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The Architecture of Ignorance

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THE ARCHITECTURE OF IGNORANCE

Gregg P. Macey*

Abstract

This Article develops an approach to environmental law that I refer to as "data-intensive regulation." The origins of data-intensive regulation lie in the public's ability to gather, for the first time, data at spatial and temporal scales of its choosing. This capability, and the knowledge-building efforts it supports, will eclipse the theoretical and computational procedures that guided environmental law's enactment. As environmental law evolves from a data-starved to data-rich enterprise, pollution control and ecosystem management will need to respond in two ways, focusing less on data supply and more on the demands of data users and the data's underlying architecture. Legal scholars neglect these questions, offering proposals to bridge and fill gaps in data. At the same time, environmental law has surrounded itself with supportive structures to accommodate these gaps, which are useful in data-limited contexts. I explore this architecture, and its next phase of evolution, through case studies of citizen monitoring arrays, hazardous substances and microenvironments, and disaster planning and peer-to-peer response. Data-intensive regulation promises to recast debates over regulatory design and federalism. It calls for the coordinated use of previously neglected regulatory tools. And it addresses a wider range of transaction costs, and their influence over responses to environmental harms, than costs related to data supply.

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INTRODUCTION

Environmental law arose in a world of data scarcity. Computing power was expensive, and much of it was housed in mainframes.[1] Only a few people on earth could gather, manipulate, and share spatial data.[2] Experts tinkered with local weather data in the absence of a general circulation model.[3] Climate change was not studied as a global phenomenon.[4] There were few known carcinogens.[5] Ecosystem dynamics, and the fate of species inhabiting them, were largely hidden from view.[6]

It was a world without ubiquitous computing or "mobisense."[7] T-shirts did not react to the air.[8] Clothing accessories were not nodes in an invisible network.[9]

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[1] *See* Timothy F. Bresnahan & Shane Greenstein, *Technological Competition and the Structure of the Computer Industry*, 47 J. INDUS. ECON. 1, 4–5 (1999) (examining the IBM System 360 and its central role in the structure of mainframe segments).

[2] *See* Timothy W. Foresman, *GIS Early Years and the Threads of Evolution*, *in* THE HISTORY OF GEOGRAPHIC INFORMATION SYSTEMS: PERSPECTIVES FROM THE PIONEERS 3, 4–5 (Timothy W. Foresman ed., 1998) (reviewing the evolution of GIS from hand-drawn maps to the first industry-scale computer-based system).

[3] *See* SPENCER R. WEART, THE DISCOVERY OF GLOBAL WARMING 10–12 (2003).

[4] *See* Clark A. Miller, *Climate Science and the Making of a Global Political Order*, *in* STATES OF KNOWLEDGE: THE CO-PRODUCTION OF SCIENCE AND SOCIAL ORDER 46, 50–53 (Sheila Jasanoff ed., 2004).

[5] Richard Wilson, *Risks Caused by Low Levels of Pollution*, 51 YALE J. BIOLOGY & MED. 37, 47–48 (1978) (explaining that the only known carcinogens in 1958 were soot, radiation, tobacco smoke, and *B*-naphthylamine).

[6] *See, e.g.*, Preston E. Cloud, Jr., & V.E. McKelvey, *The Environmental Sciences and National Goals*, *in* APPLIED SCIENCE AND TECHNOLOGICAL PROGRESS: A REPORT TO THE COMMITTEE ON SCIENCE AND ASTRONAUTICS, U.S. HOUSE OF REPS. 229, 234 (1967); ROBERT M. MAY, STABILITY AND COMPLEXITY IN MODEL ECOSYSTEMS 4–5 (2001).

[7] *See* Sasank Reddy et al., *MobiSense—Mobile Network Services for Coordinated Participatory Sensing*, 9TH INT'L SYMP. AUTONOMOUS DECENTRALIZATION SYS. (2009) (at p. 1 of .pdf manuscript) (describing networks of mobile devices that gather and share environmental data at different scales), *available at* http://nesl.ee.ucla.edu/~neslfw/documents/conference/2009/ISADS2009.pdf.

[8] *See* Sunyoung Kim et al., *WearAir: Expressive T-Shirts for Air Quality Sensing*, 4TH INT'L CONF. ON TANGIBLE, EMBEDDED, AND EMBODIED INTERACTION 295, 295–296 (2010) (evaluating T-shirts that measure volatile organic compounds and visually express air quality with light-emitting diodes (LEDs)), *available at* http://www.cs.cmu.edu/~sk1/papers/tei10.pdf.

Weather balloons did not self-organize into lightscapes to communicate public concerns.[10] GLACSWEB and CMOP were random mixtures of letters.[11] Drafters of the modern administrative state hailed taxicabs that simply took them from one place to the next. The vehicles did not double as mobile air monitors.[12]

Those legislators knew that there was much to learn.[13] Environmental laws are elaborate admissions of ignorance. Their preambles express lofty goals, whether seeking "integrity,"[14] zero emissions,[15] or to eliminate "damage to the environment."[16] By their goals, they signal confidence in comprehensive rationality[17] and the managerial might of a society that landed capsules on the moon. But further along, the texts concede the unknown. The National Environmental Policy Act, the Clean Air Act, the Clean Water Act, and other statutes call for data gathering and technical assistance.[18] They envision research

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[9] *See* Wesley Willett et al., *Common Sense Community: Scaffolding Mobile Sensing and Analysis for Novice Users, in* PERVASIVE 2010, at 301, 308 (Patrik Floréen et al. eds., 2010) (reporting on an initiative where devices clipped to clothing were used to transmit carbon monoxide and ozone readings over a wireless connection at regular intervals).

[10] *See generally* Stacey Kuznetsov et al., *Red Balloon, Green Balloon, Sensors in the Sky*, UBICOMP '11: PROC. 13TH INT'L CONF. UBIQUITOUS COMPUTING (2011) (presenting a proof of concept for LED-infused balloons that measure and report ground-level air quality), *available at* http://www.paulos.net/papers/2011/BalloonSensingUbicomp2011.pdf.

[11] *See* Young Jin Jung et al., *Design of Sensor Data Processing Steps in an Air Pollution Monitoring System*, 11 SENSORS 11235, 11237 (2011) (providing examples of environmental applications of sensors, including GLACSWEB, which monitors glacier movement, and the Center for Coastal Margin Observation & Prediction (CMOP), focused on coastal change), *available at* http://www.mdpi.com/1424-8220/11/12/11235.

[12] *See generally* Eric Paulos et al., *Sensing Atmosphere*, 2007 HUMAN-COMPUTER INTERACTION INST. (reporting on a field study in Ghana, where dash-mounted tubes in taxicabs collected carbon monoxide and sulfur dioxide readings over a twenty-four-hour period), *available at* http://www.paulos.net/papers/2007/Sensing%20Atmosphere%20(Sensys%202007%20Workshop).pdf.

[13] *See* SUBCOMM. ON SCI., RESEARCH, AND DEV. TO THE HOUSE COMM. ON SCI. AND ASTRONAUTICS, MANAGING THE ENVIRONMENT 28–29 (Comm. Print 1968).

[14] 33 U.S.C. § 1251(a) (2006).

[15] *See id.* § 1251(a)(1).

[16] 42 U.S.C. § 4321.

[17] *See* Bradley C. Karkkainen, *Toward a Smarter NEPA: Monitoring and Managing Government's Environmental Performance*, 102 COLUM. L. REV. 903, 911–12 (2002).

[18] *See, e.g.*, 42 U.S.C. § 4344 ("It shall be the duty and function of the Council . . . to conduct investigations, studies, surveys, research, and analyses relating to ecological systems and environmental quality"); *id.* § 4372(d) ("In carrying out his functions the Director [of the Office of Environmental Quality] shall . . . review[] the adequacy of existing systems for monitoring and predicting environmental changes in order to achieve effective coverage and efficient use of research facilities and other resources . . . ."); 42 U.S.C. § 7403(a) ("The Administrator shall establish a national research and development program for the prevention and control of air pollution and . . . conduct, and promote the coordination and acceleration of research, investigations, experiments, demonstrations, surveys, and studies . . . . "); 33 U.S.C. § 1251 ("In order to achieve [the objective of restoring and maintaining the chemical, physical, and biological integrity of the Nation's waters] . . . it is the national policy that a major research and demonstration effort be made

programs, studies, and updates to standards,[19] each an effort to "fill" data gaps. Environmental law generally organizes itself around limits in available data. The Clean Water Act embraced technology-based standards after attempts to directly control water quality proved too complex.[20] The Clean Air Act Amendments require "maximum achievable control technology" rather than ambient standards that would more closely regulate the effects of air toxics on those exposed.[21] Elsewhere, regulators base their decisions on the "best scientific . . . data available,"[22] although the precise scope of data they must use is unclear. These attempts to "bridge" data gaps endure, reducing the amount of data needed to trigger a regulatory response.

I argue that after decades of bridging and filling data gaps, environmental law is surrounded by an architecture that only makes sense in a world where data are scarce.[23] It is constructed as statutes are stretched to accommodate spatial and temporal gaps in understanding. We gather data at broad spatial scales rather than along streetscapes, within neighborhoods, or in other realms of individual experience.[24] We regulate dangerous products and substances although we often cannot identify immediate or long-term health effects.[25] Or we build emergency response teams and plans, unaware of how the public will respond to a crisis.[26] In each instance, accommodations are made in space and time. We extrapolate exposure, model estimates of the environment, and theorize citizen response upon which contingency planning may proceed. This Article sets out the flaws in this approach to regulation, and explains why they matter at a time when data are not scarce, but rich, and often overwhelmingly so.

In place of the old architecture, this Article offers a "data-intensive" approach to regulation. The public has unprecedented means of generating data, aided by wireless sensor networks,[27] personal exposure assessments that peer inside unregulated spaces such as the home and human body,[28] and peer-to-peer data sharing.[29] Using sensed, networked data, the public is no longer made up of mere "receptors" of toxic substances or "victims" of unfortunate events. They organize around data; work with private labs, agencies, academics, and community organizations to gather data at new scales; and build tools to visualize and interact

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to develop technology necessary to eliminate the discharge of pollutants into the navigable waters.").

[19] *See, e.g.*, 42 U.S.C. § 7409.

[20] S. Rep. No. 92-414, at 5 (1971).

[21] 42 U.S.C. § 7412(g)(2)(A)–(B).

[22] 16 U.S.C. § 1533(b)(1)(A).

[23] Whether in the built environment or in a digital sense, architecture is concerned with figuring out "the needs of the user of a structure and then designing to meet those needs as effectively as possible." Frederick P. Brooks, Jr., *Architectural Philosophy*, *in* PLANNING A COMPUTER SYSTEM 5, 5 (Werner Buchholz ed., 1962).

[24] *See infra* Part II.A.1.

[25] *See infra* Part II.A.3.

[26] *See infra* Part II.A.5.

[27] *See infra* Part II.A.2.

[28] *See infra* Part II.A.4.

[29] *See infra* Part II.A.6.

with the data.[30] Some data gathering efforts have colorful names, such as WearAir[31] and CenceMe.[32] Others build around simple objects that people carry as they go about their day.[33] Still others are limited only by the public's interest in activating certain applications on their cell phones.[34] What these efforts share is the ability, for the first time, to fine-tune the spatial and temporal scale of inquiry into environmental problems.

As environmental law evolves from a data-poor to data-intensive enterprise, the study of pollution control and ecosystem management will have to respond in two ways, focusing less on the data itself and more on the demands of data users and the data's underlying architecture. First, the search for and supply of data will become secondary to the question of how agencies manage and encourage demand for new regulatory practices. Second, the conversion of data into useful, policy-relevant knowledge will change dramatically. Environmental law developed during two distinct eras of knowledge creation: theoretical science, and simulation and modeling.[35] Both are marshaled to address data gaps. But knowledge creation in a data-intensive context does not rely solely on hypothesis testing or the simulation of events that are otherwise inaccessible for study. Rather, it brings together diverse data user communities to visualize and extract meaning from correlations and other associations of data.[36] These efforts require a supportive structure that differs from the "architecture of ignorance"[37] that is currently in place.

Legal scholars take their cues from the existing architecture, offering solutions to the challenges of a data-starved world. Their proposals mirror the

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[30] *See infra* notes 301–316 and accompanying text.

[31] Kim et al., *supra* note 8, at 295.

[32] Emiliano Miluzzo et al., *CenceMe—Injecting Sensing Presence into Social Networking Applications*, 2 EUR. CONF. ON SMART SENSING AND CONTEXT PROC. 1, 1 (2007), *available at* http://citeseerx.ist.psu.edu/viewdoc/download;jsessionid=F3B011B0A8D72D79178B45178B522B77?doi=10.1.1.129.3215&rep=rep1&type=pdf.

[33] *See generally* Stacey Kuznetsov & Eric Paulos, *Participatory Sensing in Public Spaces: Activating Urban Surfaces with Sensor Probes*, 8 AMC CONF. ON DESIGNING INTERACTIVE SYSTEMS PROC. 21 (2010), *available at* http://www.staceyk.org/hci/ParticipatorySensingKuznetsovPaulos.pdf.

[34] *See generally* Paulos et al., *supra* note 12 (describing the *Ergo* system that allows mobile phone users to access air quality data for their location).

[35] *See, e.g.*, Steve Kelling et al., *Data-Intensive Science: A New Paradigm for Biodiversity Studies*, 59 BIOSCIENCE 613, 614 (2009).

[36] *See, e.g.*, Gordon Bell et al., *Beyond the Data Deluge*, 323 SCI. 1297, 1297–98 (2009).

[37] Recent work in the sociology of science distinguishes among several forms of ignorance, including "nonknowledge" (which is addressed through assessments of risk and uncertainty and used in decision making), "negative knowledge" (which is not selected as an area to address, either intentionally or because of structural conditions), and "nescience" (more commonly referred to as "unknown unknowns," or the "lack of knowledge or the awareness of the limits of knowledge"). David J. Hess, *The Potentials and Limitations of Civil Society Research: Getting Undone Science Done*, 79 SOC. INQUIRY 306, 307–08 (2009). My use of the term "ignorance" refers to the first two categories, areas of nonknowledge and negative knowledge in environmental protection.

law's gap-filling and gap-bridging functions.[38] They focus on how to increase the supply of data. Two towering normative frameworks inform their efforts: regulatory design, meaning the appropriate mix of centralized, market, and other tools to ensure compliance and enforcement; and environmental federalism, which is concerned with the scale at which these tools should be put to use.[39] This Article opens up a third normative front—the data's unique qualities and supporting architecture—that allows us to explore a broader range of transaction costs that shape our response to environmental harms.

Data-intensive practices will reshape environmental law, including how ancient debates over regulatory tools, the scale of governance, and the role of the courts are resolved. Part I explores the scholarly literature on data gaps and its emphasis on increasing data supply. In Part II, I present three case studies of how spatial and temporal data gaps are accommodated using computational and theoretical, rather than data-intensive, techniques in environmental law. Each builds on analysis of archival documents and accounts, followed by a discussion of how the public has acquired, for the first time, the means to question these gaps. Part III.A sets out how data-intensive practices can be enabled, treating diverse data user groups as social movements that aim to influence existing regulatory approaches. In Part III.B, I discuss how to sustain these practices, with a focus on data pooling, provenance, and survival, and how these supportive functions will alter debates over regulatory design and scale.

I. GAPS AND SILENCES

The limiting role of knowledge, which is the application of data in meaningful contexts, is recognized but understudied in environmental law.[40] A sizable literature focuses on "data gaps" and how to increase the supply of useful data—raw numbers and symbols that when placed in context express events such as an emissions exceedance or species die-off. We learn that data-starved agencies such as the Environmental Protection Agency (EPA) descend into vicious cycles, as amendments to enabling legislation increase oversight and limit resources.[41] Regulators rely on models, surrogates, proxies (and proxies-on-proxies[42]), and

[38] *See infra* Part I.

[39] *See infra* notes 98–116 and accompanying text.

[40] *See, e.g.*, John S. Applegate, *Bridging the Data Gap: Balancing Supply and Demand for Chemical Information*, 86 TEX. L. REV. 1365, 1365 (2008); Holly Doremus, *Data Gaps in Natural Resource Management: Sniffing for Leaks Along the Information Pipeline*, 83 IND. L.J. 407, 408 (2008); Daniel C. Esty, *Environmental Protection in the Information Age*, 79 N.Y.U. L. REV. 115, 117–18 (2004); Wendy Wagner, *Commons Ignorance: The Failure of Environmental Law to Produce Needed Information on Health and the Environment*, 53 DUKE L.J. 1619, 1622–23 (2004).

[41] *See* Richard J. Lazarus, *The Tragedy of Distrust in the Implementation of Federal Environmental Law*, 54 LAW & CONTEMP. PROBS. 311, 314–15 (1991).

[42] *See* Wendy Wagner et al., *Misunderstanding Models in Environmental and Public Health Regulation*, 18 N.Y.U. ENVTL. L.J. 293, 297–313 (2010).

policy-driven assumptions to fill data gaps.[43] Models are built without a framework to evaluate judgments made when small pieces of the natural world are isolated, analyzed, and scaled up.[44] A "science charade" pervades pollution control and, increasingly, ecosystem management, aided by the Administrative Procedure Act ("APA") and unpredictable use of super deference by the courts.[45] Statutes call for a level of certainty in standard setting and enforcement that science simply cannot provide, so agencies "exaggerate the contributions made by science" to buffer decisions against hard-look review.[46] The science charade is a crude response to data gaps. But it remains difficult for courts or the public to distinguish science-informed options from the assumptions agencies make when choosing among them.[47]

Legal scholars unearth a variety of approaches to fill data gaps, mirroring the progression of tools (e.g., standards, markets) that appear in debates over regulatory design.[48] First are the solutions styled after state-centric, command-and-control regulation. Scholars call for more stringent disclosure mandates or shifts in the burdens of data production. They focus considerable attention on the Toxic Substances Control Act (TSCA),[49] a statute that does not require risk assessment or chemical testing on a regular basis. EPA may call for testing of chemicals produced in "substantial quantities" or that will result in "substantial human exposure," terms that stand for one million pounds and more than 100,000 people, respectively.[50] But to do so, EPA must endure lengthy rulemaking procedures averaging two to ten years.[51] Manufacturers of new or significant new uses of chemicals must submit a notice to EPA.[52] But most notices lack basic health-related data.[53] To call for additional data, EPA must prove that a substance poses

[43] Robert L. Glicksman, *Bridging Data Gaps Through Modeling and Evaluation of Surrogates: Use of the Best Available Science to Protect Biological Diversity Under the National Forest Management Act*, 83 IND. L.J. 465, 466–68 (2008).

[44] *See* Wagner et al., *supra* note 42, at 294; *infra* Part II.A.1.

[45] *See* Wendy E. Wagner, *The Science Charade in Toxic Risk Regulation*, 95 COLUM. L. REV. 1613, 1654–67, 1712 (1995).

[46] *Id.* at 1617.

[47] *See* Thomas O. McGarity, *Regulatory Analysis and Regulatory Reform*, 65 TEX. L. REV. 1243, 1287–89 (1987).

[48] *See generally* NEIL K. KOMESAR, IMPERFECT ALTERNATIVES: CHOOSING INSTITUTIONS IN LAW, ECONOMICS, AND PUBLIC POLICY 98–122 (1994).

[49] *See, e.g.*, John S. Applegate, *Synthesizing TSCA and REACH: Practical Principles for Chemical Regulation Reform*, 35 ECOLOGY L.Q. 721, 729–30 (2008).

[50] *See* Chem. Mfrs. Ass'n v. EPA, 899 F.2d 344, 359 (5th Cir. 1990); TSCA Section 4(a)(1)(B) Final Statement of Policy; Criteria for Evaluating Substantial Production, Substantial Release, and Substantial or Significant Human Exposure, 58 Fed. Reg. 28,738, 28,744 (May 14, 1993).

[51] Noah M. Sachs, *Rescuing the Strong Precautionary Principle from its Critics*, 2011 U. ILL. L. REV. 1285, 1301.

[52] *See* U.S. GOV'T ACCOUNTABILITY OFFICE, CHEMICAL REGULATION: OPTIONS EXIST TO IMPROVE EPA'S ABILITY TO ASSESS HEALTH RISKS AND MANAGE ITS CHEMICAL REVIEW PROGRAM 7–8 (2005).

[53] *Id.* at 11.

an "unreasonable risk."[54] TSCA's mixed burdens of proof and production lead to predictable results: 82,000 chemicals in commerce, with toxicity data available for a small fraction of them.[55]

"Gap-filling" proposals thus begin with more expansive disclosure requirements or tweaks to data production triggers. Scholars present TSCA alongside its European analogue, REACH (Registration, Evaluation, Authorization, and Restriction of Chemicals), which makes toxicity data a precondition for access to markets and is viewed as a model for TSCA reform.[56] In addition, scholars offer licensing, which is an important element of pesticide control, as a tool to increase data production.[57] These approaches would fix laws such as TSCA that encourage firms to shield data or maintain a purposeful ignorance of the harms they cause. They aim to improve data supply.

A second response to data gaps addresses the problem at a higher level of abstraction.[58] It echoes an interest among sociologists of science in the neglect of socially useful scientific fields, including those that would improve the practice of environmental law.[59] At the heart of this sociology are "research silences,"[60] which distort the raw materials available for regulatory responses to complex problems. It is not surprising that research silences exist; research, by definition, asks limited questions and follows some lines of inquiry while ignoring others.[61] Over time, fields lose their interpretive flexibility,[62] as theoretical commitments and classifications accrue. Recently, scholars explored the "systematic distortion of a [field's] total research portfolio."[63] A research field such as toxicology is not an autonomous, isolated endeavor. Both intrinsic (e.g., tacit rules) and extrinsic (e.g.,

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[54] *Id.* at 1, 4. EPA abandoned this approach after the decision in *Corrosion Proof Fittings v. EPA*, 947 F.2d 1201, 1215 (5th Cir. 1991).

[55] *See* Bradley C. Karkkainen, *Framing Rules: Breaking the Information Bottleneck*, 17 N.Y.U. ENVTL. L.J. 75, 80 (2008).

[56] *See, e.g.*, Noah M. Sachs, *Jumping the Pond: Transnational Law and the Future of Chemical Regulation*, 62 VAND. L. REV. 1817, 1818–20 (2009). REACH is an example of a regime governed by the "precautionary principle," which shifts the burden of proof for the safety of a product or activity from government to the private sector. *See* Sachs, *Rescuing the Strong Precautionary Principle from its Critics*, *supra* note 51, at 1302.

[57] *See, e.g.*, Applegate, *supra* note 40, at 1389–90.

