directly into decisions about which water bodies are impaired and require more stringent regulation, or they provided reports on problems that were viewed as credible and were acted on by regulators to take enforcement action, write permits, or make other decisions such as placing regulatory-quality monitors. There were also examples, however, in which regulators rejected even sophisticated work by citizen scientists. In some cases, the result was mixed; data were not accepted for decisionmaking but are being taken into account in the agency's planning and priority setting.

Some factors making citizen scientists impactful are within their own control. Volunteer water monitoring programs are starting to understand the characteristics that are most likely to influence government decisions and actions. In addition, many of the projects worked with scientists to select technology or design programs as a means of increasing the credibility of the work. Other factors that seem to support impact on government decisions and actions include the age of the program, the budget, and the ability for volunteers to play multiple roles in the research process.[182]

The amount of external support a project receives may also influence the potential for success in influencing policy or management decisions.[183] Most volunteer water quality monitoring programs report significant support from internal leaders of an organization or external decisionmakers.[184]

Limited resources are, of course, a constraint on most efforts, even as technology change reduces the cost of monitoring devices. Another impediment, depending on the specific circumstances, is the lack of any clear statement by agencies of their expectations for the citizen science data they will be willing to consider and use. This lack of guidance means that citizen scientists may be guessing at what is needed, and may find that they invest a great deal of time and effort without results. Another issue, with regard to air pollution, is that citizen science efforts are often focused on local- and neighborhood-scale conditions, whereas the regulatory framework is designed either around assessing conditions on a very large scale or enforcing against individual sources. This issue goes beyond citizen science and relates to larger problems with regard to agency capacity to respond to environmental justice concerns.

Finally, it is important not to think of "impact" too narrowly. Groups conducting citizen science usually have goals that extend beyond influencing specific government decisions. In almost every project we studied, other goals were equally central—especially motivating and empowering the public, and giving citizen scientists a way in which they could call attention to their concerns.[185] Some also produced publishable research.[186] Others provided usable information to local residents,[187] or made presentations to scientific groups to establish the validity of a new testing method.[188]

V. Recommendations

Based on our assessment of the potential and current uses of citizen science, and in particular on evaluation of our case studies, we provide the following recommendations that are designed to enhance the value of citizen science for those engaged in those efforts, federal and state environmental agencies, and the public whose interests environmental legislation is designed to protect.

A. Agencies Should Take Specific Steps to Encourage and Support the Development of Citizen Science

1. EPA Should Adopt a Citizen Science Strategy

First, environmental agencies should formally embrace citizen science and convey that message throughout their programs. The message should originate from the top, not just from isolated pockets as is currently the case. EPA's inspector general has concluded that EPA "does not currently have a clear vision and objectives for using citizen science to meet those strategic objectives," and should define a strategic vision that links the use of citizen science to the Agency's goals.[189] The ultimate goal should be to build recognition of the value of citizen science into the culture of agency programs and better integrate citizen science into EPA's routine decisionmaking in contexts such as rulemaking, permitting, and enforcement. As we discussed above, the effort that had to be undertaken over many years to build wide understanding of the role of environmental justice across the Agency's programs may provide a useful model for this work.[190]

An essential part of this strategy must be to show agency staff in concrete ways how citizen science can be used to help them achieve their goals (i.e., that the interests of those conducting citizen science and agency officials converge). Each program should proactively examine, within its respective sphere, the potential for citizen science to serve as a resource (and that will allow agencies to maximize the use of their own resources). This evaluation must be done separately by each program, as applications may be very different in each setting and because it is only at the implementation level that practical, concrete uses of citizen-generated data will be found. Such analysis should extend beyond air and water programs to others in which

182. *See* Stepenuck & Genskow, *supra* note 25.
183. *See id.* at 60 (citing Petra Christmann, *Multinational Companies and the Natural Environment: Determinants of Global Environmental Policy Standardization*, 47 Acad. Mgmt. J. 747-60 (2004); Milbrey W. McLaughlin, *Learning From Experience: Lessons From Policy Implementation*, 9 Educ. Evaluation & Pol'y Analysis 171 (1987)).
184. *Id.*
185. For example, CAC mentioned enhanced public awareness as a key aim of its monitoring effort. AAH submitted its data to EPA, but had a broader aim of raising awareness at the city level of environmental conditions in lower-income neighborhoods.
186. For example, data collected by the RCP were used as the basis for a published study that expanded knowledge of health impacts of urban oil and gas operations. *See* CAC, *supra* note 136.
187. This was true of the Gardenroots project, which was able to assure residents that it was safe to eat the food grown in their gardens.
188. This was a major activity of the director of the NWN.
189. U.S. EPA, Office of Inspector General, *supra* note 23, at 12.
190. *See generally* Rutledge et al., *supra* note 78.