[58] *See* Abby J. Kinchy & Simona L. Perry, *Can Volunteers Pick up the Slack? Efforts to Remedy Knowledge Gaps about the Watershed Impacts of Marcellus Shale Gas Development*, 22 DUKE ENVTL. L. & POL'Y F. 303, 311–12 (2012).

[59] *Id.*

[60] PHIL BROWN, TOXIC EXPOSURES: CONTESTED ILLNESS AND THE ENVIRONMENTAL HEALTH MOVEMENT 261 (2007).

[61] *See* Joanna Kempner et al., *Forbidden Knowledge: Public Controversy and the Production of Nonknowledge*, 26 SOC. F. 475, 477–78 (2011).

[62] *See, e.g.*, H.M. Collins & Robert Evans, *The Third Wave in Science Studies: Studies of Expertise and Experience*, 32 SOC. STUD. SCI. 235, 239–40 (2002).

[63] Edward Woodhouse et al., *Science Studies and Activism: Possibilities and Problems for Reconstructivist Agendas*, 32 SOC. STUD. SCI. 297, 304 (2002).

resources, guidelines) forces shape its development.[64] At the hands of structural and cultural influences, research fields develop unevenly. Military support after World War II shifted academic physics from basic research to applications and techniques.[65] The modern university is beset by research silences caused by the academy's diversification away from public funds.[66] Sociologists identify fields such as breast cancer genetics that are hampered by the lock-in of suboptimal tools.[67] They examine others such as green chemistry that challenge dominant industry practices and remain underfunded.[68] Legal scholars have briefly considered the uneven development of research fields as a cause of data gaps in environmental law. These scholars call for insulating and promoting vital fields, using them to give agency decisions legitimacy.[69] They highlight the role of the state in funding environmental management priorities and addressing structural market failures.[70] The research silences literature offers robust accounts of the origins of data gaps in environmental law.

In addition to newly required data and supported disciplines, scholars consider a third approach to filling data gaps: incentives for firms to produce and share data. There are two primary options: exploit asymmetries among firms, or target a broader industry with provisions such as penalty defaults. Cary Coglianese, Richard Zeckhauser, and Edward Parson highlight the first approach. Regulators can call for data "from the firms likely to be affected least by a new regulation" but whose data can still "be generalized across the industry."[71] To fill data gaps, agencies can exploit differences among firms, including their cost structure, market position, use of technology, and degree to which they are regulated. These differences can be harnessed to encourage a subset of market actors to reveal data.[72] Bradley Karkkainen and others suggest that we should target incentives

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[64] *See* David J. Hess, *Medical Modernisation, Scientific Research Fields and the Epistemic Politics of Health Social Movements*, 26 SOC. HEALTH & ILLNESS 695, 700 (2004).

[65] Paul Forman, *Behind Quantum Electronics: National Security as Basis for Physical Research in the United States, 1940–1960*, 18 HIST. STUD. IN THE PHYSICAL & BIOLOGICAL SCI. 149, 170–73 (1987).

[66] Daniel Lee Kleinman & Steven P. Vallas, *Contradiction in Convergence: Universities and Industry in the Biotechnology Field*, *in* THE NEW POLITICAL SOCIOLOGY OF SCIENCE: INSTITUTIONS, NETWORKS, AND POWER 35, 38–39 (Scott Frickel & Kelly Moore eds., 2006).

[67] *See* Jennifer Fosket, *Constructing "High-Risk Women": The Development and Standardization of a Breast Cancer Risk Assessment Tool*, 29 SCI. TECH. & HUM. VALUES 291, 296–99 (2004).

[68] *See, e.g.*, Edward J. Woodhouse, *Nanoscience, Green Chemistry, and the Privileged Position of Science*, *in* THE NEW POLITICAL SOCIOLOGY OF SCIENCE, *supra* note 66, at 171–72.

[69] *See* Eric Biber, *Which Science? Whose Science? How Scientific Disciplines Can Shape Environmental Law*, 79 CHI. L. REV. 471, 513–28 (2012).

[70] *Id.* at 515–16.

[71] Cary Coglianese et al., *Seeking Truth for Power: Informational Strategy and Regulatory Policymaking*, 89 MINN. L. REV. 277, 298 (2004).

[72] *Id.* at 298–99.

more broadly. For example, harsh provisions ("penalty defaults") can be set to kick in across firms, unless they demonstrate that their practices are safe, an approach used to great effect in California's Proposition 65.[73] Penalty defaults add a level of sophistication to provisions such as the Toxics Release Inventory (TRI) that simply require disclosure of data by a subset of industry actors.[74]

Other gap-filling proposals blend mandates, incentives, and rating schemes. Wagner's "competition-based" regulation would create an entirely new market for chemical safety information. Firms would compete for certification of their products as "superior" and "inferior," and the latter would be subjected to bans or use restrictions.[75] Such proposals face innumerable barriers to implementation and might require greater use of scarce resources, such as rulemaking, than existing regimes. But they mirror the literature's turn to multimodal approaches to solving persistent problems in environmental law.[76] Holly Doremus focuses on the ex ante supply of data to decision makers as well as the loss of data along what she likens to an oil supply chain.[77] This metaphor addresses the fact that "little attention has been paid to the processes by which [data are] supplied."[78] Her proposals include evaluating the costs and benefits of data supply and acknowledging questions that cannot be answered solely with additional data.[79] Daniel Esty, who along with Kenneth Markowitz shared an early interest in how legal systems might adjust to technologies such as remote sensing,[80] has a similarly rigorous view of data gaps. His taxonomy of points where data are needed along an environmental decision-making process is a welcome extension of the data gaps conversation beyond post-*Cathedral*[81] debates over property rules versus liability rules,[82] where "A causes harm to B" and the central issue is whether one side is better positioned to control

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[73] Safe Drinking Water and Toxic Enforcement Act of 1986, CAL. HEALTH & SAFETY CODE §§ 25249.5–.13 (West 2006). For applications of penalty defaults to ecosystem management and environmental impact statements, see Bradley Karkkainen, *Adaptive Ecosystem Management and Regulatory Defaults: Toward a Bounded Pragmatism*, 87 MINN. L. REV. 943, 970–75 (2003) and Karkkainen, *supra* note 17, at 936.

[74] *See* 42 U.S.C. § 11023 (2006) (requiring information disclosure for certain users of toxic chemicals).

[75] Wendy Wagner, *Using Competition-Based Regulation to Bridge the Toxics Data Gap*, 83 IND. L.J. 629, 640–41 (2008).

[76] *See, e.g.*, Craig Anthony (Tony) Arnold, *Fourth-Generation Environmental Law: Integrationist and Multimodal*, 35 WM. & MARY ENVTL. L. & POL'Y REV. 771, 792–97 (2011).

[77] Doremus, *supra* note 40, at 417; *see also* Douglas A. Kysar & James Salzman, *Making Sense of Information for Environmental Protection*, 86 TEX. L. REV. 1347, 1349–50 (2008) (sketching how data might flow through a regulatory institution).

[78] Doremus, *supra* note 40, at 407.

[79] *Id.* at 444–47.

[80] *See generally* Kenneth J. Markowitz, *Legal Challenges and Market Rewards to the Use and Acceptance of Remote Sensing and Digital Information as Evidence*, 12 DUKE ENVTL. L. & POL'Y F. 219 (2002).

[81] *See generally* Guido Calabresi & A. Douglas Malamed, *Property Rules, Liability Rules, and Inalienability: One View of the Cathedral*, 85 HARV. L. REV. 1089 (1972).

[82] Esty, *supra* note 40, at 130.

harms.[83] While recognizing the limits of a purely property rights-based approach to regulation,[84] Esty sees promise in how technology can increase the supply of data, making it easier to price emissions and lower some of the costs that Ronald Coase warned will limit bargaining.[85] Other scholars are less sanguine about the transaction cost savings of technology-enabled data supply.[86]

There are numerous problems with gap filling as a response to ignorance in environmental law. First, it experiences diminishing returns of time and expense, as efforts to increase chemical testing and other activities continue.[87] It also encourages reflexive box-checking exercises that tend to data gaps as opposed to policy-relevant data requirements.[88] Proposals for more collaborative or voluntary data-supply programs fall short in the amount of data generated and the level of accountability assured through mutual monitoring or third-party certification.[89] Assuming data are supplied, they address only a subset of the transaction costs (which include data acquisition and exchange, collective action challenges that influence negotiation and enforcement of commitments, and coordination and other administrative costs)[90] that limit bargaining over or control of harms, however precisely the harms may be defined.

In response, some scholars turn their attention to bridging, as opposed to filling, data gaps. Bridging means reducing the demand for certain data in a regulatory regime.[91] There are two approaches. One is embodied in technology-based standards and decisions based on, for example, the "best available scientific

[83] *Id.* at 131 ("[T]he *Cathedral* examples—and a focus on nuisance cases more generally—stylize the environmental problem in a way that oversimplifies the information issues, highlighting a few concerns . . . to the exclusion of others.").

[84] *Id.* at 147 ("[I]t is unlikely that any single institutional strategy will produce optimal results.").

[85] *Id.* at 182 ("These gap-filling gains are important because a well-functioning tort system is a necessary backstop for a property-rights-based environmental regime.").

[86] *See, e.g.*, Albert C. Lin, *Beyond Tort: Compensating Victims of Environmental Toxic Injury*, 78 S. CAL. L. REV. 1439, 1442–43 (2005) ("Such contractual exchanges offer the potential to internalize upfront the costs to [a] community, but they are suitable for only a handful of environmental exposure situations . . . . Like contractual approaches, tort approaches would offer only limited relief to the environmentally injured . . . ."); Lynn E. Blais & Wendy E. Wagner, *Emerging Science, Adaptive Regulation, and the Problem of Rulemaking Ruts*, 86 TEX. L. REV. 1701, 1701 n.1 (2008) ("[Information cost reductions will not likely be] the case in all areas, particularly where enhanced information technologies will remain relatively inaccessible to the public and incomplete in their ability to overcome significant uncertainties . . . .").

[87] *See* Applegate, *supra* note 40, at 1385–95.

[88] *See* Todd Stedeford & Marek Banasik, *International Chemical Control Laws and the Future of Regulatory Testing for Risk Assessment*, 22 GEO. INT'L ENVTL. L. REV. 619, 646 (2010).

[89] *See, e.g.*, Glicksman, *supra* note 43, at 469–74; Cameron Holley, *Facilitating Monitoring, Subverting Self-Interest and Limiting Discretion: Learning from "New" Forms of Accountability in Practice*, 35 COLUM. J. ENVTL. L. 127, 143–48 (2010); Wagner, *supra* note 40, at 624–25.

[90] Ronald Coase, *The Problem of Social Cost*, 3 J.L. & ECON. 1, 15 (1960).

[91] Applegate, *supra* note 40, at 1385.

data" or "all appropriate inquiries": lower the amount of data required to trigger a regulatory response. The courts encourage this approach when data gaps abound for issues such as contribution to response costs at a Superfund site.[92] Another, the "precautionary principle," is a more drastic commitment to act in the absence of risk or harm data.[93] Regulation based on the strong precautionary principle tries to avoid Type II (false negative) as opposed to Type I (false positive) errors.[94] A precautionary principle regime is more likely to restrict products from entering a market until further review proves them safe.[95] As it stands, domestic environmental law is strongly aligned with the prevention of Type I errors, most visibly in the area of chemical regulation.[96]

The focus on filling and, to a lesser extent, bridging data gaps ignores a broader illness in environmental law, which is the focus of this Article. The proposals offered in the relevant literature, from disclosure mandates to industry incentives, are concerned with calibration, including the necessary level of data and how to set thresholds so that decisions are made in the face of data of limited range or specificity. It is largely a story of data supply, one that is anticipated and aided by existing laws. A broader architecture that acts in the face of severe knowledge constraints is less often challenged. The literature suggests welcome improvements to regulatory practice and importantly updates James Krier's work on the data implications of institutional choice.[97] However, it spends less time questioning the unintended consequences of decisions to accommodate persistent data gaps.

As I demonstrate, we have no choice but to question this underlying architecture. The scale of data available, the practice of translating them into usable knowledge, and the participants in those efforts are each experiencing qualitative shifts. The ultimate challenge to this architecture is a regulatory environment that is not data-starved, but data-rich. Agencies must grapple with a paradigmatic change in how policy-relevant knowledge is produced, as well as with the demand for new regulatory practices that it will bring. Merely tweaking how the existing architecture triggers action, extracts or collects greater data, or is shielded from judicial scrutiny when it uses limited data ignores this more profound challenge.

II. THE ARCHITECTURE OF IGNORANCE

Regulatory design can be a bleak exercise. There are strikingly limited ways in which the law can target groups, avoid unintended consequences, and stave off

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[92] *See, e.g.*, Burlington N. & Santa Fe Ry. Co. v. United States, 556 U.S. 599, 617–18 (2009); Curtis v. M&S Petroleum, Inc., 174 F.3d 661, 671–72 (5th Cir. 1999).

[93] *See generally* Sachs, *supra* note 51 (reassessing the "Strong Precautionary Principle").

[94] *Id.* at 1303.

[95] *Id.* at 1315 n.142.

[96] *See id.* at 1303–04.

[97] *See* James E. Krier & W. David Montgomery, *Resource Allocation, Information Cost and the Form of Government Intervention*, 13 NAT. RESOURCES J. 89, 96–97 (1973).

crises of legitimacy.[98] In areas such as environmental law, scholars address this "trilemma."[99] They more or less avoid the straw man view of agencies as maximizers of consumer welfare.[100] They are also wary of public choice dramatizations of the "ruthless people" in the public sphere.[101] Neither archetypal approach adequately treats the nature of preferences[102] or collective action problems that plague the administrative state.[103] Abandoning the comforts of grand theory, they turn to mid-range accounts of why we regulate: we must police inefficient markets, restrict activity, eliminate anticompetitive practices, or provide public goods such as environmental data.[104]

Regulatory practice is explained as an evolution of instruments ("tools") that serve these functions. We theoretically parse environmental law this way, according to the kinds of tools it implements at a certain point in its history. Be they precise compliance methods (such as a standard for best available control technology),[105] economic incentives (such as a tax or negotiated reduction in penalties),[106] new data about the performance of a market player (such as emissions inventories),[107] or a more flexible or thicker process (such as an adaptive

[98] Gunther Teubner, *Juridification: Concepts, Aspects, Limits, Solutions*, *in* JURIDIFICATION OF SOCIAL SPHERES: A COMPARATIVE ANALYSIS IN THE AREAS OF LABOR, CORPORATE, ANTITRUST AND SOCIAL WELFARE LAW 3, 3–5 (Gunther Teubner ed., 1987).

[99] *Id.*; *see, e.g.*, David Hess, *Social Reporting: A Reflexive Law Approach to Corporate Social Responsiveness*, 25 J. CORP. L. 41, 58–59 (1999) (discussing why it is difficult to design regulations that produce "socially responsible behavior from corporations").

[100] DANIEL CARPENTER, REPUTATION AND POWER: ORGANIZATIONAL IMAGE AND PHARMACEUTICAL REGULATION AT THE FDA 36–37 (Ira Katznelson et al. eds., 2010).

[101] Mark Kelman, *On Democracy-Bashing: A Skeptical Look at the Theoretical and "Empirical" Practice of the Public Choice Movement*, 74 VA. L. REV. 199, 205–06 (1988). For a standard critique of public choice theory, see Daniel A. Farber & Philip P. Frickey, *Public Choice Revisited*, 96 MICH. L. REV. 1715 (1998). For an application of public choice to environmental law, see Richard L. Revesz, *Federalism and Environmental Regulation: A Public Choice Analysis*, 115 HARV. L. REV. 553 (2001).

[102] *See, e.g.*, Lynn E. Blais, *Beyond Cost/Benefit: The Maturation of Economic Analysis of the Law and Its Consequences for Environmental Policymaking*, 2000 U. ILL. L. REV. 237, 244; Martha C. Nussbaum, *Flawed Foundations: The Philosophical Critique of (a Particular Type of) Economics*, 64 U. CHI. L. REV. 1197, 1211–12 (1997).

[103] *See* ROBERT BALDWIN ET AL., UNDERSTANDING REGULATION: THEORY, STRATEGY, AND PRACTICE 43–49 (2d ed. 2012).

[104] For an excellent overview of these solutions to market failure, see Joseph E. Stiglitz, *Government Failure vs. Market Failure: Principles of Regulation*, *in* GOVERNMENT AND MARKETS: TOWARD A NEW THEORY OF REGULATION 13 (Edward J. Balleisen & David A. Moss eds., 2010).

[105] *See generally* Wendy E. Wagner, *The Triumph of Technology-Based Standards*, 2000 U. ILL. L. REV. 83.

[106] *See* Richard B. Stewart, *A New Generation of Environmental Regulation?*, 29 CAP. U. L. REV. 21, 32 (2001).

[107] *See* Jody Freeman, *The Private Role in Public Governance*, 75 N.Y.U. L. REV. 543, 657–64 (2000) (discussing the role of both the regulated industry and third parties in obtaining data).

watershed management regime),[108] when we speak of a "generation" of environmental law, we conjure a time when one or more sets of tools predominates.

These tools fall in and out of favor, but they share a quality of incomplete theoretical development. When we adopt standards, the likelihood of under- or overregulation is high.[109] As the focus shifts from these to more experimental[110] approaches, the theoretical problems mount. We lack precise definitions or means to evaluate their relative effectiveness.[111] Without them, the mix of tools to address a concern might replicate problems that led us to migrate from command and control in the first place. For instance, experimental approaches (often called "new governance") present the risk of capture and opacity at the hands of well-organized, decentralized stakeholders.[112] In areas such as financial services and environmental regulation, there may in fact be a pressing need for bright-line rules, either alone or as a baseline for other approaches.[113] Or it may be unclear how tools such as benchmarking should interact with legal rules or incentives.[114] Even proponents of approaches that depart from state-centric regulation note that the tools available "[do] not make self-evident how to plan for and respond" to events such as global climate change, invoking the specter of "a glorious mess."[115] When

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[108] *See* Bradley C. Karkkainen, *Information-Forcing Environmental Regulation*, 33 FLA. ST. U. L. REV. 861, 862–63 (2006).

[109] Standards-based regulations are promulgated under two kinds of statutes: those that direct an agency to act "to the extent feasible" and those that require the agency to consider costs and benefits as they regulate behavior. For a critique of feasibility and cost-benefit analysis, the tools used to implement these statutes, see Jonathan S. Masur & Eric A. Posner, *Against Feasibility Analysis*, 77 U. CHI. L. REV. 657 (2010).

[110] *See* Eric W. Orts, *Reflexive Environmental Law*, 89 NW. U. L. REV. 1227, 1313–26 (1995); Charles F. Sabel & William H. Simon, *Minimalism and Experimentalism in the Administrative State*, 100 GEO. L.J. 53, 78–93 (2011).

[111] For a critique of new governance's lack of mechanisms for implementation, see Amy J. Cohen, *Negotiation, Meet New Governance: Interests, Skills, and Selves*, 33 LAW & SOC. INQUIRY 503, 512–14 (2008). For critiques of "standardless" adaptive regimes, see Craig Anthony (Tony) Arnold, *Adaptive Watershed Planning and Climate Change*, 5 ENVTL. & ENERGY L. & POL'Y J. 417, 436–38 (2010). For broader difficulties inherent in achieving "optimal" regulation, see Jonathan S. Masur & Jonathan Remy Nash, *The Institutional Dynamics of Transition Relief*, 85 N.Y.U. L. REV. 391, 404, 422–26 (2010); Saul Levmore, *Interest Groups and the Problem with Incrementalism*, 158 U. PA. L. REV. 815, 823–27 (2010).

[112] *See, e.g.*, John M. Conley & Cynthia A. Williams, *Engage, Embed, and Embellish: Theory Versus Practice in the Corporate Social Responsibility Movement*, 31 J. CORP. L. 1, 32–33 (2005); Richard S. Saver, *Health Care Reform's Wild Card: The Uncertain Effectiveness of Comparative Effectiveness Research*, 159 U. PA. L. REV. 2147, 2187–88 (2011).

[113] *See* Cristie Ford, *New Governance in the Teeth of Human Frailty: Lessons from Financial Regulation*, 2010 WIS. L. REV. 441, 482.

[114] *See* Louise G. Trubek, *New Governance and Soft Law in Health Care Reform*, 3 IND. HEALTH L. REV. 139, 149 (2006).

[115] J.B. Ruhl & James Salzman, *Climate Change, Dead Zones, and Massive Problems in the Administrative State: A Guide for Whittling Away*, 98 CALIF. L. REV. 59, 107 (2010).

we depart from the tidy separations of regulatory approaches that we find in the literature, their underlying mechanisms and how they would best interact are undertheorized at best.

Proposals offered by the data gaps literature note that an increase in data supply will alter the optimal mix of regulatory tools, even as they struggle with the above limitations. Scholars try to shore up each available tool by either expanding the range of data to inform its use or calibrating how it shapes what data are available. But in the attempt to answer what Jody Freeman and Daniel Farber label one of the two major normative questions of environmental law,[116] we overlook a broader reality informed by the collective mass of provisions, guidances, and other texts that give shape to environmental law. The laws are designed to make decisions in a data-poor context: based on data that agencies do not have (and firms might be in a better position to provide), with regulatory responses that occur despite what agencies do not know. It is upon this foundation that we set in motion regulatory tools, or improve tools using innovations such as burden shifting or creative disclosure.

Data in environmental law are primarily spatial or temporal, or complex mixtures of the two. Environmental law accommodates spatiotemporal gaps in a variety of ways, which I describe below. Note that in each case, technology-enabled efforts to fill or bridge data gaps prove self-limiting, because they are incompatible with agency practices that have arisen to accommodate those gaps. Mere improvements to these accommodations would be made at the expense of an architecture better suited for other, increasingly more relevant data environments. We are entering one such environment now. In it, overwhelming data and new approaches to knowledge creation are the norm, and policy-relevant knowledge is generated beyond the agency-firm dyad that is the focus of research on regulatory tools such as standards and incentives.

A. Spatiotemporal Accommodation

1. The Unknowns of Air

The most basic gaps that environmental law accommodates are spatial data gaps, although there is rarely a complete separation of space and time. Consider air quality, from the simplest smog alert to global pollutants that fuel climate change. In the wake of *Massachusetts v. EPA*,[117] agencies began in earnest to inventory and regulate greenhouse gas emissions,[118] steps later endorsed by the D.C. Circuit.[119]

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[116] *See* Jody Freeman & Daniel A. Farber, *Modular Environmental Regulation*, 54 DUKE L.J. 795, 797 (2005) (proposing a modular conception of regulation and resource management in response to two normative questions: first, what level of government ought to regulate? And second, using what tools?)

[117] 549 U.S. 497 (2007).

[118] *See, e.g.*, Mandatory Reporting of Greenhouse Gases, 74 Fed. Reg. 16,448, 16,457–61 (Apr. 10, 2009) (later codified at scattered parts of 40 C.F.R.).

[119] *See generally* Coal. for Responsible Regulation, Inc. v. EPA, 684 F.3d 102 (D.C. Cir. 2012).

Yet we find ourselves at a loss when faced with long-standing puzzles about the air we breathe, such as how pollutants persist at ground level, how a hot spot moves through an unsuspecting community, and how air emissions are experienced across a region.[120] Scattered parts of the world may have restricted air pollution as early as 1273 AD.[121] Some cities had surprisingly sophisticated regulations by the mid-1800s.[122] But we lack the basic spatial knowledge to police this species of externality.

To chart the yawning data chasms and the architecture that accommodates them, imagine that you have a strong interest in air quality. Perhaps you have an asthmatic child and your home is downwind of a chrome-plating shop or at the intersection of Interstates 405 and 5 in California.[123] Or your agency issued its first prima facie finding of a violation of Title VI of the Civil Rights Act of 1964.[124] Your job is to negotiate a settlement with a state agency that allowed farmers to apply a toxic fumigant near schools in Latino communities. Or you are a litigator trying to prove a violation of environmental or civil rights laws.[125] By way of example, assume that you live in California near the dawn of the twenty-first century. Your focus is the Bay Area. You would like to know whether the region faces disparate impacts of a decision made by a state environmental department.

You first compile data. You notice that there is, at the moment, no comprehensive analysis of environmental disparities in Northern California,[126] decades after protests in the rural South launched a global movement for environmental justice.[127] Undaunted, you mine databases for air emissions,

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[120] *See* Leonard M. Zwack et al., *Modeling Spatial Patterns of Traffic-Related Air Pollutants in Complex Urban Terrain*, 119 ENVTL. HEALTH PERSP. 852, 857–858 (2011) (discussing the difficulty of modeling traffic emissions and mobile-source air pollutant concentrations).

[121] ANTHONY KESSEL, AIR, THE ENVIRONMENT, AND PUBLIC HEALTH 51–52 (2006).

[122] *See id.* at 52 (detailing air pollution regulations in England from 1273 to 1968 including six regulations passed in the 1800s).

[123] *See, e.g.*, Davyda M. Hammond et al., *Sources of Ambient Fine Particulate Matter at Two Community Sites in Detroit, Michigan*, 42 ATMOSPHERIC ENV'T 720, 721–24 (2008); Doug Brugge et al., *Near-Highway Pollutants in Motor Vehicle Exhaust: A Review of Epidemiologic Evidence of Cardiac and Pulmonary Health Risks*, 6 ENVTL. HEALTH 23 (2007).

[124] *See* AGREEMENT BETWEEN CAL. DEP'T OF PESTICIDE REGULATION AND U.S. ENVTL. PROT. AGENCY (Aug. 24, 2011), *available at* http://www.epa.gov/ocr/TitleVIcases/title6-settlement-agreement-signed.pdf; Press Release, Center on Race, Poverty, and the Environment, EPA Fails to Enforce Civil Rights Act, (Aug. 25, 2011), *available at* http://www.ejnet.org/ej/angelitac-crpe-pr.pdf.

[125] *See* Richard J. Lazarus, *Pursuing "Environmental Justice": The Distributional Effects of Environmental Protection*, 87 NW. U. L. REV. 787, 827–842 (1992) (arguing for civil-rights litigation to effectuate environmental law).

[126] MANUEL PASTOR ET AL., STILL TOXIC AFTER ALL THESE YEARS: AIR QUALITY AND ENVIRONMENTAL JUSTICE IN THE SAN FRANCISCO BAY AREA 2 (2007) [hereinafter STILL TOXIC] ("[T]here have been no published analyses of the overall state of environmental disparity in the region.").

[127] For a history of the PCB landfill site and protests in Afton, North Carolina in 1982, see Eileen Maura McGurty, *Warren County, NC, and the Emergence of the Environmental*

concentration, and demographics data. You combine them to test whether there is a link between income and race and the level of toxic pollutants in outdoor air.[128] Quickly the problems mount. You accept that what you are building is largely a fantasy: the data for each variable were created in different years. But combining them to make cross-sectional comparisons is accepted practice.[129] For example, you decide to compare 2000 census data with industry-reported emissions from the 2003 TRI[130] and annual average air toxics from mobile and stationary sources from EPA's 1999 National Air Toxics Assessment.[131]

Even absent these artificial comparisons, each database presents its own prepackaged existential crisis. The Air Toxics Assessment includes data on 177 of the 187 air toxics listed under the Clean Air Act Amendments.[132] But the data are only estimates of health risk based on annual emissions from certain point and mobile sources.[133] They are derived from a model that guesses how chemicals move through the air once they are released from, say, a smokestack.[134] The model is deeply flawed.[135] And model-derived estimates of average annual air quality are presented by census tract,[136] which normalizes, and therefore eliminates, a number

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Justice Movement: Unlikely Coalitions and Shared Meanings in Local Collective Action, 13 SOC'Y & NAT. RESOURCES 373 (2000).

[128] For a review of these studies, see Evan J. Ringquist, *Assessing Evidence of Environmental Inequities: A Meta-Analysis*, 24 J. POL'Y ANALYSIS & MGMT. 223 (2005).

[129] *See generally* Paul Mohai & Robin Saha, *Racial Inequality in the Distribution of Hazardous Waste: A National-Level Reassessment*, 54 SOC. PROBLEMS 343 (2007).

[130] U.S. ENVTL. PROT. AGENCY, CALIFORNIA REPORT: 2003 TOXICS RELEASE INVENTORY (2005), *available at* http://www.epa.gov/region9/tri/report/03/california.pdf.

[131] *See 1999 National-Scale Air Toxics Assessment*, U.S. ENVTL. PROT. AGENCY (Apr. 15, 2010), http://www.epa.gov/ttn/atw/nata1999.

[132] *See 2005 National-Scale Air Toxics Assessment*, U.S. ENVTL. PROT. AGENCY (May 21, 2012), http://www.epa.gov/ttn/atw/nata2005.

[133] *See Summary of Results for the 2005 National-Scale Assessment*, U.S. ENVTL. PROT. AGENCY (Feb. 17, 2011), http://www.epa.gov/ttn/atw/nata2005/05pdf/sum_results.pdf.

[134] Gaussian dispersion models rely on assumptions about topography, weather, pollution, and how they interact. Weather data include wind speed and direction, temperature, and solar radiation. Emissions data include release parameters such as stack height, diameter, temperature, and velocity. Assumptions, such as the relation between wind speed at stack height and observed wind speed, and how a plume changes as it drifts through built environments, power the Industrial Source Complex model, which estimates air quality for New Source Review permits and state implementation plans. *See* U.S. ENVTL. PROT. AGENCY, USER'S GUIDE FOR THE INDUSTRIAL SOURCE COMPLEX (ISC3) DISPERSION MODELS VOLUME II—DESCRIPTION OF MODEL ALGORITHMS, 1.2–1.3 (1995).

[135] *See* Leonard M. Zwack et al., *Using Advanced Dispersion Models and Mobile Monitoring to Characterize Spatial Patterns of Ultrafine Particles in an Urban Area*, 45 ATMOSPHERIC ENV'T 4822, 4822–28 (2011) (discussing the challenges associated with using dispersion models when characterizing the relationship between traffic and ambient air pollution, especially with regards to ultrafine particles).

[136] *National Air Toxics Assessments*, U.S. ENVTL. PROT. AGENCY (May 21, 2012), http://www.epa.gov/nata ("Ambient and exposure concentrations, and estimates of risk and hazard for air toxics in each State are typically generated at the census tract level.").

of spatial (e.g., neighborhood-level impacts) as well as temporal (e.g., spikes in air toxics concentrations after an accident) concerns.

The TRI is less helpful for three reasons. Not only are the data self-reported,[137] but the fabled Form R is submitted by a subset of Northern California industries, blinding you to threats from dry cleaners, auto body paint shops, and diesel trucks, to name a few.[138] Firms that qualify for the program base their air emissions data on estimates from facility input-output models rather than actual readings of toxins leaving each plant.[139] The estimates do not account for episodic incidents such as accidents or flaring, because they assume normal operating conditions.[140] California air toxics data share similar shortcomings, whether they are based on estimates, leave out important sources, or fail to provide data in sufficiently fine-grained detail to be useful to neighborhoods.[141] None of the information gives you *actual* pollution concentrations in the air at neighborhood level.

Imagine that you live in a neighborhood that shows up on one of those grainy maps of dispersion model results. Perhaps you own a home in Richmond, West Oakland, or San Rafael's Canal district. You want to know the air quality in your neighborhood and have less interest in coefficients or p-values. Stripped of statistics, you want to know the amount of substances a through n in the air at ground level at time t. You live in a region with nine counties, millions of people, and a massive road network.[142] To know what is in the air, you rely on a small number of government-installed stations, sophisticated devices that mimic the shortcomings of emissions databases: they focus on a tiny subset of pollutants,[143] collect air many meters above the ground,[144] and ignore concentrations further

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[137] Bradley C. Karkkainen, *Information as Environmental Regulation: TRI and Performance Benchmarking, Precursor to a New Paradigm?*, 89 GEO. L.J. 257, 286–87 (2001).

[138] *See* U.S. ENVTL. PROT. AGENCY, FACTORS TO CONSIDER WHEN USING TOXIC RELEASE INVENTORY DATA 7–8 (2012), *available at* http://www2.epa.gov/sites/production /files/2013-09/documents/tri_factors_to_consider_2013.pdf (noting that a facility must report if it meets three threshold criteria: (1) the facility is included in a TRI-reportable industry sector or is federally owned/operated; (2) the facility has ten or more full-time employees; and (3) the facility manufactures, processes, or otherwise uses a TRI-listed chemical above a threshold level). These factors exclude a considerable range of sources of toxic emissions. *See* William F. Pedersen, *Regulation and Information Disclosure: Parallel Universes and Beyond*, 25 HARV. ENVTL. L. REV. 151, 159 (2001).

[139] OFFICE OF INSPECTOR GENERAL, U.S. ENVTL. PROT. AGENCY, EPA CAN IMPROVE EMISSIONS FACTORS DEVELOPMENT AND MANAGEMENT 2–3 (2006).

[140] Karkkainen, *supra* note 137, at 321 n.270.

[141] STILL TOXIC, *supra* note 126, at 4–5.

[142] *Id.* at 6.

[143] *See Technology Transfer Network Air Quality System Data Mart, Basic Information*, U.S. ENVTL. PROT. AGENCY (Feb. 11, 2013), http://www.epa.gov/ttn/airs/aqsd atamart/basic_info.htm.

[144] Current regulations allow a distance of three to fifteen meters between ground and probe for SO_2, CO, ozone, and NO_2, and two to fifteen meters for particulate matter. Carlos Restrepo et al., *A Comparison of Ground-Level Air Quality Data with New York State*

afield[145] unless they are married to dispersion models and spit out by census tract on a government website.[146] This problem of sparse or "coarse" spatial data is repeated in other parts of the country.

Even if you scale back your concerns about air quality, you reach similar limits in short order. Perhaps you live near a unique source of a pollutant, such as hydrogen sulfide emanating from a refinery.[147] You could try to get information about its *release*, which, depending on the regulation, might take the form of continuous emissions data or the results of more modeling.[148] But there are few incentives for a firm to collect spatial data on air *quality*, especially beyond a facility's fence line. This is true despite the range of authorities that could be used to encourage an industry to track emissions, install monitoring systems, and improve the accuracy of available data. EPA's strategic planning documents, including an expanded version of a former General Counsel's survey of available regulations,[149] identify provisions that could raise performance monitoring and compliance review requirements for facility owners and operators.[150] But even if they were put to use, agencies would face stark limits to the amount of ground-level, community-scale, continuous data with which to ensure health and safety.

The public's burden to fill these spatial data gaps is steep. Ten years ago, the public attempted to do so.[151] But an architecture that accommodates data scarcity makes it difficult for third parties to offer useful, actionable improvements to data shared among regulators and firms. A first wave of initiatives showed promise:

Department of Environmental Conservation Monitoring Stations Data in South Bronx, New York, 38 ATMOSPHERIC ENV'T 5295, 5297 (2004).

[145] *See* Dane Westerdahl et al., *Mobile Platform Measurements of Ultrafine Particles and Associated Pollutant Concentrations on Freeways and Residential Streets in Los Angeles*, 39 ATMOSPHERIC ENV'T 3597, 3598–3601 (2005).

[146] *See, e.g.*, *Technology Transfer Network 1996 National-Scale Air Toxics Assessment, The ASPEN Model*, U.S. ENVTL. PROT. AGENCY (Apr. 15, 2010), http://www.epa.gov/ttn/atw/nata/aspen.html.

[147] In refineries, hydrogen sulfide is produced when hydrogen is used to remove sulfur from petroleum. *See* R.O. Beauchamp, Jr., et al., *A Critical Review of the Literature on Hydrogen Sulfide Toxicity*, 13 CRITICAL REVIEWS IN TOXICOLOGY 25, 51–52 (1984).

[148] *See, e.g.*, 42 U.S.C. § 7651k(a) (2006).

[149] *See generally* Memorandum from Gary S. Guzy, Gen. Counsel, Office of Gen. Counsel, U.S. Envtl. Prot. Agency, to Assistant Administrators, EPA Statutory and Regulatory Authorities Under Which Environmental Justice Issues may be Addressed in Permitting (Dec. 1, 2000), *available at* http://www.epa.gov/region1/ej/pdfs/gary_guzy_memo.pdf.

[150] *See, e.g.*, U.S. ENVTL. PROT. AGENCY, PLAN EJ 2014 LEGAL TOOLS 4 (2011) (identifying, for example, section 111 of the Clean Air Act as a potential means of addressing location-specific concerns through new source performance standards), *available at* http://www.epa.gov/environmentaljustice/resources/policy/plan-ej-2014/ej-legal-tools.pdf.

[151] *See, e.g.*, Dara O'Rourke & Gregg P. Macey, *Community Environmental Policing: Assessing New Strategies of Public Participation in Environmental Regulation*, 22 J. POL'Y ANALYSIS & MGMT. 383, 384–85 (2003).

drift activism in Central California[152] and fenceline monitoring in chemical corridors in Northern California, port towns in Texas, and river communities between New Orleans and Baton Rouge.[153] Drift activism responds to the failure of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA)[154] to require spatial data on pesticide drift—the "airborne movement of agricultural pesticides into residential areas, schools, and other public spaces."[155] Drift is caused by spraying and other application methods. Pesticides, available "in tens of thousands of formulations," are susceptible to movement via rain, wind, and fog.[156] Drift is a frequent phenomenon,[157] infusing neighborhoods near orange groves and even open fields with a sense of foreboding. An account from Earlimart, California captures the confusion that mounts when drift occurs:

> Throughout the course of the evening of November 13, at least 170 residents of the small, agricultural community of Earlimart repeatedly experienced frightening and inexplicable acute illness, including vomiting, impaired breathing, dizziness, and burning eyes and lungs. Emergency crews responding to the scene did not speak Spanish and thus could not effectively communicate with many of the residents. Moreover, they could not identify the cause of the illness and were unsure of how to advise the victims, telling some to stay indoors while directing others to leave the vicinity. . . . A subsequent investigation revealed that a poisonous cloud of a soil fumigant called metam sodium, a known carcinogen as well as reproductive and developmental toxicant, had volatilized more quickly than anticipated from an agricultural field one quarter of a mile away, drifted into the town, and poisoned the residents.[158]

Drift is invisible to regulators because of the lack of air quality data for fumigants and pesticides. Pesticide regulation is principally concerned with product registration and labeling,[159] standard gap-filling techniques. Fenceline monitoring grew out of a similar need to provide data near homes and schools that are far

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[152] *See* JILL LINDSEY HARRISON, PESTICIDE DRIFT AND THE PURSUIT OF ENVIRONMENTAL JUSTICE 121–38 (2011) (discussing the phenomenon and the value of pesticide drift activism).

[153] *See 10-Year Anniversary Report*, Global Community Monitor 3, 6 (2011), *available at* http://www.gcmonitor.org/downloads/GCM10thAnnivReport_1.pdf.

[154] 7 U.S.C. §§ 136–136y (2006); 40 C.F.R. §§ 150–189 (2010). For examples of FIFRA oversights, see Clifford Rechtschaffen, *Advancing Environmental Justice Norms*, 37 U.C. DAVIS L. REV. 95, 108–109 (2003).

[155] Jill Lindsey Harrison, *Parsing "Participation" in Action Research: Navigating the Challenges of Lay Involvement in Technically Complex Participatory Science Projects*, 24 SOC'Y & NAT. RESOURCES 702, 705 (2011).

[156] HARRISON, *supra* note 152, at 3, 96.

[157] *Id.* at 5.

[158] *Id.* at 4–5.

[159] *See* Marina M. Lolley, Comment, *Carcinogen Roulette: The Game Played Under FIFRA*, 49 MD. L. REV. 975, 976–81 (1990).

removed from agency monitors, which, along with dispersion models and technology-based controls, accommodate data gaps in air toxics regulation.

Drift activism and fenceline monitoring span spatial data gaps in similar yet limited ways. Each is built around a "grab sampler," which takes a brief sample of air that is shipped via FedEx to a laboratory for analysis. A drift catcher works as follows: "a vacuum pump . . . pulls air through [a] glass sampling tube[] filled with a special resin that traps pesticides."[160] A bucket sampler uses a vacuum pump to pull air into a bag that was earlier purged of impurities.[161] The devices are brought into the field to take samples during drift incidents and facility upsets. Also similar are efforts to provide quality assurance/quality control (QA/QC) during the sampling process. For example, residents of New Sarpy, Louisiana were trained to record contextual data (e.g., wind direction, whether the sample was taken near automobile exhaust) when using the device.[162] Pesticide Action Network North America instructs drift activists to gather pump flow rate and other data and to ensure the integrity of filters and completed samples.[163] Analysis is designed to mirror, where possible, federal regulations for government equipment. Analyzing a drift catcher or bucket sample for chemical concentrations follows methods published in the Federal Register.[164]

Grab samples alter the dynamics among residents, facility operators, and regulators. Sampling results are used to lodge complaints with operators and regulators as well as the press, leading to adjustments in enforcement priorities and targeted sampling to fix isolated malfunctions.[165] Data-driven campaigns for relocation and improved monitoring (such as the use of open-path systems)[166] are waged in the press, and data are used to promote protective buffer zones around schools and sensitive populations.[167] But grab samples fall short in their ability to offer fine-grained geographic coverage. Drift catchers and buckets are limited by the cost of analyzing a sample. For example, New Sarpy residents, living in the

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[160] HARRISON, *supra* note 152, at 706.

[161] O'Rourke & Macey, *supra* note 151, at 389.

[162] Gwen Ellen Ottinger, Grounds for Action: Community and Science in Environmental Justice Controversy 186 (2005) (unpublished Ph.D. dissertation, University of California at Berkeley) (on file with author).

[163] *See* HARRISON, *supra* note 152, at 706–07.

[164] Ottinger, *supra* note 162, at 186 n.36; *see also* HARRISON, *supra* note 152, at 706 ("The primary technical goals for the Drift Catcher device and its accompanying protocol were that they be . . . functionally equivalent to regulatory agencies' own air monitoring systems.").

[165] *See Chalmette Residents Go High Tech to Monitor Exxon's Emissions: State of the Art System Gives Immediate Readings of Pollutants in the Air*, LOUISIANA BUCKET BRIGADE (Dec. 8, 2003), http://www.labucketbrigade.org/article.php?id=822.

[166] *Id.*

[167] *See Buffer Zones: Just Common Sense*, PESTICIDE ACTION NETWORK (July 12, 2012, 3:41 PM), http://www.panna.org/blog/buffer-zones-just-common-sense; *Tulare County Residents Win Greater Protection from Dangerous Pesticides: New Rules Announced for Pesticide Applications Around Schools, Homes and Labor Camps*, CALIFORNIANS FOR PESTICIDE REFORM (Feb. 20, 2008), http://www.panna.org/sites/default /files/imported/files/CPR20080220.pdf.

shadow of a refinery, analyzed six samples over a one-year period at the height of their organizing, at a cost of $400 apiece.[168] Sparse field use and a relatively small number of samples make it difficult to design sampling around a specific question of interest to the public.

More troubling is the relationship between sample results and the law's accommodation of spatial data gaps. Agency standards designed with spatial gaps in mind are incompatible with citizen monitoring results. Citizen monitors draw attention to the small number of states with ambient air quality standards for toxic pollutants. Louisiana's Toxic Air Pollutant Ambient Air Standards set maximum concentrations for toxins over an eight-hour or one-year period, based on our understanding of occupational exposure and increased cancer risk over longer periods of time.[169] A three-minute grab sample might reveal benzene concentrations in a resident's yard that are ten times higher than the Louisiana standard.[170] But regulators respond that it is not possible to know whether the reading would persist over extended (eight-hour, one-year) time periods.[171] This data mismatch distracts from efforts to understand, at scales useful to the public, the experience of air quality. Drift activists and bucket brigades point to the lack of ground-level data in residential areas. But as sampling proliferates and influences community benefits agreements and post-*Rosemere* Title VI settlements,[172] the space between the data they collect and agency response spreads across acres of burning light and waves of churning dust.

2. Near Real-Time

In the air quality arena, citizen samplers are the first wave of challenges to the architecture of ignorance. Next is the sensing revolution.[173] "Sensing" is the use of a device to detect something in the physical environment and translate it into a readable signal. The prototypical air quality sensor[174] works as follows: a device is fashioned with a semiconductor surface such as tin oxide. When the surface absorbs something we want to detect (say, sulfur dioxide), its conductivity

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[168] Ottinger, *supra* note 162, at 183.

[169] Gwen Ottinger, *Buckets of Resistance: Standards and the Effectiveness of Citizen Science*, 35 SCI. TECH. & HUMAN VALUES 244, 252 (2009).

[170] *See* Ottinger, *supra* note 162, at 187.

[171] Ottinger, *supra* note 169, at 252–54.

[172] *See* Rosemere Neighborhood Ass'n v. EPA, 581 F.3d 1169 (9th Cir. 2009) (finding a "consistent pattern of delay" in EPA's processing of Title VI administrative complaints). For a discussion of the benefits and drawbacks of community benefits agreements, see Vicki Been, *Community Benefits Agreements: A New Local Government Tool or Another Variation on the Exactions Theme?*, 77 U. CHI. L. REV. 5, 5–6 (2010).