citizen science has been used less extensively but could make valuable contributions in the future (e.g., monitoring drinking water quality, assessing exposure to lead paint, or assessing the impacts of pesticide application).

2. Agencies Should Meet Citizen Scientists Halfway

After identifying ways in which citizen science may be helpful, agencies should do more to meet citizen scientists halfway—building a bridge for a flow of information.[191] Doing so will not only help enhance capacity in citizen groups, but make it more likely that data provided by citizen scientists will be used—a better outcome for all concerned. Agencies might, for example:

- establish clear procedures and platforms for submitting information,
- provide guidance on research design,
- provide guidance on what kinds of data will be considered acceptable for different potential uses,
- develop protocols for making use of data that do not comport with normal agency requirements, but which can be informative or may provide value in interpreting official data, and
- analyze and, if possible, develop protocols for crowdsourcing, to recognize that data from large numbers of lower-cost devices may provide highly reliable conclusions even if the individual devices are not approved for regulatory use.

While agency resources are tight, programs can consider the possibility of providing grants to fund citizen science that directly supports their mission. Current EPA grants, which are primarily made through the Office of Research and Development, primarily support research activities and not those that directly aid program functions.[192]

Agencies can look to the more successful state water quality programs as a model for other programs. Those state programs offer funding and training to citizen groups, and review and approve the groups' research plans in advance, ensuring that data collected pursuant to those plans will be useful for regulatory purposes. They also provide transparency regarding the potential use of data of differing quality and set clear guidelines for the kind of data considered acceptable, which allows groups to design their efforts accordingly. While all of this requires an investment of resources, it can greatly leverage the expertise of agencies' own staff.

Meeting citizen scientists halfway also means thinking creatively about ways to use data that may not be perfect, or where the technologies used, or the nature of the data, is different from what the agencies normally use.[193] For example, unofficial data from low-cost sensors can complement data from widely dispersed agency monitors to provide a richer understanding of conditions. It also seems likely that agencies can develop protocols to consider the overall data quality of results from large numbers of less precise, low-cost sensors, allowing them to be given greater weight than when used individually. Developing such protocols should be a priority.

B. Citizen Scientists Should Learn From the Successes of Others

Second, for their part, citizen science groups should study instances in which citizen science has been used successfully so that they can recreate conditions that enhance the chances that the recipients of citizen science will use it in ways that correspond to researchers' goals. They need to think ahead about what actions they may ask government agencies to take and what information is most likely to be effective for that purpose. And they need to commit to generating data that will be viewed as meeting rigorous scientific standards.

The examples we have reported on suggest some best practices. Further research could undoubtedly expand the following list.

- To demonstrate scientific rigor, citizen scientists could partner closely with academic researchers and other experts to select their tools and design their studies. Some researchers are already making a specialty of providing such assistance.
- Where established avenues for agency-citizen collaboration do not exist, citizen scientists should take the initiative to reach out to agencies even before they begin their data collection; it may take effort to connect with agency staff, but early contact increases the chance that data will be given consideration later on.
- Citizen scientists may find their efforts are more effective if they identify at the outset an agency customer and understand the decisions that customer will be making, so research can be designed with an end use in mind.

C. Air Programs Should Use Citizen-Generated Data to Better Understand Local Air Pollution Problems

Citizen science can provide an opportunity to improve agency action on local air quality issues. EPA and state

191. The 2018 NACEPT report contains a similar recommendation that EPA "[c]atalyze action from citizen science data and information by providing guidance and leveraging collaboration." NACEPT II, *supra* note 22, at 9.

192. *See id.* at 19 (recommending "prioritizing better support for grassroots and community-based partnerships in EPA grant-funding strategies").