[173] For an overview, see G. Eranna et al., *Oxide Materials for Development of Integrated Gas Sensors—A Comprehensive Review*, 29 CRITICAL REVIEWS IN SOLID ST. & MATERIALS SCI. 111 (2004).

[174] For a review of "biosensors," which instead of a chemical surface use microorganisms to detect environmental conditions, see Hae Shin, *Genetically Engineered Microbial Biosensors for In Situ Monitoring of Environmental Pollution*, 89 APPLIED MICROBIAL BIOTECHNOLOGY 867 (2011).

changes. The device interprets changes in conductivity as a concentration of sulfur dioxide.[175] Sometimes the device can sense multiple agents, a virtual "laboratory on a chip."[176] Innovations in chemical sensing allow reliable and accurate monitoring for a wide range of applications including homeland security, machine-failure diagnosis, and wildlife habitats.[177] Companies pursue smaller, more sensitive, and cheaper ways to detect chemicals in their facilities.[178] As firms limit the use of chemicals, either after an enforcement action, as a self-regulatory step, or in response to new standards, they need sensors with lower detection limits to observe chemical concentrations in foods and beverages,[179] wastewater,[180] and indoor air.[181] Sensors proliferate in textile manufacturing, medicine and health, and other industries.[182] Regulators also rely on them, and there are sensor arrays to keep track of everything from endangered species to tsunamis as part of an early warning system.[183] These demands increase not only the use of sensors but also the diversity of chemicals they can detect.[184]

An air quality sensor can fit in the palm of your hand. Every ten or twenty seconds, it can detect substances without the need to send samples to a lab. These devices are evolving at a rapid pace. Nanotechnology improves the sensing surface of a device so that it can detect chemicals at lower concentrations, including levels that are more precise than regulatory standards require.[185] Nanosensing also

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[175] For a comparison of these "heating semiconductors" to other gas sensors, see Sukwon Choi et al., *Micro Sensor Node for Air Pollutant Monitoring: Hardware and Software Issues*, 9 SENSORS 7970, 7984 (2009).

[176] Leroy Hood et al., *Systems Biology and New Technologies Enable Predictive and Preventive Medicine*, 306 SCI. 640, 642 (2004).

[177] *See, e.g.*, Mohammad Upal Mahfuz & Kazi M. Ahmed, *A Review of Micro-Nano-Scale Wireless Sensor Networks for Environmental Protection: Prospects and Challenges*, 6 SCI. & TECH. ADVANCED MATERIALS 302, 302–03 (2005).

[178] *See* Joseph Wang, *Real-Time Electrochemical Monitoring: Toward Green Analytical Chemistry*, 35 ACCOUNTS OF CHEMICAL RES. 811, 812–13 (2002).

[179] Jaime Castillo, *Biosensors for Life Quality: Design, Development, and Applications*, 102 SENSORS & ACTUATORS B 179, 183–88 (2004).

[180] Wilfrid Bourgeois et al., *The Use of Sensor Arrays for Environmental Monitoring: Interests and Limitations*, 5 J. ENVTL. MONITORING 852, 854 (2003).

[181] Evgeni Eltzov et al., *Creation of a Fiber Optic Based Biosensor for Air Toxicity Monitoring*, 155 SENSORS & ACTUATORS B 859, 863–65 (2011).

[182] Ornprapa Pummakarnchana et al., *Air Pollution Monitoring and GIS Modeling: A New Use of Nanotechnology Based Solid State Gas Sensors*, 6 SCI. & TECH. ADVANCED MATERIALS 251, 252 (2005).

[183] Jung et al., *supra* note 11, at 11236–37.

[184] For a representative list of the gas species that can be observed via sensing devices, see Eranna et al., *supra* note 173, at 113.

[185] Liza Rassaei et al., *Nanoparticles in Electrochemical Sensors for Environmental Monitoring*, 30 TRENDS IN ANALYTICAL CHEMISTRY 1704, 1706–07 (2011). For example, a sensing device can be embedded with layers of nanoparticles to pick up the presence of criteria air pollutants at the following thresholds: 3 parts per million (ppm) (CO), 15 parts per billion (ppb) (NO_2), and 15 ppb (O_3). Marie-Isabelle Baraton & Lhadi Merhari, *Advances in Air Quality Monitoring Via Nanotechnology*, 6 J. NANOPARTICLE RES. 107, 109 tbl.1 (2004). By comparison, EPA's maximum allowable concentrations for these

improves quality control. The most important advances in quality control have to do with sensitivity and selectivity. To be useful, a sensor must detect extremely low levels of a chemical (sensitivity) and distinguish it from potentially interfering compounds (selectivity) while avoiding distortions due to humidity, temperature, the flow rate of air entering the sensor, and other factors (cross-sensitivity). It must operate "in the field" (*in situ*) and give accurate readings (reliability) for extended periods of time (power), avoiding changes in the reactivity of the sensing surface (drift). In addition, it has to analyze chemicals rapidly (response time). Improvements along each of these criteria are mind-boggling.[186] Nanotechnology is responsible for many of them—through reductions in sensor surfaces, devices are smaller and lighter, with lower power requirements and higher sensitivity. Similar improvements have been made with biological (as opposed to chemical) sensing devices.[187]

Sensors do not operate in a vacuum. They can be placed in wireless networks, communicating among themselves and with central servers.[188] A sensor detects and provides data about conditions in the physical world. But wireless networks of sensors (WSNs), developed by the Defense Advanced Research Projects Agency in the 1970s,[189] will change how we pursue data about our surroundings. A WSN might include dozens or hundreds of sensors scattered across an area (e.g., a field or a body of water) or attached to points of infrastructure (e.g., along highways or on trucks).[190] The sensors—optimized to detect chemicals; distinguish them from other compounds; and correct for changes in temperature, humidity, and wind.

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pollutants are 35 ppm (one hour average), 53 ppb (annual mean), and .075 ppm (eight hour average), respectively. *Id.*

[186] *See generally* Waldemar Wardencki et al., *The State of the Art in the Field of Non-Stationary Instruments for the Determination and Monitoring of Atmospheric Pollutants*, 38 CRITICAL REVIEWS IN ANALYTICAL CHEMISTRY 259 (2008) (reviewing recent innovations in nonstationary instrumentation for air monitoring).

[187] Biosensors are used in remediation to monitor the rate of pollution reduction. The innovations lie in recombinant DNA as opposed to nanotechnology. For example, an enzyme commonly found in fireflies is often linked to a strain of bacteria adapted for hydrocarbon detection. *See* Eliora Z. Ron, *Biosensing Environmental Pollution*, 18 CURRENT OPINION IN BIOTECHNOLOGY 252, 252 (2007). The amount of light the enzyme emits is measured to assess the presence of hydrocarbons. *Id.* at 252–53. Biosensors offer advantages similar to chemical nanosensors, such as near-real-time readings without the need to send samples to a laboratory. *Id.* at 254. They can be outfitted with different bacteria to detect multiple substances. *Id.* They have the advantage of detecting only biologically active pollutants, although some provide relative as opposed to absolute values of a substance. *Id.*

[188] *See generally* Jennifer Yick et al., *Wireless Sensor Network Survey*, 52 COMPUTER NETWORKS 2292 (2008).

[189] Alfredo J. Perez et al., *G-Sense: A Scalable Architecture for Global Sensing and Montioring*, IEEE NETWORK, July–Aug. 2010, at 57, 58 ("The idea was to build nodes of small size (as small as 2 mm^2) that could be able to sense, transmit data, and harvest their energy needs from the environment, so they could be active for years and cheap enough to be deployed everywhere.").

[190] *See* Yick et al., *supra* note 188, at 2294–95.

speed—send signals (such as change in conductivity) to a digital processor, which then transfers the data to a nearby or distant (base station) location via Ultra Wideband, where it is gathered and processed.[191] A WSN of air quality sensors resolves many of the shortcomings of fixed government stations and citizen monitors. It offers dense spatial coverage and near-real-time readings of the environment. Importantly, each node in a WSN can be occupied by a person.[192]

WSNs address spatial as well as temporal limits of environmental data. The combination of locational and background sensing capabilities in a sensor network offers a higher level of quality control. Cell phones and the network itself can verify data, data are tagged with network-verified location and timestamp information, and mobile sensors automatically take measurements of wind direction and speed, temperature, humidity, and other variables that influence data quality. Because many nodes in a sensor network are not fixed, they can be used to form networks at will among communities of interest, including regulators, environmental managers, and the public. In this way, sensor networks will strain environmental law's architecture of ignorance. They will provide far more data than regulations were established to handle. In addition, they will generate data that are not keyed to gap-filling accommodations long since codified.

3. *The Body Burden Abyss*

Data gaps haunt every scale of regulatory interest in environmental law, from the quality of a far-flung corner of the atmosphere to the frailty of a single human cell. Efforts to accommodate them are temporal as well as spatial. Even a molecule of a dangerous substance can lead to disease at the cellular level. Armed with this understanding, agencies try to control exposure to compounds not only in the air,

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[191] *See id.* at 2318.

[192] Roughly three quarters of the world's population has access to a mobile phone. Press Release, The World Bank, Mobile Phone Access Reaches Three Quarters of Planet's Population (July 17, 2012), *available at* http://www.worldbank.org/en/news/press-release/2012/07/17/mobile-phone-access-reaches-three-quarters-planets-population. Phones already gather real-time environmental data in the form of cell tower signal strength. They can also gauge temperature, noise, light, wind speed and direction, and, using plug-ins, levels of everything from pollen to carbon monoxide. *See generally* Charu C. Aggarwal & Tarek Abdelzaher, *Social Sensing*, *in* MANAGING AND MINING SENSOR DATA 37 (Charu C. Aggarwal ed., 2013) (evaluating ways in which sensor networks can be integrated). Mobile phones are being outfitted with chemical nanosensors in field trials and other proofs of concept, and can communicate with handheld sensors via technologies such as Bluetooth. *See id.* at 68. Most importantly, cell phones are linked to the Internet. Every device that links to the Internet must have its own address. A revised Internet Protocol, IPv6, will increase the number of devices that can connect to the web by pushing the number of available addresses. This will make it possible for sensors, whether onboard (built into a mobile phone), worn (on clothing or carried), or left behind (such as attached to street signs), to communicate with each other, as part of a decentralized system of smart objects known as the "first mile of the Internet" or "Internet of Things." Antoine Bagula et al., *Ubiquitous Sensor Networking for Development (USN4D): An Application to Pollution Monitoring*, 12 SENSORS 391, 392 (2012).

but also in our food and water supply. Herein lies a problem with devices as populist as drift catchers and as elegant as sensor arrays: they do not tell the user their *actual* exposure to pesticides or toxins. The most useful data are not proximity to or even contact with a pollutant, but the "biologically effective dose" of a substance over time, the amount that reaches a part of the human body that is susceptible to disease.[193] Of course, it is not the fault of those working on projects like drift activism that they have not bridged this gap. Epidemiologists, toxicologists, and other scientists have been unable to address this question for decades.[194] In response, environmental laws accommodate our inability to gauge exposure to unsafe substances and their effects over time.

Consider the dawn of federal pesticide and food and drug regulation. From the beginning, agencies worried whether pesticides cause cancer. In its first five years, for example, EPA suspended or canceled the use of DDT, aldrin and dieldrin, and chlordane and heptachlor.[195] This was an improvement over the 1950s, when only ionizing radiation was regulated on the basis of its carcinogenic effects[196] and the only known carcinogens were soot, radiation, tobacco smoke, and *B*-naphthylamine.[197] EPA's method was simple. Identify a chemical of concern. Then, eliminate its use. EPA did not quantify risks from pesticide exposure because, frankly, it did not have the internal procedures to do so. Instead, it relied on data from scientists outside of the agency.[198] After scientists found that aldrin and dieldrin caused liver tumors in laboratory mice, EPA announced that the pesticide posed a "high risk of [causing] cancer in man."[199] After studies found tumors in rodents exposed to high doses of DDT, EPA declared that DDT was a "potential human carcinogen."[200] EPA tempered its statements with qualifications. Risks posed by DDT were, according to EPA, "remote and unquantifiable."[201]

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[193] Brenda K. Weis et al., *Personalized Exposure Assessment: Promising Approaches for Human Environmental Health Research*, 113 ENVTL. HEALTH PERSP. 840, 841 (2005).

[194] *See* David J. Briggs et al., *Uncertainty in Epidemiology and Health Risk and Impact Assessment*, 31 ENVTL. GEOCHEMICAL HEALTH 189, 190–91 (2009).

[195] *See generally* Envtl. Def. Fund, Inc. v. EPA, 489 F.2d 1247 (D.C. Cir. 1973) (upholding EPA's decision to cancel registration for DDT); Envtl. Def. Fund, Inc. v. EPA, 510 F.2d 1292 (D.C. Cir. 1975) (upholding EPA's suspension of aldrin and dieldrin); Envtl. Def. Fund, Inc. v. EPA, 548 F.2d 998 (D.C. Cir. 1976) (affirming EPA's suspension of chlordane and heptachlor).

[196] Health Risk and Economic Impact Assessments of Suspected Carcinogens, 41 Fed. Reg. 21,402, 21,402–03 (May 25, 1976).

[197] Wilson, *supra* note 5, at 48.

[198] *See generally* Nat'l Cancer Advisory Bd., *General Criteria for Assessing the Evidence of Carcinogenicity of Chemical Substances: Report of the Subcommittee on Environmental Carcinogenesis*, 58 J. NAT'L CANCER INST. 461 (1977) (reporting on the risks of carcinogens to humans).

[199] Consolidated Aldrin/Dieldrin Hearing, 39 Fed. Reg. 37,246, 37,259 (Oct. 18, 1974).

[200] Consolidated DDT Hearings, Opinion and Order of Aministrator, 37 Fed. Reg. 13,369, 13,371 (July 2, 1972).

[201] *Id.*

FDA's power to control dangerous substances was achieved earlier, with the Food, Drug, and Cosmetic Act ("the Act") of 1938.[202] The Act gave FDA control over substances added to or found in foods. It prohibited adding a substance to food if it was "poisonous or deleterious" such that it rendered the food "injurious to health."[203] Food containing a poisonous substance escapes scrutiny (i.e., is not considered "adulterated") if the quantity of the substance does not "ordinarily render it injurious to health."[204] Provisions covering added contaminants, existing constituents, and substances that are unavoidable gave FDA the chance to regulate environmental contaminants in food, such as lead and mercury.[205]

Vague text such as "deleterious" and "injurious" lay dormant at first, belying our ability to characterize human exposure over time. The need to wield it with greater precision was soon apparent. FDA adopted a set of provisions in the Food Additives Amendment of 1958 (the original "Delaney Clause"),[206] Color Additives Amendments of 1960,[207] and Animal Drug Amendments of 1968.[208] The Food Additives Amendment is illustrative:

> [N]o [food or drug] additive shall be deemed to be safe if it is found to induce cancer when ingested by man or animal, or if it is found, after tests which are appropriate for the evaluation of the safety of food additives, to induce cancer in man or animal.[209]

With the Delaney Clause, FDA mirrored EPA's control of pesticides in the early 1970s: identify a carcinogen and eliminate it from the food supply. The first approach to ignorance of safe levels of human exposure to dangerous substances was thus an outright ban.

This approach was quickly abandoned. Within a few years, Congress, concerned about the economic impact of the bans, passed a series of provisos. For example, Congress allowed carcinogens in animal feed if the carcinogen residue did not appear in edible portions of the animal.[210] FDA recognized that drugs, such as diethylstilbestrol, offered cost savings for livestock production, even as they posed health risks. Its retreat from the Delaney Clause was similar to developments

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[202] 21 U.S.C. §§ 301–392 (2006).

[203] *Id.* § 342(a)(1).

[204] *Id.*

[205] Poisonous or Deleterious Substances in Food, 39 Fed. Reg. 42,743, 42,743–44 (Dec. 6, 1974).

[206] 21 U.S.C. § 348 (applying to constituents whose use in packaging and other materials means that they will reasonably be expected to become components of food). If a food includes an additive the use of which FDA has not approved as "safe," or if it has an additive that exceeds a quantity specified by FDA, it is considered adulterated. *Id.*

[207] 21 U.S.C. § 379e(b) (requiring agency approval of any use of a color in foods or cosmetics). Foods or cosmetics that contain color additives that are not listed by FDA are considered adulterated. *Id.* § 342(c).

[208] 21 U.S.C. § 360b (stating that no animal drug that is likely to leave residue in animal tissues may be used without FDA approval).

[209] 21 U.S.C. § 348(c)(3)(A).

[210] 21 U.S.C. §§ 348(c)(3)(A)(ii).

at EPA.[211] Both conceded that, in the words of one EPA Administrator, "in many areas risks cannot be eliminated completely without unacceptable social and economic consequences."[212] Each agency in turn allowed carcinogens to enter the food supply as pesticides, food additives, animal drugs, and other sources of exposure.

To move from an outright ban to limited use of a carcinogen requires an agency to set a threshold, a socially acceptable level of risk from the substance. Ideally, this is done using longitudinal studies of human exposure. EPA recognized this as it outlined its approach to setting acceptable levels of toxins: "The best evidence . . . comes from epidemiological studies . . . ."[213] With the exception of workplace chemicals, studies rarely link human exposure to health outcomes. A study based on the exposure of each individual of the study population over time was and remains elusive to regulators.[214]

To address this temporal data gap, agencies develop a theoretical construct, just as they do for spatial estimates of air quality. We learned that air quality databases do not tell us the actual amount of a substance in the air. They rely on models of the transport of chemicals from a point in geographic space over, say, one year's time. Similarly, levels of "exposure" to allowable amounts of pesticide residue or food additives require two leaps of faith. We link laboratory studies ("bioassays") of other species exposed to high doses of a chemical to estimates of the effects of human exposure to low doses of the chemical using models.

FDA's concern over the validity of bioassays was apparent by the 1950s, when it argued that "positive results in . . . animal tests can be taken as creating a suspicion that the chemical under study may be carcinogenic for man, but do not prove it to be so."[215] The technique was viewed as "crude, difficult to perform, and was characterized by a low degree of accuracy and precision."[216] Similar to leaps required in the study of air quality, the problems linking levels of a substance in an animal test to an estimated response among human beings are manifold. Most simply, a negative lab test result does not mean that a chemical is safe. The FDA Advisory Committee on Protocols for Safety Evaluation reported in 1971 that, given one thousand test animals and a 90% confidence interval, an experiment yielding no disease tells us that the chemical produces a *maximum* of two to three cases of cancer per thousand individuals.[217] Because of the lack of sensitivity of

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[211] Health Risk and Economic Impact Assessments of Suspected Carcinogens, 41 Fed. Reg. 21,402, 21,402–03 (May 25, 1976).

[212] *Id.*

[213] *Id.* at 21,404.

[214] *See id.*

[215] Arnold J. Lehman et al., *Procedures for the Appraisal of the Toxicity of Chemicals in Foods, Drugs, and Cosmetics*, 10 FOOD DRUG COSM. L.J. 679, 720 (1955).

[216] Joseph V. Rodricks, *Origins of Risk Assessment in Food Safety Decision Making*, 7 J. AM. C. TOXICOLOGY 539, 540 (1988).

[217] Food & Drug Admin. Advisory Comm. on Protocols for Safety Evaluation, *Panel on Carcinogenesis Report on Cancer Testing on the Safety Evaluation of Food Additives and Pesticides*, 20 TOXICOLOGY & APPLIED PHARMACOLOGY 419, 431 (1971).

lab results, the Committee recommended that animal testing be designed to yield the maximum likelihood of disease response.[218]

Ratcheting up the sensitivity of bioassays with extremely high doses leads inexorably to a second leap: extrapolating from artificially high doses to exposure levels one would expect among human beings over a lifetime.[219] The same level of concern over the use of theoretical exposure to set policy for actual human exposure can be found in the early days of EPA pesticide regulation.[220]

By the early 1980s, it was clear that "[t]he choice of model to use for the extrapolation is critical, in that the act of [model] selection may be of greater import than even the data on carcinogenicity itself . . . ."[221] In 1985, an FDA official declared "the basic problem in risk assessment—the lack of scientific knowledge and the sparseness of the data base—is almost as severe now as it was 15 years ago."[222] In 1997, the National Center for Toxicological Research summarized the state of the science: "[r]isk assessment of carcinogens is currently not completely rigorous from a biological viewpoint."[223] These problems, and their accommodation, persist. Agency documents reiterate concerns identified at the outset, with animal bioassays and high to low-dose extrapolation.[224]

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[218] *Id.* at 435–36.

[219] The method involves choosing a point on a dose-response plot below which data from animal studies are not available. A straight line is drawn from the upper confidence limit for cancer risk at that point on the graph (corresponding to the lowest experimental dose used at that point) to the origin. David W. Gaylor & Ralph L. Kodell, *Linear Interpolation Algorithm for Low Dose Risk Assessment of Toxic Substances*, 4 J. ENVTL. PATHOLOGY & TOXICOLOGY 305, 309 (1980). The choice of mathematical function to extrapolate from observable data to theoretical points closer to human exposure has a huge influence over the dose found "safe." *Id.* Of equal concern is distinguishing one mathematical function from another in the observable data range (the range generated by animal studies). *See* Nat'l Cancer Advisory Bd., *supra* note 198, at 462.

[220] EPA's Interim Guidelines in the 1970s committed to linking animal studies to estimates of human exposure. Regardless of the statistical method, the consensus was that "current understanding . . . is not adequate to permit reliable extrapolations from animal experimentation and simpler assay systems to actual quantified hazards to human health." COMMITTEE ON PROTOTYPE EXPLICIT ANALYSES FOR PESTICIDES, REGULATING PESTICIDES 81 (1980); *see also* Food & Drug Admin. Advisory Comm. on Protocols for Safety Evaluation, *supra* note 217, at 420, 422, 429 (noting several criticisms of using animal research of carcinogens to extrapolate to human health hazards).

[221] Memorandum from Peter Preuss, Assoc. Exec. Dir., Directorate of Health Sciences, United States Consumer Prod. Safety Comm'n, to United States Consumer Prod. Safety Comm'n, at 2 (Dec. 29, 1980).

[222] Joseph Rodricks, Consistency of SOM with Current Methods in Risk Assessment, Address Before the Animal Health Institute Symposium on SOM (Jan. 14, 1985).

[223] David W. Gaylor et al., *Health Risk Assessment Practices in the U.S. Food and Drug Administration*, 26 REG. TOXICOLOGY & PHARMACOLOGY 307, 310 (1997).

[224] *See, e.g.*, U.S. Office of Science and Technology Policy, Chemical Carcinogens: A Review of the Science and its Associated Principles, Principle 29, 50 Fed. Reg. 10,378 (March 14, 1985); Ronald H. White et al., *State-of-the-Science Workshop Report: Issues and Approaches in Low-Dose-Response Extrapolation for Environmental Health Risk Assessment*, 117 ENVTL. HEALTH PERSP. 283, 283–84 (2009).

Note the context in which these temporal accommodations are made. Regulators define relationships between exposure and outcomes over time. One outcome is disease, or more specifically, a clinical diagnosis of disease such as cancer. That is but a single point along a temporal continuum that begins with exposure and moves through many steps before yielding the clarity of a clinical finding, perhaps thirty years down the road. The continuum might move through the following weigh stations:

> Proximity to source → fate and transport from source to individual → **external dose** from source (plus other sources in air, water, food, soil) from inhalation, skin absorption, ingestion → internal dose → biologically effective dose → early biologic response → altered cell and tissue function → **clinical disease**.[225]

Regulations accrue to accommodate the lack of data along much of this continuum. From the early days of pesticide regulation, they were designed to link theoretical measures of external dose to extrapolated estimates of clinical disease. Absent an understanding of genetic, chemical, and biological dynamics at work along the continuum, regulators define terms such as "injurious" and "deleterious" in artificial ways. While critiques of those definitions—and the available methods to link theoretical exposure to a clinical diagnosis—are important, they distract from a more foundational decision. Temporal gaps lead regulators to ignore the majority of lived experience. As is true of air quality standards that are policed with spatial estimates, lifetime cancer risk estimates are complex yet crude tools for accommodating temporal ignorance.

4. Dust and Other Personal Exposures

Sensors can gather data on our general or even immediate surroundings. Other innovations peer inside the human body, amassing data that, with the rare exception, have eluded us.[226] Under the banner of "personal exposure assessment," environmental, consumer advocacy, and rights-based organizations already use these data.[227] Personal exposure data cover novel spatial and temporal scales. They draw the public's attention to moments along the disease continuum that were previously ignored by regulators.

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[225] For the genetic and biological markers of exposure and response along this continuum, see Weis et al., *supra* note 193, at 841.

[226] Exceptions include blood lead testing during the phaseout of leaded gasoline in the 1970s. Ken Sexton et al., *Human Biomonitoring of Environmental Chemicals: Measuring Chemicals in Human Tissues is the "Gold Standard" for Assessing People's Exposure to Pollution*, 92 AMER. SCI. 38, 42 (2004).

[227] For an overview of the use of personal exposure assessment data by advocacy organizations, see generally TECHNOSCIENCE AND ENVIRONMENTAL JUSTICE: EXPERT CULTURES IN A GRASSROOTS MOVEMENT (Gwen Ottinger & Benjamin R. Cohen eds., 2011).

Personal exposure data are gathered through two approaches: biomonitoring and "microenvironment" sampling of matter as mundane as household dust.[228] Biomonitoring measures the presence or internal dose of chemicals in the human body, using tiny samples of, among other things, tissue, blood, hair, or breath.[229] The field is undergoing innovations along dimensions such as sensitivity, specificity, and cost.[230] With biomonitoring, a community concerned with its "body burden"[231] from proximity to highways or a chrome plating facility can unequivocally identify its exposure to certain compounds.[232] Depending on the substance, the data are as precise as parts per quadrillion.[233]

That sample will soon be able to reveal thousands of changes in gene expression, each change a miniature early warning system for future health effects.[234] These data ("biomarkers") fall into three categories. Biomarkers of exposure, such as metabolites of common pesticides, tell us about internal or biologically effective dose.[235] Effect biomarkers, such as protein levels, reveal early reactions to a substance in the body, such as damage caused by heavy metals.[236] And biomarkers of susceptibility, such as enzyme levels that indicate DNA repair, identify individuals who are less likely to cope with an exposure.[237]

Biomonitoring reduces the need for many of the accommodations carried out in FDA and EPA assessments. It can reveal actual as opposed to theoretical exposure. It can speak to multiple points along ranges of time that link exposure and response, rather than only linking to external exposure and clinical endpoints.

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228 *See, e.g.*, Paul J. Lioy et al., *Dust: A Metric for Use in Residential and Building Exposure Assessment and Source Characterization*, 110 ENVTL. HEALTH PERSP. 969, 972–73 (2002).

229 *See, e.g.*, Rachel Morello-Frosch et al., *Toxic Ignorance and Right-to-Know in Biomonitoring Results Communication: A Survey of Scientists and Study Participants*, 8 ENVTL. HEALTH 1, 2 (2009).

230 *See* Susan W. Metcalf & Kenneth G. Orloff, *Biomarkers of Exposure in Community Settings*, 67 J. TOXICOLOGY & ENVTL. HEALTH 715, 717–19 (2004).

231 While some begrudge the term as not technically accurate, "body burden" is an effective label for the presence of chemicals in the human body. For criticism of the term, see Dennis Paustenbach & David Galbraith, *Biomonitoring: Is Body Burden Relevant to Public Health*, 44 REG. TOXICOLOGY & PHARMACOLOGY 249, 249 (2006).

232 Biomarkers are available for numerous chemicals, including metals, polychlorinated biphenols, pesticides, and volatile organic compounds. Sexton et al., *supra* note 226, at 41.

233 Metcalf & Orloff, *supra* note 230, at 717.

234 *See* Mark Toraason et al., *Applying New Biotechnologies to the Study of Occupational Cancer—A Workshop Summary*, 112 ENVTL. HEALTH PERSP. 413, 414–15 (2004). The field of toxicogenomics, which studies how the human genome reacts to hazardous substances, is at the root of this innovation. *Id.* at 412. *But see* David E. Adelman, *The False Promise of the Genomics Revolution for Environmental Law*, 29 HARV. ENVTL. L. REV. 117, 147–55 (2005) (explaining the limits of toxicogenomics and challenges to adjusting legal standards according to advances in our understanding of disease).

235 Metcalf & Orloff, *supra* note 230, at 715–17.

236 *Id.*

237 *Id.*

Along much of the continuum, advocacy groups,[238] academics,[239] and agencies such as the Centers for Disease Control[240] will find their efforts limited by existing agency practices that accommodate ignorance.

Members of a community, perhaps host to a Superfund site or residents of the Ninth Ward in New Orleans, might not trust an agency announcement that it is safe to return to their homes after an event risking chemical exposure. Standard tools that might yield such an agency claim include soil samples and models to convert concentrations of chemicals underground to estimates of exposure aboveground.[241] Residents might choose not to rely on statements that teeter on proxies for human behavior (such as whether children will engage in hand-to-mouth behavior) and default values for chemical movement through soil. They will turn to microenvironments in their homes, taking samples of surfaces or indoor air. Personal exposure assessments target exposures that reside in unregulated, private settings.[242] Along with biomonitoring, personal exposure assessments hold the promise to shift the roles of agencies and the public considerably. Such assessments will be used as much by citizens to discover threats to health as by agencies to confirm—or debunk—them.[243]

Wielding data to frame problems as well as verify concerns, the public is in a position to speak to points of their choosing along the exposure-disease continuum. Eschewing standard institutional review board reporting procedures, they organize around body burden hot spots or according to unique microenvironment concerns that are invisible to regulators.[244] As drift activists and bucket brigades discovered, they produce data that, by virtue of their spatial (e.g., household ventilation systems) or temporal (e.g., early biological effects) nature, fail to speak to the accommodations made in order to implement existing cleanup standards.[245]

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[238] *See, e.g.*, KATHLEEN CURTIS & BOBBI CHASE WILDING, BODY BURDEN WORK GRP. & COMMONWEAL BIOMONITORING RES. CTR., IS IT IN US? CHEMICAL CONTAMINATION IN OUR BODIES, 4–5 (2007), *available at* http://www.isitinus.org/documents/Is%20It%20In%20Us%20Report.pdf.

[239] *See, e.g.*, Phil Brown et al., *"A Lab of Our Own": Environmental Causation of Breast Cancer and Challenges to the Dominant Epidemiological Paradigm*, 31 SCI. TECH. & HUMAN VALUES 499, 502 (2006).

[240] *See, e.g.*, CENTERS FOR DISEASE CONTROL AND PREVENTION, THIRD NATIONAL REPORT ON HUMAN EXPOSURE TO ENVIRONMENTAL CHEMICALS 5, 7–9, 465 (2005).

[241] *See* Bernard D. Goldstein, *Advances in Risk Assessment and Communication*, 26 ANN. REV. PUB. HEALTH 141, 146–48 (2005).

[242] The Clean Air Act gives EPA authority to regulate open as opposed to indoor air. *See, e.g.*, 40 C.F.R. § 50.1(e) (2012).

[243] Rebecca Gasior Altman et al., *Pollution Comes Home and Gets Personal: Women's Experience of Household Chemical Exposure*, 49 J. HEALTH & SOC. BEHAVIOR 417, 418–19 (2008).

[244] *See* Julia Green Brody et al., *"Is it Safe?": New Ethics for Reporting Personal Exposures to Environmental Chemicals*, 97 AMER. J. PUB. HEALTH 1547, 1549–51 (2007) (discussing individual reporting approaches).

[245] *See, e.g.*, Carus Chem. Co. v. EPA, 395 F.3d 434, 437 (D.C. Cir. 2005) ("With respect to each pathway and threat to be scored, the [Hazard Ranking System] calls for the EPA to measure . . . likelihood of release (or likelihood of exposure); waste characteristics;

5. The Community Under Stress

The sensing revolution reveals the broad contours of the architecture of ignorance. The public has begun to question the spatial location of data, taking samples on residential streets and in schoolyards at ground level, places ignored by government stations. But the samples do not provide continuous information about air quality, and cost limits the geographic coverage of the devices used. So we lack actual (as opposed to estimated), real-time (as opposed to interval), and fine-grained (as opposed to coarse) data across broad swaths of terrain.

Personal exposure data reveal how the regulation of dangerous substances is hindered by a lack of actual exposure data over time. Outcomes of significance to regulators can take decades to identify. In response, we speed up the process of disease in other species and guess the implications of bioassays for human health generations from now. Even these leaps seem reasonable compared to our lack of understanding of the biologically effective dose of a substance or implications of a body burdened by a host of pollutants.

At times, regulatory concerns may not span considerable geographic space, or their effects may need to be addressed immediately. In areas such as emergency response, spatiotemporal accommodation is collapsed. We need not return to a defining moment in the history of disasters[246] to appreciate this. Instead, a collection of towns near Denver, Colorado, is illustrative. Several working-class neighborhoods lie under Interstate 70, which rises above them on viaducts.[247] Before I-70 was in place, people moved to the towns to work in packinghouses. Industry further clustered in the area after the highway was finished. Zoning helped to shape facility location.[248] Railroad switching and holding terminals moved from downtown to outer-lying areas,[249] such as Swansea.

Here is a brief account of what might occur at one of the terminals. Hydrochloric acid (HCl) is stored in tanker cars there. A barbed-wire fence separates the tankers from a playground. It is 2:40 in the afternoon. The sole employee on duty learns that HCl is eating a hole through the bottom of one of the cars.[250] He notifies the fire department, as 3,300 gallons form a vapor cloud that moves toward homes nearby.[251] His company tells the National Response Center

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and targets, which may include an individual, a human population, resources, and sensitive environments." (internal quotation marks omitted)).

[246] *See, e.g.*, WILLIAM R. FREUDENBURG ET AL., CATASTROPHE IN THE MAKING: THE ENGINEERING OF KATRINA AND THE DISASTERS OF TOMORROW 6–7 (2009).

[247] Berny Morson, *In the Shadow of I-70 Elyria, Swansea and Globeville Stew in Pollution and Noise—and More's on the Way*, DENVER ROCKY MOUNTAIN NEWS, Nov. 19, 1995, at 36A.

[248] Residents note that the City of Denver decided to turn the communities of Swansea and Elyria into an "industrial park" in 1958. Interview with Resident of Swansea, in Swansea, Colo. (Mar. 8, 2002).

[249] *Id.*

[250] Letter from Gene R. Meyer, Manager, Vulcan Chemicals, to James Knoy, U.S. EPA (May 1, 1995) (on file with author).

[251] *Id.*

about the incident later that evening.[252] A hazardous materials team arrives, establishes a base of operations upwind, and interrogates the employee about what is needed to remove the contents of the damaged car. The city's Office of Emergency Preparedness requests equipment to monitor the vapor cloud five hours later. The GATX car is offloaded by 12:45 a.m. A contractor arrives in the middle of the night to remove HCl from the ground but does not have the right equipment. An air staffer at EPA receives complaints of burning eyes at 8:45 the next morning, and the transfer of spilled HCl continues until 9:00 a.m. Over two days, three hundred people evacuate a twenty-block area. They are allowed to return when the fire department confirms that there is no remaining HCl cloud at 10:10 a.m. The cloud drifts eastward, away from homes.[253]

Town meetings identify limited community warning and improper reporting under the Emergency Planning and Community Right-to-Know Act (EPCRA).[254] There are coordination problems among city services, and agencies lack information about the situation as it unfolds.[255] In the months that follow, the city learns from the accident.[256] It agrees to develop a more specific evacuation plan.[257] EPA files an administrative complaint. The parties agree to participate in a Supplemental Environmental Project to assist the Denver Fire Prevention Bureau with its EPCRA obligations.[258] As accidents go, the leak and evacuation of a small area seem relatively straightforward. Facility management problems are identified, and violations are laid out in notices to the company. The accident involves a designated hazardous substance as well as reporting violations under federal law.[259]

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[252] *Id.*

[253] The events in this paragraph were reconstructed from the following materials: U.S. DEPT. OF TRANSP., OFFICE OF HAZARDOUS MATERIALS SAFETY, HAZARDOUS MATERIALS INCIDENT REPORT NO. 95050318 (July 6, 1995); COLO. DEPT. OF HEALTH, EMERGENCY MGMT. UNIT, INCIDENT REPORT CODH950028 (Mar. 29, 1995); DENVER FIRE DEPT., FIELD INCIDENT REPORT NO. 14149 (Mar. 29, 1995).

[254] Meeting with Public Concerning HCl Release (Mar. 30, 1995) (on file with author).

[255] *Id.*

[256] Letter from Michael Michalek, Staff Assistant, Office of Emergency Preparedness, to Debbie Gomez, Dept. of Health and Hospitals (July 17, 1995) (on file with author) (outlining agency responsibilities, multilingual cards, multilingual public information officers, and multiple calls per phone number to provide incident updates to residents); DENVER FIRE DEPT., CRITIQUE FOR INCIDENT NO. 14149, HYDROCHLORIC ACID LEAK (Apr. 4, 1995) (arguing that training should be conducted with mutual aid departments); Memorandum from Captain Steve Maddock, Critique of Hydrochloric Acid Spill 3-29-95 (Apr. 4, 1995) (on file with author) (listing the need to define warm and hot zones, rethink the use of soda ash to mitigate vapor clouds, and provide in-suit communication).

[257] Meeting with Public, *supra* note 254.

[258] Consent Agreement at 2–4, EPA v. Vulcan Materials Co., CERCLA-VIII-95-25 (Oct. 2, 1995).

[259] Hydrochloric acid is listed as a CERCLA hazardous substance at 40 C.F.R. § 302 (2012) (Table 302.4), and a hazardous chemical under EPCRA, 42 U.S.C. §§ 11021(e), 11049(5) (2006).

But the community is concerned about a more insidious problem. The public heard about the HCl release from neighbors, relatives, and the media. They took an inventory of people in need of assistance, including the elderly and families without transportation.[260] They made calls to schools, recreation centers, and public officials to alert as many as they could and collect information. A makeshift evacuation grew out of these activities. But an image met them as they left their homes: a barricade at the edge of town. At first, police refused to leave the barricade to enter the neighborhood.[261] The official evacuation began two-and-a-half hours later, when the fire department started knocking on doors. Some did not hear from responders until five hours into the accident.[262] While litigation may have focused on EPCRA violations, it was the failure of the city to build on the public's evacuation efforts that troubled them the most.

The public's sense that it was ignored and isolated during the response is unfortunately a prosaic one. Emergency response is based on long-standing beliefs about how the public reacts to a disruption such as a fire or earthquake.[263] The traditional approach to a release or large-scale disaster, such as the Deepwater Horizon oil spill, is to treat them as "events" that happen more or less randomly triggering chaos and disorderly behavior.[264] This is the classic, cold-war definition of a disaster based on studies predicting the aftermath of a nuclear attack on a homogeneous population: an event, concentrated in time and space, leads to a breakdown in social structure and an interruption in services such as public safety and hospitals.[265]

The traditionally used, event-based model influenced funding for disaster response research. It was enshrined in statutes such as the Disaster Relief Act, which focused on restoring public infrastructure.[266] Through the 1980s, disaster management's primary concern was preparing for nuclear war.[267] Calls for military involvement in emergency response intensified again post-9/11 and Hurricane Katrina.[268] In that time, we find proposals for military personnel to take a greater role in search and rescue, evacuation, and traffic management,[269] despite limits set

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[260] Interview with Resident of Swansea, *supra* note 248.

[261] *Id.*

[262] *Id.*

[263] Kathleen J. Tierney, *From the Margins to the Mainstream? Disaster Research at the Crossroads*, 33 ANN. REV. SOC. 503, 504–05 (2007).

[264] *See* William R. Freudenburg et al., *Organizing Hazards, Engineering Disasters? Improving the Recognition of Political-Economic Factors in the Creation of Disasters*, 87 SOC. FORCES 1015, 1017 (2008).

[265] Tierney, *supra* note 263, at 504–06.

[266] *Id.* at 505–07. *See generally* Disaster Relief Act of 1950, Pub. L. No. 81-875, 64 Stat. 1109.

[267] Kathleen Tierney & Christine Bevc, *Disaster as War: Militarism and the Social Construction of Disaster in New Orleans*, *in* THE SOCIOLOGY OF KATRINA: PERSPECTIVES ON A MODERN CATASTROPHE 38 (David L. Brunsma et al. eds., 2nd ed. 2010).

[268] *Id.* at 39–45.

[269] *See, e.g.*, U.S. CONFERENCE OF MAYORS, 2005 NATIONAL ACTION PLAN ON SAFETY AND SECURITY IN AMERICA'S CITIES 3–4 (2005).

by the Posse Comitatus Act.[270] The premise is that the public is unable to participate in response efforts because they are neutralized by "disaster syndrome," characterized by shock, panic, and socially disintegrative behavior.[271] In its place, agencies must centralize disaster planning and build out a response so that it can meet every conceivable contingency.[272] This is an attempt to bridge data gaps by developing an artificial list of disaster outcomes and planning for them, as opposed to finding ways to use data that emerge from the productive involvement of citizens. It is an inherently incomplete exercise.[273]

Consider the National Incident Management System (NIMS) developed after the 9/11 terrorist attacks.[274] Bureaucracies that rise in the wake of the *Exxon Valdez* oil spill,[275] 9/11,[276] and other disasters are impressively dense and scripted. The NIMS triggers the National Contingency Plan (NCP) for multijurisdictional response to the BP oil spill and other crises. The NCP was drafted in 1968 and revised post-*Valdez*.[277] It links fifteen agencies with national, regional, and local committees and response teams.[278] It takes pains to fix coordination and communication problems revealed in prior disasters—data points that it considers legitimate.[279] It does so by looking inward at internal dynamics and how data were communicated within and among agencies during past events.

The questions asked post-disaster demonstrate this bias in how spatiotemporal data gaps are bridged as agencies plan: Why did agency *A* not receive information from field office *X*?[280] How can information be shared up and across hierarchies in a way that preserves critical detail?[281] What preapprovals and prepositioning can

[270] The statute prohibits domestic use of the army or air force for law enforcement except for "cases and under circumstances expressly authorized by the Constitution or Act of Congress." 18 U.S.C. § 1385 (2006).

[271] Ronald W. Perry & Michael K. Lindell, *Understanding Citizen Response to Disasters with Implications for Terrorism*, 11 J. CONTINGENCIES & CRISIS MGMT. 49, 50–53 (2003).

[272] *See* Stewart Williams, *Rethinking the Nature of Disaster: From Failed Instruments of Learning to a Post-Social Understanding*, 87 SOC. FORCES 1115, 1121 (2008).

[273] *See* Charles F. Parker et al., *Preventable Catastrophe? The Hurricane Katrina Disaster Revisited*, 17 J. CONTINGENCIES & CRISIS MGMT. 206, 208–11 (2009).

[274] *See generally* U.S. DEP'T OF HOMELAND SEC., NATIONAL INCIDENT MANAGEMENT SYSTEM (2008), *available at* http://www.fema.gov/pdf/emergency/nims/NIMS_core.pdf.

[275] Oil Pollution Act of 1990, 33 U.S.C. §§ 2701–2762 (2006).

[276] Homeland Security Act of 2002, Pub. L. No. 107-296, 116 Stat. 2135 (codified at scattered titles and sections of U.S.C.).

[277] National Oil and Hazardous Substances Pollution Contingency Plan, 40 C.F.R. § 300 (2012).

[278] *Id.* at §§ 300.120(a)(1), .110, .115, .175(b).

[279] The goal of the NIMS, for example, is to "provide[] a consistent nationwide template" for federal, state, and local governments. NATIONAL INCIDENT MANAGEMENT SYSTEM, *supra* note 274, at i.

[280] *See, e.g.*, NAT'L COMM'N ON TERRORIST ATTACKS UPON THE U.S., THE 9/11 COMMISSION REPORT: FINAL REPORT OF THE NATIONAL COMMISSION ON TERRORIST ATTACKS UPON THE UNITED STATES 353–57 (2004).

[281] *See id.* at 417–18.

be done so that when a response plan is triggered, it can be scaled up to meet the complexity of a disaster?[282] In response, formal plans and standard operating procedures assist coordination. Spaces are created for interagency communication. Much of this happens in the background, unless something goes wrong. And plenty does: planning at multiple levels and across organizations fails in predictable ways. The more hierarchical and centralized the NCP and other apparatuses become, the more data are not shared in sufficient detail and situational awareness (understanding the "big picture" of a disaster) is lost.[283] As members of a hierarchy lose accurate depictions of core tasks and how they should be carried out, the scale and scope of a disaster can increase. There is irony in dealing with data gaps this way: in place of other sources of data, including the public, we substitute systems that can worsen a disaster's impact. These systems also limit our ability to respond to warnings and learn from near misses, as revealed in accounts of the years leading up to Hurricane Katrina and 9/11.[284]

6. The Public as Data Point

For years, sociologists catalogued the public's role in early warning, crisis response, and other tasks even as their results were overlooked. But a top-down, inwardly focused response system heightens data sharing and awareness problems.[285] By comparison, sensed, networked data render the public vital to government response and can help reverse these design flaws. Communities historically respond to dynamic change in productive ways.[286] Sensed data can leave clear traces of their efforts. The data are shared instantaneously, in forms that can be searched, linked, and leveraged. These data make numerous appearances,

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[282] *See, e.g.*, NAT'L COMM'N ON THE BP DEEPWATER HORIZON OIL SPILL & OFFSHORE DRILLING, DEEP WATER: THE GULF OIL DISASTER AND THE FUTURE OF OFFSHORE DRILLING 150–51 (2011); Nat'l Comm'n on the BP Deepwater Horizon Oil Spill & Offshore Drilling, *The Use of Surface and Subsea Dispersants During the BP Deepwater Horizon Oil Spill* 4–7 (Staff Working Paper No. 4, 2011).