193. *See* Brett, *supra* note 3, at 19 ("Understanding that there is a place for less than perfect data is effectively a prerequisite for including citizen science in regulatory contexts.").

air programs have sophisticated systems for measuring air quality at a regional scale, but do not have as much data at the local or neighborhood level. These local issues are the source of many citizen scientist concerns, especially in environmental justice communities.

Community groups are increasingly developing the capacity to use new air sensors to assess local air quality. Although these devices may not be approved for regulatory use, the information these groups are gathering can be useful in filling gaps in our understanding of issues at the neighborhood level. Agencies should work with these groups to take advantage of this new capability, agree on protocols for analysis, and use the resulting information in designing plans for addressing local concerns. Data from citizen scientists can also help to ensure that official monitors are properly located to accurately detect air quality problems.

D. Unnecessary Legal Barriers Should Be Removed

We did not find legal barriers to be a major impediment to the citizen scientists in the examples we studied. However, some states have adopted laws restricting the use of data gathered by citizen scientists, which elevate special interests over more general public interests. The Wyoming statute discussed in Part II served the interests of landowners without adequately considering the larger public interest in data about pollution. If states are concerned about the impact of environmental regulation on important business sectors, they may have appropriate ways of responding, but preventing the gathering of information about those sectors is not one of them.

The same is largely true of the other legal barriers discussed in Part II, such as ag-gag laws and restrictions on the use of certain technologies. While issues of privacy and trespass likely require some balancing of interests,[194] they do not justify broadly shielding the actions of regulated parties from public view. States can also act to limit the effect of SLAPP suits, balancing the legitimate interests of parties that may be affected by citizen activism with the right of citizen scientists to disseminate data that have been gathered through scientifically valid research.[195]

E. Emerging Technologies Should Be Validated

The new technologies available to citizen scientists, especially for measuring air pollution, are not necessarily well-proven, creating a potential impediment to the credibility of citizen scientists. We found that this concern was being effectively anticipated and addressed by citizen science groups who work with experts and take steps such as co-locating sensors with regulatory quality monitors. However, a centralized and shared process for validation would avoid the need for each group to act on its own. Some efforts are already under way, and work in this area should continue.[196]

VI. Further Research

The research reported here only begins to scratch the surface of this complex topic, and suggests a number of lines of potentially valuable further inquiry:

1. Further case studies are needed. This Article has looked into only a handful of examples; many more are needed to establish a full picture of the situation on the ground. An effort should be made to find examples addressing issues other than air and water pollution.
2. A focused look at the role of citizen science in addressing environmental justice concerns would be especially valuable, along with an exploration of potential policy changes to address neighborhood-scale pollution problems.
3. It would be useful to explore whether there are more examples of the use of citizen science to support enforcement efforts, especially to:
    a. find cases in which groups attempted to introduce citizen-generated data into evidence,
    b. assess the degree of success in doing so, and
    c. determine whether skepticism about the admissibility of such evidence is justified.
4. Because citizen science has been used frequently to affect water pollution regulatory programs, it would be helpful to conduct a comprehensive 50-state analysis of water programs to learn how they vary and which ones have been most successful.
5. Researchers should explore the value of citizen science and monitoring related to greenhouse gas emissions in communities.
6. Researchers should also try to assess the extent and value of the use of central databases available on the Internet to coordinate and disseminate the results of citizen science information-gathering efforts.
7. Researchers should analyze the potential for crowdsourcing—the use of large numbers of low-cost sensors—and how it might reduce concerns about the quality and accuracy of such sensors, as well as provide information of a type not available from traditional monitors.

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194. *See supra* Section II.B.4. (discussing citizen monitoring of critical infrastructure using drones).
195. On anti-SLAPP legislation, see Pring, *supra* note 125.
196. A suggested action plan is described in Hindin et al., *supra* note 79.

VII. Conclusion

This Article seeks to complement the existing literature on the emerging field of citizen science, and in particular the legal issues that it confronts, with a practical survey of activities going on in the field. It has identified some aspects that have not been widely noted previously, such as the fact that citizen scientists often work with professional researchers and are producing work of high quality. It has also identified some important policy and programmatic steps needed to fully take advantage of the opportunity that citizen science presents. We hope that this will serve as a step toward practical and meaningful work to fully integrate citizen science as a component of our overall system of environmental protection.