[283] *See, e.g.*, Samer Faraj & Yan Xiao, *Coordination in Fast-Response Organizations*, 52 MGMT. SCI. 1155, 1156–58 (2006); Edgar A. Maldonado et al., *Collaborative Systems Development in Disaster Relief: The Impact of Multi-Level Governance*, 12 INFO. SYS. FRONTIERS 9, 9–10 (2010).

[284] *See, e.g.*, Steven Kelman, *9/11 and the Challenges of Public Management*, 51 ADMIN. SCI. Q. 129, 129–41 (2006) (reviewing NAT'L COMM'N ON TERRORIST ATTACKS UPON THE U.S., THE 9/11 COMMISSION REPORT: FINAL REPORT OF THE NATIONAL COMMISSION ON TERRORIST ATTACKS UPON THE UNITED STATES (2004)); Parker et al., *supra* note 273, at 211–14; Kathleen Tierney, *The Red Pill*, UNDERSTANDING KATRINA: PERSPECTIVES FROM THE SOCIAL SCIENCES (June 11, 2006), http://forums.ssrc.org/understandingkatrina/the-red-pill/.

[285] For the challenge of maintaining situational awareness in a hierarchical organization, see Gregory A. Bigley & Karlene H. Roberts, *The Incident Command System: High-Reliability Organizing for Complex and Volatile Task Environments*, 44 ACAD. MGMT. J. 1281, 1290 (2001).

[286] James M. Kendra & Tricia Wachtendorf, *Community Innovation and Disasters*, *in* HANDBOOK OF DISASTER RESEARCH 316, 320–26 (Havidán Rodríguez et al. eds., 2006).

including after the Fukushima Daiichi nuclear disaster;[287] the 2008 Sichuan earthquake in China;[288] the Mumbai terrorist attacks;[289] and during fire suppression, hurricane relief, and other responses in the United States.[290] Peer-to-peer communication using Twitter and other microblogs renders the public relevant in a crisis for three reasons: it creates permanent, searchable records of emergent behavior; enables problem solving that an incident command system has difficulty achieving; and promotes situational awareness by operating at scales that better mimic the scope of a disaster.

As Swansea residents discovered, the emergency response infrastructure traditionally looks inward. Peer-to-peer communication challenges this approach. Microblogging, for example, leaves a record of self-organizing behavior among the public that can be examined and compared to an official response. One way to collect these data is by using an application programming interface, which aggregates publicly available messages to generate timelines of activity.[291]

What we find is that a peer-distributed information system can be more timely and accurate than an emergency response system.[292] For example, in the hours after the April 2007 shootings at Virginia Tech, social media activity was widespread. Residents of Blacksburg and elsewhere joined social systems that did not exist hours earlier, including more than 500 Facebook groups devoted to the incident and a rush of Twitter activity and Wikipedia updates.[293] With these tools, they made sense of the crisis. Norms emerged, allowing the public to self-police data and establish its credibility.[294] People adopted different roles, including data

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[287] NAT'L DIET OF JAPAN, OFFICIAL REPORT OF THE FUKUSHIMA NUCLEAR ACCIDENT Independent Investigation Commission 39 (July 5, 2012), http://www.nirs.org/fukushima/naiic_report.pdf.

[288] *See* Leysia Palen et al., *A Vision for Technology-Mediated Support for Public Participation and Assistance in Mass Emergencies and Disasters*, 2010 PROC. ACM-BCS VISIONS OF COMPUTER SCI. (at p. 5 of .pdf manuscript), *available at* http://www.bcs.org/upload/pdf/ewic_vs10_s4paper2.pdf.

[289] Amanda Lee Hughes & Leysia Palen, *Twitter Adoption and Use in Mass Convergence and Emergency Events*, PROC. 6TH INT'L ISCRAM CONF. (2009) (at p. 1 of .pdf manuscript), *available at* http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.156.8385&rep=rep1&type=pdf.

[290] *See* Palen, *supra* note 288, at 5; Leysia Palen & Sarah Vieweg, *The Emergence of Online Widescale Interaction in Unexpected Events: Assistance, Alliance & Retreat*, 2008 PROC. ACM CONF. ON COMPUTER SUPPORTED COOPERATIVE WORK 117, 119–24 (2008).

[291] Cornelia Caragea et al., *Classifying Text Messages for Emergency Response*, PROC. 8TH INT'L ISCRAM CONF. (2011) (at pp. 1–5 of .pdf manuscript), *available at* http://www.cse.unt.edu/~ccaragea/papers/mlsc10.pdf.

[292] Leysia Palen et al., *Crisis in a Networked World: Features of Computer-Mediated Communication in the April 16, 2007, Virginia Tech Event*, 27 SOC. SCI. COMPUTER REV. 467, 468 (2009).

[293] *Id.*

[294] *See* Andrea H. Tapia et al., *Seeking the Trustworthy Tweet: Can Microblogged Data Fit the Information Needs of Disaster Response and Humanitarian Relief Organizations*, PROC. 8TH INT'L ISCRAM CONF. (2011) (at pp. 3–4 of .pdf manuscript), *available at* http://citeseerx.ist.psu.edu/viewdoc/download?rep=rep1&type=pdf&doi=10.1.1.206.5192.

broker, list builder, and problem solver.[295] Applying these emergent norms and roles to the crisis, the public identified time-sensitive data, including data about the victims, before official sources.[296]

A similar pattern follows disasters of varying scales, leading to dispersed data gathering and validation tied to specific locations and categories of concern. During the October 2007 wildfires in Southern California, tweets shared evacuation, road closing, fire line movement, and other data.[297] Location-referencing tweets gave a wide range of updates after floods in North Dakota in 2009.[298] Far more complex exchanges occurred after the Port-au-Prince earthquake in Haiti in January 2010. Using Ushahidi, an open-source program built to evade media censorship in Kenya, the public sent text messages with time-critical information that were automatically geolocated and mapped on a website.[299] Responders viewed maps for data on food and water shortages, sanitation issues, shelter availability, collapsed buildings, service capacity, and immediate individual needs.[300]

The public's advantage over contingency planning will increase as sensing is linked to peer-to-peer technologies. The public's historic role as true first responders will widen. Many of the advances in wireless sensor networks will apply. Peer networks will provide data redundancy, and vulnerable populations will be motivated to share locational and contextual information. Handheld and onboard sensors will provide superior granularity to data available to emergency responders. Mash-ups of social and locational data such as Ushahidi will be more common. These activities stand in contrast to an official response, where time-sensitive plan elements prove incompatible, details fall away as data move from local to national response teams, and incident command systems lose situational awareness.

III. TOWARD A NEW ARCHITECTURE

The Bay Area litigator, pesticide-drift activist, and Swansea resident operate within the existing architecture. Whether they confront a Boötes void of data, a constrained understanding of disease, or a cloud of HCl hovering near their home,

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[295] *See* Sarah Vieweg et al., *Collective Intelligence in Disaster: Examination of the Phenomenon in the Aftermath of the 2007 Virginia Tech Shooting*, PROC. 5TH INT'L ISCRAM CONF. (2008) (at p. 7 of .pdf manuscript), *available at* http://www.jeannette sutton.com/uploads/CollectiveIntelligenceISCRAM08.pdf.

[296] *Id.*

[297] Jeannette Sutton et al., *Backchannels on the Front Lines: Emergent Uses of Social Media in the 2007 Southern California Wildfires*, PROC. 5TH INT'L ISCRAM CONF. (2008) (at pp. 3–6 of .pdf manuscript), *available at* https://www.cs.colorado.edu/~palen/Papers/isc ram08/BackchannelsISCRAM08.pdf.

[298] Sarah Vieweg et al., *Microblogging During Two Natural Hazards Events: What Twitter May Contribute to Situational Awareness*, PROC. 28TH INT'L CONF. HUMAN FACTORS COMPUTING SYS. 1079, 1085 (2010).

[299] *See* Caragea et al., *supra* note 291 (at p. 3 of .pdf manuscript).

[300] *See id.*

each tries to fill data gaps. Their strategies are self-limiting because they are incompatible with agency practices that formed to accommodate those gaps. But a shift is underway in environmental law and related fields. In the time-compressed, mass convergence of disaster response, the public emerges, supplying new kinds of data and shoring up situational awareness. In microenvironments at work and in the home, personal exposure data and biomonitoring obviate the need to regulate at only certain points along the disease continuum. Across geographies, data are gathered at new scales and in near real time, through nimble networks in which members of the public can serve as nodes.

These data have broad as well as fine-grained coverage. They can be used to set baselines, detect changes from baselines, and correlate changes with a number of outcomes. They provide direct rather than theoretical indicators of changes in the environment. The public is often at the vanguard of gathering these data. Each time they do, the public confronts the spatial and temporal accommodations made through the enactment of environmental law, from the logical leaps of an air quality model to the use of distance and other proxies for toxic exposure, steps that were taken in a data-starved world.

The range of questions raised by sensed, networked data is boundless. For example, ten people in a field study in Ghana gathered air quality readings from tubes attached to taxicabs. A single day's worth of data "expose[d] a previously unmeasured and diverse range of air quality across the city."[301] Worlds away, wireless sensor networks are set up to target roads, to explore the three hundred meters between a right-of-way and the point where pollution returns to background levels and is no longer of interest to regulators.[302] In West Oakland, California, a community-based organization and academics distribute handheld air quality sensors to residents. Throughout the day, the devices send readings and location data to a central server. The alliance develops tools to visualize and interact with the data, add contextual information, cross-reference findings, and make inferences about what is observed.[303] Exposures, concentrations, and sources of vulnerability are identified and linked to dozens of events, connecting fragments of physical context previously viewed in isolation. New constituencies become aware of and mobilize around common concerns, through rich and public displays of data. Efforts linking advocacy organizations, self-organizing hack-a-thons,[304] private labs, and academics encourage public visualizations of air quality and personal exposure data. Projects with colorful names such as WearAir[305] and My Exposure[306] abound. Others are built around found objects. In one project, tiny modular probes of exhaust, smog, and dust can be picked up and placed

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[301] Paulos et al., *supra* note 12 (at p. 2 of .pdf manuscript).

[302] Westerdahl et al., *supra* note 145, at 3598.

[303] Willett et al., *supra* note 9, at 307–09. For example, one volunteer, a former port worker, viewed a map of sensing data and added information about additional sources of exposure, including diesel trucks and dredging activity. *Id.* at 316.

[304] *See, e.g.*, *Chicago #AirQualityEgg 'Hackshop'*, MEETUP.COM (July 24, 2012, 10:00 AM), http://www.meetup.com/sensemakers/events/72719592.

[305] Kim et al., *supra* note 8, at 295.

[306] Willett, *supra* note 9, at 309–10.

anywhere,[307] inviting participation by passersby. In another, LED-infused balloons depict air quality by glowing red, yellow, or green, creating mobile lightscapes in urban areas.[308]

Each initiative calls on the public to author spaces around them as they gather data.[309] They elicit new questions and lead to further advances in data sharing. The public produces data and displays it in ways that generate additional data and unique spatial, temporal, and thematic links. All of this is possible because the data shift the focus from targets of regulation (such as a source of pollution, a manufacturer of a product, or a responsible party) to the bearers of externalities themselves. Previously maligned and neglected "receptors," organized around sensed data, are thrust to the forefront of regulatory response, demanding new practices that will give shape to their findings.

A new architecture, and a theoretical approach to its study, must address the demand for new regulatory practices raised by sensed, networked data, as opposed to the data supply concerns of old. So far, this Article has focused on novel kinds of data that when collected reveal spatial and temporal accommodations in the law. To this we must add how the data are used, as well as challenges inherent in supporting their unique uses. Together, these questions open a third normative front in the study of environmental law, along with regulatory design and environmental federalism. I refer to this third front as "data-intensive regulation." Its focuses are the demand for new uses of data and the nature of knowledge creation in contexts that are data rich. The first front, regulatory design, tries to ensure compliance in a data-starved environment by adjusting the mixture of tools brought to bear on a problem. The second, environmental federalism, asks at which level of governance we should enact policy, also in the presence of data gaps and economies of scale that are achieved as they are filled.[310]

Data-intensive regulation, in contrast, addresses how a body of law responds to a deluge of data but a scarcity of useful, policy-relevant knowledge. To do this, we turn to the uses and users of the new data, as well as the collective action and administrative costs that receive less attention in the data gaps literature than the costs of data acquisition and exchange.[311] Attempts to accommodate data gaps in environmental law follow a common pattern. A theoretical understanding drives generalizations about conditions when data are unavailable, such as the theory of disaster syndrome that informed contingency planning. Alternatively, a model or simulation is created to represent a phenomenon for which data are absent, such as a dispersion model instead of actual data on air quality. These are increasingly dated strategies for dealing with data. Much of human history saw knowledge

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[307] Kuznetsov & Paulos, *supra* note 33 (at pp. 3–5 of .pdf manuscript).

[308] Kuznetsov et al., *supra* note 10, at 237.

[309] *See* Giles Lane, *Urban Tapestries: Wireless Networking, Public Authoring and Social Knowledge*, 7 PERSONAL & UBIQUITOUS COMPUTING 169, 169 (2003).

[310] Esty, *supra* note 40, at 175, 183–84 (noting the importance of increased data supply for institutional choice and governance approaches such as the matching principle).

[311] *See* Coase, *supra* note 90, at 15–17 (describing solutions to resource problems based on alternate forms of collective action and the importance of coordination and other administrative costs on the choice of solution).

emerge through empirical description of the environment. The last few hundred years added knowledge creation through theory, and for a few decades, models and simulations gave us a way to address complex elements of nature when experiments were impractical.[312] The approaches increasingly relied on experts, their domain-specific knowledge to review results for hypothesized outcomes, and proxies to represent parts of a model for which actual data cannot be attained.[313]

The first three waves of knowledge creation were known as observational, experimental, and computational. A fourth, which appeared by the first decade of the twenty-first century, responds to a new problem: the accumulation of vast amounts of heterogeneous data, "collected across a wide range of scales by both individuals and large teams,"[314] that if not placed in appropriate context will not be translated into useful knowledge. This problem of data intensity appears in fields from genetics to hydrology.[315] The challenge is to enable diverse, often dispersed teams to collaborate, explore and interpret systematic associations among data, and consider candidate relationships that explain the data.[316] The conditions for data-intensive knowledge creation are distinct from those in data-starved environments, where modeling and simulation predominate. An architecture to support the new efforts must encourage diverse users to collaborate and tend to the complete data cycle. It must accommodate not only data gaps, but also the volume of data, a greater number of data sources, and a wider range of communities interested in the data. I discuss the demand for new regulatory practices that rich data sets will generate, as collective action costs are addressed. Then I sketch the necessary architecture for knowledge creation given data abundance, which presents its own unique administrative costs.

A. From Supply to Demand

The scale of collaboration invited by environmental problems, and the data available to address them, is vast. Global temperatures rise according to "radiant heat reflected from polar ice sheets, wasting of floating ice shelves caused by small increases in ocean temperature, the health of mangrove forests,"[317] and many other factors. Land cover, vegetation, soil characteristics, weather patterns, climate, and

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[312] Deb Agarwal, *Data-Intesive Science: The Terapixel and MODISAzure Projects*, 25 INT'L J. HIGH-PERFORMANCE COMPUTER APP. 304, 304 (2011); Bell et al., *supra* note 36.

[313] *See* Kelling et al., *supra* note 35, at 613–14.

[314] William K. Michener & Matthew B. Jones, *Ecoinformatics*, 27 TRENDS IN ECOL. & EVOL. 85, 92 (2012).

[315] *See, e.g.*, Tony Hey, *The Next Scientific Revolution: How Data Mashups Can Help Save the World*, HARV. BUS. REV., Nov. 2010, at 57; Arnold Smith, *Biology and Data-Intensive Scientific Discovery in the Beginning of the 21st Century*, 15 OMICS: J. INTEGRATIVE BIO. 209, 209–12 (2011).

[316] For an example of environmental science as a data-intensive exercise, see Mark A. Parsons, *A Conceptual Framework for Managing Very Diverse Data for Complex, Interdisciplinary Science*, 37 J. INFO. SCI. 555, 556–57 (2011).

[317] Hey, *supra* note 315, at 63.

human settlements shape the distribution of species on a continent.[318] Biological systems, oil and dispersant chemistry, ocean currents, and atmospheric conditions plot the course of an oil spill.[319] Data arrive from an equally confounding array of sources: sensors, radar, satellites, and mobile and *in situ* observations.[320] Comparatively mundane tasks, such as monitoring a single location, yield a similar fire hose of data. For instance, since 2009, EPA has used the VIPER wireless communications system to enable remote sensing of everything from a garbage dump in the Virgin Islands to the Republican National Convention.[321] One sensor array might link several instruments that report parameters every second to a remote, virtual computer in New Jersey, amassing millions of measurements.[322]

The quantity and variety of data, which can appear as ubiquitous as ether,[323] are of little value until two things occur: a range of users collaboratively analyzes the data, and the data are placed in a meaningful, policy-relevant context. This section examines the collaborative use of sensed data and demand for new agency practices that it will generate. Then I will turn to its underlying architecture.

For the foreseeable future, a sizable, but limited, number of people will make use of sensed, networked environmental data. As others suggest,[324] it is a gross understatement to say that there will be lumpiness in how these data are gathered, displayed, and used. There are several reasons for this. Privacy concerns and the security of user data will limit the number of individuals who add themselves as nodes in wireless sensor networks or participate in biomonitoring.[325] This will be true even as the public can choose the resolution at which data are reported and

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[318] Kelling et al., *supra* note 35, at 614–15.

[319] O.J. Reichman et al., *Challenges and Opportunities of Open Data in Ecology*, 331 SCI. 703, 703 (2011).

[320] James P Ahrens, *Data-Intensive Science in the U.S. Department of Energy*, 11 COMPUTING SCI. & ENG. 14, 17 (2011).

[321] Interview with Environmental Scientist, Envtl. Prot. Agency Envtl. Response Team, in Edison, N.J. (Oct. 12, 2012). The VIPER system enables near-real-time data transmission from sensors deployed in the field. It includes a "Gateway," a weatherproof Pelican case housing a wireless access point for Wi-Fi communication with "Lincs," battery-powered modules that attach to gas and other sensors. Envtl. Prot. Agency Emergency Response Team, VIPER Wireless Monitoring, Presentation at VIPER Data Workshop (Dec. 21, 2011) (on file with author). VIPER has been in limited use since October 2009. *See id.*

[322] *See* Interview with Environmental Scientist, *supra* note 321.

[323] NAT'L SCI. FOUND., KNOWLEDGE LOST IN INFORMATION: REPORT OF THE NSF WORKSHOP ON RESEARCH DIRECTIONS FOR DIGITAL LIBRARIES 1 (2003).

[324] *See, e.g.*, Blais & Wagner, *supra* note 86, at 1701.

[325] Revelations about the National Security Agency's PRISM and other data mining programs highlight the enormous privacy concerns inherent in reliance on Internet intermediaries for digital communication and data storage. *See* Barton Gellman & Laura Poitras, *U.S. Mines Internet Firms' Data, Documents Show*, WASH. POST, June 7, 2013, at A1; *see also* Frank Pasquale, *Beyond Innovation and Competition: The Need for Qualified Transparency in Internet Intermediaries*, 104 NW. U. L. REV. 105, 153–54 (2010).

networks are set up to encourage trustworthy results.[326] Ownership uncertainty will limit the amount of data shared, whether they are passively generated with on-board sensors on cell phones or purposefully gathered using plug-ins.[327] While agencies have begun to deploy sensor arrays supported by systems such as VIPER, their use is limited in scope.[328]

Sensing an environmental medium or microenvironment is often low in cost, but the complexity of setting up networks and sampling protocols remains. Making full use of these data will require the public to work in concert with technologists and technicians, raising standard collective action challenges. Thus, in the near term, we can expect data-intensive regulation to be driven not by the public writ large, but by "loosely organized coalitions with a goal of contesting prominent social and cultural practices through sustained campaigns."[329] Social scientists refer to these coalitions as social movements. Understanding how they can influence agency practices will be key to determining how to support data-intensive regulation. Sensed, networked data will provide the raw material for new social movements, but whether they succeed in improving regulatory practice will be a subject of intense interest.

Using social movement theory (SMT), we can identify circumstances in which data-intensive regulation will succeed or fail. SMT is a sophisticated approach to Albert Hirschman's "voice," or expressions of influence in a society.[330] It offers a menu of mechanisms by which collective action can influence regulatory response. SMT grew out of sixties-era conceptions of resource mobilization aimed at the state.[331] The theory was concerned with how movements falter when they take on professional or bureaucratic qualities.[332] Since then, SMT has turned to examining how a movement influences a variety of targeted practices. Three developments in social science made this shift possible.

First, SMT no longer views the influence of a social movement on an existing practice as deterministic. Initially, social movement scholars looked at how certain

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[326] For "resolution control" and other privacy assurance methods, see Reddy et al., *supra* note 7, at 5–6.

[327] For the bottlenecks caused by government and private filtering schemes in the context of Internet security, see Jonathan L. Zittrain, *The Generative Internet*, 119 HARV. L. REV. 1974, 2013, 2033 (2006).

[328] *See* sources cited *supra* note 321; *see also Scientists Evaluate Air Sensors Developed During EPA's Air Sensor Evaluation and Collaboration Event*, U.S. ENVTL. PROTECTION AGENCY, http://www.epa.gov/nerl/features/sensors.html (last updated Aug. 7, 2013) (outlining EPA's September 2012 collaboration with sensor and app developers).

[329] Klaus Weber et al., *Forage for Thought: Mobilizing Codes in the Movement for Grass-Fed Meat and Dairy Products*, 53 ADMIN. SCI. Q. 529, 531 (2008).

[330] ALBERT O. HIRSCHMAN, EXIT, VOICE, AND LOYALTY: RESPONSES TO DECLINE IN FIRMS, ORGANIZATIONS, AND STATES 3–5 (1970).

[331] *See* Elizabeth A. Armstrong & Mary Bernstein, *Culture, Power, and Institutions: A Multi-Institutional Politics Approach to Social Movements*, 26 SOC. THEORY 74, 75–77 (2008).

[332] *See* Philip Selznick, *Institutionalism "Old" and "New,"* 41 ADMIN. SCI. Q. 270, 276–77 (1996).

processes sustained collective action.[333] Now they study how movements build cultural frames to challenge existing beliefs.[334] Social movements contest the meaning of issues using frames. A frame reduces complexity, allowing us to "locate, perceive, identify, and label" events that take place.[335] It gives meaning to events, organizes experience, and guides action. Social movement scholars inventory how movements develop and use frames. A movement might define a regulatory problem and who is to blame for it, articulate how to reach a solution, use a frame to attract followers, or spread the frame to other arenas.[336]

For example, a movement might promote recycling. The movement encourages a few states to adopt recycling programs, framing the problem as one of "resource recovery." Then, the Resource Conservation and Recovery Act becomes law. It gives the movement a way to frame recycling in technical (such as the comparative risks of recycling and incineration) as opposed to ecological terms. As a result, the practice is adopted more widely.[337] In this example, the state acts, followed by organizations "that [become] key players in the erosion and recombination of elements in the then standard resource recovery frame."[338] Framing relies on a movement's formal (e.g., professional or grassroots organizations) and informal (e.g., social networks) resource base.[339] It is constrained by and takes advantage of political opportunities, which act as signals for movements to heighten their efforts. For example, an industry targeted by a social movement might experience a sudden rise in failure rate or a change in corporate structure, increasing the likelihood that a new frame will be adopted.[340]

A second development improves SMT's ability to explain change in a movement's targets—its focus on institutions. Institutions determine the stability of social systems, which are maintained by norms, rules, and beliefs "forged in ongoing interaction" or "borrowed from [the] environment[]."[341] Institutional arrangements can be as innocuous as a stoplight or as complex as a legal system.[342] Individuals are embedded in social contexts. They have limited information about

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[333] Doug McAdam & W. Richard Scott, *Organizations and Movements*, *in* SOCIAL MOVEMENTS AND ORGANIZATION THEORY 4, 6–7 (Gerald F. Davis et al. eds., 2005).

[334] *See* Robert D. Benford & David A. Snow, *Framing Processes and Social Movements: An Overview and Assessment*, 26 ANN. REV. SOC. 611, 614 (2000).

[335] ERVING GOFFMAN, FRAME ANALYSIS: AN ESSAY ON THE ORGANIZATION OF EXPERIENCE 21 (1974).

[336] *See, e.g.*, Sarah Kaplan, *Framing Contests: Strategy Making Under Uncertainty*, 19 ORG. SCI. 729, 730–32 (2008).

[337] Michael Lounsbury et al., *Social Movements, Field Frames and Industry Emergence: A Cultural-Political Perspective on U.S. Recycling*, 1 SOCIO-ECONOMIC REV. 71, 72–74 (2003).

[338] *Id.* at 73.

[339] Brayden King, *A Social Movement Perspective of Stakeholder Collective Action and Influence*, 47 BUS. & SOC'Y 21, 27–28 (2008).

[340] *Id.* at 20–30.

[341] W. Richard Scott, *Approaching Adulthood: The Maturing of Institutional Theory*, 37 THEORY & SOC'Y 427, 429 (2008).

[342] Timothy J. Hargrave & Andrew H. Van de Ven, *A Collective Action Model of Institutional Innovation*, 31 ACAD. MGMT. REV. 864, 866 (2006).

their surroundings, relying on symbols and cultural accounts to guide their behavior. Social order is achieved as these elements are taken for granted, further influencing expectations.[343] Agencies and other organizations are constrained by the institutional building blocks "littered around the societal landscape,"[344] eventually adopting similar formal structures in pursuit of legitimacy and survival. SMT sets out how this happens. We observe a regulatory practice as a collection of "roles and units whose purposes and procedures come from a variety of external sources, not a unitary internal superior,"[345] which allows us to better explain changes to that practice.

A third development in SMT takes this analysis further. We no longer accept the constraining forces of institutions as given. Institutional accounts once told a story of firms adopting influences reflexively, through mimicry and other means. They now include the possibility of agency.[346] People respond to, but are also capable of changing, their institutional context. While institutions provide templates for action, those templates can be derailed, altered, or replaced. Individuals are both "empowered and controlled by institutional contexts."[347] Because multiple institutions influence a targeted practice,[348] a movement can exploit ambiguities and contradictions among them.[349] Institutional change is described by defining the context, or "field," in which this takes place.[350]

Arrangements of scientists, technologists, sympathetic members of agencies, and dispersed teams in data-intensive research face a number of constraints. An increasingly relevant limitation will be past spatiotemporal accommodations. Each accommodation occurs within an institutional field.[351] The field influences "critical exchange partners, sources of funding, regulatory groups, professional and trade associations . . . and other sources of normative or cognitive influence."[352] A social

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[343] John W. Meyer, *Reflections on Institutional Theories of Organizations*, *in* SAGE HANDBOOK OF ORGANIZATIONAL INSTITUTIONALISM 788, 792–93 (Royston Greenwood et al. eds., 2008).

[344] John W. Meyer & Brian Rowan, *Institutional Organizations: Formal Structure as Myth and Ceremony*, 83 AM. J. SOC. 340, 345 (1977).

[345] Ronald L. Jepperson, *The Development and Application of Sociological Neoinstitutionalism*, *in* NEW DIRECTIONS IN CONTEMPORARY SOCIOLOGICAL THEORY 229, 238 (Joseph Berger & Morris Zelditch Jr. eds., 2002).

[346] Myeong-Gu Seo & W.E. Douglas Creed, *Institutional Contradictions, Praxis, and Institutional Change: A Dialectical Perspective*, 27 ACAD. MGMT. REV. 222, 222–26 (2002).

[347] Meyer, *supra* note 343, at 791–92.

[348] *See* Forrest Briscoe & Sean Safford, *The Nixon-in-China Effect: Activism, Imitation, and the Institutionalization of Contentious Practices*, 53 ADMIN. SCI. Q. 460, 482–84 (2008).

[349] Marc Schneiberg & Michael Lounsbury, *Social Movements and Institutional Analysis*, *in* SAGE HANDBOOK, *supra* note 343, at 648, 648–50.

[350] *See* Michael Lounsbury, *Institutional Transformation and Status Mobility: The Professionalization of the Field of Finance*, 45 ACAD. MGMT. J. 255, 263–64 (2002).

[351] Andrew J. Hoffman, *Linking Organizational and Field-Level Analyses: The Diffusion of Corporate and Environmental Practice*, 14 ORG. & ENV'T 133, 135 (2001).

[352] *Id.* at 136.

movement can disrupt or change an established practice, like a risk assessment convention or air monitoring approach, according to the field in which that practice sits. Does the movement take advantage of multiple, competing institutional logics, evoke a legitimacy crisis around a previously taken-for-granted practice, or introduce a new organizational form? What roles will agencies play as facilitators of these efforts? We might ask, for example, why some firms are more aggressive than others in adopting compliance practices. We might want to encourage the spread of a rating scheme,[353] a new regulation,[354] or a technology.[355] To do so, we need to know "who within [a] field is driving that concern, what cultural framing of the issue results, and how the organization enacts that frame and invokes a response."[356]

Social movement theory can guide research into the collaborative work of data-intensive research, as well as the conditions under which it will influence regulatory practices formed earlier in data-starved contexts. It can also help determine the mix of tools needed to encourage this form of knowledge creation. Using the concepts of movement practices, fields, and institutional change, we can isolate the mechanisms responsible for its success. Empirical studies[357] in SMT offer clues as to how this research should proceed. I divide the mechanisms uncovered by SMT into three categories: *frames*, *boundaries*, and *networks*. They identify how data-intensive collaboration can influence the entrenched practices of environmental law.

Each time we consider a data point unusable or an experience irrelevant, frames are at work. Frames form as groups try to understand a practice and its underlying norms.[358] Returning to the recycling example, we can identify frames such as "resource recovery" and "waste-to-energy" as they emerge. However, we have to understand the broader field in which they appear to gauge how they become locked in or replaced. As a field matures, its practices and patterns of interaction stabilize, making it difficult to change them. But the possibility for change remains, depending on the qualities of the field in which a frame operates. Social movements promote new frames and try to destabilize existing frames. They are more likely to succeed when targeting a practice in a centralized, immature field or in a destabilized field. A field's stability is affected by internal governance

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[353] *See id.* at 151–52.

[354] *See* Marc Schneiberg & Sarah A. Soule, *Institutionalization as a Contested, Multilevel Process: The Case of Rate Regulation in American Fire Insurance*, *in* SOCIAL MOVEMENTS AND ORGANIZATION THEORY, *supra* note 333, at 122, 128–34.

[355] *See* Wesley D. Sine & Brandon H. Lee, *Tilting At Windmills? The Environmental Movement and the Emergence of the U.S. Wind Energy Sector*, 54 ADMIN. SCI. Q. 123, 125–27 (2009).

[356] Hoffman, *supra* note 351, at 137.

[357] Social movement studies use longitudinal data sets to test hypotheses about the spread, translation, or adoption of practices; the emergence of new organizational forms; and the influence of organizational fields on the establishment and disruption of practices. They also employ ethnography and comparative case methods. *See, e.g.*, Gerald F. Davis et al., *Introduction: Social Movements in Organizations and Markets*, 53 ADMIN. SCI. Q. 389, 390–93 (2008).

[358] Lounsbury et al., *supra* note 337, at 76–77.

mechanisms (e.g., membership criteria) and external certification. New frames take hold because of their empirical credibility and the authority of their proponents. Existing frames are transformed, bridged, and extended to new circumstances. Frames often do not reach acceptance until after a considerable amount of time, often ten years or more, has passed.[359]

Efforts to dislodge spatial and temporal accommodations will also concern the strength of alliances that form around sensed data. Here, we focus on the connections made within data-intensive collaborations. I refer to these as boundary and network mechanisms. Data-intensive research brings together disparate elements such as academic researchers, human-computer interaction specialists, and community organizations. There is a need for collaboration among these stakeholders. SMT identifies how this takes place across diverse groups, which develop frames, mobilize support, and take advantage of political opportunities to challenge existing practices. The critical tools for accomplishing these goals are boundary objects.

Boundary objects are based on the idea that groups collaborate when they can articulate concerns, identify mutual benefits, and preserve their unique interests.[360] Boundary objects include databases, maps, and methods.[361] They can be physical as well as electronic. Susan Leigh Star and James Griesemer developed the theory of boundary objects to show how diverse groups such as "amateur naturalists, professional biologists, the general public, philanthropists, conservationists, [and] university administrators"[362] can collectively manage a place such as a museum. A more recent example finds boundary objects that facilitate work among field researchers, modelers, and environmental organizations in climate change research.[363] A boundary object must "adapt to local needs and the constraints of the several parties . . . yet [be] robust enough to maintain a common identity across sites."[364] There are strong links between the use of boundary objects and improved

[359] *See* Benford & Snow, *supra* note 334, at 622–28; John L. Campbell, *Where Do We Stand? Common Mechanisms in Organizations and Social Movements Research, in* SOCIAL MOVEMENTS AND ORGANIZATION THEORY, *supra* note 333, at 41, 48–53; Neil Fligstein & Doug McAdam, *Toward A General Theory of Strategic Action Fields*, 29 SOC. THEORY 1, 11 (2011); Kaplan, *supra* note 336, at 732–33, 738–44; Martin Kitchener, *Social Movement Challenges to Structural Archetypes: Abortion Rights, AIDS, and Long-Term Care, in* SOCIAL MOVEMENTS AND THE TRANSFORMATION OF AMERICAN HEALTH CARE 128, 137–40 (Jane C. Banaszak-Holl et al. eds., 2010); Lounsbury et. al., *supra* note 337, at 80–95; Schneiberg & Lounsbury, *supra* note 349, at 651.

[360] Siobhán O'Mahony & Beth A. Bechky, *Boundary Organizations: Enabling Collaboration Among Unexpected Allies*, 53 ADMIN. SCI. Q. 422, 424, 451 (2008).

[361] Paul R. Carlile, *A Pragmatic View of Knowledge and Boundaries: Boundary Objects in New Product Development*, 13 ORG. SCI. 442, 451 (2002).

[362] Susan Leigh Star & James R. Griesemer, *Institutional Ecology, "Translations" and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907–39*, 19 SOC. STUD. SCI. 387, 396 (1989).

[363] Mikaela Sundberg, *Parameterizations as Boundary Objects on the Climate Arena*, 37 SOC. STUD. SCI. 473, 474, 482–84 (2007).

[364] Star & Griesemer, *supra* note 362, at 393. Similarly, boundary organizations allow actors to reconfigure their roles and responsibilities and organize them around shared

data sharing among diverse groups. They provide a shared language to represent what is at stake for each group, assume roles that are difficult for individual groups to play,[365] and ensure legitimate, independent contributions by each group.[366]

At the heart of data-intensive regulation will be collaborative work that leads to increased demand for new practices. Much of this work will be done using frames and boundary spanning within a variety of networks. Networks lower the costs of collective action and increase the likelihood that knowledge is shared. Under the right conditions, networks encourage shared definitions of problems and the diffusion of new practices. As diverse groups form around data-intensive projects, the structure of their networks will matter as much as traditional resource concerns such as funding. Some network structures are more favorable to the diffusion of practices than others.[367] Practices that take the place of existing spatial and temporal accommodations will spread by mutual monitoring, codification by professional associations, and actions by the state to translate or endorse them. Networks will facilitate their adoption. They will provide forums in which shared interests and identities develop through interaction. They will be constrained by regulations (by agencies, professional associations, and scientific communities) and resources (such as training, insurance, and financing). Networks are more likely to encourage adoption of new practices when they have a degree of formal connection to established organizations. They undergo distinct periods of evolution depending on the kinds of practices that they target.[368]

Through frames, boundaries, and networks, we can study the collective action costs of data-intensive collaboration as it seeks to influence existing regulatory practices. To reduce costs, agencies can (1) legitimate the empirical credibility of collaborative findings; (2) inventory the elements of new frames that are generated and facilitate their diffusion; (3) support network ties using boundary objects; and (4) map the fields that surround prior gap-filling and bridging decisions. These activities will call upon presently neglected and underfunded regulatory tools. They should be pursued in combination and over extended periods of time (often more

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interests. Examples include neutral policy analysis bodies such as the Office of Technology Assessment and nonprofit foundations set up by open-source software programmers and technology firms. David H. Guston, *Boundary Organizations in Environmental Policy and Science: An Introduction*, 26 SCI. TECH. & HUM. VALUES 399, 402–03 (2001); O'Mahony & Bechky, *supra* note 360, at 451.

[365] *See* Guston, *supra* note 364, at 403.

[366] *See* Beth A. Bechky, *Sharing Meaning Across Occupational Communities: The Transformation of Understanding on a Production Floor*, 14 ORG. SCI. 312, 326–27 (2003); Carlile, *supra* note 361, at 451–53; Guston, *supra* note 364, at 400–02; O'Mahony & Bechky, *supra* note 360, at 437–49; Star & Griesemer, *supra* note 362, at 404–13.

[367] Brayden G. King, *A Political Mediation Model of Corporate Response to Social Movement Activism*, 53 ADMIN. SCI. Q. 395, 400–02 (2008).

[368] *See* Campbell, *supra* note 359, at 61; Scott Frickel, *Shadow Mobilization for Environmental Health and Justice*, *in* SOCIAL MOVEMENTS AND THE TRANSFORMATION OF AMERICAN HEALTH CARE, *supra* note 359, at 171, 171–80; Hargrave & Van de Ven, *supra* note 342, at 871–74; David J. Hess, *Technology- and Product-Oriented Movements: Approximating Social Movement Studies and Science and Technology Studies*, 30 SCI. TECH. & HUM. VALUES 515, 519–21 (2005).

than ten years). To legitimate data-intensive practices, agencies will have to rethink their use of interagency work groups, technical assistance grant programs, and guidance documents. Executive orders that address interagency concerns sometimes call for data gathering and coordination.[369] They can lead to demonstration projects and other grant-based programs.[370] But they focus on collaboration within ongoing disputes or actions.[371] They are less concerned with advancing new frame elements or using performance measures to track how elements are incorporated into agency practices.[372]

To meet the demand for new practices, data-intensive regulation will require novel uses of guidance documents. Guidances are increasingly prepared to avoid the strictures of rulemaking, including notice-and-comment procedures.[373] They can be issued quickly, although they can also languish in draft form.[374] Of greater concern will be how, in the face of growing skepticism in the courts,[375] guidances

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369 *See, e.g.*, Exec. Order No. 12,898, 3 C.F.R. 859 (1995), *reprinted as amended in* 42 U.S.C. § 4321 at §§ 1-101, 1-103(a), 3-302 (2006).

370 *See, e.g.*, *Cooperative Agreements to Support Communities Affected by the BP Oil Spill*, U.S. ENVTL. PROT. AGENCY, http://www.epa.gov/compliance/ej/grants/bp-spill-grants.html (last updated May 24, 2012); *Environmental Justice Showcase Communities*, U.S. ENVTL. PROT. AGENCY, http://www.epa.gov/compliance/ej/grants/ej-showcase.html (last updated May 24, 2012).

371 *See, e.g.*, 42 U.S.C. § 9617(e) (providing for Technical Assistance Grant program to involve communities in technical elements of site assessments and decisions); *EJ Collaborative Problem-Solving Cooperative Agreements Program*, U.S. ENVTL. PROT. AGENCY, http://www.epa.gov/compliance/ej/grants/ej-cps-grants.html (last updated May 24, 2012) (describing requirements for applicants to receive federal funding).

372 *See, e.g.*, OFFICE OF INSPECTOR GENERAL, U.S. ENVTL. PROT. AGENCY, EVALUATION REPORT: EPA NEEDS TO CONDUCT ENVIRONMENTAL JUSTICE REVIEWS OF ITS PROGRAMS, POLICIES, AND ACTIVITIES 5–7 (Sept. 18, 2006).

373 *See, e.g.*, Appalachian Power Co. v. EPA, 208 F.3d 1015, 1020 (D.C. Cir. 2000) (critiquing the proliferation of guidance documents at EPA); Erica Seiguer & John J. Smith, *Perception and Process at the Food and Drug Adminsitration: Obligations and Trade-Offs in Rules and Guidances*, 60 FOOD & DRUG L.J. 17, 25–26 (2005) (examining the rate of production of guidance documents and rules at FDA). Rulemaking requirements include notice-and-comment procedures and other steps under section 553 of the APA, 5 U.S.C. § 553, as well as, *inter alia*, regulatory flexibility analysis, 5 U.S.C. §§ 601–12, and compliance with the Unfunded Mandates Reform Act, 2 U.S.C. § 1501, and Data Quality Act, 44 U.S.C. § 3516.

374 A recent example is the analytic approach to identifying disparate impacts of decisions made by recipients of federal funds under Title VI of the Civil Rights Act of 1964, which is explained in a draft guidance document in 2000 that was never finalized. *See* U.S. Envtl. Prot. Agency, Draft Revised Guidance for Investigating Title VI Administrative Complaints Challenging Permits, 65 Fed. Reg. 39,668 (June 27, 2000).

375 *See, e.g.*, Nat'l Mining Ass'n v. Jackson, 768 F. Supp. 2d 34, 49 (D.D.C. 2011) (finding guidance documents that introduced a new screening methodology for section 402 permitting under the Clean Water Act "'effectively amend[ed]' the [Act's] permitting process"); Ensco Offshore Co. v. Salazar, No. 10-1941, 2010 WL 4116892, at *5 (E.D. La. Oct. 19, 2010) (finding notices to lessees are substantive rules that require notice and comment).

can support data-intensive work. This work involves combining and sifting through data sets to reveal patterns at previously ignored scales. It leads to findings that prove incompatible with existing regulatory practices, as witnessed in the age of grab samplers. It is unlikely that rulemaking will be able to address this challenge. Existing standards, such as effluent and new source performance requirements, are on average more than twenty years old; more than seventy percent of the standards have never been revised; and others in most instances have been revised only once.[376] Some were enacted as rules even though, in the case of the Clean Water Act, the statute called for "guidelines."[377]

Guidance documents, by comparison, can respond to the growing pace at which sensed, networked data render existing standards obsolete and depart from their traditional role of lending clarity to regulations. They can chart the development of practices, suggest time horizons for proof of concept and wide-scale adoption, take advantage of informational economies of scale to shape "best practices," and make clear how, at a later date, standards would be reexamined. A recent example is EPA's *Proposed Regional Actions to Promote Public Participation in the Permitting Process*, which surveys regional offices and permit applicants to identify best practices to "promote greater public involvement of overburdened communities."[378] This contrasts with more reactive uses of guidance documents, such as a recent synthesis of Supreme Court jurisprudence defining which "waters" are protected under the Clean Water Act.[379]

Data-intensive regulation calls for coordinated use of the above tools to legitimate the practices that grow out of collaborative analysis of massive data sets. In addition, agencies can establish the credibility of new practices, managing the market-based standards that develop around them including standard-form contracts and certification services. While market-based standards are traditionally the purview of trade associations, the financial crisis and Deepwater Horizon oil spill led to calls for agency involvement in their creation.[380] In addition, agencies can strengthen ties between alliances and formal organizations—and shield experts

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[376] Blais & Wagner, *supra* note 86, at 1720–25.

[377] 33 U.S.C. § 1314(b); *See* E.I. DuPont de Nemours & Co. v. Train, 430 U.S. 112, 136 (1977) (regarding the Clean Water Act's call for EPA to promulgate effluent limitations guidelines).

[378] U.S. Envtl. Prot. Agency, EPA Activities to Promote Environmental Justice in the Permit Application Process, 77 Fed. Reg. 38,051, 38,053 (June 26, 2012).

[379] U.S. Envtl. Prot. Agency and Army Corps of Engineers, Draft Guidance Regarding Identification of Waters Protected by the Clean Water Act, 76 Fed. Reg. 24,479 (May 2, 2011); *see also* Rapanos v. United States, 547 U.S. 715, 742 (2006) (holding that coverage under the Clean Water Act does not extend to wetlands that lack a continuous surface connection with navigable waters).

[380] *See, e.g.*, Charles K. Whitehead, *Destructive Coordination*, 96 CORNELL L. REV. 323, 326–27 (2011); Nat'l Comm'n on the BP Deepwater Horizon Oil Spill & Offshore Drilling, *Industry's Role in Supporting Health, Safety, and Environmental Standards: Options and Models for the Offshore Oil and Gas Sector* 9–11 (Staff Working Paper No. 9, 2011).

from reprisal by their profession—should they choose to assist an informal network of data-intensive researchers.[381]

To decrease the cost of collaboration within alliances, as well as between the supporters and challengers of existing practices, agencies should construct useful boundary objects. Statutes and executive orders already call for boundary-spanning devices, such as schedules appended to the National Contingency Plan or EPA's Environmental Justice Strategic Enforcement Tool. But they tend to be built for internal decision-making, such as how best to target enforcement or how agencies should engage in emergency response.[382] By comparison, boundary objects should be jointly developed and revised to allow for independent contributions by different data user groups, as they link data sets, generate hypotheses, and manage data over extended periods of time.

Inventorying and enabling the diffusion of new practices will add nuance to environmental disclosure regimes. Disclosing data previously locked in firms and bureaucracies is a proven approach in securities, environmental, and other areas of regulation.[383] Agencies can build on that success to address not only the supply of data but also the demand for new practices. This would involve building markets for practices long before they become a source for regulatory standards. Moving from disclosure to market creation, interagency efforts can devote resources to support the producers of new practices, encourage shared identity among them through membership and certification, and establish rules of exchange among producers and consumers.[384] Agencies can also endorse new practices through revisions to legal tools inventories, and they can show how practices can be adapted to different settings through guidances. Inventories should speak directly to past spatial and temporal accommodations as they are identified. The coordinated use of boundary objects, guidances, inventories, and market creation to assure that new compliance and enforcement practices emerge is an approach to "multimodal" governance[385] that is attuned to a data-rich world. It offers mechanisms, including frames, boundary objects, and network strength, that are largely absent from the regulatory design literature.

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381 *See generally* Frickel, *supra* note 368, at 171–87 (recognizing the involvement of government agencies in the promotion of the environmental justice movement).

382 For critiques of internal decision-making schedules and models, see, for example, Staff Working Paper No. 4, *supra* note 282, at 4–5; NAT'L ENVTL. JUSTICE ADVISORY COUNCIL, NATIONALLY CONSISTENT ENVIRONMENTAL JUSTICE SCREENING APPROACHES 5–15 (2010).

383 For a convergence of these disclosure regimes, see Press Release, Sec. & Exch. Comm'n, SEC Issues Interpretive Guidance on Disclosure Related to Business or Legal Developments Regarding Climate Change (Jan. 27, 2010), *available at* http://www.sec.gov/news/press/2010/2010-15.htm.

384 For a discussion of market creation activities, see Weber et al., *supra* note 329, at 531–33.

385 Arnold, *supra* note 76, at 792–97.

B. From Ignorance to Abundance: Data-Intensive Regulation

Data-intensive regulation anticipates a shift in the enactment of environmental law, one that departs from the slow accretion of updates punctuated by innovation in response to tragic events.[386] Its central dynamic is the exploratory use of data captured from multiple sources, including efforts to bring regulatory practice in line with what the data reveal. But there is a second dynamic, one with implications for debates over regulatory design and federalism, which are the standard normative fronts in the field. Environmental law will evolve not only through movements for changed regulatory practices, but also through the management of sensed, networked data throughout its life cycle. The two dynamics are closely linked. Together, they reveal a truth that will alter debates over the appropriate scale of governance, optimal choice of regulatory tools, and proper standard of judicial review of agency decisions. The truth is that in data-intensive regulation, the long-term management of data can have greater potential value than the data itself.

Data-intensive regulation occurs under three circumstances. The first is a transition from data-starved to data-rich regulatory environments.[387] Second is the collaborative use of intensive data to identify and correct past spatiotemporal accommodations.[388] This will require more systematic use of inventories, guidances, and other tools that receive little scholarly attention compared to standards and incentives. The third circumstance is knowledge creation where data are abundant and captured from numerous sources. Increasingly, in environmental science and other disciplines, knowledge does not arrive from a hypothesis tested or model constructed. Rather, groups access and explore data through visualization using maps, graphs, and other means,[389] and they discover systematic associations that demand further attention.[390] This process recasts the role of data in environmental law. New questions must be addressed about data context and provenance as well as data curation and repurposing. To answer them is to contemplate environmental law's supportive architecture.

Bridging and filling data gaps has been a preoccupation of environmental law since its inception, but it does not ensure that policy-relevant knowledge will be available to inform agency decisions. The transition from intensive data to knowledge takes place among diverse user groups, and it is work that is limited by the quality of metadata available. Metadata are embedded in software used to compile data and are referred to as "data about data."[391] They include units of

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[386] Lazarus, *supra* note 41, at 314–15.

[387] *See supra* Parts II.A.2, II.A.4, II.A.6.

[388] *See supra* Part III.A.

[389] *See, e.g.*, DEP'T OF ENERGY, OFFICE OF ADVANCED SCIENTIFIC COMPUTING RESEARCH, VISUALIZATION AND KNOWLEDGE DISCOVERY: REPORT FROM THE DOE/ASCR WORKSHOP ON VISUAL ANALYSIS AND DATA EXPLORATION AT EXTREME SCALE 4–5 (2007).

[390] Michener & Jones, *supra* note 314, at 88.

[391] Tony Hey & Anne Trefethen, *E-Science and Its Implications*, 361 PHIL. TRANS. ROYAL SOC. LONDON 1809, 1820 (2003).

measurement, details about the process by which data are gathered, and other elements.[392] Some metadata can be pieced together from scratch, relying on prior training and expertise (such as viewing data and figuring out the instrument by which it was collected). Most metadata, however, have to be added to a data set as it is created, or they will be lost.[393] Data must be annotated and processed during their collection so that later they can be linked to other kinds of data and re-create findings after aggregation and analysis take place. A number of provisions, from NEPA to the TRI, require certain data to inform practices such as permit approval, enforcement, and compliance assurance. Some laws encourage data production and sharing in digital form.[394] But maximizing the amount of data does not ensure that they will be integrated for productive access, use, and reuse in other contexts. Metadata guide this continuous process.

Metadata facilitate data integration. Near-real-time streams of data from handheld, embedded, and scattered sensors, for example, cannot be analyzed until they are properly joined, which is difficult when they are collected in diverse formats, such as numeric and visual formats. Thus, metadata are the "key component in a common technical fabric for linking independent digital libraries and creating coherence on [different] scales."[395] As the scale and quantity of environmental data increase, the need to automate how metadata are attached to data objects will intensify. Users of networked, sensed data will need to agree to metadata standards, so that increasingly automated approaches can avoid isolating data sets and rendering them noninteroperable. The design of metadata standards can serve as boundary objects, facilitating collaboration across research communities, including nonprofits, private labs, citizen sensor organizations, and agencies. The practice of generating standards will allow data user groups to build what is at stake for each group into formal metadata specifications, through unique terminologies, units of measure, and approaches to research design.

Metadata standards address the challenge of making data sets interoperable. The goal is to ensure that data sets can be pooled so that outputs from one serve as inputs for others.[396] Standards were first created for geospatial data in the 1990s, specifying which spatial references and data quality indicators should be added to a

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[392] *See* NAT'L SCI. FOUND., NSF'S CYBERINFRASTRUCTURE VISION FOR 21ST CENTURY DISCOVERY 17, 20–21 (Version 5.0, 2006).

[393] James E. Frew & Jeff Dozier, *Environmental Informatics*, 37 ANN. REV. ENVTL. RES. 449, 459 (2012).

[394] *See* Paperwork Reduction Act, 44 U.S.C. § 3501 (2006) (describing the goal of "maximiz[ing] the utility of information created, collected, maintained, used, shared, and disseminated and retained by or for the Federal Government"); *Office of Management and Budget Circular No. A-130 Revised*, WHITEHOUSE.GOV, http://www.whitehouse.gov/omb/circulars_a130_a130trans4 (last visited Dec. 1, 2013) (encouraging "open and efficient exchange of scientific and technical government information"); Copyright Act, 17 U.S.C. § 105 ("Copyright protection under this title is not available for any work of the United States Government . . . .").

[395] NAT'L SCI. FOUND., *supra* note 323, at 15.

[396] *See* Roger Barga et al., *Bioinformatics and Data-Intensive Scientific Discovery in the Beginning of the 21st Century*, 15 OMICS: J. INTEGRATIVE BIO. 199, 200 (2011).

database.[397] International metadata standards emerged around the same time.[398] Multiple approaches are now being considered, each with a different level of automation.[399] The development of metadata standards will inform debates over environmental federalism. In a data-rich context, justifications for state, as opposed to federal, regulation face new constraints. Standard questions include how to match a regulatory jurisdiction to the effects of pollution,[400] take advantage of economies of scale for data such as health effects and best available technology,[401] and ensure that diverse interest groups reach critical mass and influence policymaking.[402] These questions were historically posed of data-poor environments and of limited data that were used repeatedly, presenting a risk of duplicative effort. But in a data-rich context, we have to balance the scale of data pooling necessary to yield policy-relevant knowledge (which might counsel in favor of federal data gathering) with the scale at which diverse users are able to develop metadata standards (which might require decentralized collaboration among particular communities of data users). The resources necessary to collect data might run counter to the scale at which interoperable datasets can be developed across user communities.

Some level of metadata standardization will be required to enable the merger of data sets and allow users to ascertain data provenance. Provenance means that data users can figure out "if an object has reliable antecedents [and] find the descendants of an object, in case there is some problem with it."[403] Put simply, if provenance is assured, users will be able to retrace findings to the original data and trust the data's origins. The principal obstacles facing bucket and drift-catcher samplers were the capture of data that proved incompatible with existing standards, as well as the lack of trust in the data's provenance among regulators.[404] Data provenance invites us to reconsider regulatory design. When scholars evaluate environmental standards, for example, the goals of ensuring data pooling and provenance could be added to long-standing objectives such as "technology-

[397] FEDERAL GEOGRAPHIC DATA COMMITTEE, METADATA AD HOC WORK GROUP, CONTENT STANDARD FOR DIGITAL GEOSPATIAL METADATA: EXTENSIONS FOR REMOTE SENSING METADATA 1–3 (1998).

[398] *See generally* INT'L ORG. FOR STANDARDIZATION, GEOGRAPHIC INFORMATION–METADATA (1st ed. 2003).

[399] Frew & Dozier, *supra* note 393, at 453–55.

[400] *See generally* Henry N. Butler & Jonathan R. Macey, *Externalities and the Matching Principle: The Case for Reallocating Environmental Regulatory Authority*, 14 YALE L. & POL'Y REV. 23 (1996) (examining the allocation of regulatory authority depending on the scale of a pollution problem).

[401] *See* Ruhl & Salzman, *supra* note 115, at 104–05 (describing economies of scale as a justification for dynamic federalism).

[402] Daniel C. Esty, *Revitalizing Environmental Federalism*, 95 MICH. L. REV. 570, 649–50, 650 n.302 (1996).

[403] Frew & Dozier, *supra* note 393, at 458.

[404] *See supra* notes 151–172 and accompanying text.

forcing."[405] Data disclosure approaches, including discharge monitoring reports,[406] environmental impact statements,[407] and release inventories[408] could also be viewed through this lens. At present, they are gauged according to whether they improve firm or agency decision-making and aid citizens in their role as private attorneys general. Karkkainen notes that the TRI is particularly well suited to improve environmental management because the data are reported in standard units.[409] They can be compared and used as benchmarks to encourage progress within a facility or across an industry. There is less attention to whether standardized reporting approaches in one regime impede pooling with other data sets or impact trust in the data. Litigation over disclosure aims at whether reporting is triggered or what must be disclosed, such as whether a chemical should be included in the TRI list.[410] Whether attempts to encourage merger of the TRI with other data sets (e.g., through metadata automation and estimation) will influence the public's trust in the data, however, has yet to receive attention.

Metadata increase the value of environmental data over time, enabling them to be repurposed to explore correlations with other data sets. The curation, or long-term maintenance of sensed, networked data, presents a challenge to environmental law. Regulators will have to be attuned to the entire life cycle of data: its capture, access, integration, analysis, and visualization.[411] They will grapple with a growing number of data sets of varying sizes, collected by different communities. Over time, data sets will run the risk of becoming orphaned—a project ends, user groups disband, or metadata fall out of use or are no longer compatible with earlier versions. The need to make data reusable calls for situating metadata standards within a broader data management program.[412] In this instance, regulatory design and federalism will need to be revisited because of the unique time horizons along which data curation takes place.

The motivating question for data curation is whether data will remain available beyond the viability of the research alliances that collect them. For example, scholars view the TRI as a cost-effective disclosure regime, although total emissions have recently increased.[413] But as the program enters its second

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[405] *See, e.g.*, J.B. Ruhl & James Salzman, *Gaming the Past: The Theory and Practice of Historic Baselines in the Administrative State*, 64 VAND. L. REV. 1, 43 (2011) (noting the authority granted to EPA to ensure that technology advancement goals were met).

[406] 40 C.F.R. § 122.41(*l*)(4) (2013).

[407] National Environmental Policy Act of 1969 § 102(2)(C), 42 U.S.C. § 4332(2)(C) (2006).

[408] Emergency Planning and Community Right-to-Know Act of 1986, 42 U.S.C. § 11023.

[409] Karkkainen, *supra* note 137, at 261.

[410] *See, e.g.*, Am. Chemistry Council v. Johnson, 406 F.3d 738, 739 (D.C. Cir. 2005).

[411] *See* Smith, *supra* note 315, at 209.

[412] *Cf.* Ahrens, *supra* note 320, at 14–23 (highlighting these challenges as they relate to the U.S. Department of Energy).

[413] Press Release, U.S. Envtl. Prot. Agency, EPA's 2011 Toxics Release Inventory Shows Air Pollutants Continue to Decline/Total Toxic Chemicals Increase as Result of Mining (Jan. 16, 2013), *available at* http://yosemite.epa.gov/opa/admpress.nsf/bd4379a92ceceeac8525735900400c27/c50e11354ba76aae85257af500581f24.

quarter-century, how do we recognize whether it is experiencing diminishing returns? Scholars explain historic emissions declines by teasing out TRI reporting from broader changes in industry,[414] but they ignore whether the data set will remain available, accessible, and useful ten, twenty, or fifty years hence. They further overlook how such goals should be achieved. Similarly, environmental standards call for review and updates at crudely defined intervals (e.g., every five years).[415] Decisions to revise a technology- or ambient-based standard are based on available data about a substance or the practices of a regulated community. But what are the appropriate intervals for revisiting data management templates, data repository decisions, and related practices? And how do the time horizons for responsible environmental data curation change the frequency and scale at which updates to standards should take place?

The interoperability and long-term survival of data will also cast new light on the role of the courts. One of the influences over how agencies address data gaps is "super deference," the principle that "courts ought to be at their 'most deferential' when reviewing an agency's scientific determinations."[416] Super deference can lead an agency to increase its use of available data, so that a reviewing court will consider its decisions "scientific."[417] The standard might also contribute to regulatory ossification.[418] Empirical work finds that the principle is used less often than assumed, and there is some evidence that the courts are moving back to greater use of "hard-look review."[419] But the risk of hard-look review also distorts agency incentives, particularly when the agencies operate in data-poor environments. In response to the threat of hard-look review, agencies add needless detail to the rulemaking record, making it difficult to separate useful data from the policy judgments that fill data gaps.[420] The effects of standard of review on the speed or complexity of agency decision-making are important dynamics. But what standard of review should be applied in a data-rich context, where the value of a data set may exceed the value of discrete decisions to which it contributes?

Courts wrestle with how to encourage decisions "that can be held up to the scrutiny of the scientific community and the public."[421] While courts may not impose procedures that are absent from the Administrative Procedure Act, enabling statutes, and agency rules, they can interpret requirements that already exist.[422] In some contexts, reviewing courts could remand a decision that

[414] *See* Mark Stephan, *Environmental Information Disclosure Programs: They Work, But Why?*, 83 SOC. SCI. Q. 190, 197–200 (2002) (examining theories from various disciplines that attempt to explain how TRI has led to reductions in emissions).

[415] 42 U.S.C. § 7409(d)(2)(B) (2006).

[416] Emily Hammond Meazell, *Super Deference, The Science Obsession, and Judicial Review as Translation of Agency Science*, 109 MICH. L. REV. 733, 734 (2011).

[417] *Id.* at 751.

[418] *Id.* at 750–51.

[419] *Id.* at 738.

[420] *See* Wagner, *supra* note 45, at 1628.

[421] Ethyl Corp. v. EPA, 541 F.2d 1, 66 (D.C. Cir. 1976) (en banc) (Bazelon, C.J., concurring) (quoting Int'l Harvester Co. v. Ruckelshaus, 478 F.2d 615, 652 (1973)).

[422] *See* Vt. Yankee Nuclear Power Corp. v. NRDC, 435 U.S. 519, 542–45 (1978).

jeopardizes the long-term availability or survival of data. For example, regulations governing the production of environmental impact statements call for agencies to ensure the "professional integrity, including scientific integrity" of the analysis.[423] Ensuring data linkage and viability over time would be particularly important where cross-disciplinary data need to be analyzed on an ongoing basis after an agency decision, such as when an agency issues a mitigated Finding of No Significant Impact under NEPA.[424] Courts can also encourage better data-intensive practices by giving weight to science advisory panel findings on whether decision-making threatens data integrity,[425] or by expanding the range of "material" public comments to include those regarding data interoperability, provenance, and survival that must be addressed before a decision is reached.[426]

An equally valid concern is triggering judicial review in the first place. Guidance documents that encourage the diffusion and adoption of new regulatory practices will face an uncertain level of scrutiny compared to the *Chevron* deference typically applied to agency rules.[427] Guidances are more likely to violate the APA if they represent a final agency action[428] that introduces a new position or procedure[429] or imposes a new obligation.[430] Whether guidances change prior

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[423] 40 C.F.R. § 1502.24 (2013).

[424] *See, e.g.*, Council on Envtl. Quality, Final Guidance for Federal Departments and Agencies on the Appropriate Use of Mitigation and Monitoring and Clarifying the Appropriate Use of Mitigated Findings of No Significant Impact, 76 Fed. Reg. 3843, 3848–50 (Jan. 21, 2011) (to be codified at 40 C.F.R. pts. 1500–02, 1505–08) (noting that an Environmental Management System or other data management system could serve as a useful way to integrate monitoring efforts where rigorous oversight is warranted).

[425] *See* SHEILA JASANOFF, THE FIFTH BRANCH: SCIENCE ADVISORS AS POLICYMAKERS 249 (1990); Ian Fein, Comment, *Reassessing the Role of the National Research Council: Peer Review, Political Tool, or Science Court?*, 99 CALIF. L. REV. 465, 473–74 (2011) (noting that federal agencies have "increasingly turned to expert advisory committees for guidance and regulatory peer review," which "serve[s] a quality control function above and beyond the public input and judicial review provisions" of the APA).

[426] *Cf. Vt. Yankee*, 435 U.S. at 553 ("[C]omments must be significant enough to step over a threshold requirement of materiality before any lack of agency response or consideration becomes of concern.")

[427] Christensen v. Harris Cnty., 529 U.S. 576, 587 (2000). *But see* United States v. Mead Corp., 533 U.S. 218, 226–27 (2001) ("[A]dministrative implementation of a particular statutory provision qualifies for *Chevron* deference when it appears that Congress delegated authority to the agency generally to make rules carrying the force of law . . . .").

[428] *See* Ocean Cnty. Landfill Corp. v. EPA, 631 F.3d 652, 658 (3d Cir. 2011) (holding the court lacked jurisdiction to review EPA's common control determination because the determination was not a final agency action); Barrick Goldstrike Mines Inc. v. Browner, 215 F.3d 45, 47–50 (D.C. Cir. 2000) (holding EPA's guidance was a final agency action subject to judicial review and remanding for the district court to determine whether the guidance was invalid).

[429] *See, e.g.*, Nat'l Mining Ass'n v. Jackson, 768 F. Supp. 2d 34, 49 (D.D.C. 2011) (holding a Guidance Memorandum issued by EPA violated the APA because EPA "encroached upon the role carved out for the states under the Clean Water Act by setting region-wide conductivity standards").

agency positions speaks to the importance of the rules that they inform and how rules should be drafted in a data-intensive context. EPA is presently building a compliance program that will rely on "simpler rules promoting high compliance."[431] The program's goal is to structure rules so they make clear who is subject to the rule and are self-implementing for the "80% who want to comply."[432] Rules that clarify the regulated universe should be drafted to tolerate a greater range of methods to measure, determine, publicize, and assure a return to compliance. Guidances should regularly inventory available approaches. For example, a technology-based standard might call for reducing "residual risk" to a "maximally exposed individual" to below a certain threshold.[433] Guidances could indicate best practices, informed by microenvironment data, for identifying the individual most exposed to facility emissions.

CONCLUSION

The architecture of ignorance, and its grip over the public through spatial and temporal accommodation, is being unearthed by alliances wielding sensed, networked data. Whether it gives way to practices better tailored to a data-rich world is a question that will dominate environmental law in the future. The transition to data-rich environments, exploratory uses of data and diffusion of practices, and attainment of policy-relevant knowledge through data linkage and survival mark a third normative front in the field. This Article sets the groundwork for understanding data-intensive regulation and its challenges to regulatory design and federalism. It recasts these debates, which historically suffered from a lack of discernable mechanism or limited empirical evidence. At the heart of data-intensive regulation are two questions: How can we support networks that make use of rich environmental data and legitimate their demand for new practices? And how will choices among regulatory tools and governance scales stimulate or stifle the practice of data-intensive knowledge creation? This approach promises to reveal previously untapped lessons for health and safety, the environment, and wicked problems that we are just beginning to understand.

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[430] *See, e.g.*, Ensco Offshore Co. v. Salazar, No. 10-1941, 2010 WL 4116892, at *5 (E.D. La. Oct. 19, 2010) (holding a notice issued by the Secretary of the Interior violated the APA because the notice imposed additional duties without giving the public notice and an opportunity to comment, as required by the Act).

[431] David Nicholas, U.S. Envtl. Protection Agency, Next Generation Compliance, 2012 National Environmental Enforcement Information Meeting, at 10 (July 26, 2012), http://www.epa.gov/compliance/data/systems/icis/vmeeting/vmeeting6a-panel.pdf.

[432] Interview with Attorney, Office of General Counsel, U.S. Envtl. Protection Agency, in D.C. (Sept. 12, 2012).

[433] *See Risk and Technology Review*, Posting to *Technology Transfer Network Air Toxics Web Site*, U.S. ENVTL. PROT. AGENCY, http://www.epa.gov/airtoxics/rrisk/rtrpg.html (last updated May 31, 2013) (providing schedules for residual risk rules by source category). Section 112(f) of the Clean Air Act requires additional standards for a source category when MACT standards do not reduce lifetime excess cancer risk to the "individual most exposed to emissions from a source in the category" to less than one in one million. 42 U.S.C. § 7412(f)(2)(A) (2006).